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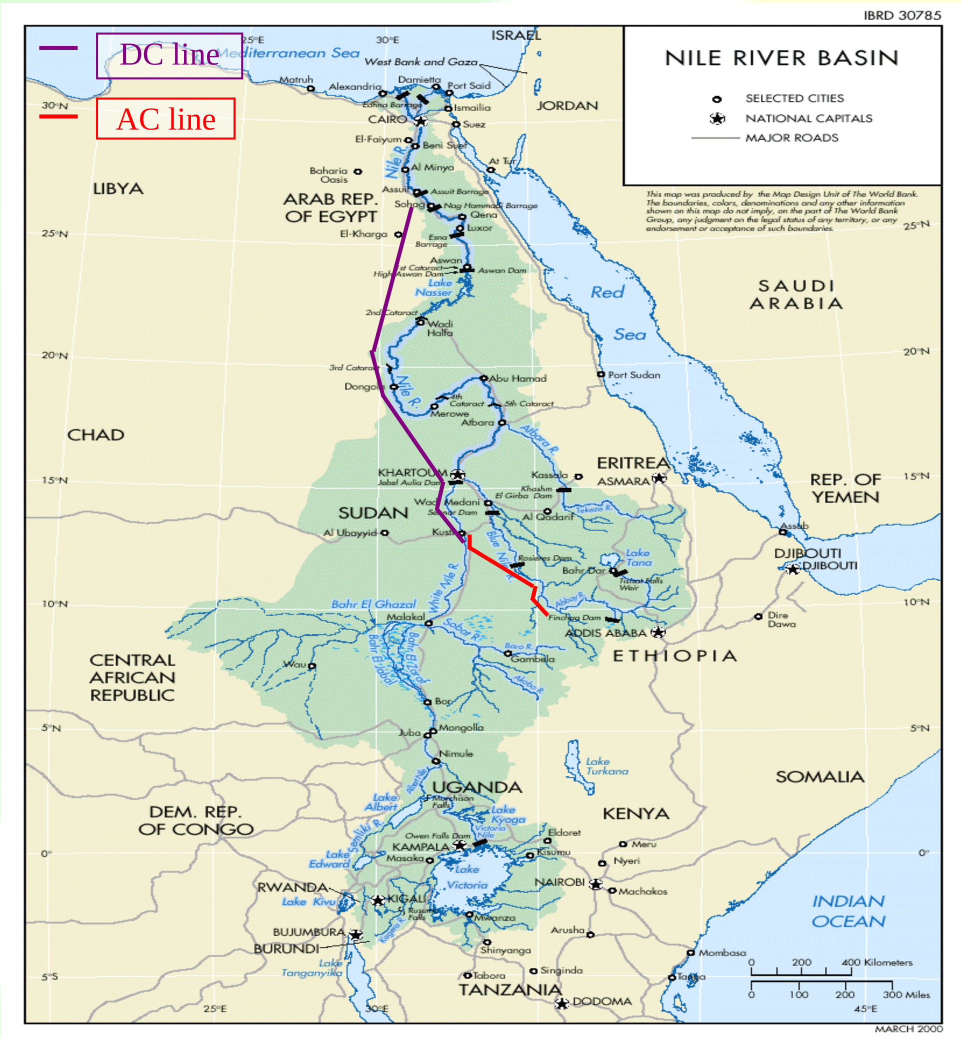
Nile Basin Initiative
Eastern Nile Subsidiary Action Program
Eastern Nile Technical Regional Office

FINAL REPORT

EASTERN NILE POWER TRADE PROJECT

VOLUME 3: PREPARATION OF SPECIFICATIONS



Nile Basin Initiative
Eastern Nile Subsidiary Action Program
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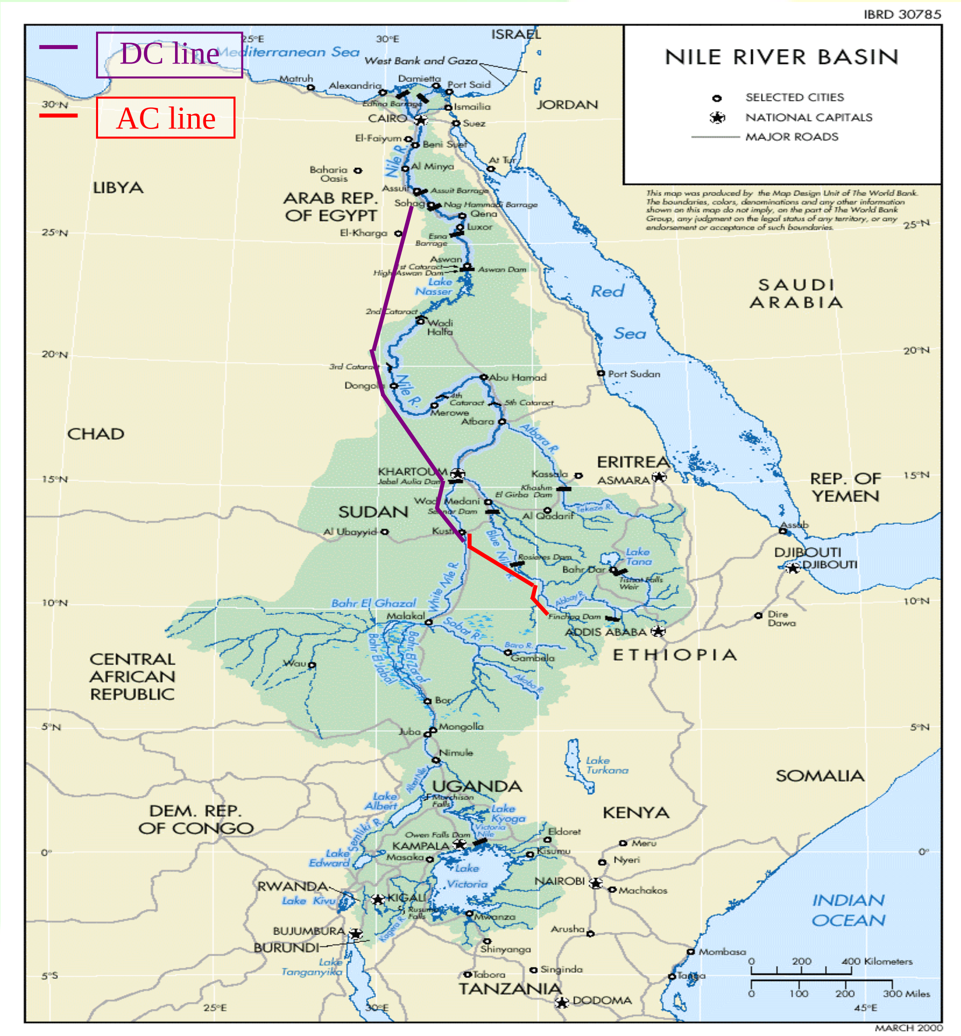
EASTERN NILE POWER TRADE PROGRAM STUDY



EXECUTIVE SUMMARY

The Eastern Nile Power Trade Program Study is fully funded by the African Development Bank with the general **objective of promoting regional power trade between Egypt, Ethiopia and Sudan** through creation of an enabling environment, coordinated regional investment planning of power generation and transmission interconnection projects.

The **Eastern Nile Power Trade Program Study** is divided in 2 phases:

- Phase 1: **Cooperative Regional Assessment of Power Trade Opportunities** between Ethiopia, Egypt and Sudan
- Phase 2: **Feasibility Study of the Power Interconnection** between Egypt, Ethiopia and Sudan to export, from Ethiopia, 2 000 MW to Egypt and 1 200 MW to Sudan.

In phase 2, two implementation scenarios have been analyzed :

- Commissioning a 700 MW capacity interconnection Ethiopia-Sudan in 2015 then commissioning the whole Egypt-Ethiopia-Sudan interconnection after Mandaya commissioned in 2020 (with anticipation)
- Commissioning the whole interconnection in 2020 (without anticipation)

The **Phase 1** concluded on the **economic profitability** of the Egypt-Ethiopia-Sudan power interconnection. The project is characterized by good business indicators, as a short payback period and a high benefit to cost ratio under a wide range of hypothesis.

The **Phase 2** concludes on **technical, environmental and financial feasibility**, according the development of a strong institutional framework allowing the building and the operation of this regional interconnection in a progressive way.

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Economic results

Investment costs are estimated about **1 860 MSD_{2006}** , O&M costs are about **18 MSD_{2006} per year** and revamping costs about **230 MSD_{2006}** Social mitigation costs are about **16 MSD_{2006}** .

Net present value (NPV) of the project is positive for both demand scenarios: **1 810 MSD_{2006}** for medium Ethiopian demand and **2 210 MSD_{2006}** for low Ethiopian demand, 10% discount rate, medium fuel price projection. About 160 MUD to 320 MUSD must be added to NPVs from CO_2 savings, if this project is eligible to Clean Development Mechanism.

The **payback period** is reached after **8 full years** of operation for low Ethiopian demand and **7 full years** for medium Ethiopian demand.

The Benefit to Cost Ratio (**BCR**) of the both scenarios are **above 3** for a 10% discount rate, and remains superior to 2 for 8% and 12% discount rates.

Both scenarios have high Economic Internal Rate of Return (EIRR), **respectively 18% and 17%**.

The **sensitivity analysis** executed for a low Ethiopian demand including updated fuel prices projection, shows that the variant with anticipation is even more profitable, with a BCR of 4.9. High fuel prices assumption enhances the interest of the Eastern Nile Regional Power Interconnection project, with a BCR as high as 8.1.

Financial results

With anticipation, assuming a quinquennial tariff mode, a public financing and corporate income tax exoneration, the optimal transmission tariff, ensuring its viability, is **USD_{2006} 7.6 / MWh excluding tax** (equivalent to USD_{2010} 10.6 / MWh)

The variant **without anticipation** is less attractive, requiring a 13% higher average transmission tariff. Under a technical scenario without anticipation, the tariff is **USD_{2006} 8.6 / MWh** excluding tax (equivalent to USD_{2010} 12.0 / MWh).

Transmission tariff is highly sensitive to the proportion of private financing in the financing plan. The average tariff would double under a private financing scheme **USD_{2006} 15.2 /MWh excluding tax** (equivalent to USD_{2010} 21.2 / MWh) compared with the base public financing scheme. The financing strategy will therefore have to focus on raising the large amount of public resources, marketing the project to development aid partners in order to negotiate optimal concessional terms for long-term loans.

Regarding hydrologic risk mitigation, it is recommended to set tariffs for the first 10 years at a level around 5% higher than the equilibrium for the base hydrology scenario, at around USD_{2006} 8.0 / MWh (equivalent to USD_{2010}11.1 / MWh).

Regarding sensitivity on financing plan, the financial and tariff modeling shows that the financing strategy will have to take into account both long-term optimization and the capacity for the stakeholders' states to raise fund from public budget.

Regarding loan negotiation with lenders, the strategy will also have to conciliate long-term optimization and the maximum admissible transmission tariff during the debt service period.

The introduction of a 30% corporate income tax has a limited impact under public financing (+ 2% on average tariffs) but a stronger impact under a private financing (+25%) as profit have to be generated, and therefore taxed, to pay out shareholders. Nevertheless, the decision to exempt the Project Company from corporate income tax or not shall depend of an economic “arbitrage” between the additional cost of electricity transmission and the revenue generated by this taxation.

Institutional Recommendations

A global institutional scheme emphasizing the **necessity of a collaborative approach**, mixing multilateral agreements and multilateral institutions, is proposed so as to finance, build, own and operate the Egypt-Sudan-Ethiopian power interconnection.

A suitable model turns out to be a scheme carried out by transnational entity distinct from national Transmission System Operators.

A **convention binding the three EN Countries** is proposed **to set-up a project structure**, in charge of implementing a **Project Company** and of running the **financing project**. The project structure will refine finance, build and operate schemes, in the objective to minimize risks and therefore, costs.

In addition, a multinational **Interconnection Regulator** shall guarantee a continuous control of the development, scrutinizing the compliance with future transparent and non-discriminatory rules.

According a Convention signed in 2009, the financing closure could happen by 2011, making the challenging anticipation scenario possible.

Social and Environmental impacts

This environmental and social impact assessment of the project-affected areas in the three EN Countries reveals no significant issue because the line route has been designed to avoid populated areas. It has also been optimized to avoid sensitive zones such historical & archeological sites, wildlife reserves, large crop areas, existing overhead line crossing.

A **16 MUSD$_{2006}$** environmental and social mitigation measure plan has been estimated to mainly compensate crop and fruit trees in Ethiopia and Sudan and to enforce community gains in Egypt. This budget represents less than **1%** of the total project budget.

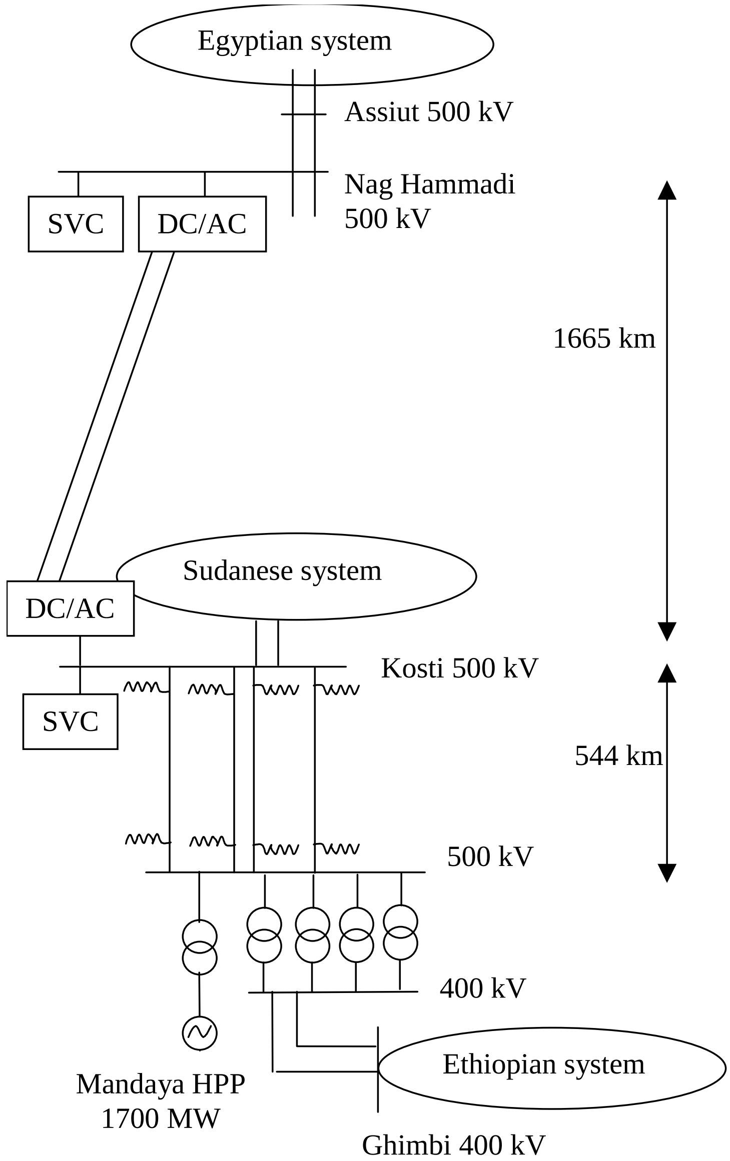
Despite this small ratio, this **Resettlement Action Plan is a key point for the implementation** of the interconnection. The project company shall take a special care and monitor closely that Contractor to fulfill ESIA recommendations and assignments.

Technical Feasibility

EN countries have selected an interconnection scheme consisting in:

- One AC 500 kV link including two 544 km double circuit lines between a 500/400 kV substation at Mandaya in Ethiopia and the AC 500 kV station at Kosti in Sudan
- One DC +/-600 kV link including a 1 665 km bipolar DC line between Kosti and Nag Hammadi in Egypt, a 2 150 MW AC/DC converter station located at each end of the link. One 500 MVAr and one 300 MVAr static var compensators are installed at Kosti and Nag Hammadi.

This interconnection operates in parallel with the Gonder (Ethiopia) and Gedaref (Sudan) 220 kV to be commissioned in the coming year 2009.



Power Studies

To assess the feasibility of this interconnection, different situations were analyzed :

- Peak load situation in 2015
- Peak and intermediate load situation in 2020/2021
- Peak load situation in 2025/2026
- Peak load situation in 2029/2030

The study has demonstrated that **it is possible** to export 3 200 MW from Ethiopia, delivering 1200 MW to Sudan and 2000 MW to Egypt.

The operation of whole interconnected systems **is acceptable**.

DC interconnection optimization study: An economical optimization study for the DC interconnection have lead to select a DC 600 kV scheme.

Operation in parallel of the 220 and 500 kV interconnections: It is advantageous to operate in parallel the 220 and the 500 kV interconnections, for security and economical reasons, with a 250 MVA phase-shift transformer.

DC +/-600 kV, AC 220 kV and 500 kV interconnections: The tripping of one of the poles of the DC interconnection is acceptable. The tripping or a short-circuit on the 220 kV interconnection has a limited impact on the system behavior. In case of short circuit on 500 kV interconnection, for stability reasons the export power to Egypt has been reduced to half. The increase of the short-circuit power and the commissioning of Border lift up this constraint.

Egyptian system : Egyptian system behavior is satisfying with a 300 MVA SVC in Nag Hammadi. The system face safely the tripping of Egypt main steam unit.

Ethiopian system: Ethiopian system behavior is satisfying. In 2020, the Mandaya and Addis Ababa 400 kV backbone is heavily loaded, fulfilling N-1 criteria. The commissioning of Geba 1&2 in 2021 and specifically Border in 2030 will release load constraints. The Ethiopia - Sudan system faces safely the tripping of Ethiopia main unit.

Sudanese system: The behavior of the Sudanese system is satisfying in case of tripping and short-circuit on the neighboring circuits of Kosti. The Ethiopia - Sudan system face safely the tripping of Sudan main unit.

Anticipation of the AC 500 kV interconnection in 2015: The anticipation of Mandaya-Kosti AC interconnection would enable to export the Ethiopian hydro surplus before 2020, and to increase the power export from 200 MW (with the 220 kV AC interconnection) to 700 MW. The energizing of the interconnection is an issue due to harmonic transient over-voltage risks, generated by 400/500 kV Mandaya transformers. This potential issue needs to be studied in a detailed way with the final known characteristics of the network. Several technical and operational alternatives were analyzed, and the black-start with low voltage energizing from a gas turbine plant at Kosti appeared to be the best solution.

Line Routing

AC circuits between Mandaya and Kosti substation face some difficult access and relief characterized by hilly area and flooded zone near Nile.

Kosti substation localization will be decided according with other 500 kV Sudanese project lines to be committed in 2030.

Corridor of ± 600 kV DC Line between Kosti and North Omdurman is located on the West bank of the White Nile River. This line route skirts urban area between Rabak/Kosti-Khartoum, Khartoum agglomeration, future International Khartoum Airport and existing 220 kV lines.

After field investigations, the proposed areas, for ± 600 kV DC Line connection in Sudan and Egypt, are located in free of obstructions places, as highly populated areas, power lines crossing, private agricultural areas and cemeteries.

No major constraint for AC and DC line corridors has been identified after site visits.

Phasing

Arrangement works are divided in ten lots: five for AC and DC overhead lines construction, four for HVDC and SVC substations and one for control center and appropriate supervision.

This **challenging** phasing considers the time for study validation and works construction but does not take into account the bidding processes for construction and consulting services.

AC and DC Technical Specifications

No cutting-edge technologies have been chosen. **Well proven technologies** have been selected for the most part of technical equipments (cables, towers, power stations subsystems, controls systems, transformers, ..). Turn key buys are recommended, one for the both HVDC stations and one for SVC stations.

Operation and Maintenance

A **dedicated control center**, designed to **not depend on the location** and **operated in close cooperation but distinctly** from national transmission operators, handles metering, supervision and controls with local substations and telecommunication links.

Training is a significant part of the development of this project and covers numerous technical and management fields.

Eastern Nile Power Trade Program Study

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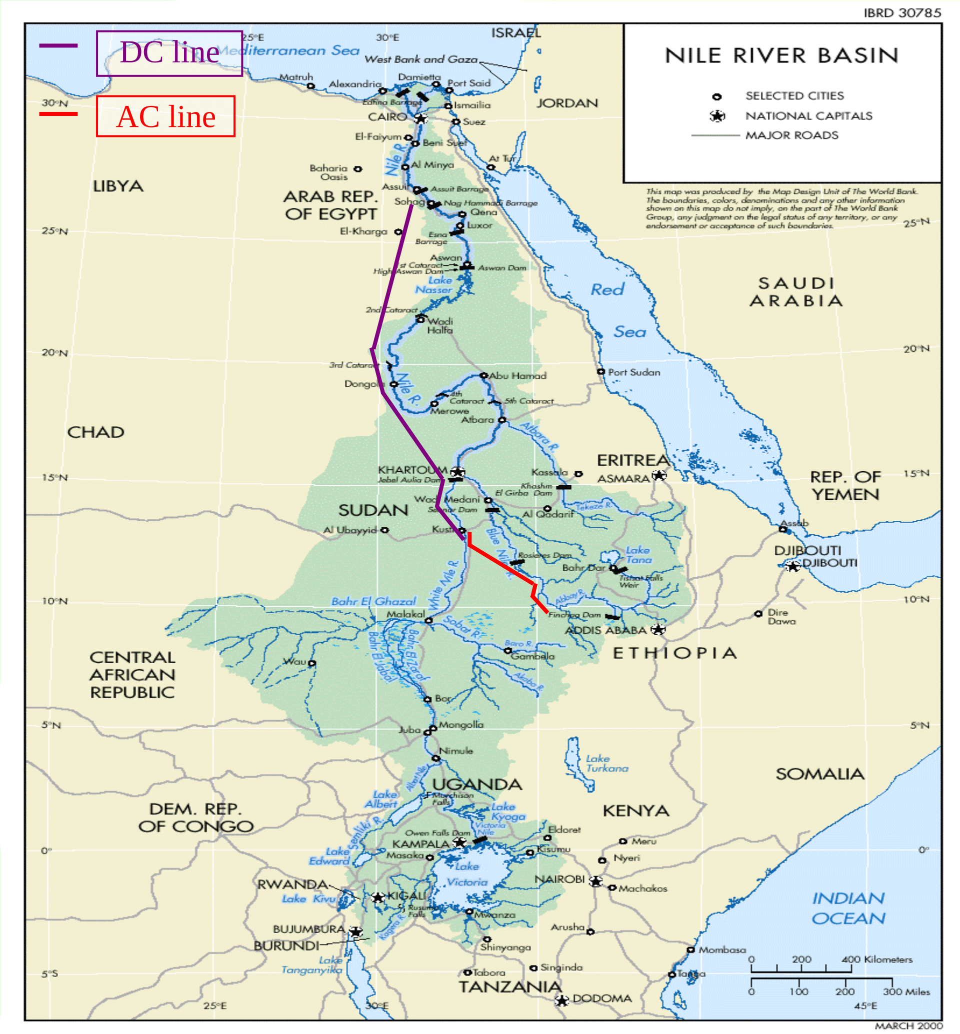

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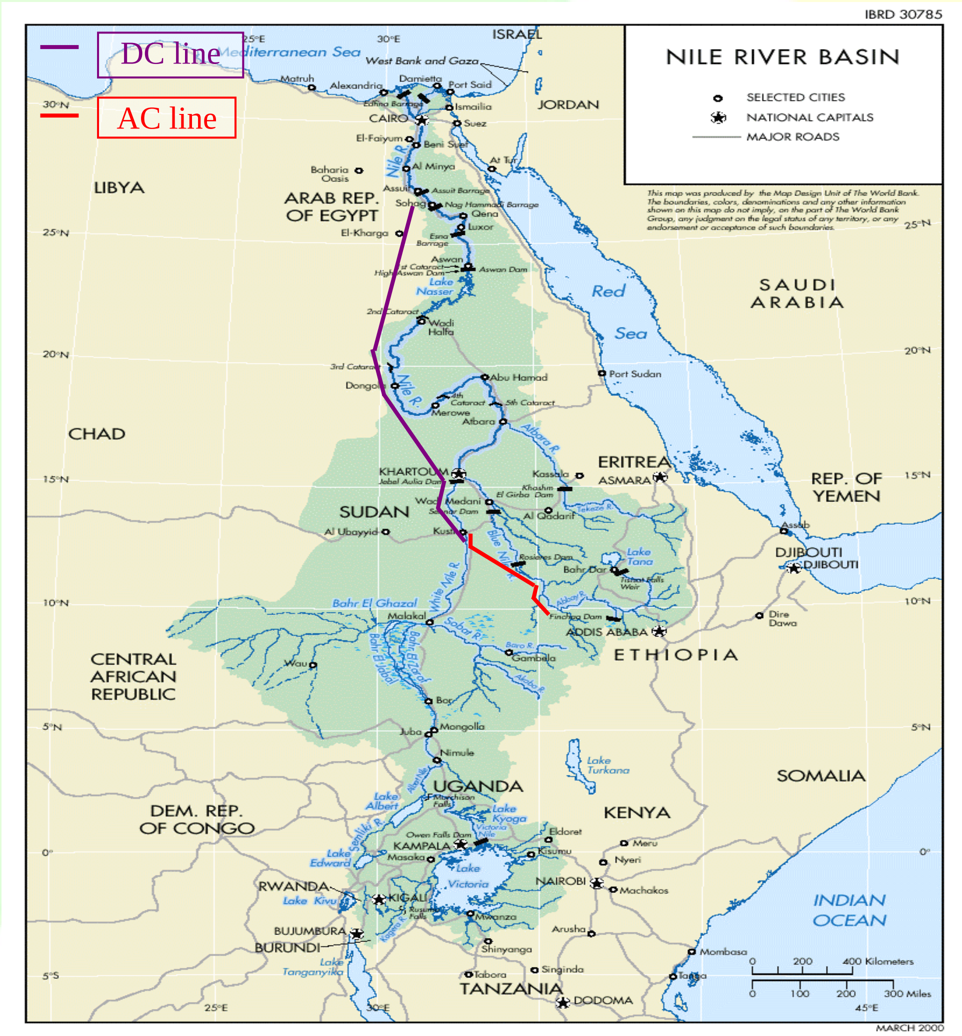

M4 – 500 kV & 400 kV AC SUBSTATIONS

EDF
Scott Wilson
EPS Electrical Power Systems Engineering Company

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
BCU	Bay Control Unit
CB	Circuit Breaker
CSCS	Control and Supervision Computerized System
CT	Current Transformer
CVT	Capacitor Voltage Transformer
DC	Direct Curent
EDF	Electricité de France
EHV	Extra High Voltage
EHVAC	Extra High Voltage Alternating Current
EMC	Electromagnetic Compatibility
ENPTPS	Eastern Nile Power Trade Program
ENTRO	Eastern Nile Technical Regional Office
HPP	Hydro Power Plant
HV	High Voltage
HVDC	High Voltage Direct Current
IEC	International Electro-technical Corporation
LV	Low Voltage
PLC	Power Line Carrier
ODAF	Oil Directed Air Forced (cooling method)
OHTL	Overhead
OLTC	On Load Tap Changer
O&M	Operations and Maintenance
ONAF	Oil Natural Air Forced (cooling method)
ONAN	Oil Natural Air Natural
OPGW	Optical Ground Wire Cable
PT	Power Transformer
SCADA	Supervision Control And Data Acquisition system
SVC	Static Voltage Compensator
SW	Scott Wilson
RMS	Root Mean Square

EXECUTIVE SUMMARY

The purpose of this document is to introduce the preparation of technical specifications for the AC substations involved by the regional interconnection project between the three countries Egypt, Ethiopia and Sudan.

This document contributes to the Module 4 package of ENPTPS Phase II, "Preparation of Technical Specifications".

This preparation of technical specifications for the substations has been done according to the scope of work detailed in the Inception report (§7.4).

As stated in the Phase II - Module 1 - Detailed network studies, the interconnection between the three countries will be made up of:

- Two double 500kV circuits (544km) between Mandaya (Ethiopia) and Kosti (Sudan). The Mandaya substation will include 4 x 510MVA power transformers and eight step up power transformers MV/500kV connected to Mandaya HPP power plant.
- One DC 600kV bipolar line between Kosti and Nag Hamadi substations. Both substations will include AC/DC converter (converters are out of scope of this document).

General technical specifications are given in the document on the substations involved by the interconnection as well as details on the related HV equipments (circuits breaker, disconnectors, power transformers, relay protections, etc…). A proposal for spare parts is given at the end of this document.

Accordingly with the scope of work of the inception report, no consideration about general technical requirements for the construction of the substations (civil works) and auxiliaries are detailed in this document.

1 INTRODUCTION

1.1 GENERAL INFORMATION

This section provides with general description on the three substations involved in the regional interconnection project between Ethiopia, Sudan and Egypt. These three substations are:

- AC 400kV- 500kV MANDAYA substation located in Ethiopia
- AC/DC 500kV KOSTI substation in Sudan connected to MANDAYA substation through two double 500kV AC circuits (544km)
- DC/AC 500kV Nag HAMMADI substation connected to KOSTI substation through one bipolar DC line (1665km)

The installation and commissioning of these substations is foreseen in three stages:

The first stage is scheduled for Kosti & Mandaya substations. One sub part of Kosti substation shall be commissioned in 2015 for the connection purpose to FULA substation (Sudan) and two circuits between Mandaya and Kosti substations shall be installed as the first step of the interconnection project.

The second stage deals with the installation of two additional circuits between Mandaya and Kosti substations. Moreover, Kosti and Nag Hammadi substations will be interconnected by one DC bipolar line. The installation and commissioning target is foreseen on 2020.

The last stage is Border substation. This will be inserted on the 500kV AC line in 2030 to connect a future 1200MW power plant.

The schedule and interconnection scheme is given here after.

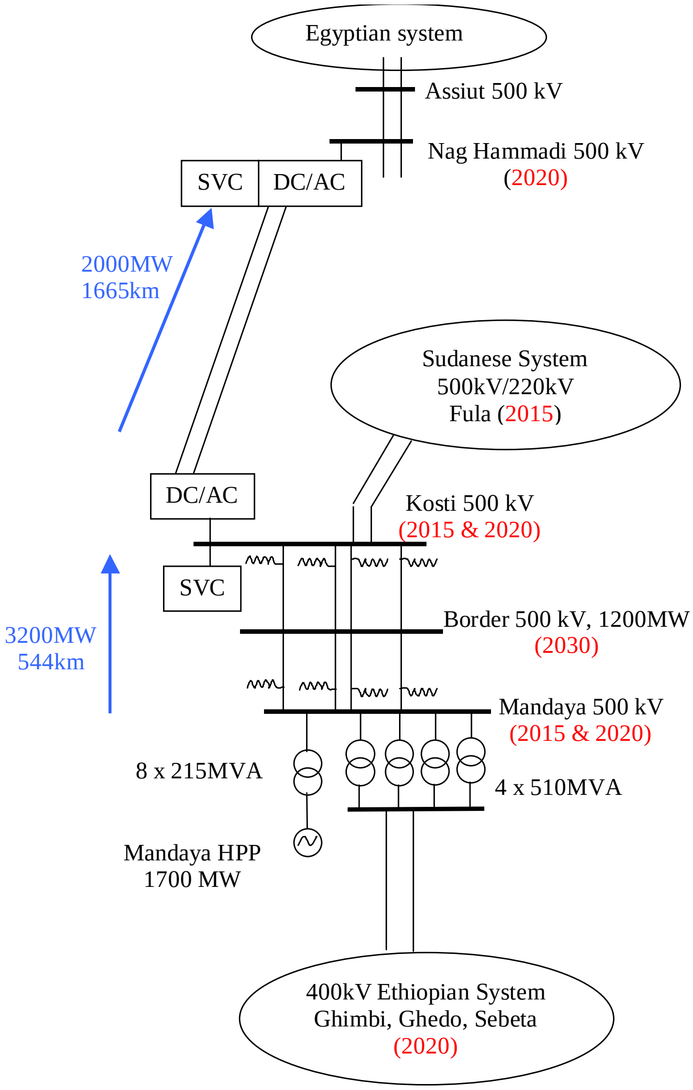


Figure 1 : Interconnection scheme and schedule

The particular technical characteristics listed hereafter are the basic requirements for the design of the substations. However, no requirements on the civil works, auxiliary equipments, installation and commissioning stages are given. These issues will be settled later during the final detailed design stage.

A list of the mandatory spare parts is proposed at the end of the document.

1.2 SCOPE OF WORK

This document is intended to describe general requirements for the design of the substations involved by the regional interconnection project. Therefore, scope of work shall focus on the following items:

1 - Standard to be applied for the design and test of HV apparatus

2 - Standard to be applied for the design and test of LV apparatus (protection relays & metering)

3- General requirement for the transmission installation in each substation:

- Main electrical scheme and general layout of the substations
- Fundamental requirements for the substation (electrical mechanical, climatic, special if any),
- Insulation requirement (selection of insulation level, minimum clearance of the live parts),
- Particular requirements for HV equipment (switchgear, power transformer, instrument transformer, surge arrester, reactors, etc …).
- Particular requirements for LV equipment (distance protection, differential protection, meters, etc. …).

4 – Spare Parts

This document does not apply on the design and the erection of any of the following :

- HVDC converters and all the related apparatus for the DC transmission.
- AC or DC transmission lines
- Auxiliary substation equipment, civil woks, fire fighting.

2 STANDARDS TO BE APPLIED FOR DESIGN AND TEST

2.1 STANDARDS FOR HV APPARATUS

Performance, testing and rating of the HV transmission equipment shall be compliant with the latest editions of relevant IEC standards, particularly the standards as listed below shall be applicable:

- IEC 60071-1 Insulation coordination – Part 1: Definitions, principles and rules
- IEC 60071-2 Insulation coordination – Part 2: Application guide
- IEC 61936-1 Power installation exceeding 1kV AC. Part 1 Common Rules.
- IEC 60694 Common specifications for high-voltage switchgear and control gear standards
- IEC 62271-100 High voltage alternating current circuit breakers.
- IEC 62271-102 Alternating current disconnectors (isolators) and earthing switches.
- IEC 60099-4 Lightning arresters. Part 1 non linear resistor types for AC systems.
- IEC 60044-1 Instruments Transformer – Part 1: Current transformers.
- IEC 60044-6 Instruments Transformer – Part 6: Requirements for protection current transformers for transient performance.
- IEC 60044-5 Instruments Transformer – Part 5: Capacitor Voltage transformers.
- IEC 60815 Guide for the selection of insulators for polluted conditions
- IEC 60273 Dimensions of indoor and outdoor post insulators and post insulator units for systems with nominal voltages greater than 1000 V.
- IEC 60137 Bushings for alternating voltages above 1000 V.
- IEC 60076, Power transformers. Part 1- 10.
- IEC 60289, Reactors.
- IEC 60353 Line traps for AC power system

2.2 STANDARDS FOR LV APPARATUS

- IEC60255 – 13 Electrical relays – Biased differential Relays.
- IEC60255 – 16 Electrical relays – Impedance Measuring Relays.
- IEC60255 – 22 Measuring relays and protection equipment – Electrical disturbance tests
- IEC 60529 Degrees of protection provided by enclosures (IP code)
- IEC 60664-1 Insulation co-ordination within LV systems

- IEC 61000-4-1 Electromagnetic compatibility (EMC) – Part 4-1: Testing and measurement techniques – Overview of 61000-4 series
- IEC 62053-22 Electricity metering equipment (AC) –Particular requirements – Part 22:Static meters for active energy (classes 0,2 S and 0,5 S)
- IEC 60688 Electrical metering transducers

3 GENERAL REQUIREMENT FOR MANDAYA SUBSTATION

3.1 *MAIN ELECTRICAL SCHEME AND LAYOUT*

The global arrangement of the 500/400kV substation consists on the following switchyards,

- Switchyard 1 : 500kV switchgear equipments
- Switchyard 2 : 400kV switchgear equipments
- Switchyard 3 : 500/400kV Power transformers,
- Switchyard 4 : HPP 500kV connection.

General layouts of the switchyards 1, 2, 4 are given in appendix 1. Switch yard n°3 depends mainly on the Power transformers size and on the cooling systems. Therefore the layout will be detailed at the final design stage.

The 500kV and 400kV substation is an outside double busbar arrangement with **one and half circuit breaker**. This arrangement has been selected to comply with the existing substations. The main features of this configuration are the followings :

Advantages	Disadvantages
<u>Cost</u> Fewer circuit breakers than double CB for the same flexibility <u>Network safety</u> In case of a line feeder fault, breaker failure at bus side does not remove any other feeder circuit from service In case of a line feeder fault, breaker failure in the middle removes only the two feeders of diameter Bus failure does not remove any feeder circuits from service <u>Operation simplicity</u> All the breakers are normally closed and disconnector switches are opened in normal operation. <u>Maintenance</u> Bus bar and circuit breaker can be taken out of service at any time for maintenance <u>Future extension</u> Convebient to build the future bay without interrupting supply.	<u>Cost</u> More circuit breakers than Single CB configuration. Higher cost on maintenance. <u>Network safety</u> Two circuit breaker to be opened in the case of fault line <u>Operation adaptability</u> None, the entire substation is connected to one electrical node. However, it is possible to have two electrical nodes by adding a two section circuit breaker. More operation to isolated a feeder : four opening and closing at each start/shut down sequence.

Table 1 : Advantages/Disadvantages of One and Half CB

Drawing of the bus section and line feeders arrangement as well as single line diagram of the 500kV substation are given in appendix 1.

The power transformers are connected to the switchgear by either rigid or flexible busbar.

The steps up power transformers from HPP are connected on the 500kV switchgear. Step up power transformers are out of scope of this document.

3.2 *FUNDAMENTAL REQUIREMENTS FOR THE SUBSTATION*

Installations and equipment shall be capable of withstanding electrical, mechanical, climatic and environmental influences anticipated on site.

3.2.1 ELECTRICAL REQUIREMENT

3.2.1.1 Methods of neutral earthing

The method of neutral earthing of a system is important with regard to the following:

- Selection of insulation level
- characteristics of overvoltage limiting devices such as spark gaps or surge arresters
- The neutral earthing of the Ethiopian system is **solid (low impedance) earthing**.

3.2.1.2 Voltage classification

According to the network studies, Module M1 phase II, the maximum operating voltage of the substation is 525kV. Pursuant the network studies, the standardized values of the highest voltage for equipment are given in here after (extraction from IEC 61936-1, annex A).

Nominal voltage of the system	Un (RMS, kV)	400 (+/- 5%)	500 (+/- 5%)
Highest voltage for equipment	Um (RMS, kV)	420	550

Table 2 : Voltage Classification

3.2.1.3 Current in normal operation

According to the network studies presented in M1 "Detailed Network Studies", Ethiopia could export 4 x 828MW to Sudan through 4 circuits in 2020.

The incoming power connected to the 500kV bus bar in Mandaya substation are

- 1700MW from HPP power plant
- 1624 MW from 4 x 510MVA power transformers designed with following main parameters: rated ratio 500/400, OLTC +/-12%, 21 taps.

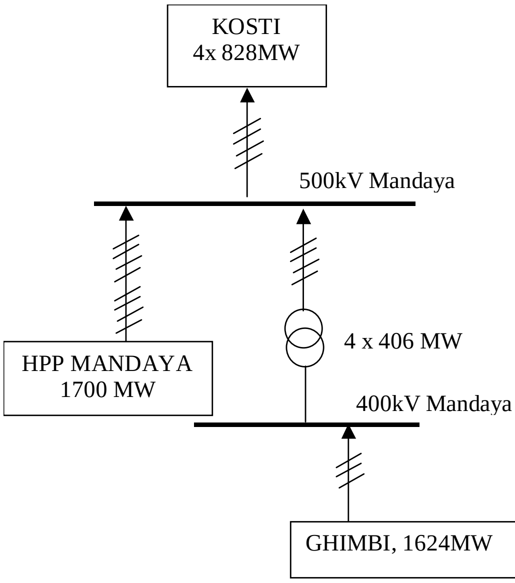


Figure 2 : Diagram of Incoming and Outgoing Feeders

Tripping situation

In case of tripping on one of the four line feeders to Kosti (N-1 situation), the load is transferred on the three reaming circuits. The load on each circuit is therefore 1105 MW.

In case of tripping on one of the four 510MVA power transformers, the load is transferred on the three reaming transformers. The load on each PT is therefore 539MW (overload of 8%).

In case of tripping on one of the three incoming 400kV line feeders from Ghimbi substation, the load is transferred on the two reaming circuits. The load on each circuit is therefore 812MW

Pursuant to these figures on incoming power and load in tripping situation, the normal operation current on 500kV and 400kV substation is calculated hereafter.

	Nominal voltage (kV)	Min voltage (kV)	Power (MW)	Nb circuit normal situation	Nb circuit N-1	Max Continuous operating current / circuit (A)
Mandaya HPP	500	475	1700	8	8	258
Mandaya - Kosti circuits	500	475	3312	4	3	1342
Main Bus	500	475	3324	2	1	4020
Power transformer (HV side)	500	475	1624	4	3	658
Power transformer (LV side)	400	380	1624	4	3	822
Main Bus	400	380	1624	2	1	2467
Line feeders Ghimbi	400	380	1624	3	2	1234

Table 3 : Maximum Operating Current Calculation

3.2.1.4 Rated Current

		Rated current (A)			
	Max Continuous operating current / circuit (A)	Switchgear	CT	Other equipment	Line trap
Mandaya HPP	258	2000	1500	2000	NA
Mandaya - Kosti circuits	1342	2000	1500	2000	2000
Main Bus	2020	NA	NA	5000	NA
Power transformer (HV side)	658	2000	1500	2000	NA
Diameter (One and half CB)	1342	2000	1500	2000	NA
Power transformer (LV side)	822	2000	1500		NA
Bus bar	2467	NA	NA	3150	NA
Ghimbi – Mandaya circuits	1234	2000	1500		2000
Diameter (One and half CB)	1324	2000	1500		NA

Table 4 : Specification of the rated current

Note 1: The value of the rated current of the switchgears (circuit breaker and disconnectors) is settled at 2000, 3150 and 5000A, taking into account the following criteria:

The rated current shall be above the maximum continuous operating current

As much as possible, the switchgear shall be identical to optimise the maintenance tasks (spare part management)

Note 2: The value of the rated current of the CTs is settled at 1500, 2500 and 4000A, taking into account the following criteria:

The rated current shall be as close as possible to the maximum continuous operating current to be within the range of the accuracy class of the measuring CT (outgoing or incoming line feeders).

The rated continuous thermal current (120% of the rated current) shall be above the maximum continuous operating current

Current measurement on HPP feeder is performed on MV side

3.2.1.5 Short circuit Current

According to the network studies, the three phases short circuit current is fixed at 31,5kA.

3.2.1.6 Rated frequency

The existing Ethiopian and Sudan network are design for 50Hz.

3.2.2 MECHANICAL REQUIREMENT

The wind load shall be taken in account in the design for the mechanical withstand of the structures.

According to the design study of overhead transmission lines (Phase II, M4, sub part Overhead lines), the wind reference is 110km/h or 30m/s.

In addition, IEC 60694 contains requirements for wind loading on switchgear and controlgear: the wind speed does not exceed 34 m/s, corresponding to 700 Pa on cylindrical surfaces.

We propose to make reference to IEC 60694 for the calculation of the mechanical strengths. Thus the wind reference is fixed at 34m/s.

3.2.3 CLIMATIC AND ENVIRONNEMENTAL CONDITIONS

Pursuant on the data collection on existing standard in Ethiopia, the meteorological conditions for the design are :

Maximum ambient temperature	35 ° C
Minimum ambient temperature	0 ° C
Mean Temperature °C	20 °C
Maximum Conductor temperature	90 °C
Minimum Conductor temperature	5 °C
Reference wind speed (IEC 60694)	34m/s
Mean annual Rainfall	129 mm
Humidity	100 %
Pollution	20 mm/kV, Class (II)
Altitude	<1000m
Earth quake	AF5

Table 5 : Climatic and environmental Conditions

Special climatic and environmental conditions

Due to the location of the substation (desert zone in vicinity), special attention shall be taken on the design of the insulators. Sand together with humidity can affect the dielectric withstand of the electrical equipment. Pollution class and material (porcelain or synthetic) shall be fixed as a result of the feedback from the Ethiopian network.

Special scheduled maintenance tasks (insulators cleaning) can be carried out to reduce flashovers occurrences.

3.3 INSULATION REQUIREMENTS

3.3.1 INSULATION LEVEL

Insulation coordination shall be in accordance with IEC 60071-1.

Nominal voltage of the system	Highest voltage for equipment	Rated short duration Power frequency withstand voltage	Rated switching impulse withstand voltage	Rated lightning impulse withstand voltage	
Un (RMS, kV)	Um (RMS, kV)	Phase/earth (RMS, kV)	250/2500µs (Peak value, kV)	Phase to earth 1.2/50µs (peak Value, kV)	Phase to Phase 1.2/50µs (peak Value, kV)
400	420	520	1050	1425	1425 (+ 315)
500	550	620	1175	1550	1550 (+315)

Table 6 : Insulation Coordination

3.3.2 MINIMUM CLEARANCE

The minimum clearances in air are given in IEC 61936 and 60071-1. These clearances apply for altitudes up to 1000 m above sea level.

Clearances	400kV	500kV
Minimum Phase-to-Earth clearance (N) Conductor – conductor parallel Rod – conductor	 2.6 m 3.4 m	 3.1 m 4.1 m
Minimum phase-to-phase clearance (N) Conductor – conductor parallel Rod – conductor	 3.6 m 4.2 m	 4,2 m 5.0 m
Minimum height over access area where pedestrian are only permitted (H = N + 2.25 m) Conductor – conductor parallel Rod – conductor	 4,85 m 5,65 m	 5,35 m 6,35 m
Minimum height over access area where vehicle are permitted = N + 2.7m	6.1 m	6,8 m

Table 7 : Minimum Clearance Recommended by IEC Standards

Clearances	400kV	500kV
Minimum ground clearance where pedestrian are only permitted	6.2 m	9.0 m
Minimum height over access area where vehicle are permitted	8.0m	9.0 m
Minimum height between bus bar and ground	8.0m	9.0m

Table 8 : Clearances Specified

3.4 PARTICULAR REQUIREMENTS FOR HV EQUIPMENT

3.4.1 SUBSTATION LEVEL

The 500 and 400 kV substations shall be equipped with air insulated outdoor switchgear. It shall be of one and half circuit breaker outside bus bar arrangement type.

The main features of the 400kV substation are the following

- 3 incoming feeders from Ethiopian system
- 4 outgoing feeders to the Power transformers switchyard
- 4 diameters, each of them includes 3 circuit breakers.
- 2 external bus bars.
- 1 central control building including the control and supervision system, relay protections.

The main features of the 500kV substation are:

- 4 incoming feeders from power transformers switchyard
- 8 incoming feeders from Mandaya HPP.
- 4 outgoing feeders to the Kosti substation
- 4 x 2 x 75MVA line reactors compensation + neutral reactor.
- 8 diameters, each of them includes 3 circuit breakers.
- 2 external bus bars.
- 1 central control building including the control and supervision system, relay protections.

The main features of the power transformer switchyard

- 4 autotransformers 500kV/400kV 510MVA
- 4 + 4 feeders to 400kV and 500kV substations.

3 poles item	Substation	
	500 kV	400kV
Circuit breaker	24	12
Pantograph disconnector	16	8
Disconnector + earthing switch	56	23
Current Transformer (oil type)	36	16
Current Transformer (Tore type)	60	4
Capacitor Transformer	6	5
Surge Arrester	20	7
Line Reactor	8	0
Neutral Reactor (single pole)	8	0
Line trap	4	3

Table 9 : Total Number of HV Equipments

	400kV	500kV
Bus bar protection (87B, 50BF)	4	4
Bus control Panel	1	1
Diff power transformer + bay controler (87T, 63, 18)	24	8
Line protection (21)	8	6
Diameter protection (87D, 67/67N, 50BF)	16	8
Shunt Reactor protection (87R-1, 67/67N, 63)	8	0
Neutral Reactor protection (87R, 63,50N)	8	0

Table 10 : Total number of LV equipments

The above HV and LV equipments are described in the following clauses.

3.4.2 Circuit Breaker

The circuit breaker shall be compliant with IEC 62271-100.

Operating mechanisms shall be motor-operated spring-charged, pneumatic or hydraulic types with DC shunt coils for tripping and closing and suitable for local control and remote control.

The circuit breaker supporting structure shall be galvanized and shall comply with the related clauses.

Type	SF6 Gas, outdoor, live-tank, single pressure	
Rated Voltage (kV)	420 kV	550 kV
Number of Interrupter per Pole	Minimum 2	
Rated Frequency (Hz)	50	
Rated normal current (A) Bus bar /others	3150/2000	5000/2000
Rated short time waistband current (kA)	31.5	
Making Capacity (kA peak)	100	
Breaking Time (cycles)	2	
Operating mechanism	Hydraulic, Spring or Pneumatic	
Operating sequence	O+0.3s+CO+1min-CO	
Type of tripping	Single-pole & Three-pole	
Pollution class	II	
Insulator	Porcelain	
Applicable Standard	IEC 62271-100 & IEC 60694	
Power Frequency Withstand Voltage Phase to earth Between phases or across open switching device and isolated distance	520 kV 610 kV	620 800
Mechanical endurance	M1	

Table 11 : Particular Requirement for Circuit Breaker

3.4.3 Disconnector and Earthing Switch

Disconnector shall be compliant with IEC 62271-102 standard.

Two column rotary disconnector

This disconnector type is used incoming feeder either for small or large switchgear installation. An earthing switch is associated to the main disconnector.

Single column pantograph disconnector

In installation for higher voltages (> 170kV) and multiple busbars, pantograph disconnectors are preferred for bus bar connection. This type of disconnector requires less space than other disconnector designs. Moreover, the switch status is clearly visible with the vertical isolating distance. A rotary-linear earthing switch is installed on every pantograph disconnector pole..

Operating mechanism

The operating mechanism for disconnector shall be DC motor operated, for three phases operation with provision for remote and local control. Earthing switch shall be local/manual operated only.

Supporting Structure

The disconnector and earthing switches supporting structure shall be galvanized.

Type Bus bar connection Other	Single column Pantograph Two – column, rotary	
Rated Voltage (kV)	420	550
Rated Current (A) Busbar/others	3150/2000	5000/2000
Rated short time withstand current (kA)	31.5	31.5
Lightning Impulse Withstand Voltage-to Earth (kV) Phase to earth Across open switching device	 1425 1425 (+240)	 1550 1550 (+315)
Power Frequency Withstand Voltage-to Earth (kV) Phase to earth Across open switching device	 520 610	 620 800
Switching Impulse Withstand Voltage-to Earth (kV) Phase to earth Across isolating distance	 1050 900 (+345)	 1175 900 (+450)
Operating Mechanism - Main Blade - Earthing Blades	 Single-pole/motor Single-pole/manual	
Pollution level	II	
Insulator	Porcelain	
Applicable Standard	IEC 62271-102 & IEC 60694	
Electrostatic coupling induced current (A)	18	25
Electrostatic coupling induced voltage (kVrms)	20	25
Electromagnetic coupling induced current (A)	10	20
Electromagnetic coupling induced voltage(kVrms)	160	160
Mechanical endurance	M0	

Table 12 : Particular Requirements for Disconnector

3.4.4 CURRENT INSTRUMENT TRANSFORMER

The equipment shall be compliant with IEC 60044-1

The instrument transformers shall be outdoor, oil filled, porcelain insulator housing.

The instrument transformer supporting structures shall be galvanized and shall comply with the related clause.

Type	Outdoor, single phase, oil filled	
Highest System Voltage(kV)	420	525[1]
Power Frequency Withstand Voltage dry/wet (kV)	630	680
Lightning Impulse Withstand Voltage (kV)	1425	1550
Switching impulse withstand voltage(kV)	1050	1175
Primary short circuit current Ipsc (kA)	31.5	
Rated primary current (A) busbar/other	2500/1500	4000/1500
Pollution level	II	
Insulator	Porcelain	
Applicable Standard	IEC 60044-1	
Accuracy Class Protection Measurement	 5P20 (long line) 0.2	

Table 13 : Particular Requirement for Current Transformer

3.4.5 CAPACITOR INSTRUMENT TRANSFORMER

The equipment shall be compliant with IEC 60044-5

The instrument transformers shall be outdoor, oil filled, porcelain insulator housing.

The instrument transformer supporting structures shall be galvanized and shall comply with the related Clause.

According to the network study, over voltage can rise up to 130% of the rated voltage during 300ms when one tripping occurs on the SVC. Therefore, the rated voltage factor of the CVT shall be design upon this transient phenomenon.

[1] 550kV does not exist in IEC 60044-1.

Type	Outdoor, single phase, oil filled	
Highest System Voltage(kV)	420	525[2]
Power Frequency Withstand Voltage dry/wet (kV)	630	680
Lightning Impulse Withstand Voltage (kV)	1425	1550
Switching impulse withstand voltage (kV)	1050	1175
Rated secondary voltage	100/√3	
Pollution level	II	
Insulator	Porcelain	
Applicable Standard	IEC60044-5	
Accuracy Class Protection Measurement	 3P 0.2	
Ferro resonance suppression device	Damping Circuit	
Rated voltage factor	1.5/30s	

Table 14 : Particular Requirement for Capacitor Instrument Transformer

3.4.6 SURGE ARRESTER

The equipment shall be compliant with IEC 60099-4 standard

The surge arresters supporting structures shall be galvanized and shall comply with the related Clause.

The continuous operating voltage of the surge arrester shall be design upon this transient phenomenon: 130%, 300ms.

[2] 550kV does not exist in IEC 60044-1.

Type	Outdoor, ZnO	
System Voltage (kV)	400	500
Rated Voltage (kV)	360	420
Maximum System Voltage (kV)	420	550
Protected Equipment BIL (kV)	1425	1550
Line Discharge Class	4	4
Pollution level	II	
Maximum residual voltage with current wave (8/20µs) - at 10kA	850 kV	977 kV
Insulator	Porcelain	
Applicable Standard	IEC60099-4	

Table 15 : Particular Requirement for Surge Arrester

3.4.7 400/500 KV POWER TRANSFORMER

The equipment shall be compliant with IEC 60076 standard.

The auto-transformer is physically smaller and has lower losses than a separate winding transformer for the same throughput power. The relative saving is greater the closer the transformation ratio is to unity. Therefore, the 400/500kV transformer shall be auto-transformer type.

Moreover, to make easier the transportation from factory to the site, single phase auto transformer is more suitable.

Type	Auto Transformer single phase Unit
Rated power ONAN / ONAF / ODAF	100MVA / 130MVA / 170MVA
Number of winding	Two + tertiary for stabilizing
Rated Voltage Primary /Secondary / Tertiary	500 kV / 400 kV / 33 kV
Vector Group	YN a0 + d
Voltage variation/ Tap range/ Nb of Tap	+/-12.5% / 1.25 / 21
Insulation Level / Primary Winding (see note below) Power frequency withstand voltage (lines/neutral) Lightning impulse level (lines/neutral) Switching impulse level	 680/275 kV 1550/650 kV 1300 kV
Insulation Level / secondary Winding (see note below) Power frequency withstand voltage (lines/neutral) Lightning impulse level (lines/neutral) Switching impulse level	 630/275 kV 1425/650 kV 1175 kV
Insulation Level / Primary Winding Power frequency withstand voltage (lines/neutral) Lightning impulse level (lines/neutral)	 95 kV 250 kV
Total Weight / pole (with oil) Transportation Mass	≈160 000 kg ≈100 000 kg

Table 16 : Particular Requirement for Power Transformer

Note : Highest insulation level is selected, but the combination of Power transformer + Surge arrester could reduce the dielectric constraints on the windings and thus lower insulation level could be selected. Insulation Co-ordination must be carried out to settle this point.

3.4.8 LINE AND NEUTRAL REACTORS

The equipment shall be compliant with IEC 60289 standard.

The line reactors are required for compensation of the 500 kV transmission line shunt capacitance to control system over-voltages when energizing the transmission lines.

Single pole switching of the 500 kV power circuit breakers requires the addition of a neutral reactor connected between the neutral bushing of the phase reactor and ground. The neutral reactor is required to reduce the secondary arc current below 20 amps to allow successful single pole re-closing. So each line reactor shall include three single phase reactors and one neutral reactor.

The neutral reactor shall be connected to the neutral open bushing of the phase reactor. The low voltage side of the neutral reactor shall be properly connected to the substation earthing grid.

The line reactor shall be design in two banks of 75MVAr reactors in parallel in order to get more flexibility on the adjustment of reactive power when the future substation of Border will be connected between Mandaya and Kosti. At the construction stage of Border substation, the total length of the OHTL between Mandaya and border will half of the Mandaya – Kosti OHTL, and therefore one bank of line reactor can be removed from Mandaya to be installed in Border substation. (identical arrangement will be performed between Kosti and Border).

	Neutral reactor	Line Reactor (One bank)
Type	One single coil	3 x Single Phase
Applicable standard	IEC60289	
Rated power (MVAR)	20	75
Cooling System	ONAN	ONAN
Rated Voltage	200kV	500 kV
Insulation Level / Primary Winding Power frequency withstand voltage (lines/neutral) Lightning impulse level (lines/neutral) Switching impulse level	 1050/250 kV 850 kV	 680/275 kV 1550/650 kV 1300 kV
Total Weight with oil Total Weight without oil	25 000 kg	90 000 kg 65 000 kg

Table 17 : Particular Requirement for Reactor

3.4.9 Control of the substation

3.4.9.1 General

The Control and Supervision Computerized System (CSCS) general architecture shall be of digital distributed type. All the components of the system shall be independent and interconnected by fibre optic according to the configuration of the substation.

The technical proposal shall provide the most cost efficient solution taking into account the following constraints:

- Minimum cabling and wiring,

- Easy installation,
- User-friendly maintenance tolls,
- User-friendly full graphic human machine interface,
- Compliance to international standard,
- Self-supervision and diagnostic,
- Redundancy and safety operation,
- Step by step implementation,
- Open system architecture.

Inside the substation itself, three main operation levels shall be considered:

1- The substation level:

The substation operation level shall give the operator the means to fully operate, supervise and maintain the whole substation from the workstation of the switchyard control room.

2- The bay level:

In case of SCADA problems or telecommunication system problems, the bay operation level shall give to the operator the means to fully operate only one bay “diameter” at time. Operation on one diameter shall not interfere with the rest of the substation. The local control bay facilities shall operate independently and the CSCS and provide a hard wire bay level Mimic Diagram.

Each Bay level Mimic panel shall symbolically represent the diameter apparatus, the circuit breaker, isolators and earthing switches. The bay level Mimic panels shall group the control and monitoring instruments required for proper operation of the diameter.

The substation and bay levels shall be processed by different microprocessor based systems with one processor for each bay, one communication interface for each bay with a local control panel and one upper processor for the substation level.

3- Device level:

Local operation of particular equipment (circuit breaker, disconnector switches, …) will be possible from equipment cabinet located near the equipment. Earthing switches will be local manual operated only.

Centralized control and supervision of switchgear operation shall be carried out by a CSCS providing the integration of control, protection and monitoring function such as :

- Control and supervision of switching devices of the switchgear circuit beakers, disconnectors and earthing switches,
- Automatic switching device,
- Operator’s workstation with video display unit, keyboard and functions required to control and supervise the substation
- Alarm view with operator help
- Standardized display of measurements curves,
- Alarm functions, storage and evaluation of time stamped events

- Status event recorder intended to chronologically record faults, operating orders and position changes occurring on site, providing a written record of events subsequent analysis (incident and post incident analysis),
- Monitoring and display of the analog values (current, voltage, frequency, power, …) of feeder and busbar,
- Calculation of the power consumed or generated for each energy meter device and execution of power balance check,
- Protection monitoring (status, events, measurements, faults measurements, parameters, ….)
- Disturbance recording, they record simultaneously the instantaneous values of currents, residual currents and voltages, shortly before and after the fault with some logical tracks (ex : actuating distance protections)
- Fault Locator recording and evaluation
- Storage of historical process data
- Communication between bay and station level via a serial fibre optics bus, time synchronization: the CSCS and other equipment shall be synchronized by a common time reference (a master clock given by a GPS).

3.4.9.2 Protection system and metering

Main features :

The system of protection for substation is based on the principle of local back up. In other terms, any fault occurring anywhere on an outgoing line, generator bays (Mandaya HPP) or on the bus bars should be detected and cleared locally by the relays and circuit breakers located in the substation concerned, before the distance protection or back up relays located in the second zone, and controlled by adjacent substation can be operated. This should be the case under normal operating conditions or in the event of the failure of one element of the protective system (i.e. the failure of a relay , circuit breaker, circuitry instrument, battery, etc, ….)

All the equipment should be conformed with IEC standards where applicable. In order to ensure the efficient functioning of the system, and mainly because of the utilization of digital protections and other static facilities, it is necessary to take precautions to protect the equipments against transients or surges transmitted by instrument transformer circuit. For this purpose, the ITs shall be compliant with the clause 11.1 of IEC 60044-2.

The substation is organized with a centralized control and telecommunication building for the whole site to shelter all the bays: lines, transformers, bus bars, etc …

The protection system must clear the fault :

- in 110ms for local end line faults
- in 80 ms for the busbar protection

In the event of a failure to interrupt fault current by the line CB's, the circuit breaker fail protection trips all the necessary adjacent circuit breakers within 200 ms starting from the fault occurrence.

The protection plan for the switchyard is described on the single line protection jointed in annex 1.5.

For overhead line, busbar and diameter, two numerical protection (main 1 and main 2) will ensure the redundant protection scheme:

- The protection is connected on different protection windings
- Every protection will act on a separate trip coil basis
- The DC supply will be provided by two different battery.
- The circuit breaker tripping device will be supplied from 2 different circuits.

Bay control Unit

All protective relaying cubicles will be monitored by a bay controller using one communication interface which will be connected to the SCADA system.

Each bay includes the following independent and dedicated equipment:

- Bay Control Unit (BCU),
- Bay level Mimic Panel (one per diameter) with their commands and display of measurements and signals for all the switchyard apparatus and auxiliaries,
- Protective devices (main, back-up)
- Automatic control equipment
- metering and measuring devices,
- I/O, A/D and modules for the interface with the HV level.
- Alarm window. Each alarm event shall activate a lighting indicator so as to warm the shift operators in case of problem and inform about the cause of the problem
- Local warning devices in case of fault (horn and/or blinking light)

Line feeder protection

The line protection scheme depends on the protection scheme of the Transmission Operator and also telecommunication means (OPGW or PLC).

Main protection: provided by two numerical distance protections will be installed and will assure the redundancy. The protection will operate independently ad in parallel, single and three pole tripping.

The protection will be coordinated with other zone protections, in order to assure a selective and fast elimination for all type of fault, this will contribute to maintain the network stability.

A protection against the resistance faults (zero-sequence current with inverse time characteristic) will complete the system of protection line for the elimination of the fault that could not be detectetd by the other relays.

Distance protection (ANSI 21)

The distance protection used as main 1 and main 2 shall have five zones protection for all types of faults are provided, four of which directional zones (ANSI 67), and one which non-directional zone. This relay shall include a power swing blocking, switch on to fault and fuse failure blocking facilities.

The two protection (Main 1 & 2) will be of different design and compliant with IEC 60255-16.

Backup protection (ANSI 67N)

A back-up function is ensured by redundancy of the main protections. In the event of high resistance faults being tackled within transmission lines, a directional earth fault protection in a directional comparison scheme using zero sequence current Io and zero voltage Vo values and inverse time curve will be provided.

Autorecloser with synchro-check (ANSI 79 + 25)

The auto recloser allows the automatic reclosure of the circuit breaker after its opening. The autorecloser may be activated by the main and back-up protections. It will be possible to select the following modes of auto reclosing:

- Single pole reclose
- Three pole reclose
- Reclose off

The recloser is high speed, first shoot for single phase and three phase reclosing and further delayed multiple shoot for three phase reclosing. After reclosing, shoot is given reclosing is blocked for duration of reclaim time adjustable 30 to 300 s. If a fault happens within the reclaim time, protection will issue three phase tripping and recloser will lockout.

When evolving fault is detected during single phase reclosing cycle, line protection will issue three phase trip command and lock-out.

This auto recloser may be dependent of a synchro-check. The synchro-check realizes the synchronism check function and the energizing check function for the three poles autoreclosing sequence.

Diameter protection

Diameter connection protection (ANSI 87D)

The connection between the three CT of outgoing bay shall be protected by two independent differential protections (ANSI 87D).

The type of the protection recommended shall be a three winding digital differential protection percentage restrain to detect phase to phase and phase to ground faults. This protection can be connected directly on main CT's having wide range of different ratios and characteristics

Bus bar protection

Differential protection (ANSI 87 BB)

Each bus bar shall be protected by two independent bus bar protections main 1 and main 2 (ANSI 87 BB). Bus bar protection merits a very careful attention because bus are faults are the most serious that can occur within an electrical system.

The type of the protection recommended shall be a digital differential protection percentage restrain to detect phase to phase and phase to ground faults. This protection can be connected directly on main CT's having wide range of different ratios and characteristics

Breaker failure (ANISI 50BF)

A breaker failure protection (ANSI 50 BF) to detect misoperation of the circuit breaker to trip is required and must act selectively and give out a trip to all connected circuit breaker on the defect busbar, working with the bus bar isolator replicas

Power transformer Protection

Transformer overheating protection (ANSI 49T)

This protection is designed to protect the transformer against overheating. The function shall be provided by relay using the resistance variation of the temperature probe. The relay shall take into consideration the failure of the probe and associated links.

Restricted earth fault (ANSI 64RF)

The purpose of this protection is to detect grounding fault in high voltage windings with a grounded neutral point in the transformer. This function shall be performed from differential protection that shall be connected to three phase current transformers and one neutral current transformer.

This protection shall be insensitive to faults outside of its supervision zone and shall supply the stabilization device and the ratio and phase compensation device needed.

Transformer differential protection (ANSI 87T)

The purpose of this protection is to detected any multiphase faults in the power transformer. This function shall be performed from a differential protection. This protection shall be insensitive to fault outside of its supervision zone and shall supply the stabilization device and the ratio and phase compensation device needed

Buchholz protection (ANSI 95 T)

The purpose of this equipment is to detect faults in the transformer causing a more or less extensive gas release, caused by the decomposition of the liquid insulant.

The fault information shall be generated by contacts corresponding to:

- a 1st step fault
- a 2nd step fault

In case of 2nd fault is detected, this protection shall trip the transformer fire protection (spray of water).

Reactor Protection

Reactor differential protection (ANSI 87R)

The purpose of this protection is to detect any multiphase faults. This function shall be performed from a differential protection. All necessary tripping relays associated with the reactor, should be provided e.g:

- Buchholz protection (ANSI 95T)
- Oil temperature sensors. (ANSI 49T)
- Winding temperature sensors. (ANSI 49T)

Overcurrent Protection (50/50 N – 51 N)

These relays used as back-up protection. The overcurrent protection device installed on HV and neutral connection, as a back-up protection, shall be a digital independent relay element able to measure ph -to -ph and ph- to- earth faults.

Metering

High accuracy metering will take place on 500 & 400kV outgoing lines feeders. Meters measuring and recording the exchange of active and reactive power will be provided for each bay. These instruments will measure the sum of the transfer on each bay and will record the power and energy transported in both directions.

For HPP Mandaya feeders, the metering is located on MV side (out of scope).

The metering shall be in accordance with IEC 62052-22 fully solid state meter type, mounted in the same enclosure measuring three-phase current – four-wire network.

Revenue metering and transducers will be provided with the following accuracy class: 0.2S.

The transducer will be of the latest state of the art solid state technology. It will comply with the latest international standards and, at least, mandatory to the IEC 60688 publication.

4 KOSTI SUBSTATION

4.1 MAIN ELECTRICAL SCHEME AND LAYOUT

The global arrangement of the 500kV substation consists on three yards, one for the HV 500kV switchgear equipments, one for HVDC and one for the Static Voltage Compensator.

The 500kV substation is an outside double busbar arrangement with one and half circuit breaker. Drawings of the bus section and line feeders arrangement as well as single line diagram of the 500kV substation are given in appendix 2.

4.2 FUNDAMENTAL REQUIREMENTS FOR THE SUBSTATION

4.2.1 ELECTRICAL REQUIREMENT

4.2.1.1 Methods of neutral earthing

The neutral earthing of the Sudanese system is **solid (low impedance) earthing**.

4.2.1.2 Voltage classification

According to the network studies, Module M1 phase II, the maximum operating voltage of the substation is 523kV. Pursuant the network studies, the standardized values of the highest voltage for equipment are given in here after (extraction from IEC 61936-1, annex A).

Nominal voltage of the system	Un (RMS, kV)	500 (+/-5%)
Highest voltage for equipment	Um (RMS, kV)	550

Table 18 : Voltage Classification

4.2.1.3 Current in normal operation

According to the network studies, Ethiopia could export 4 x 828MW to Sudan through 4 circuits in 2020.

The incoming powers connected to the 500kV bus bar in Kosti substation are

4 x 788 MW from Mandaya substation

1 x 400 MW from Eula Sustation.

Tripping situation

In case of tripping on one of the four line feeders from Mandaya (N-1 situation), the load is transferred on the three reaming circuits. The load on each circuit is therefore 1050 MW.

In case of tripping on one power plant on the Sudanese system (530MW), additional power up to 200MW will flow from Mandaya

Pursuant to these figures on incoming power, the normal operation current on 500kV substation is calculated hereafter.

	Nominal voltage (kV)	Min Voltage (kV)	Power (MW)	Nb circuit normal situation	Nb circuit N-1	Max Continuous operating current / circuit (A)
Mandaya - Kosti circuits	500	475	3152	4	3	1277
Bus bar	500	475	3752	2	1	4560
HVDC converter bay	500	475	2150	1	1	2613

Table 19 : Calculation of the Max. operating Current

4.2.1.4 Rated current

		Rated current (A)		
	Max Continuous operating current / circuit (A)	switchgear	CT	line trap
Mandaya - Kosti circuits	1277	3150	1500	2000
Bus bar	4560	5000	5000	NA
HVDC bay	2613	3150	3000	NA
SVC bay	692	3150	1500	

Table 20 : Specification of the Rated Current

4.2.1.5 Short circuit Current

According to the network studies, the three phases short circuit current is fixed at 31.5kA/1s.

4.2.1.6 Rated frequency

The existing Ethiopian and Sudan network are design for 50Hz.

4.2.2 MECHANICAL REQUIREMENT

The wind load shall be taken in account in the design for the mechanical withstand of the structures.

According to the design study of overhead transmission lines (Phase II, M4, sub part Overhead line), the wind reference is 110km/h or 30m/s.

In addition, IEC 60694 contains requirements for wind loading on switchgear and controlgear: the wind speed does not exceed 34 m/s , corresponding to 700 Pa on cylindrical surfaces.

We propose to make reference to IEC 60694 for the calculation of the mechanical strengths. Thus the wind reference is fixed at 34m/s.

4.2.3 CLIMATIC AND ENVIRONNEMENTAL CONDITIONS

Pursuant on the data collection on existing standard in Sudan, the meteorological conditions for the design are :

Maximum ambient temperature	50 ° C
Minimum ambient temperature	0 ° C
Mean Temperature °C	30 ° C
Maximum Conductor temperature	90 °C
Minimum Conductor temperature	5 °C
Reference wind speed (IEC 60694)	34m/s
Mean annual Rainfall	14 mm
Humidity	100 %
Pollution	31 mm/kV (class IV)
Altitude	<1000m

Table 21 : Climatic and Environmental Conditions

Special climatic and environmental conditions

Due to the location of the substation (desert zone in vicinity), special attention shall be taken on the design of the insulators. Sand together with humidity can affect the dielectric withstand of the electrical equipment. Pollution class and material (porcelain or synthetic) shall be fixed as a result of the feed back from the Sudanese network.

Special scheduled maintenance tasks (insulators cleaning) can be carried out to reduce flashovers occurrences.

4.3 INSULATION REQUIREMENTS

4.3.1 INSULATIONLEVEL

Insulation coordination shall be in accordance with IEC 60071-1.

Nominal voltage of the system	Highest voltage for equipment	Rated short duration Power frequency withstand voltage	Rated switching impulse withstand voltage	Rated lightning impulse withstand voltage	
Un (RMS, kV)	Um (RMS, kV)	Phase/earth (RMS, kV)	250/2500µs (Peak value, kV)	Phase to earth 1.2/50µs (peak Value, kV)	Phase to Phase 1.2/50µs (peak Value, kV)
500	550	620	1175	1550	1550 (+315)

Table 22 : Insulation Coordination

4.3.2 Minimum Clearance

Same as Mandaya 500kV (§ 3.3.2.)

4.4 Particular Requirements for Equipments

4.4.1 Substation Level

The substation shall be equipped with air insulated outdoor switchgear. It shall be of one and half circuit breaker outside bus bar arrangement type.

Refer to the single line diagram; Drawings Annex 2.

The main features of the 500kV substation are:

- 4 incoming feeders from Mandaya 500kV substation
- 2 outgoing feeders to Fula substation
- 2 outgoing feeders to HVDC switchyard
- 1 outgoing feeders to SVC switchyard
- 6 diameters, each of them includes 3 circuit breakers.
- 2 external bus bars.
- 1 central control building including the control and supervision System, relay protections.

Item (3 poles)	Number
Circuit breaker	18
Pantograph Disconnector + earthing switch	14
Two column Disconnector + earthing switch	46
CT oil type (3000 A or 1500A)	34
CT tore type	6
Capacitor Transformer	8
Surge Arrester	14
Bus bar reactor (50MVA)	4
Line Reactor (75MVA)	4
Neutral reactor	4
Line Trap	6

Table 23 : Total Number of HV equipMent

Item	**Number**
Bus bar protection (87B-1, 50BF)	4
HVDC protection (87L)	2
SVC protection (87L)	1
Line protection (21-1, 18, 79)	12
Diameter protection (87D, 67/67N, 50BF)	12
Shunt Reactor protection (87R, 67/67N, 63)	8
Neutral Reactor protection (87R, 63,50N)	4

Table 24 : Total Number of LV Equipment

4.4.2 CIRCUIT BREAKER

4.4.2.1 Requirements

The circuit breaker shall be compliant with IEC 62271-100.

Operating mechanisms shall be motor-operated spring-charged, pneumatic or hydraulic types with DC shunt coils for tripping and closing and suitable for local control and remote control.

The circuit breaker supporting structure shall be galvanized and shall comply with the related clause.

Type	SF6 Gas, outdoor, live-tank, single pressure
Rated Voltage (kV)	550 kV
Number of Interrupter per Pole	Minimum 2
Rated Frequency (Hz)	50
Rated normal current (A) Bus bar /others	5000/3150
Rated short time waistband current (kA)	31.5
Making Capacity (kA peak)	100
Breaking Time (cycles)	2
Operating mechanism	Hydraulic, Spring or Pneumatic
Operating sequence	O+0.3s+CO+1min-CO
Type of tripping	Single-pole & Three-pole
Pollution class	IV
Insulator	Porcelain
Applicable Standard	IEC 62271-100 & IEC 60694
18-Power Frequency Wisthstand Voltage Phase to earth Between phases or Acrosss open switching device and isolated distance	 620 800
Mechanical endurance	M1

Table 25 : Particular Requirement for Circuit Breaker

4.4.3 DISCONNECTOR AND EARTHING SWITCH

Discornnector shall be compliant with IEC 62271-102 standard.

Type Bus bar connection Other	 Single column Pantograph Two – column, rotary
Rated Voltage (kV)	550
Rated Current (A) Busbar/others	5000/3150
Rated short time withstand current (kA)	31.5
Lightning Impulse Withstand Voltage-to Earth (kV) Phase to earth Across open switching device	1550 1550 (+315)
Power Frequency Withstand Voltage-to Earth (kV) Phase to earth Across open switching device	620 800
Switching Impulse Withstand Voltage-to Earth (kV) Phase to earth Across isolating distance	1175 900 (+450)
Operating Mechanism - Main Blade - Earthing Blades	 Single-pole/motor Single-pole/manual
Pollution level	IV
Insulator	Porcelain
Applicable Standard	IEC 62271-102 & IEC 60694
Electrostatic coupling induced current (A)	25
Electrostatic coupling induced voltage (kVrms)	25
Electromagnetic coupling induced current (A)	20
Electromagnetic coupling induced voltage(kVrms)	160
Mechanical endurance	M0

Table 26 : Particular Requirement for Disconnector

4.4.4 CURRENT INSTRUMENT TRANSFORMER

The equipment shall be compliant with IEC 60044-1

The instrument transformers shall be outdoor, oil filled, porcelain insulator housing.

The instrument transformer supporting structures shall be galvanised and shall comply with the related Clause.

Type	Outdoor, single phase, oil filled
Highest System Voltage(kV)	525[3]
Power Frequency Withstand Voltage dry/wet (kV)	680
Lightning Impulse Withstand Voltage (kV)	1550
Switching impulse withstand voltage(kV)	1175
Primary short circuit current Ipsc (kA)	31.5
Primary rated current Bus bar AC/DC converter Line feeder	 5000 3000 1500
Pollution level	II
Insulator	Porcelain
Applicable Standard	IEC60044-1
Accuracy Class Protection Measurement	 5P20 0.2

Table 27 : Particular Requirement for Current Transformer

4.4.5 CAPACITOR INSTRUMENT TRANSFORMER

The equipment shall be compliant with IEC 60044-5

The instrument transformers shall be outdoor, oil filled, porcelain insulator housing.

The instrument transformer supporting structures shall be galvanized and shall comply with the related clauses.

[3] 550kV does not exist in IEC 60044-1.

According to the network study, over voltage can rise up to 130% of the rated voltage during 300ms when one tripping occur on the SVC. Therefore, the rated voltage factor of the CVT shall be design upon this transient phenomenon.

Type	Outdoor, single phase, oil filled
Highest System Voltage (kV)	525[4]
Power Frequency Withstand Voltage dry/wet (kV)	680
Lightning Impulse Withstand Voltage (kV)	1550
Switching impulse withstand voltage(kV)	1175
Rated secondary voltage	100/√3
Pollution level	IV
Insulator	Porcelain
Applicable Standard	IEC60044-5
Accuracy Class Protection Measurement	 3P 0.2
Ferro resonance suppression device	Damping Circuit
Rated voltage factor	1.5/30s

Table 28 : Particular Requirement for Capacitor Instrument Transformer

4.4.6 SURGE ARRESTER

The equipment shall be compliant with IEC 60099-4 standard

The surge arresters supporting structures shall be galvanised and shall comply with the related Clause.

[4] 550kV does not exist in IEC 60044-5

Type	Outdoor, ZnO
System Voltage (kV)	500
Rated Voltage (kV)	420
Maximum System Voltage (kV)	550
Protected Equipment BIL (kV)	1550
Line Discharge Class	4
Pollution level	IV
Insulator	Porcelain
Applicable Standard	IEC60099-4

Table 29 : Particular Requirement for Surge arrester

4.4.7 Line and Neutral Reactors

The equipment shall be compliant with IEC 60289 standard.

The line reactor shall be design in two banks of 75MVAR reactors in parallel (see §3.4.8)

	Neutral reactor	Line Reactor (One bank)
Type	One single coil	3 x Single Phase
Applicable standard	IEC60289	
Rated power (MVAR)	20	75
Cooling System	ONAN	ONAN
Rated Voltage	200kV	500 kV
Insulation Level / Primary Winding Power frequency withstand voltage (lines/neutral) Lightning impulse level (lines/neutral) Switching impulse level	 1050/250 kV 850 kV	 680/275 kV 1550/650 kV 1300 kV
Total Weight with oil Total Weight without oil	25 000 kg	90 000 kg 65 000 kg

Table 30 : Particular Requirement for Reactor

4.4.8 PROTECTION SYSTEM AND METERING

Meters, line and bus bar relay protection are similar as those given for Mandaya substation (Refer to 3.4.9.2.)

HVDC and SVC protection

Current differential line protection (87L)

The primary protection shall be:

- A current differential line protection providing fast and selective detection of all types of faults, including resistive faults.
- The differential relays should be phase-by-phase with variable percentage restraint characteristics as a function of current amplitude and immune to power swing phenomenon.
- A local starting ensured by relays using symmetrical components (maximum zero sequence current, maximum negative sequence current, maximum positive sequence current, maximum zero sequence voltage, maximum negative sequence voltage, minimum positive voltage and minimum positive sequence impedance) should be provided.

5 NAG HAMMADI SUBSTATION

5.1 MAIN ELECTRICAL SCHEME AND LAYOUT

The global arrangement of the 500kV substation consists on two yards, one for the HV 500kV switchgear equipments, one for the DC/AC converter.

The 500kV substation is an outside double busbar arrangement with double circuit breaker. This arrangement has been selected to comply with the existing substations.

Drawings of the bus section and line feeders' arrangement as well as single line diagram of the 500kV substation are given in appendix 3.

5.2 FUNDAMENTAL REQUIREMENTS FOR THE SUBSTATION

Installations and equipment shall be capable of withstanding electrical, mechanical, climatic and environmental influences anticipated on site.

5.2.1 ELECTRICAL REQUIREMENT

5.2.1.1 Methods of neutral earthing

The neutral earthing of the Egyptian system is **solid (low impedance) earthing**.

5.2.1.2 Voltage classification

According to detailed network studies presented in Module 1, the maximum operating voltage of the substation is 518kV. Pursuant the network studies, the standardized values of the highest voltage for equipment are given in here after (extraction from IEC 61936-1, annex A).

Nominal voltage of the system	Un (RMS, kV)	500 (+/- 5%)
Highest voltage for equipment	Um (RMS, kV)	550

Table 31 : Voltage Classification

5.2.1.3 Current in normal operation

According to detailed network studies presented in Module 1, Sudan could export 2150MW to Sudan through one DC bipolar line .

The incoming powers connected to the 500kV bus bar in Nag Hammadi substation are

2000 MW from Kosti substation (DC line)

1500 MW flowing from Egyptian system

Tripping situation

None in the scope of this study

Pursuant to these figures on incoming power, the normal operation current on 500kV substation is calculated hereafter.

	Nominal voltage (kV)	Min Voltage (kV)	Power (MW)	Nb circuit normal situation	Nb circuit N-1	Max Continuous operating current / circuit (A)
Egytian system	500	475	1500	Out of scope	Out of scope	Out of scope
Bus bar	500	475	3500	2	1	4254
DC/AC converter bay	500	475	2000	1	1	2431

Table 32 : Calculation of the max. Operating Current

		Rated current (A)		
	Max Continuous operating current / circuit (A)	Switchgear	CT	Line trap
Bus bar	4254	5000	5000	NA
DC/AC converter bay	2431	3150	2500	NA

Table 33 : Specification of the Rated Current

5.2.1.4 Short circuit Current

According to the network studies, the three phases short circuit current is fixed at **40kA/1s**[5].

5.2.1.5 Rated frequency

The existing Ethiopian and Sudan network are design for 50Hz.

5.2.2 MECHANICAL REQUIREMENT

The wind load shall be taken in account in the design for the mechanical withstand of the structures.

According to the design study of overhead transmission lines (Phase II, M4, sub part Overhead lines), the wind reference is 110km/h or 30m/s.

In addition, IEC 60694 contains requirements for wind loading on switchgear and controlgear: the wind speed does not exceed 34 m/s , corresponding to 700 Pa on cylindrical surfaces.

We propose to make reference to IEC 60694 for the calculation of the mechanical strengths. Thus the wind reference is fixed at 34m/s.

[5] 31.5kA could be suitable according to M1 studies.

5.2.3 CLIMATIC AND ENVIRONNEMENTAL CONDITIONS

Pursuant on the data collection on existing standard in Egypt, the meteorological conditions for the design are :

Maximum ambient temperature	50 ° C
Minimum ambient temperature	0 ° C
Mean Temperature °C	30 ° C
Maximum Conductor temperature	90 °C
Minimum Conductor temperature	5 °C
Reference wind speed (IEC 60694)	34m/s
Mean annual Rainfall	14 mm
Humidity	100 %
Pollution	31 mm/kV (class IV)
Altitude	<1000m

Table 34 : Climatic and Environmental Conditions

Special climatic and environmental conditions

Due to the location of the substation (desert zone in vicinity), special attention shall be taken on the design of the insulators. Sand together with humidity can affect the dielectric withstand of the electrical equipment. Pollution class and material (porcelain or synthetic) shall be fixed as a result of the feed back from the Egyptian network.

Special scheduled maintenance tasks (insulators cleaning) can be carried out to reduce of flashovers occurrences.

5.3 INSULATION REQUIREMENTS

5.3.1 INSULATION LEVEL

Insulation coordination shall be in accordance with IEC 60071-1

Nominal voltage of the system	Highest voltage for equipment	Rated short duration Power frequency withstand voltage	Rated lightning impulse withstand voltage	Rated switching impulse withstand voltage	
Un (RMS, kV)	Um (RMS, kV)	Phase/earth (RMS, kV)	1.2/50µs (Peak value, kV)	Phase to earth 250/2500µs (peak Value, kV)	Phase to Phase 250/2500µs (peak Value, kV)
500	550	620	1175	1550	1550 (+315)

Table 35 : Insulation Coordination

5.3.2 MINIMUM CLEARANCE

Refer to Mandaya substation (§3.3.2)

5.4 PARTICULAR REQUIREMENTS FOR EQUIPMENT

5.4.1 SUBSTATION LEVEL

The 500 and 400 kV substations shall be equipped with air insulated outdoor switchgear. It shall be of double circuit breaker configuration and outside bus bar arrangement type.

The main features of the substation are:

- 2 incoming feeders from HVDC switchyard
- 1 outgoing feeders to the Egyptian system
- 2 diameters, each of them includes 2 circuit breakers.
- 2 external bus bars.
- 1 central control building including the control and supervision system, relay protections.

Item (3 poles)	Number
Circuit breaker	3
Pantograph + Earthing Switch	6
Two column Rotary + earthing switch	9
CT oil type (3000 A or 1500A)	9
Capacitor Transformer	5
Surge Arrester	1
Line trap	1

Table 36 : total number of HV equipments

Item	Number
Bus bar protection (87B, 50BF)	4
Bus control Panel	1
HVDC protection (87L)	2
Line protection (21-1, 21-2, 18, 79	4
Diameter protection (87D 67/67N, 50BF)	6

Table 37 : Total Number of LV Equipment

5.4.2 CIRCUIT BREAKER

5.4.2.1 Requirements:

The circuit breaker shall be compliant with IEC 62271-100.

Operating mechanisms shall be motor-operated spring-charged, pneumatic or hydraulic types with dc shunt coils for tripping and closing and suitable for local control and remote control.

The circuit breaker supporting structure shall be galvanised and shall comply with the related clause.

Type	SF6 Gas, outdoor, live-tank, single pressure
Rated Voltage (kV)	550 kV
Number of Interrupter per Pole	Minimum 2
Rated Frequency (Hz)	50
Rated normal current (A) Bus bar /others	5000/3150
Rated short time waistband current (kA)	40
Making Capacity (kA peak)	100
Breaking Time (cycles)	2
Operating mechanism	Hydraulic, Spring or Pneumatic
Operating sequence	O+0.3s+CO+1min-CO
Type of tripping	Single-pole & Three-pole
Pollution class	IV
Insulator	Porcelain
Applicable Standard	IEC 62271-100 & IEC 60694
18-Power Frequency Wisthstand Voltage Phase to earth Between phases or Acrosss open switching device and isolated distance	 620 800
Mechanical endurance	M1

Table 38 : Particular Requirement for Circuit breaker

5.4.3 Disconnector and Earthing Switch

Discornnector shall be compliant with IEC 62271-102 standard.

Type Bus bar connection Other	Single column Pantograph Two – column, rotary
Rated Voltage (kV)	550
Rated Current (A) Busbar/others	5000/3150
Rated short time withstand current (kA)	40
Lightning Impulse Withstand Voltage-to Earth (kV) Phase to earth Across open switching device	1550 1550 (+315)
Power Frequency Withstand Voltage-to Earth (kV) Phase to earth Across open switching device	620 800
Switching Impulse Withstand Voltage-to Earth (kV) Phase to earth Across isolating distance	1175 900 (+450)
Operating Mechanism - Main Blade - Earthing Blades	Single-pole/motor Single-pole/manual
Pollution level	IV
Insulator	Porcelain
Applicable Standard	IEC 62271-102 & IEC 60694
Electrostatic coupling induced current (A)	25
Electrostatic coupling induced voltage (kVrms)	25
Electromagnetic coupling induced current (A)	20
Electromagnetic coupling induced voltage(kVrms)	160
Mechanical endurance	M0

Table 39 : Particular Requirement for Disconector

5.4.4 CURRENT INSTRUMENT TRANSFORMER

The equipment shall be compliant with IEC 60044-1

The instrument transformers shall be outdoor, oil filled, porcelain insulator housing.

The instrument transformer supporting structures shall be galvanised and shall comply with the related Clause.

Type	Outdoor, single phase, oil filled
Highest System Voltage(kV)	525[6]
Power Frequency Withstand Voltage dry/wet (kV)	680
Lightning Impulse Withstand Voltage (kV)	1550
Switching impulse withstand voltage(kV)	1175
Primary short circuit current Ipsc (kA)	40
Rated primary current (A) Busbar / others	5000/2500
Pollution level	IV
Insulator	Porcelain
Applicable Standard	IEC60044-1
Accuracy Class Protection Measurement	 5P20 0.2

Table 40 : Particular Requirement for Current Transformer

5.4.5 CAPACITOR INSTRUMENT TRANSFORMER

The equipment shall be compliant with IEC 60044-5

The instrument transformers shall be outdoor, oil filled, porcelain insulator housing.

The instrument transformer supporting structures shall be galvanised and shall comply with the related Clause.

According to the network study, over voltage can arise up to 130% of the rated voltage within 300ms when one tripping occur on the SVC. Therefore, the rated voltage factor of the CVT shall be design upon this transient phenomenon.

[6] 550kV does not exist in IEC 60044-1.

Type	Outdoor, single phase, oil filled
Highest System Voltage(kV)	525[7]
Power Frequency Withstand Voltage dry/wet (kV)	680
Lightning Impulse Withstand Voltage (kV)	1550
Switching impulse withstand voltage(kV)	1175
Rated secondary voltage	100/√3
Pollution level	IV
Insulator	Porcelain
Applicable Standard	IEC60044-5
Accuracy Class Protection Accuracy Class Measurement	3P 0.2
Ferro resonance suppression device	Damping Circuit
Rated voltage factor	1.5/30s

Table 41 : Particular Requirement for Capacitor Voltage Transformer

5.4.6 SURGE ARRESTER

The equipment shall be compliant with IEC 60099-4 standard.

The surge arresters supporting structures shall be galvanized and shall comply with clauses:

Type	Outdoor, ZnO
System Voltage (kV)	500
Rated Voltage (kV)	420
Maximum System Voltage (kV)	550
Protected Equipment BIL (kV)	1550
Line Discharge Class	4
Pollution level	IV
Insulator	Porcelain
Applicable Standard	IEC60099-4

Table 42 : Particular Requirement for Surge Arrester

5.4.7 PROTECTION SYSTEM AND METERING

Characteristics of the protection devices are identical to those specified for Kosti substation (§ 4.4.8)

[7] 550kV does not exist in IEC 60044-5.

6 SPARE PARTS

The recommended spare parts for emergency or corrective maintenance purpose are listed hereafter. These spare parts, stored in a warehouse nearby the substation, are at any contractor the disposal for trouble shouting.

The spare parts for preventive or conditional maintenance as well as consumable material are excluded. These materials shall be procured under maintenance contract with the manufacturer of the HV equipment. Outsourced maintenance will be detailed at the final stage of the design study.

6.1 SPARE PARTS FOR MANDAYA SUBSTATION

Item	Number	
HV equipment: single pole	500kV	400kV
Circuit breaker	1	1
Pantograph Disconnector + Earthing switch	3	3
Two column Rotary Disconnector + earthing switch	3	3
Current Transformer (oil type)	1	1
Current Transformer (Tore type)	1	1
Capacitor Transformer	1	1
Surge Arrester	1	1
Line Reactor (2 x 75MVA)	1	0
Neutral Reactor (single pole)	1	0
Line trap	1	1
Bus bar protection (87B, 50BF)	1	0
Diff power transformer + bay controler (87T, 63, 18)	1	0
Line protection (21)	1	0
Diameter protection (87D, 67/67N, 50BF)	1	0
Reactor protection (87R-1, 67/67N, 63)	1	0

Table 43 : Spare parts for Mandaya Substation

6.2 SPARE PARTS FOR KOSTI SUBSTATION

Item	Number
HV equipment : Single pole	
Circuit breaker	1
Pantograph Disconnector + Earthing switch	3
Two column Rotary Disconnector + earthing switch	3
CT oil type (3000 A or 1500A)	1
CT tore type	1
Capacitor Transformer	1
Surge Arrester	1
Bus bar reactor (50MVA)	1
Line Reactor (75MVA)	1
neutral reactor	1
Line Trap	1
LV equipment	
Bus bar protection (87B-1, 87B-2, 50BF)	1
HVDC protection (87L)	1
Line protection (21-1 , 79)	1
Diameter protection (87D, 67/67N, 50BF)	1
Reactor protection (87R-1, 67/67N, 63)	1

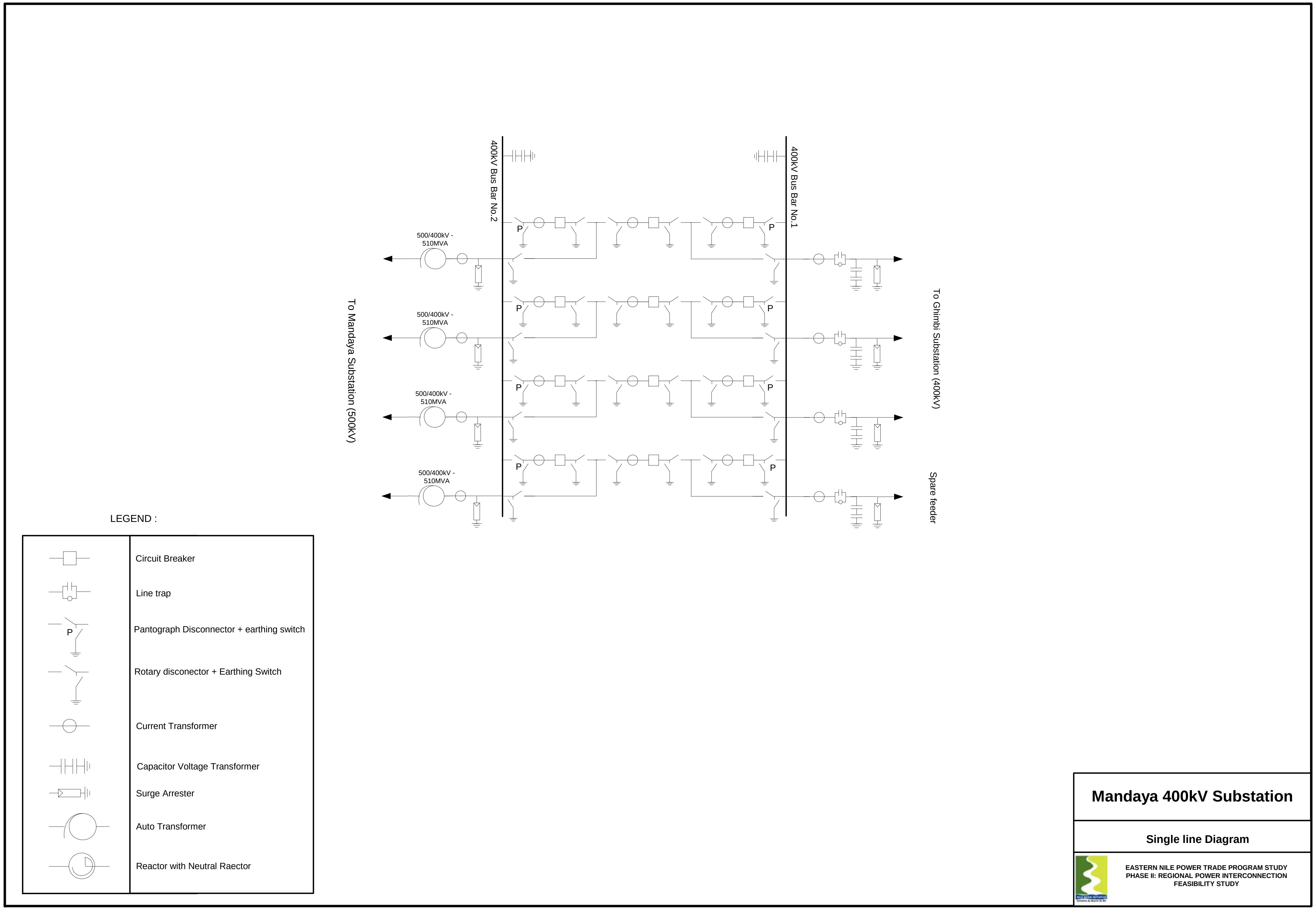
Table 44 : Spare Parts for Kosti Substation

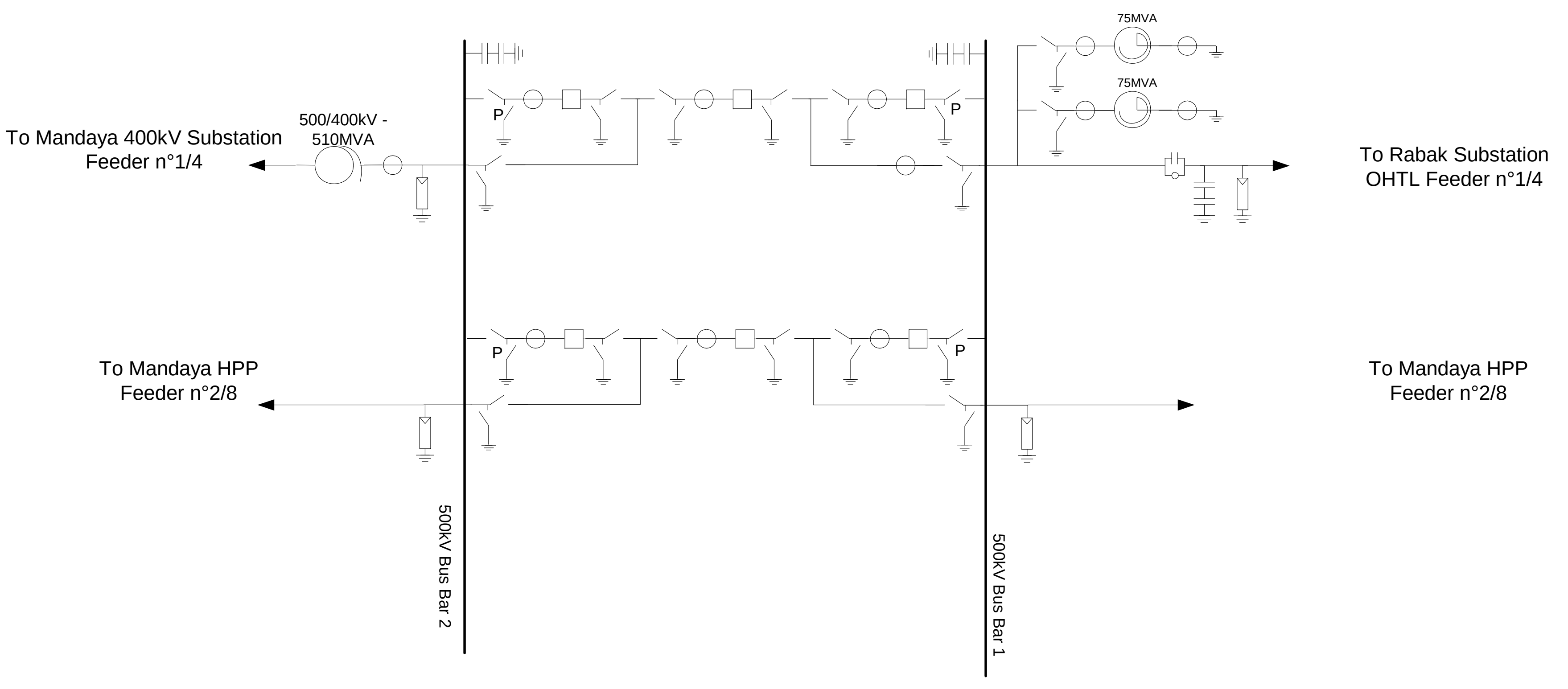
6.3 SPARE PARTS FOR NAG HAMMADI SUBSTATION

Item	Number
HV equipment : single pole	
Circuit breaker	1
Pantograph Disconnector + Earthing switch	3
Two column Rotary Disconnector + earthing switch	3
CT oil type (3000 A or 1500A)	1
CT tore type	0
Capacitor Transformer	1
Surge Arrester	1
Line trap	1
LV equipment	
Bus bar protection (87B, 50BF)	1
HVDC protection (87L)	1
Line protection (21-1, 18, 79	1
Diameter protection (87D 67/67N, 50BF)	1

Table 45 : Spare Parts for Nag Hammadi Substation

Appendix 1: Main Electrical Scheme of Mandaya Substation





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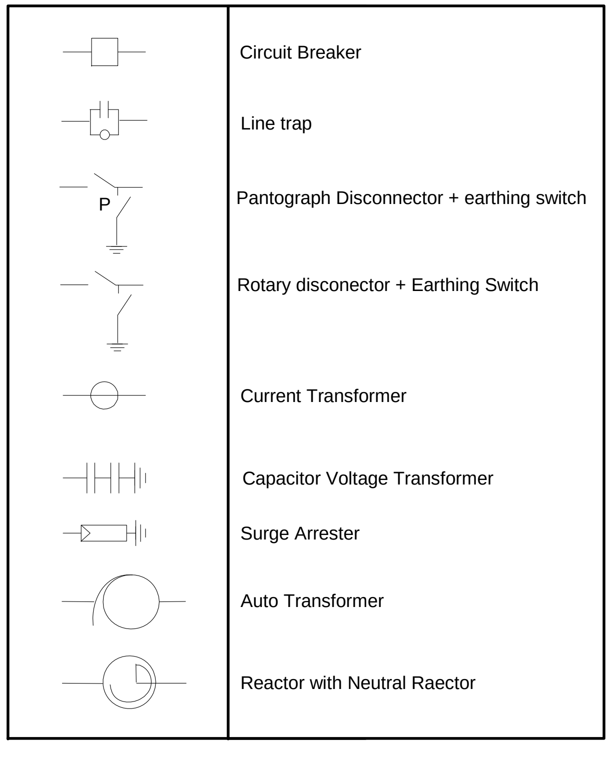
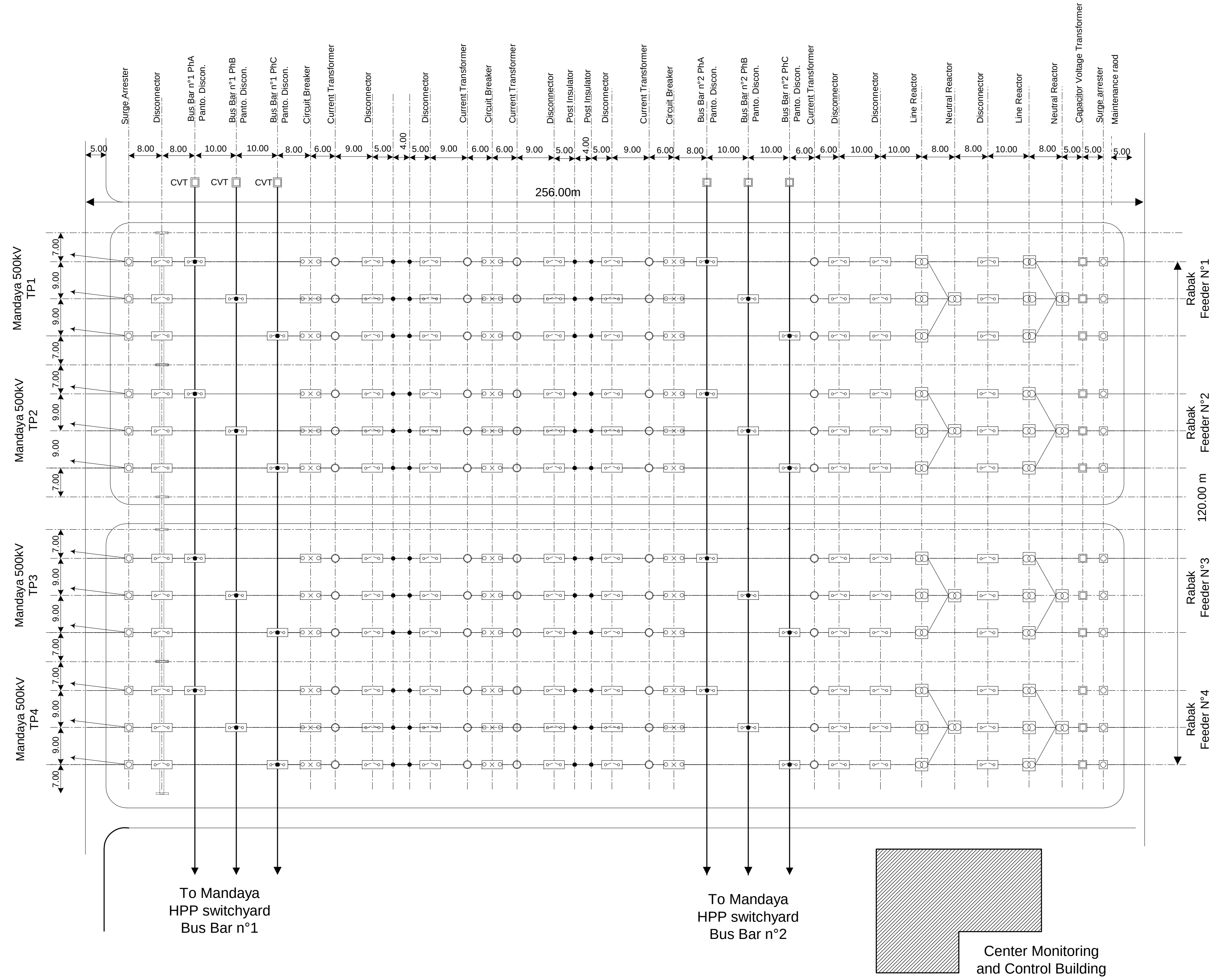


Mandaya 500kV Substation

Single line Diagram

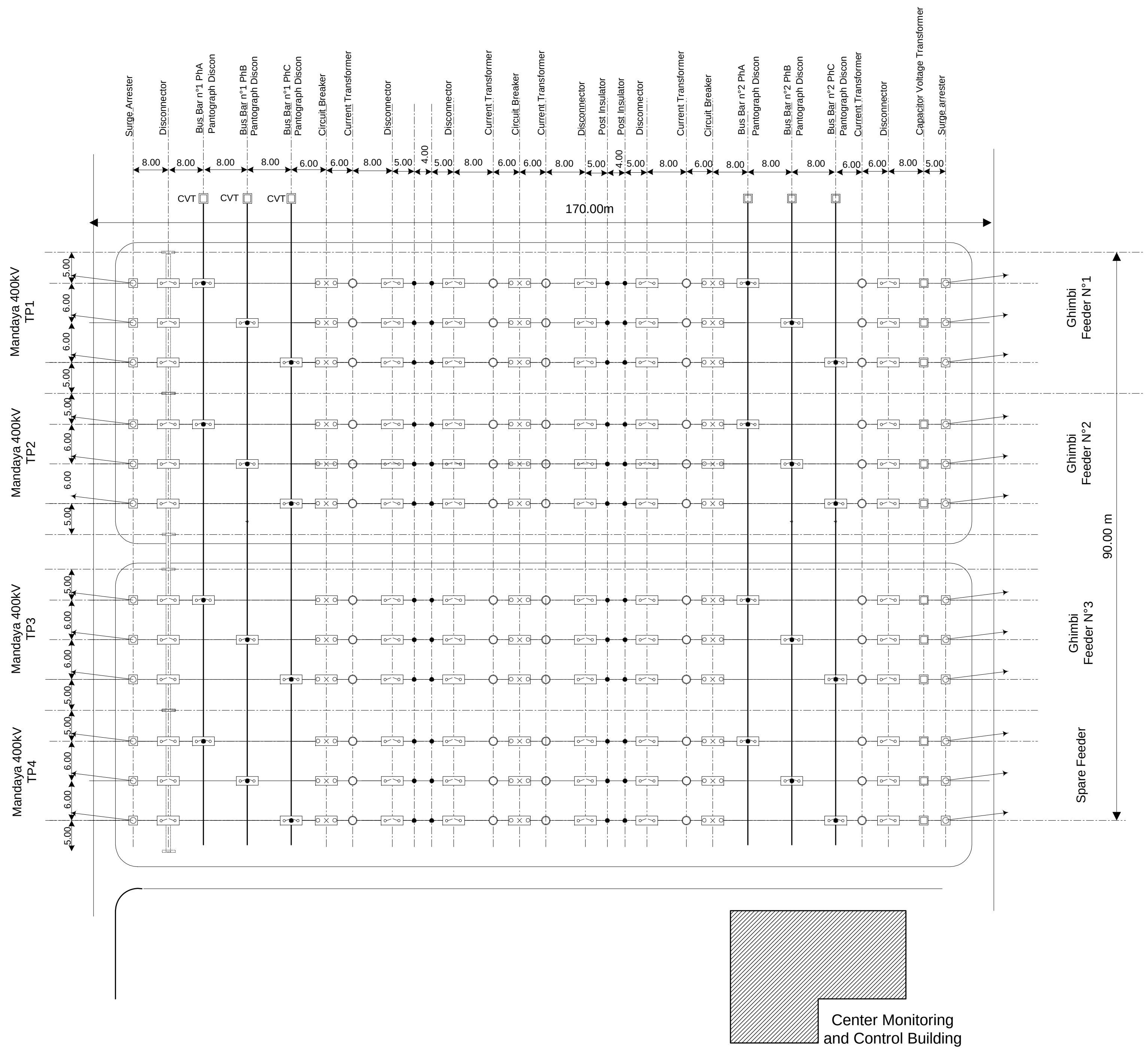
EASTERN NILE POWER TRADE PROGRAM STUDY
PHASE II: REGIONAL POWER INTERCONNECTION
FEASIBILITY STUDY



Mandaya 500kV Substation

SUBSTATION 500kV GENERAL LAYOUT

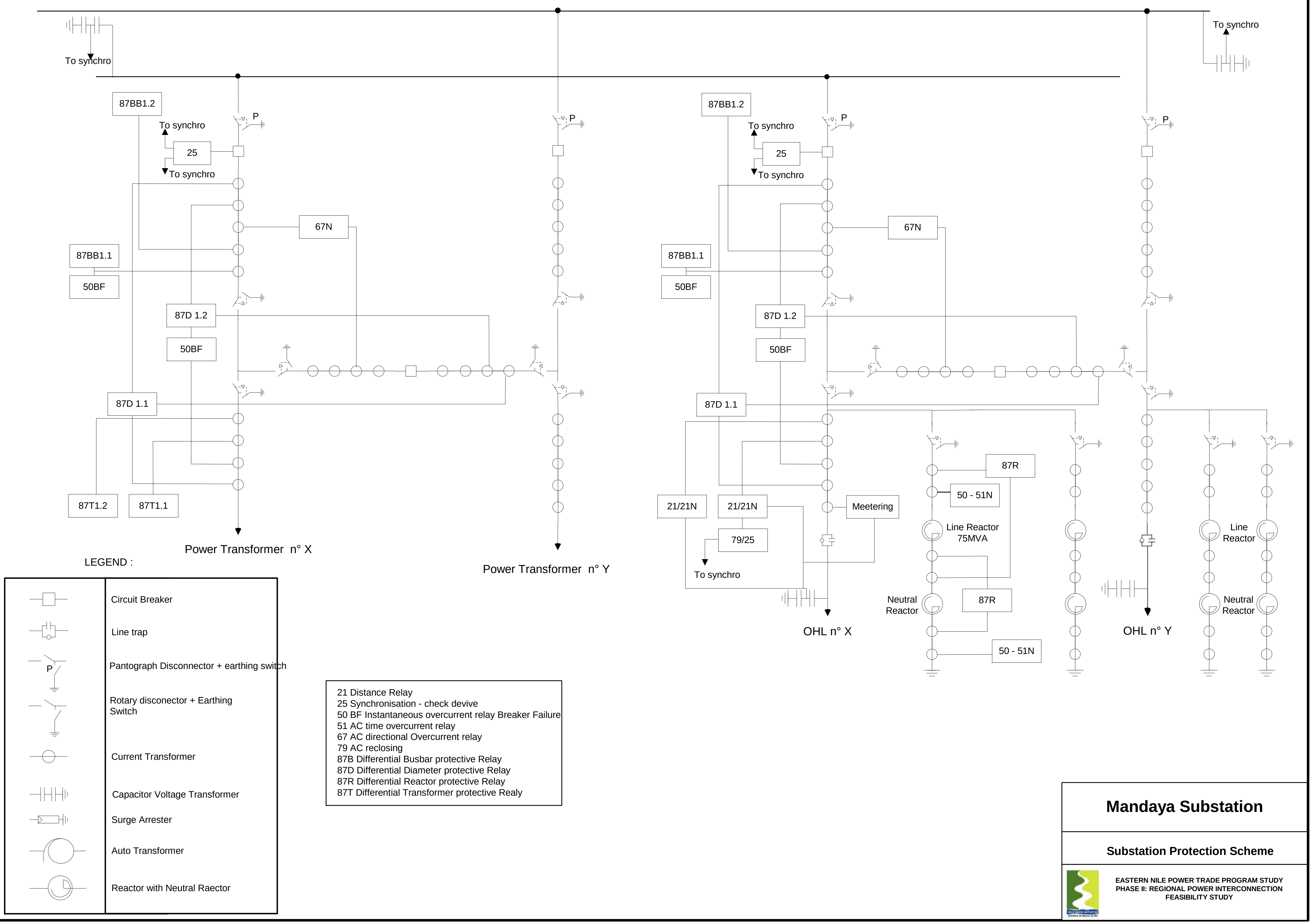
**EASTERN NILE POWER TRADE PROGRAM STUDY
PHASE II: REGIONAL POWER INTERCONNECTION
FEASIBILITY STUDY**



Mandaya 400kV Substation

SUBSTATION 500kV GENERAL LAYOUT

EASTERN NILE POWER TRADE PROGRAM STUDY
PHASE II: REGIONAL POWER INTERCONNECTION
FEASIBILITY STUDY



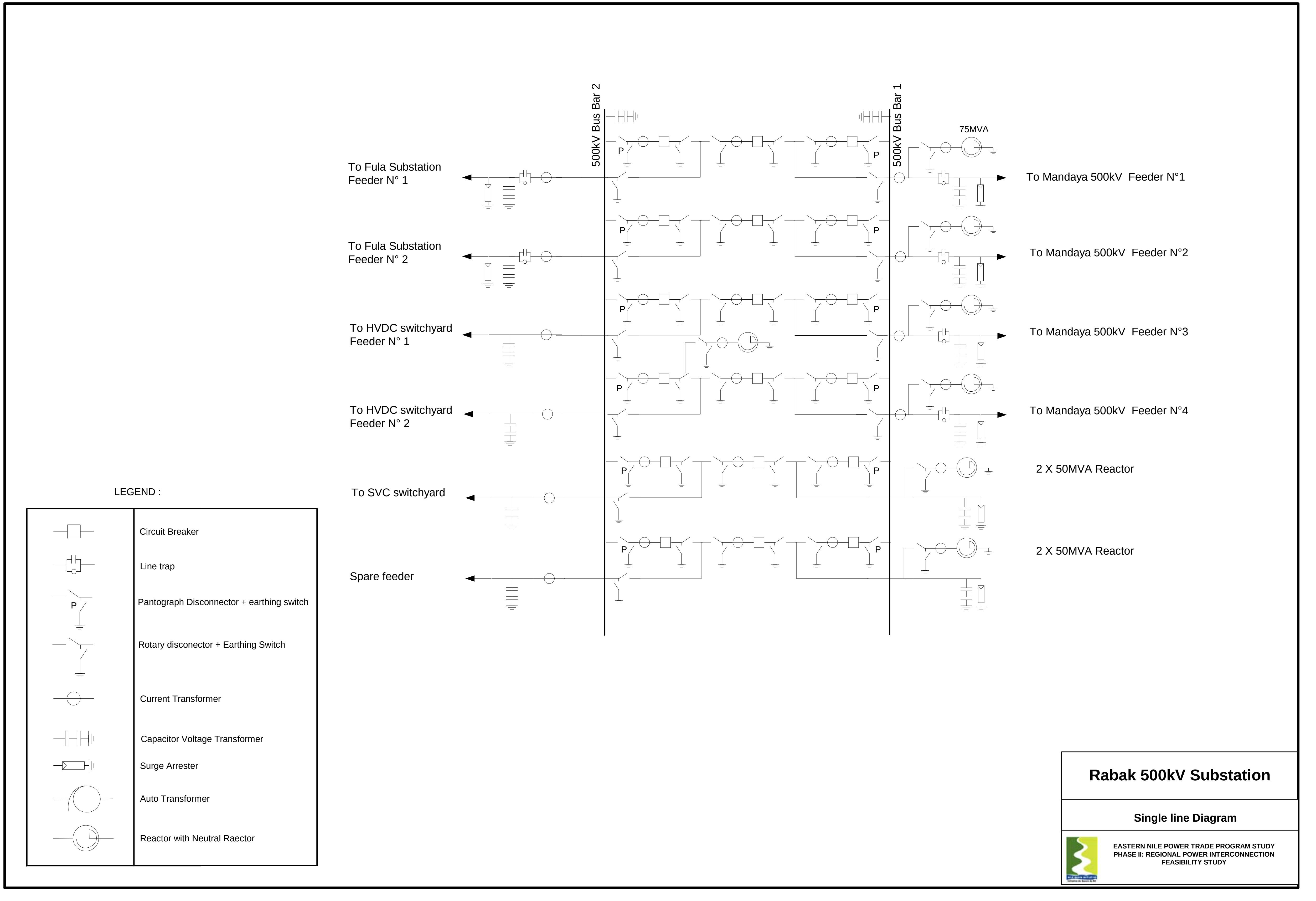
21 Distance Relay
25 Synchronisation - check devive
50 BF Instantaneous overcurrent relay Breaker Failure
51 AC time overcurrent relay
67 AC directional Overcurrent relay
79 AC reclosing
87B Differential Busbar protective Relay
87D Differential Diameter protective Relay
87R Differential Reactor protective Relay
87T Differential Transformer protective Realy

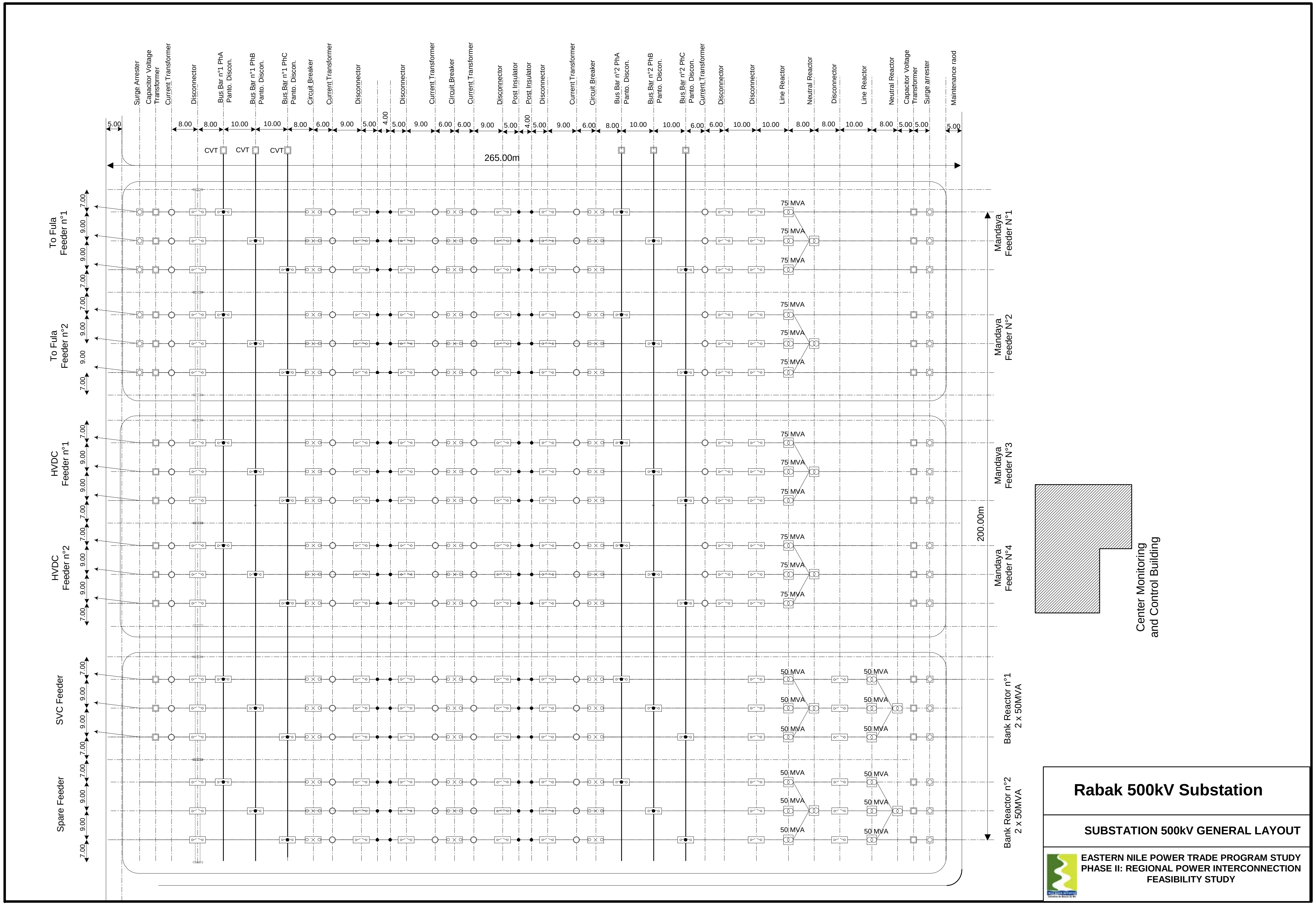
Mandaya Substation

Substation Protection Scheme

EASTERN NILE POWER TRADE PROGRAM STUDY
PHASE II: REGIONAL POWER INTERCONNECTION
FEASIBILITY STUDY

Appendix 2: Main Electrical Scheme of Kosti/Rabak Substation



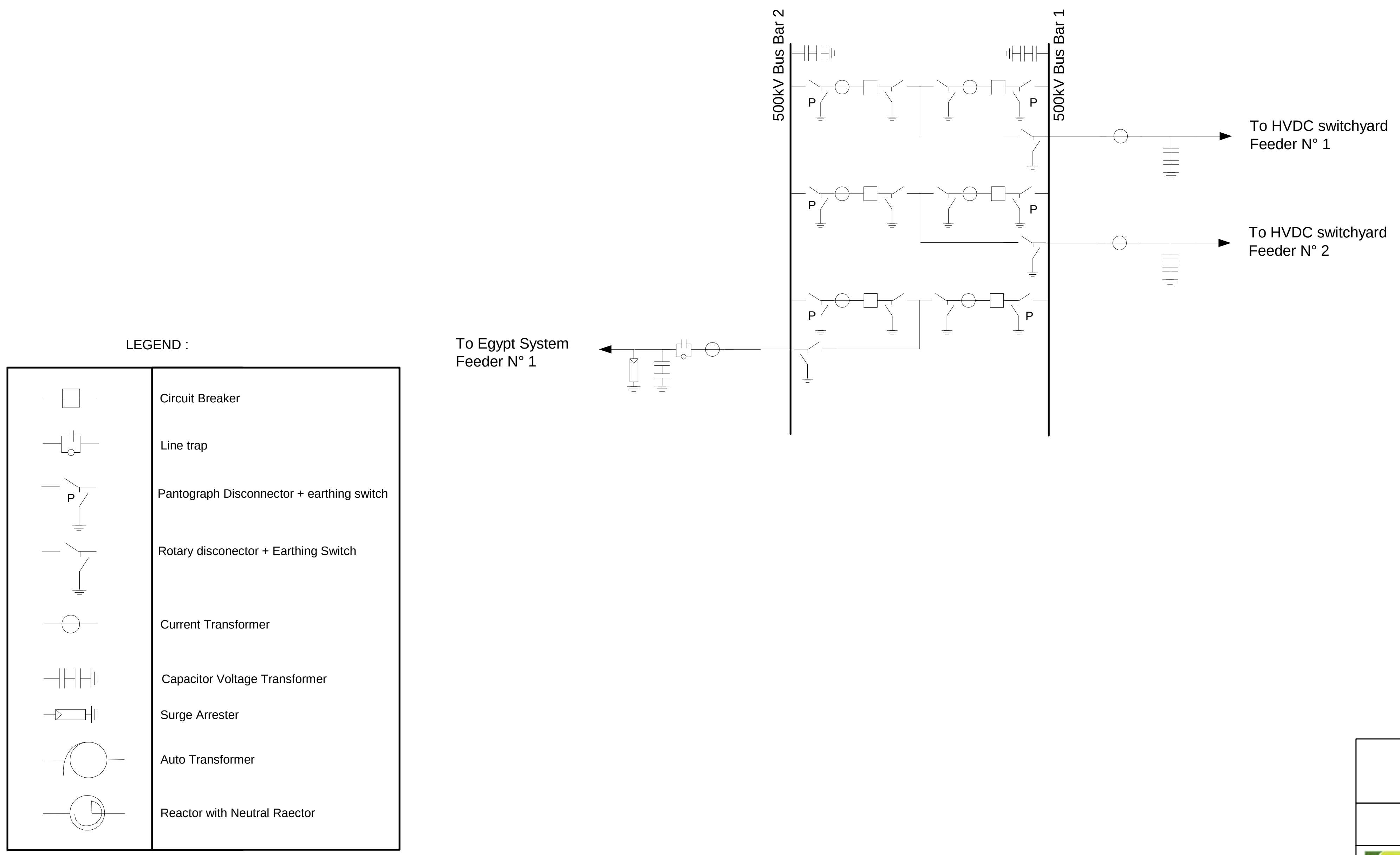


Rabak 500kV Substation

SUBSTATION 500kV GENERAL LAYOUT

EASTERN NILE POWER TRADE PROGRAM STUDY
PHASE II: REGIONAL POWER INTERCONNECTION
FEASIBILITY STUDY

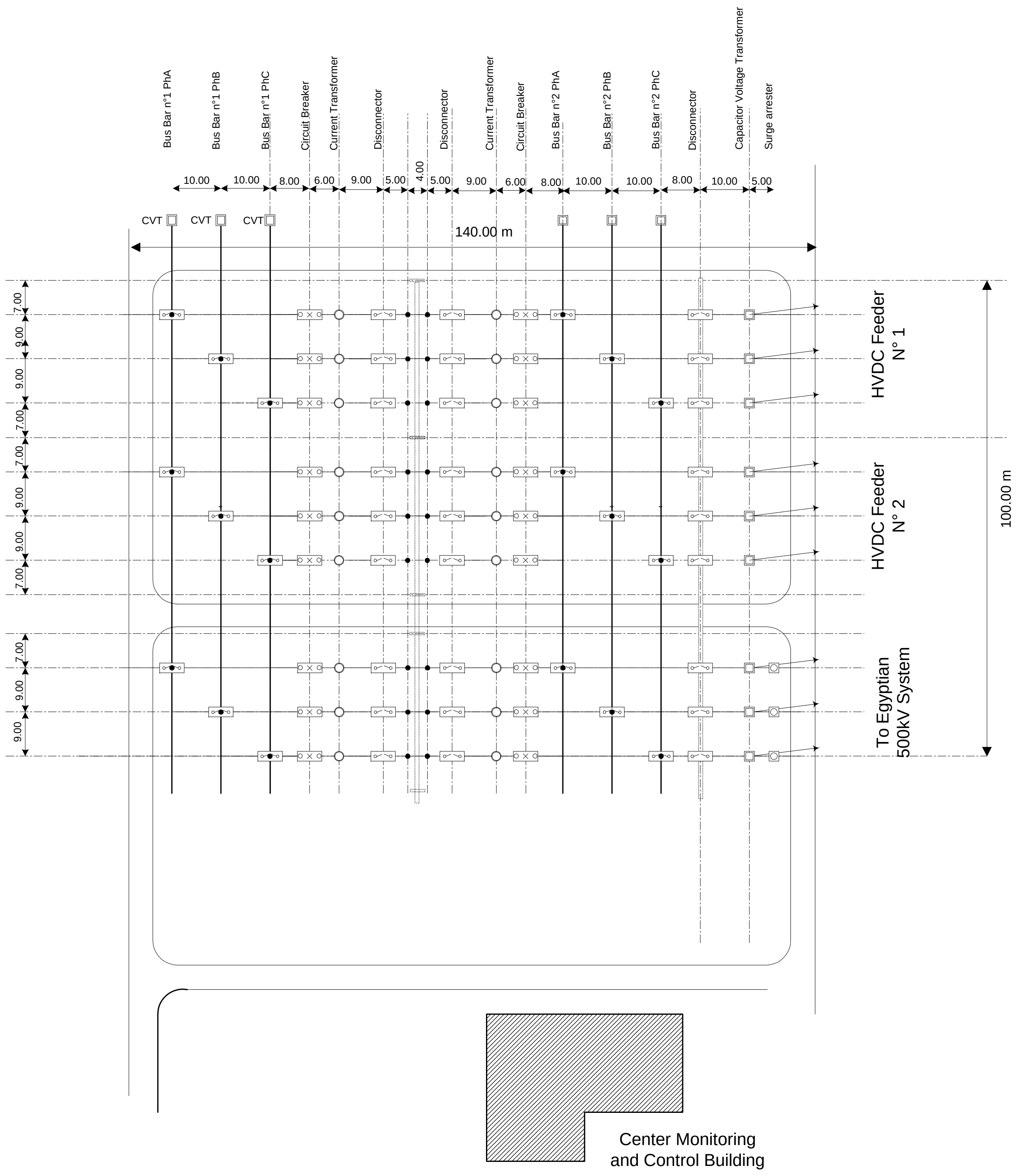
Appendix 3 : Main Electrical Scheme of Nag Hammadi Substation



Nag Hammadi 500kV Substation

Single line Diagram

EASTERN NILE POWER TRADE PROGRAM STUDY
PHASE II: REGIONAL POWER INTERCONNECTION
FEASIBILITY STUDY



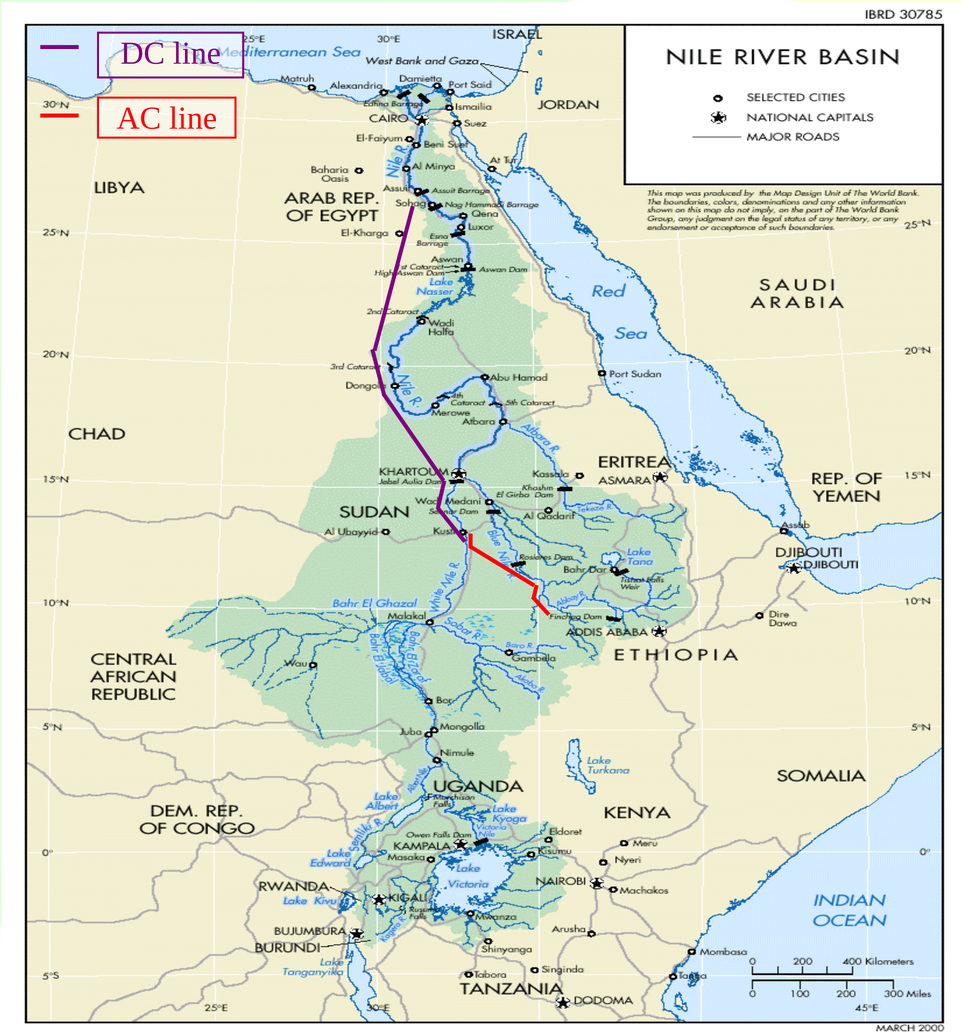
Nag Hammadi 500kV Substation

SUBSTATION 500kV GENERAL LAYOUT

**EASTERN NILE POWER TRADE PROGRAM STUDY
PHASE II: REGIONAL POWER INTERCONNECTION
FEASIBILITY STUDY**

Nile Basin Initiative
Eastern Nile Subsidiary Action Program
Eastern Nile Technical Regional Office

EASTERN NILE POWER TRADE PROGRAM STUDY



M4 – SVC PREPARATION OF SPECIFICATIONS

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
DC	Direct Current
EDF	Electricité de France
EHV	Extra High Voltage
EHVAC	Extra High Voltage Alternating Current
EMC	Electro-Magnetic Compatibility
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
HMI	Human Machine Interface
HV	High Voltage
HVAC	High Voltage Alternative Current
HVDC	High Voltage Direct Current
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
MCB	Micro Circuit Breaker
NBI	Nile Basin Initiative
PCB	PolyChloroBiphényles
p.u	Per Unit
SCADA	Supervisory Control And Data Acquisition
SVC	Static Voltage Compensator
TCR	Thyristor Controlled Reactor
THD	Total Voltage Distortion Factor
TSC	Thyristor Switched Capacitor
TSR	Thyristor Switched Reactor

EXECUTIVE SUMMARY

SVC's in transmission systems are used to control the voltage at the bus where they are connected. The voltage control is typically a closed loop, three-phase symetrical voltage control with a set droop that allows the voltage to vary a few percent.

The SVC can be seen as a dynamic source of reactive current. Using thyristor valves as fast switches, capacitor banks can be switched in and out. Additionally, the thyristor valves can, by means of phase angle modulation, continuously control the current through an air core reactor. This combination of switching capacitors and controlling reactors provides continuous control of the reactive current output between two extremes dictated by component rating selection.

In order to avoid excessive harmonic distortion in the transmission grid, such SVC's have internal harmonic filters (mainly 5^{th} and 7^{th} harmonics). The 3^{rd} harmonic is destroid in the delta winding of the step up transformer.

The present document gives the guidelines for the technical specification of the total turn key project of the 500 kV SVC of KOSTI substation.

It is a part of ENPTPS module M4 part "500 & 400 kV AC substations – Preparation of Technical specifications – Final Design Report".

1 General Requirements

1.1 Introduction and Purpose

The KOSTI SVC will be connected to the 500 kV KOSTI bus bar.

The main purpose of the KOSTI SVC is to perform steady state voltage control.

1.2 Type

The SVC for KOSTI substation shall have a nominal dynamic range of **500 Mvar capacitive to 500 Mvar inductive reactive power compensation**. The Bidder may propose an SVC design that meets the requirements of this specification utilizing any configuration of Thyristor Controlled Reactors (TCR), Thyristor Switched Reactors (TSR), Thyristor Switched Capacitors (TSC) and harmonic filters. The full dynamic range shall consist of thyristor controlled or thyristor switched elements.

1.3 Scope of Works

This is the guideline for a turn-key specification of a complete Static Var Compensator (SVC), connected at the Kosti Substation

The successful bidder shall be responsible for the design, engineering, fabrication, delivery, civil works, erection, installation, testing commissioning and field verification of the SVC.

All equipments shall be designed as needed to meet the requirements in this report. Any equipment and/or function of the SVC not specifically specified herein should be designed as required by the overall design of the SVC system in order to ensure the satisfactory operation of the same.

1.3.1 Equipment

The successful Bidder's Scope of Works shall include all equipment up to and including the pads of the breaker connecting the SVC to the 500 kV main bus.

In particular the following (but not limited to this) is to be included in the successful Bidder's Scope of Work:

1. All engineering, fabrication and supply of the components of the SVC, their assemblies and accessories.
2. The thyristor valves for reactive power control, including their protection, control, monitoring and cooling system.
3. All reactors and capacitor banks as required by the design.
4. Harmonic filters as required by the specified harmonic performance levels.
5. Surge protection as required.

6. All power transformers required by the SVC system.
7. All instrument transformers as required.
8. All circuit breakers and disconnect switches as required.
9. All switchgear equipments on the primary side of the step-down transformer, incl. circuit breakers, disconnect switches, instrument transformers, surge arresters, etc., as required.
10. All necessary equipments for the control, protection, signaling and measurement system of the SVC and their interfaces to the Customer network control, as required.
11. System for fault recording as required.
12. Operator's interface (HMI) as required and standard ISO SCADA interface
13. Auxiliary AC and DC power distribution, including protection, batteries and chargers as required.
14. An automatic switch between the two Customer supplied AC feeders (if applicable).
15. Surge protection and overhead lightning protection of the SVC yard as required.
16. SVC yard lighting as required.
17. All equipment support structures and foundations as well as trenches, as required.
18. All bus work including steel structures, foundations, insulators, connectors, joints, fittings etc., as required.
19. A ground mat installed at the SVC yard, and connected to the existing substation ground mat.
20. All power and control cables for the equipment in the SVC yard.
21. Complete SVC building with foundation, plumbing, lighting, fire protection and electrical outlets as well as facilities for ambient temperature and humidity control, as required.
22. Any other equipment and engineering required for the proper functioning of the SVC.

1.3.2 SPARE PARTS AND SPECIAL TOOLS

The successful Bidder shall furnish recommended spare parts for the SVC system as well as all special tools needed for the maintenance of the SVC, as required. The scope of spare parts and special tools must be coordinated with the requirements/guarantees for reliability and availability (refer to Section 6 below).

1.3.3 SERVICES

The following services shall be part of the successful Bidder's Scope of Works:

1. Delivery of all equipment under the Scope of Works to the Site at KOSTI Substation as well as the civil works, erection, installation, assembly, commissioning and field verification of all equipment supplied as required to form a complete SVC system.
2. Design and installation of a proper ground mat at the site. The grounding mat is to be connected to the existing grounding system in the substation.
3. Commissioning of the complete SVC.
4. Testing of individual components as well as the whole SVC system (field verification) as required.
5. One week of on-site training of the Customer's personnel, which will enable them to operate and maintain the SVC.

1.3.4 DOCUMENTATION

Supply of the following documentation shall be part of the successful Bidder's Scope of Works:

1. All drawings, instructions and manuals necessary to operate and maintain the SVC and associated equipment. The drawings shall include the complete set of plans, elevations, sections, wiring, schematics, piping, etc. of the complete SVC system.

1.4 EQUIPMENT AND SERVICES FURNISHED BY THE CUSTOMER

The following equipment and services will be furnished by the Customer and is subsequently not part of the successful Bidder's Scope of Works.

1. A dedicated piece of land in the KOSTI substation where the SVC system will be installed (about 1500 to 2000 m²).
2. A cleared, graded, surfaced, compacted and fenced-in Site with properly designed and installed drainage as required.
3. One or Two (independent) auxiliary AC feeders (380 V (or as required) three phase, ± 10%). Maximum Load and quality of the supply, will be as per the successful Bidder's requirements.
4. Water, 380 V AC power, etc., for temporary use, as required for installation of the equipment and to facilitate reasonable working conditions for the successful Bidder's personnel.
5. A dedicated telephone line at site will be made available to the successful Bidder at start of installation work.

6. Access/right of entry to the Site at any day of the week during civil works, erection, installation and commissioning. This shall include an access road for transport of heavy equipment.

7. All clearance, duties, permits necessary for the import, delivery to site and installation of the equipment.

8. Available as-built reference data and drawings for the successful Bidder's use in the design and interconnection of the SVC system.

9. Temporary storage area for equipment.

10. Storage area for spare parts.

1.5 STANDARDS

The successful Bidder shall design and manufacture all equipment in accordance with metric standards. All documents, drawings, instruction manuals and test certificates shall use metric units.

All Works connected with the supply of the SVC system shall be in accordance with the requirements of the appropriate IEC/ISO standards. Where no IEC/ISO standard exist the SVC system shall comply with recognized standards and design practices. If the requirements of this specification conflict with any of the above standards or practices, this specification shall apply.

For the major SVC components the following standards in particular shall apply:

Description:	**Standard:**
Metric Standards	ISO 1000:1992 + A1:1998
Quality Assurance	ISO 9001:2008
Hot-dip Galvanizing	ISO 1459,1461:1999
High Voltage Test Techniques	IEC 60060:1989
Insulation Coordination	IEC 60071-1:2006 ;-2:1996
Tests on Post Insulators	IEC 60168:2001
Testing of Thyristor Valves for Static Var Compensators	IEC 61954:2003
Semiconductor Devices	IEC 60747:2006
Power Transformers	IEC 60076:2000
Shunt Capacitors	IEC/TR 60871-1;-4:2005
Reactors	IEC 60076-6 :2007
Voltage Transformers	IEC 60044-2:2003
Current Transformers	IEC 60044-1:2003
Bushings	IEC 60137:2008

Selection of insulators	IEC/TR 60815:2008
Disconnectors and Earthing Switches	CEI 62271-102:2001
High Voltage Circuit Breakers	EC 62271–100:2008
Surge Arresters	IEC 60099–4:2006
Transducers for Electrical Measurements	IEC 60688:2002
Optical Fibre Cables	IEC 60794:2003
Insulating Oil for Transformers and Switchgear	IEC 60296:2003
Common clauses for HV switchgear and controls standards	IEC 60694:2001
Low voltage switchgear/control gear assemblies	IEC 60439:2004
Electrical Protective Relays	IEC 60255:2008
Control Systems EMC (immunity)	IEC 61000-4-2:2006,-3:2008,-4, -5:2008

Table 1 : Applicable standards

For special electric components for which no IEC standards are available, the Supplier shall propose applicable recommendations.

1.6 QUALITY ASSURANCE

The Bidder shall include a general Quality Assurance Manual in his bid describing the quality assurance procedures routinely carried out at the Bidder's works. In connection with this Manual the Bidders shall submit certificate according to Quality Standard ISO 9001.

The Bidder shall in addition to the above submit a Quality Plan for the proposed delivery. The Quality Plan shall define the systems and procedures which will be used by the successful Bidder to ensure that the delivery will comply with the requirements of the Customer as detailed in this specification.

2 POWER SYSTEM CHARACTERISTICS

For design purpose, the power system characteristics at Kosti substation shall be considered as defined in this chapter.

NOTE: All references to per unit (pu) are on **500** MVA, **500** kV, **50** Hz base, unless otherwise stated.

2.1 *VOLTAGE AND FREQUENCY*

1. Nominal voltage is **500** kV (1.0 pu) phase to phase.
2. Minimum continuous voltage of **475** kV.
3. Maximum continuous voltage of **525** kV.
4. Maximum temporary voltage of **650** kV for **5** sec.
5. Max negative sequence voltage during normal operation of 1 %
6. Maximum phase to phase voltage unbalance of **2** %.
7. Normal base frequency of **50** Hz. Minimum continuous frequency of **49,5** Hz. Maximum continuous frequency of **50,5** Hz.
8. Minimum temporary frequency of **49** Hz for **1** hour, **47** Hz for **10** min maximum temporary frequency of **51** Hz for **1** hour, **52** Hz for **10** min

2.2 *EXISTING INSULATION LEVELS*

The following insulation levels exist in the Kosti substation where the SVC will be located:

Minimum Basic Lightning Impulse Insulation Level	**1550** kV.
Minimum Switching Impulse Insulation Level	**1300** kV.
Rated surge arrester voltage	**420** kV.
Line circuit breaker BIL	**1550** kV.

2.3 *SHORT CIRCUIT LEVELS AND IMPEDANCES*

2.3.1 *SHORT-CIRCUIT LEVELS:*

1. The following three phase fault levels are specified at the connection point of the SVC:

Strong system	**8000** MVA
Weak system	**6000** MVA

2. The short circuit withstand capability of all apparatus shall be designed assuming an available three phase or single phase fault level corresponding to the maximum future short circuit level as specified above on the high (primary) side of the main step-down transformer(s).

2.4 FAULT CLEARING TIME

The following clearing times are anticipated for faults in the **500** kV system:

Initiating relaying	Time
Primary Line	**120 ms**.
Back-up Line	**500 ms**.
Breaker Failure	**1 s**

2.5 TRANSMISSION SYSTEM DATA FOR HARMONIC STUDIES

2.5.1 EXISTING HARMONICS

The existing individual harmonic voltage distortion shall need a specific study and site measurements.

Typical existing distortion in the AC system are proposed below.

Maximum steady state harmonic distortion:

	Unit	System A	System B
5th harmonic	**[%]**	1	1
7th harmonic	**[%]**	1	1

Table 2 : Maximum steady state harmonic distortion

Maximum temporary harmonic distortion:

	Unit	System A	System B
5th harmonic/duration	**[%]/[s]**	1.5 / Steady state (for equipment rating)	1.5 / Steady state (for equipment rating)
7th harmonic/duration	**[%]/[s]**	1.5 / Steady state (for equipment rating)	1.5 / Steady state (for equipment rating)

Table 3 : Maximum temporary harmonic distortion

3 SITE CONDITIONS

3.1.1 LOCATION

The SVC system will be located in Kosti Substation.

The Customer should here specify particulars, affecting the way of transportation to the future SVC site.

3.1.2 AMBIENT CONDITIONS

The ambient conditions listed below shall be assumed in the design of all equipment unless specified otherwise elsewhere in this specification. The equipment shall be capable of operating continuously at any output, appropriate to the ambient conditions, regardless of how long these ambient conditions have prevailed.

Condition:	Value:
Altitude Above Sea Level	**400** m
Max. Relative Humidity	**100** %
Min. Relative Humidity	**0** %
Max. Outdoor Temperature	**50** ºC
Max Daily Average Outdoor Temperature	**30** º C
Min. Outdoor Temperature	**0** ºC
Pollution (ref. To IEC/TR 60815)	**31**mm/kV
Wind Load : maximum velocity	160 km/h**.**
Snow Load	**0** mm
Ice Load (radial thickness)	**0** mm
Max Solar Constant	**1100** kW/m^2

Table 4 : Ambient conditions

3.1.3 SEISMIC REQUIREMENTS

The peak ground acceleration at Kosti substation is 0,4 m/s^2.

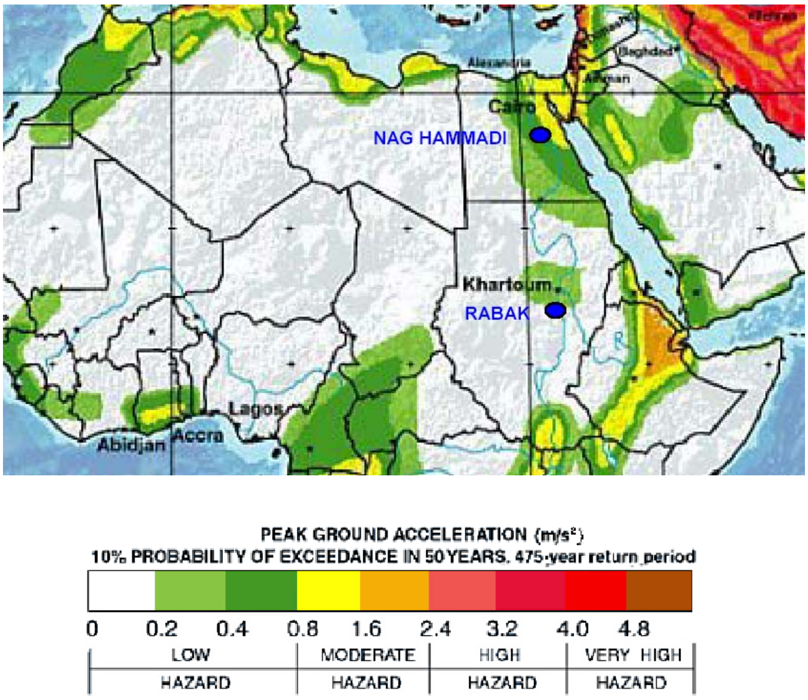


Figure 1: Seismic Activity

4 FUNCTIONAL CHARACTERISTICS OF THE SVC

4.1 VOLTAGE AND REACTIVE OUTPUT RATING

4.1.1 CONTINUOUS RATING

1. The SVC shall be capable of continuous operation from **0,8** pu to **1,075** pu primary voltage.

2. The Bidder shall select the nominal operating voltage for the low voltage side of the step-down transformer, in order to optimize the design of the SVC.

3. The nominal continuous operating capability shall be no less than **500** MVar capacitive to no less than **500** Mvar inductive at 1.0 pu voltage as measured from the primary side of the step-down transformer.

4. The SVC shall be capable of continuous operation for system frequencies specified in Article 2.1 Item 6.

5. The voltage reference for the voltage control should be continuously controllable in the interval **0,90** pu to **1,075** pu.

6. Slope shall be chosen between 1% and 3%. Slope (S) is defined by :

$$\mathbf{S = (U_{HV} - U_{Ref}) / I_{SVC}}$$

7. The SVC configuration must allow for that under normal steady state operation, including operation with partial rating, the SVC output must not exhibit any transients larger than **100** Mvar (due to switching of non-controlled reactive elements within the SVC).

The resulting continuous operating characteristic of the SVC is illustrated in Figure 2.

Points	A	B	C	E	F	H	J
U (pu)	1	1	1,30	*~1,065*	*~ 1,09*	*~0,895*	*~0,93*
I (pu)	- 1	1	-	-	-	-	-
U_{ref} (pu)				1,075	1,075	0,9	0,9
slope				1%	3%	3%	1%
duration	permanent	permanent	5 s	permanent	permanent	permanent	permanent

Table 5 : Continuous Operating Characteristics

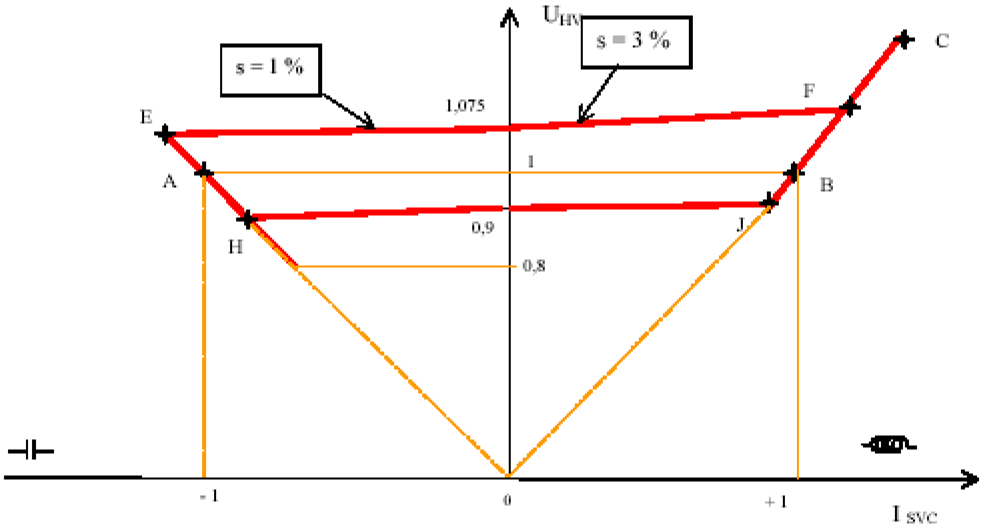


Figure 2: SVC Continuous Operating Characteristic.

The SVC shall be capable of unrestricted repetitive response throughout the entire dynamic operating range, in accordance with the above ratings.

4.1.2 SHORT-TIME RATING

1. The SVC must be designed to withstand the overvoltage in Article 2.1 Item 4 for the specified time.
2. The SVC shall be designed to be able to operate at the temporary frequency deviations specified in Article 2.1 Item 7.
3. During the short term overvoltage condition with primary voltage larger than **1,3** pu, TSC branches shall be designed to immediately block conduction in order to prevent further increase of overvoltage. The TCR (TSR) branches shall be designed for operation with continuous firing pulse (see also Section 4.2.3 below).

4.2 OVERALL CONTROL CONCEPT

The control system shall coordinate the operation of the SVC to regulate the primary voltage. Operation logic's for the breakers, disconnectors and earth-switches in the SVC shall also be incorporated in the control system. The control shall be fully computerized and programmable and have sufficient scope and flexibility to permit re-programming according to future changes in the power system.

The control system must function such that under normal steady state operation, including operation with partial rating, the SVC output must not exhibit any transients (due to switching of non-controlled reactive elements within the SVC) larger than **100** Mvar.

4.2.1 MAJOR CONTROL FUNCTIONS

The major control strategy for the output control of the SVC is voltage control :

In this control mode the control system should perform a three phase voltage regulation based on a voltage error and using a slope correction for stationary output control. The slope should be controllable in the interval specified in Article 4.1.1.

Measurement and signal conversion of the voltage error should not exceed **0.3%.**

When in voltage control mode, the SVC shall meet the following requirements on speed of response time to a Step Change:

1.	Maximum overshoot :	10% of the step
2.	Setting time :	300 ms
3.	Response time :	100 ms

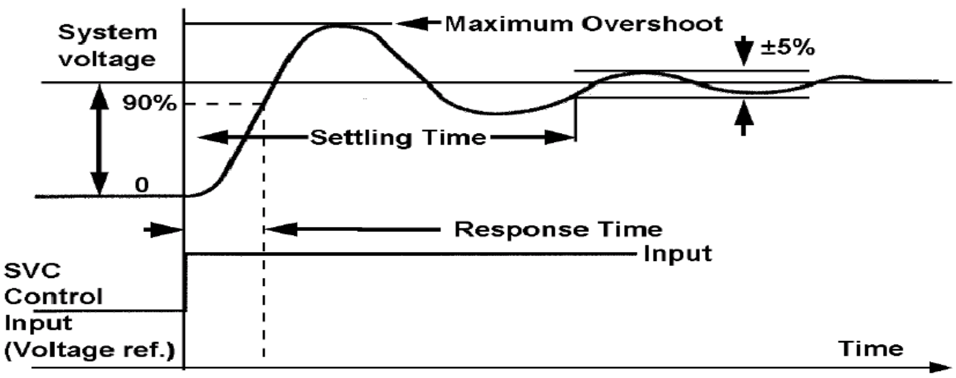


Figure 3: SVC response

4.3 HARMONIC PERFORMANCE

The SVC contribution to the harmonic distortion levels at the SVC connection point to the transmission system shall not exceed the limits below :

Below (as an example), the maximum limits are given using denominations according to IEEE STD 519-1981. The 2nd to the 25th harmonics should be considered.

Individual harmonics voltage distortion (D_n)	1 %
Total voltage distortion factor ($D_{r.r.s.}$ or THD)	1.5 %

4.4 Insulation Coordination

The successful Bidder shall be responsible for the insulation coordination of the SVC. The responsibility includes the high voltage equipment installed on the **500** kV side specified in the scope of supply. The insulation coordination shall comply with relevant parts of the latest edition of applicable IEC standards.

4.4.1 Design Criteria

The events to be used for insulation coordination shall include normal to abnormal occurrences not only in the SVC itself, but also in the surrounding network including but not limited to:

1. Overvoltages on the ac system including dynamic overvoltages, switching surges and lightning.
2. **500** kV bus or line faults.
3. SVC bus or other low side equipment (including valves) faults.
4. SVC valve or control disoperation or malfunction.

4.4.2 Design Margins

For all equipment except for the thyristor valves the insulation levels of equipment shall include minimum margins above surge arrester protection levels of:

Switching Surges: (Impulses with a front time greater than 30 microsec)	25 %
Lightning Impulse Surges (1.2/50 microsec.)	25 %

For the insulation requirements for the thyristor valves, IEC 61954 is referred to.

4.4.3 Creepage Distances

Creepage distances shall be selected according **to level 4** of the IEC 60815 **(31 mm/kV**).

4.4.4 Strike/Clearance Distances

The strike/clearance distance between outdoor live conductors and between energized parts and ground shall be selected according to IEC 60071.

5 ENVIRONMENTAL IMPACT

5.1 AUDIBLE NOISE

The level of audible noise inside the SVC building should not exceed 80 dB(A) in areas where personnel are permitted during SVC operation. Audible sound shall be further limited to not exceed 50 dB(A) in the control room.

The successful Bidder shall make audible noise measurements after commissioning to verify the compliance with the requirements above. At these measurements the background audible noise shall be deducted when calculating the audible noise level for the SVC as specified in the first paragraph. Measurements shall be made at several locations in order to eliminate local interference effects.

5.2 LOSSES

5.2.1 CALCULATION OF LOSSES

The bidder shall provide a summarized loss evaluation of the total proposed SVC system. The summarized losses shall include losses on all SVC components up to the main **500** kV bus connection and shall in particular include:

1. Main step-down transformer.
2. Thyristor valves.
3. Reactor banks.
4. Capacitor banks.
5. Control and protection equipment.
6. SVC auxiliary equipment.

The total system losses shall be calculated, assuming an outside temperature of 20 deg. C and with the 500 kV bus voltage at 1.0 pu, at the following operating points:

1. Total system losses, P_1 (kW), at 1 pu inductive output.
2. Total system losses, P_2 (kW), at 0, 5 pu inductive output
3. Total system losses, P_3 (kW), at 0 MVar output
4. Total system losses, P_4(kW), at 0,5 pu
5. Total system losses, P_5(kW), at 1 pu capacitive output

The assumed average duration for each operating point above are :

1. 5 % of total time at 1 pu inductive output.
2. 10 % of total time at 0, 5 pu inductive output

3. 70% of total time at 0 MVar output
4. 10% of total time at 0,5 pu
5. 5% of total time at 1 pu capacitive output

In this context, the total losses for economic evaluation (Pt) will be given by :

$$\mathbf{Pt = 0,05\ P_1 + 0,10\ P_2 + 0,70\ P_3 + 0,10\ P_4 + 0,05\ P_5}$$

As-built SVC losses should be based on factory measurements and calculations.

6 Reliability and Availability

The SVC system is being installed to provide steady state and transient voltage support, in order to improve the stability margins of the transmission system and enhance the reliability and quality of power delivery .

6.1.1 Definitions

1. **Forced outages** are outages caused by the SVC equipment which result in loss of the essential function of the SVC. These outages are initiated by protective devices.

2. **Scheduled outages** are outages necessary for preventive maintenance to assure continued and reliable operation of the SVC.

3. **Outage duration** is the elapsed time from the instant the SVC is out of service to the instant it is returned to service. If the SVC is available for service during non-working time spans such as nights, such time will not be included in the outage duration, should the Customer elect not to return the equipment to service.

The following will be included in outage duration:

1. The time required to determine the cause of an outage or to determine which equipment or units of equipment must be repaired or replaced.

2. The time required by system operators/technicians for disconnection and grounding of equipment in preparation for repair work, and for removal of grounds and reconnection of equipment after repairs are complete.

Delays caused by unavailability of qualified Customer personnel shall be excluded from the outage duration.

6.1.2 Annual Availability

The annual equivalent availability for forced outages in % is defined as:

6.1.3 Required Availability and Reliability

1. The annual equivalent availability for forced outages for the SVC shall be at least **98** %.

2. There should be less than five forced outages of the SVC per year.

7 MAIN SVC COMPONENTS

7.1 MAIN STEP-DOWN TRANSFORMER

7.1.1 GENERAL REQUIREMENTS

The transformers shall be “one phase” type, in order to facilitate the transportation.

The installation shall be designed to facilitate the connection of the spare transformer and the removal of the failed transformer.

The transformer winding configuration shall be determined by the Bidder, as required by the proposed SVC design.

7.1.2 RATING

The transformer shall be designed to comply with the continuous and short-time MVar requirements in Articles 4.1.1 and 4.1.2. The capacity of the transformer must be designed to meet these requirements without exceeding normal loss of life or increase in the level of internal partial discharges.

Components such as bushings, winding leads etc. shall not limit the transformer’s capability to meet the requirements. The rating of the transformer shall be specified at a ***50/55*** °C (winding/top oil) average temperature rise over a **50**°C ambient temperature.

Bidders shall specify the type of cooling. Transformer design shall employ both self and forced cooling. Sufficient reserve capacity shall be provided, so that SVC capacity is not reduced upon loss of a cooling pump, fan, etc.

7.1.3 IMPEDANCES

The transformer impedance shall be determined by the Bidder as required by the SVC design and shall be chosen so that the transformer will withstand all fault currents at the maximum fault level current specified in Article 2.3.1 Article 2.

7.1.4 VOLTAGE RATING AND BIL

The transformers voltage rating shall be as required by the SVC design. The nominal secondary voltage shall be chosen by the bidder. The BIL rating shall be determined by the bidder as required by the SVC design and the insulation requirements given in Article 4.4.

7.1.5 AUDIBLE NOISE

Audible noise levels from the step-down transformer shall be coordinated to meet the requirements for the SVC installation in Article 5.1 and the applicable IEC standards.

7.1.6 OTHER REQUIREMENTS

Step-down transformer accessories shall include, but not be limited to:

1. Pressure relief device.
2. Provisions for lifting and moving.
3. Valves and connections for oil handling.
4. Liquid level indicator.
5. Thermometer.
6. Ground connection.
7. Manhole.
8. Nameplate.
9. Bushings.
10. Oil.
11. Oil preservation system.
12. Control cabinet.
13. Sudden pressure relay.

7.1.7 OIL CONTAINMENT

The oil containment shall be able to withstand a 1mb pressure.

7.1.8 STANDARDS AND TESTS

The design and test of the step-down transformer shall comply with the latest revision of relevant IEC standards (ref. Section 1.5 above).

7.2 THYRISTOR VALVES

7.2.1 FUNCTION

The thyristor valves that are connected to the TSC capacitor banks and/or TSR reactors, are used to switch individual capacitor banks and/or reactors fully on or fully off, thus providing controlled step changes in MVar output. The combination of thyristor switched capacitors (TSC), thyristor switched reactors (TSR) and the thyristor controlled reactors (TCR) allows continuously variable control of the MVars that is exchanged with the network.

7.2.2 GENERAL REQUIREMENTS

1. The thyristor valves and all associated equipment shall be designed to withstand the stresses associated with the steady state and transient operation conditions in

Articles 4.1.1 and 4.1.2. The basis for calculation of overcurrent stresses should be the maximum fault level current.

2. The design of the thyristor structure shall permit easy access for visual inspection and maintenance.
3. Each single phase thyristor stack (or equivalent) shall consist of anti-parallel series connected thyristor functions, including all necessary heat sinks, snubber circuits, voltage grading circuits and firing circuits.
4. The thyristor valve design shall include a minimum of 10% redundant series thyristors, but not less than one redundant series thyristor, in each single-phase thyristor valve. All rating, performance and protection requirements shall be met with all redundant thyristors short-circuited.
5. A continuous monitoring system shall be provided to detect failed thyristors and provide indication of each failure and its location in the valve. The SVC shall be automatically tripped if the number of failed thyristors and associated electronics is more than the number of redundant thyristors.
6. It should be possible to replace failed thyristors without opening of the cooling water circuit.

7.2.3 STANDARDS AND TESTS

The design and tests of the thyristor valve shall be in accordance with the IEC 61954 standard on "Testing of thyristor valves for Static Var Compensators".

7.2.4 INFORMATION SUPPLIED IN THE BID

The information on the thyristor valves shall include but not be limited to:

1. Continuous and short-time current and voltage ratings of thyristor valve.
2. Voltage and current capability of thyristors.
3. Number of thyristors in series and number of redundant thyristors.
4. Insulation level.
5. Principles of Firing system and Monitoring system
6. Weights and physical dimensions.
7. Valve overvoltage, overcurrent and misfiring protection scheme.

7.3 CAPACITOR BANKS

The capacitors are utilized in the TSCs to provide capacitive Mvar output, and in harmonic filters. They have the dual purpose of providing reactive power and being a filter for harmonic currents.

7.3.1 General Requirements

1. The capacitor banks shall be designed to avoid resonance with other SVC branches as well as the network on the primary side of the step-down transformer.
2. Reactors for limiting of inrush currents shall be connected in series with the capacitor banks in the TSCs.
3. The capacitor units shall be constructed with materials resulting in minimum losses and maximum reliability. Each unit shall be free of PCB.
4. The capacitor units should be interchangeable among all capacitor banks to the extent practical.
5. The individual capacitor units shall be individually fused. Both internally and externally fused capacitors could be used.
6. Capacitor dielectric losses shall not exceed 0.15 W/kvar.
7. The capacitor units shall use internal discharge resistors that reduce the residual voltage to below 50V in not more than 5 minutes.

7.3.2 Standards and Tests

The design and test of the capacitor banks shall be in compliance with the latest revision of relevant IEC standards (ref. Section 1.5 above).

7.3.3 Information Supplied in the Bid

The information on the capacitor banks shall include but not be limited to:

1. Capacitance including manufacturing tolerances.
2. Rated voltage of Capacitor units
3. Insulation level.
4. Description of Fuse system.
5. Weights and physical dimensions.
6. Losses.
7. Bank configuration, including number of series and parallel units.

7.4 Reactors

The reactors are utilized in the TCR (TSR) branches to provide the inductive Mvar output and in the TSC branches to limit inrush currents. Reactors are also used as tuning elements of the harmonic filters.

7.4.1 GENERAL REQUIREMENTS

1. The reactors shall be of single phase, air-core design, self-cooled and suitable for outdoor installation (ambient conditions in Section 3.1.2 shall be considered).
2. Reactors shall be capable of withstanding short circuit forces based on maximum design fault levels.
3. Audible noise levels from the reactors shall be coordinated to meet the requirements for the SVC installation in Article 5.1 and the applicable IEC standards.

7.4.2 STANDARDS AND TESTS

The design and test of the reactors shall be in compliance with the latest revision of relevant IEC standards (ref. Section 1.5 above).

7.4.3 INFORMATION SUPPLIED IN THE BID

The information on the reactors shall include but not be limited to:

1. Inductance Including manufacturing tolerances.
2. Continuous and short-time current and voltage ratings, indicating contribution from harmonic currents.
3. Design criteria for maximum temperature.
4. Insulation level.
5. Weights and physical dimensions.

7.5 SURGE ARRESTERS

All necessary surge arresters shall be supplied for protecting the equipment particularly the main step-down transformer and the TSC thyristor valve.

The surge arresters shall be of metal oxide type. On the primary side of the step-down transformer the arresters shall be of class 4 or better, on the low voltage side of the transformer the arresters shall be of class 3 or better referring to IEC 60099-4.

7.5.1 STANDARDS AND TESTS

The design and tests of the surge arresters shall comply with relevant parts of the latest editions of relevant IEC standards (ref. Section 1.5 above).

7.5.2 INFORMATION SUPPLIED IN THE BID

The information on the surge arresters shall include but not be limited to:

1. Type and Rating.

2. Energy discharge capability.
3. Insulation level.
4. Creepage distances.
5. Weights and physical dimensions.

All surge arresters shall be indicated on the SVC Single Line Diagram provided by the Bidder.

7.6 Disconnect and Earthing Switches

The disconnect switches are required to isolate any apparatus for which maintenance is needed. The following major components shall have disconnect and earthing switches:

1. Each thyristor controlled reactor branch.
2. Each thyristor switched capacitor bank.
3. Each fixed capacitor bank.
4. Filter branches.

7.6.1 General Requirements

1. All disconnect switches shall be motor operated.
2. The disconnect switches shall also be capable of being operated by hand.
3. All earthing switches shall be manually operated.
4. The switches shall be adequately sized to carry the maximum steady-state and overload currents including fault, inrush and harmonic currents.
5. The switches shall meet the insulation requirements in Article 4.4.
6. Thermostatically operated heaters shall be supplied for temperature control and prevention of condensation build-up.
7. All operating equipment, including auxiliary switches shall be housed in a weatherproof cabinet.

7.6.2 Standards and Tests

The design and tests of the disconnect and earthing switches shall comply with relevant parts of the latest editions of relevant IEC standards (ref. Section 1.5 above).

7.6.3 Information Supplied in the Bid

The information on the disconnector and earthing switches shall include but not be limited to:

1. Type and rating.

2. Insulation level.
3. Creepage distances.

All disconnect and earthing switches shall be indicated on the SVC Single Line Diagram provided by the Bidder.

7.7 INSULATORS AND BUS

All buswork shall be rated and designed for the SVC application. The insulation requirements in Article 4.4 shall be met.

7.7.1 INFORMATION SUPPLIED IN THE BID

The information on the bus and insulators shall include but not be limited to:

1. Insulation level.
2. Creep and strike distances.

7.8 INSTRUMENT TRANSFORMERS

The successful Bidder shall supply all necessary voltage and current transformers on the high voltage as well as on the low voltage side of the step-down transformer. The voltage transformers shall have a voltage factor V_f of 1.9 for 8 h. Further no ferro-resonance conditions shall occur between voltage transformers and capacitors including stray capacitances.

7.8.1 STANDARDS AND TESTS

The design and tests of the current and voltage transformers shall comply with relevant parts of the latest editions of relevant IEC standards (ref. Section 1.5 above).

7.8.2 INFORMATION SUPPLIED IN THE BID

The numbers of current and voltage transformer and corresponding current and voltage rating should be Indicated on the Protection Block Diagram (see Section 7.6.4 above.)

7.9 CONTROL AND MONITORING SYSTEM

7.9.1 GENERAL REQUIREMENTS

A digital programmable controller shall be supplied to regulate the reactive output from the SVC.

The application software shall be written and documented in a high level language, using graphical symbols for functional blocks, logic circuits and numerical elements

The controller shall have diagnostics and self-checking features.

7.9.2 STATION CONTROL AND MONITORING REQUIREMENTS

The successful Bidder shall submit a local digital Station Control and Monitoring system with, at a minimum, the following capabilities and features:

1. Supervision and recording of events. Resolution shall be 1ms or better. The event information shall be stored on a recoverable data media, for later access.
2. Disturbance recording, with a resolution of 1ms or better.
3. Indication of equipment status (local and remote)
4. Alarms (local and remote)
5. Setting/adjustment (local and remote) of certain control parameters/protection settings
6. Command of operating equipment (breakers, disconnectors etc.).

All features of the local Station Control and Monitoring system shall be precisely identified to enable proper use by the system operators.

7.9.3 STANDARDS AND TESTS

All control plant and material shall be type tested for Surge Withstand Capability according to IEC 1000-4-5, Electrostatic Discharge according to IEC 1000-4-2, Electrical Fast Transient Burst according to IEC 1000-4-4 and Radio Frequency Interference according to IEC 1000-4-3.

7.9.4 INFORMATION SUPPLIED IN THE BID

An overall description of the structure of the control and monitoring system shall be supplied in the bid. Key performance data (e.g. resolution in voltage control, resolution and symmetry in triggering angle, response time in voltage acquisition, intrinsic filtering of voltage harmonics etc.) shall be given and explained.

7.10 Protection Equipment

In addition to the protective features provided as part of the control system, a complete protection system based on conventional relay techniques shall also be provided, to protect the compensator equipment against abnormal operating conditions which may occur.

7.10.1 General Requirements

1. The protection relays and equipment shall be mounted separate from the SVC control and interface cabinets.
2. The protection system shall, to the extent applicable, be built on the principle of a main and a back-up protection, for each protected zone/object. The two protections must be connected to separate DC auxiliary supplies, and to separate instrument transformer circuits.
3. All protection equipment are to be properly coordinated to provide reliable and safe protection and to prevent incorrect operation under transient or steady-state conditions.

7.10.2 Minimum Required Protection

The following is a list of minimum protection requirements. The Bidder shall provide additional protection as considered to be necessary.

Transformer and 500 kV Bus

1. Transformer and SVC bus differential protection (main).
2. SVC primary bus overcurrent protection (back-up).
3. Transformer neutral differential protection (main).
4. Breaker failure function (main).
5. Over temperature protection for oil and windings (main).
6. Low oil level protection (main).
7. Fault-pressure device (main).

SVC Low Voltage Bus

1. Overvoltage protection (back-up).
2. Undervoltage protection (back-up).
3. Voltage zero-sequence protection (main).
4. Ground fault protection (back-up).

Thyristor Controlled Reactors

1. Three phase overcurrent protection for the TCR (TSR) branch (back-up).
2. Three single-phase differential protections for the TCR (TSR) delta, (main).
3. Thermal overload protection of reactors (back-up).

Thyristor Switched Capacitors

1. Three phase overcurrent protection for the TSC-branch (back-up).
2. Three single-phase differential protections for the TSC delta (main).
3. Capacitor overload protection for the TSC delta (back-up).
4. Capacitor bank unbalance protection for the TSC delta (main).

Harmonic Filters

1. Three phase overcurrent protection for the filter branch (main).
2. Capacitor overload protection for the filter branch (back-up).
3. Capacitor bank unbalance protection for the filter branch (main).

7.10.3 STANDARDS AND TESTS

The design and testing of the relays shall comply with relevant clauses of applicable IEC standards (ref. Section 1.5 above).

7.10.4 INFORMATION SUPPLIED IN THE BID

A preliminary Protection Block Diagram shall be included in the bid.

7.11 COOLING SYSTEM FOR THYRISTOR VALVES

The purpose of the thyristor valve cooling system is to remove the heat produced by the thyristor valve operation and transfer this heat to the outside ambient air.

7.11.1 GENERAL REQUIREMENTS

1. Water or a water/glycol mixture shall be used throughout the entire cooling system to prevent freezing in the event of loss of station auxiliary power.
2. A closed circuit de-ionized recirculating cooling medium system shall be used. The piping for each thyristor branch shall have manual valves to isolate it from the rest of the system without disrupting the operating flow.

3. Replacements of thyristors shall be possible without the need for opening the cooling circuit.

4. The heat transfer from the closed cooling system to the outside ambient air shall take place in a water to air heat exchanger.

5. The cooling system shall use two motor driven pumps that each are normally capable of supplying 100% of the required maximum cooling medium flow.

6. All valves, strainers, pumps and piping in the cooling system shall be made of stainless steel.

7. The heat exchangers shall have at least one standby fan.

7.11.2 INFORMATION SUPPLIED IN THE BID

The information on the cooling system shall include :

1. Overall diagram of the cooling system and its components including gauges.

2. Rated values on flow, temperature, pressure drop and liquid volume.

3. Cooling medium.

4. Ratings of pumps and fans.

5. Alarm and trip signals from the control system

7.12 REQUIREMENTS ON AUXILIARY POWER DISTRIBUTION

The SVC auxiliary power distribution, shall include a 380V AC distribution and a 125V DC distribution. The following principal requirements shall be met:

1. Two independent input feeders shall be installed for the AC auxiliary supply.
2. An automatic switching sequence, for selection of input AC feeder, shall be provided. Switching must not cause significant disturbances in the Mvar output of the SVC.
3. The DC distribution, and the main batteries, shall be separated into two independent circuits. Each battery shall be rated for the full load, in order to assure unrestricted SVC operation in case of battery failure.

7.13 BUILDING REQUIREMENTS

Here, the Customer should outline any special requirements on the SVC Building, if applicable. This can include any special requirements on the overall design, general facilities, HVAC, fire detection and suppression, pressure relief, acoustic alarm etc.

7.14 YARD REQUIREMENTS

Here, the Customer should outline any special requirements on the SVC yard, if applicable. This can include any special requirements on lighting, security etc.

7.15 SPARE PARTS

All spare parts offered must be of the same quality as, and completely interchangeable with, the original parts.

The scope of spare parts and special tools must be coordinated with the requirements/guarantees for reliability and availability (refer to Section 6 above).

The spare parts shall include but not be limited to the items in the following list.

7.15.1 MAIN STEP-DOWN TRANSFORMER

If the main power transformers comprises single-phase units, one spare unit shall be provided.

Quantity	Description
1	A spare unit (installed in the SVC area, filled and equipped of all accessories)
1 set	Relays, control switches, contactors of each type.
1	Silicagel cartridge including container.
1	Thermometers and gauges of each type.
1	Bushing of each type.
1	Complete cooling fan.
1	Oil pump (if applicable).
1 set	Gaskets

Table 6 : Spare parts for main step-down transformers

7.15.2 THYRISTOR VALVES

Quantity	Description
1 set	Thyristors (quantity to cover e.g. one TSC string).
1 set	Snubber circuits, heat sinks, water feeding pipes.
1 set	Valve electronics.

Table 7 : Spare parts for thyristor valves

7.15.3 CAPACITORS

Quantity	Description
5 %	Percent of installed capacitor units.
1 set	Insulators.

Table 8 : Spare parts for capacitors

7.15.4 PROTECTION AND CONTROL EQUIPMENT

Quantity	Description
1 set	Computer circuit board of each type.
1 set	Relays.

Table 9 : Spare parts for protection and control equipment

7.15.5 MAIN-CIRCUIT BREAKER

Quantity	Description
1 set	Gaskets.
1	Density gauge (SF6 type of breaker).
2	Close/Trip coils, each.

Table 10 : Spare parts for main-circuit breaker

7.15.6 DISCONNECTORS

Quantity	Description
1 set	Service parts acc. to manufacturer.

Table 11 : Spare parts for disconnectors

7.15.7 INSULATORS

Quantity	Description
1 set	Insulators.
1	Wall bushing.

Table 12 : Spare parts for insulators

7.15.8 COOLING SYSTEM

Quantity	Description
1 set	Service parts for main pump.
1 set	Filters, filter cartridges.
1 set	Service parts (fan, filters, contactors) for electronics.
1 set	Rubber compensators, valves, gauges, meters.
1	Complete fan with motor.

Table 13 : Spare parts for cooling system

7.15.9 AUXILIARY POWER EQUIPMENT

Quantity	Description
1 set	Battery charger items.
1	AC/DC fuses, MCBs.
1	Contactors, Relays, Switches.

Table 14 : Spare parts for auxiliaries power equipment

7.15.10 SPECIAL TOOLS

Quantity	Description
1	Capacitance measuring device.
1	Relay test set.
1	Thyristor removal tool.
1	Thyristor test set.
1	Terminal for programming of controls.
1	Capacitor lifting device.

Table 15 : Spare parts for special tools

8 DESIGN STUDIES

The purpose of the studies and simulations is to analyze different rating and control issues in the design stage of the SVC. The successful Bidder shall perform the studies at his own facilities to ensure proper design and operation of the SVC system.

The studies made by the successful Bidder shall result in reports which shall be issued to the Customer for information. The reports shall include :

1. **Main Component Design**
   In this report the analysis for the rating of the main high voltage components should be presented (for the thyristor valves see further below). Power system characteristics should be clearly stated and a summary of the rating of the SVC components should be given.

2. **Insulation Coordination**
   In this report analysis for the insulation levels should be presented.

3. **Thyristor Valve Design and Protection**
   In this report the calculations for the rating of the thyristor valves should be presented. Coordination of break over device levels and other protective functions should be described. Control strategies for possible misfiring should be specified in detail and cooling requirements should also be stated in this report.

4. **Control System**
   In this report the control strategies implemented in the control system should be described in detail. The verification of the main strategies should be done by running the real control system together with a simulator implementing a network equivalent together with the SVC high voltage components. The verification can be done during the factory validation test of the control system.

5. **Protective Relay Coordination**
   In this report the calculation of relay protection setting levels shall be presented together with the principles for protection coordination. A summarized list of the protection settings shall be given.

6. **Loss Evaluation**
   In this report the total SVC losses shall be calculated and compared with guaranteed values. Explanations to discrepancies, if any, should be given. The final Loss Evaluation report shall be based on component loss data obtained from factory tests.

7. **Harmonic Design**
   In this report the harmonic filter design shall be described and the resulting maximum harmonic distortion generated by the SVC shall be presented.

- ## Appendix 1 : Single Line Diagram

The single line diagram is not imposed by the technical specification. It depend on the bidder optimization (number of branches, arrangements , etc…). But the most probable scheme is the one shown in fig. 3 hereafter.

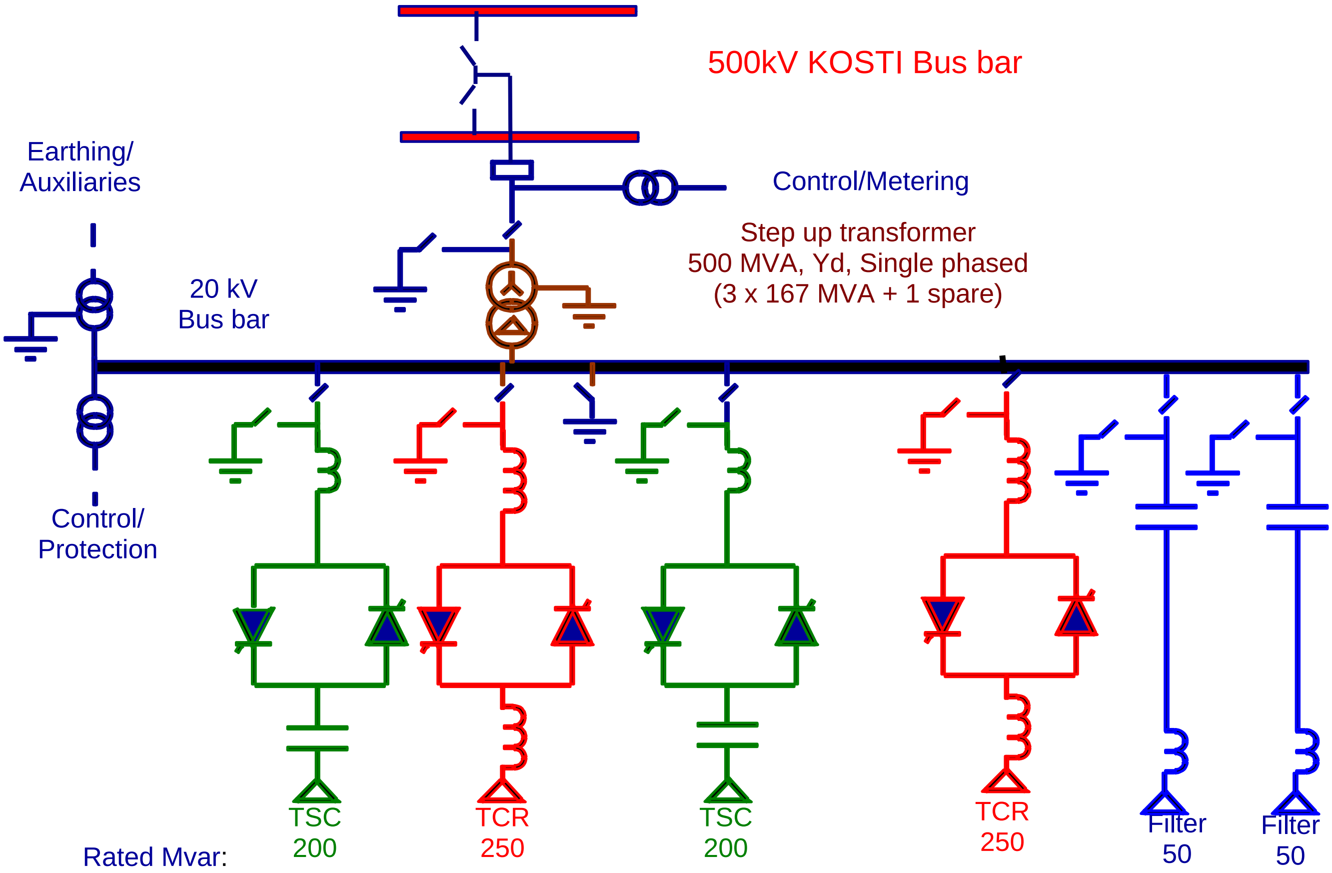
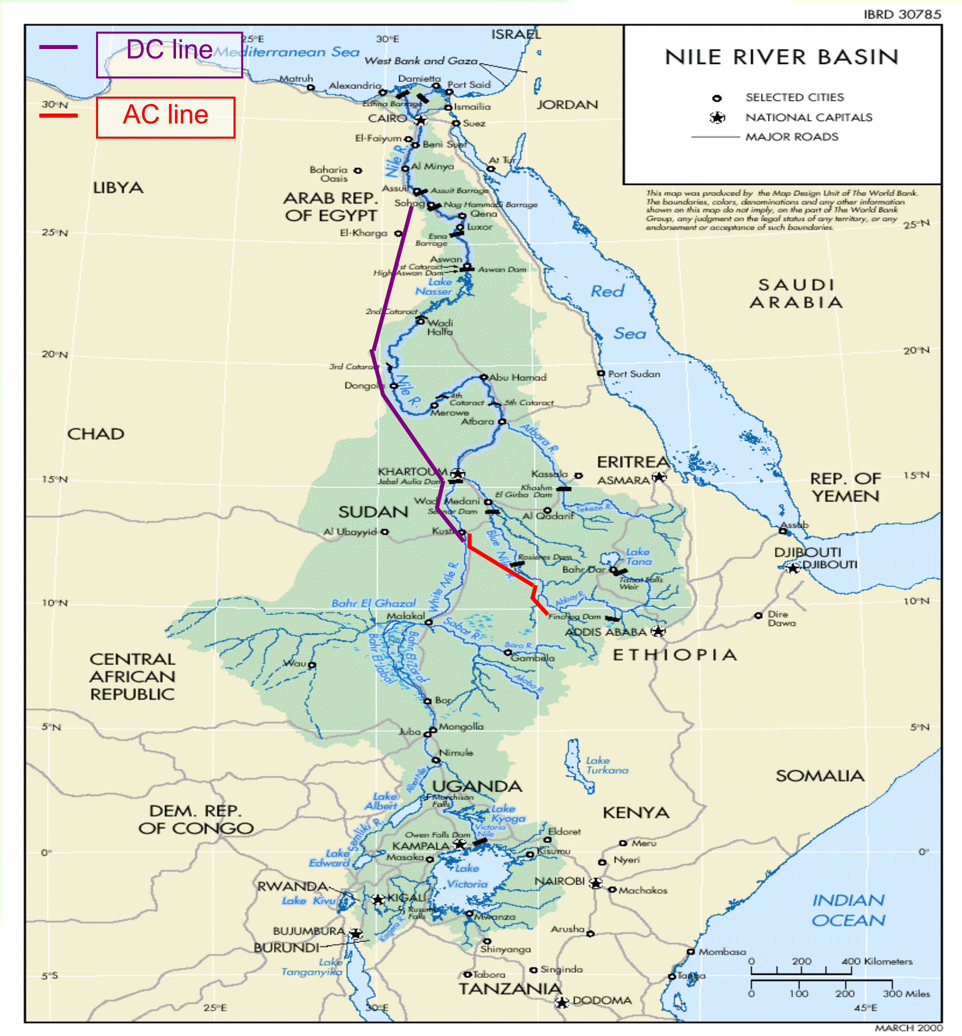


Figure 4: KOSTI SVC – Possible Single Line Diagram

Nile Basin Initiative
Eastern Nile Subsidiary Action Program
Eastern Nile Technical Regional Office

EASTERN NILE POWER TRADE PROGRAM STUDY



M4 - Telecommunication, SCADA and Metering

EDF Scott Wilson EPS Electrical Power Systems Engineering Company

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ABBREVIATIONS AND ACRONYMS

Here follows main used acronyms definitions: referred with a (*) in the text below.

- **General ENTRO abbreviations and acronyms:**

AC	Alternative Current
DC	Direct Current
EEHC	Egyptian Electricity Holding Company
EEPCO	Ethiopian Electric Power Corporation
EHV	Extra High Voltage
ENTRO	Eastern Nile Technical Regional Office
ENTRO PCU	Eastern Nile Technical Regional Office Power Coordination Unit
HV	High Voltage
HVDC	High Voltage Direct Current
NBI	Nile Basin Initiative
NEC	National Electricity Corporation (Sudan)
SVC	Static Voltage Compensator

- **Specific M4 module abbreviations and acronyms:**

API	Application Portable Interface: software interface between several sub-functions.
CNP	Connection Network Processor: a CNP consists of a computer running a communication software and at least two (2) link applications.
DCS	Digital Control System: system to collect and transmit control at substation / generation plants.
EMS	Energy Management System: set of equipment (hardware, software) for supervising an electrical network.
ICCP	Inter-Control Center Communications Protocol
IEC	International Electrical Commission
ISO	Interconnection System Operator: entity that should be in charge of interconnector Operation
IT	Information Technology
LFC	Load Frequency Control (system for frequency and tie-line interchange regulation)
NTP	Network Time Protocol (used for equipment time synchronisation through LAN and other communication links).
OPGW	Optical fiber composite overhead ground wire (safeguard power line cable fitted with optical fibers inside).

PDH	Plesiochronous Digital Hierarchy (lower level for telecommunication transmission through optical fibres).
RTU	Remote Terminal Unit: local mini-computer, dedicated to bi-directionally transmit supervision data.
SCADA	Supervisory Control And Data Acquisition
SDH	Synchronous Digital Hierarchy (higher level for telecommunication transmission through optical fibres).
SOE	Sequence Of Events: particular log, available on SCADA system, summarizing with accurate time details (up to millisecond, provided adequate protocol and synchronizing system is provided) occurrence time of an event that happened on electrical network (such as switching devices trips, tap changers positions etc…),

EXECUTIVE SUMMARY

This document details the proposed design for Telecommunications, Metering and Control systems. This document describes the functional aspects and the general specifications for remote and centralized supervision and control for Egypt-Ethiopia-Sudan interconnection.

One basic principle is retained for supervision and monitoring is a dedicated and independent organization to operate the interconnector for technical consistency and impartial operation. This operator is named **Interconnection System Operator "I.S.O."** (see module 7 report)

These specifications cover:

- Data exchanges with national TSO's dispatchings
- Metering and controls with Nag Hammadi, Mandaya and Kosti substations,
- Telecommunication links between local substations
- Mandaya, Kosti and Nag Hammadi power stations local control links with national dispatchings

1 DOCUMENT OVERVIEW

This document details the proposed design for Telecommunications, Metering and Control systems),

This document describes the functional aspects and the general specifications for remote and centralized supervision and control for Egypt-Ethiopia-Sudan interconnection.
To cover items mentioned in executive summary, the present document is splitted in 5 chapters: from general aspects to particular detailed characteristics.

Emphasis is put on SCADA and metering functionalities. All along specifications, international applicable standards are mentioned. It is an important and required that no proprietary equipment is involved in the project and therefore, compliance to these standards is mandatory for future contractors.

A set of tables and a set of figures are also provided to illustrate particular requirements.

2 ROLES OF CONTROL SYSTEMS

By integrating telecommunication, supervisory, control and metering functions, the controls systems are a significant component of the interconnector. These functions are supporting real-time operation, asset management, accounting, and maintenance, training needs.

Control systems are also the technical information link between ISO and TSO. Technical data as energy, voltage, frequency, reactive power…collected on interconnector equipment are broadcasted to national dispatchings.

Consequently, we are considering that this centralized supervision and control will manage equipments, will recover appropriate data, and will run in parallel of each of the three national entities. Nevertheless, a data link should exist between this centralized system towards each of the three national transmission system Operator. This is provided to allow electronic communication between dispatching centers

Control systems architecture is drawn up in the diagram:**"Appendix 1 – System Operator - Supervisory control architecture".** It includes:

- Telecommunications equipment (SDH* / PDH* loop),
- Centralized SCADA* and LFC*, along with links with backup and System Operator. corporate I.T.* network,
- Remote control equipment embedded in all AC and DC stations such as DCS*.

3 GENERAL SPECIFICATIONS FOR TELECOM, SCADA AND METERING EQUIPMENTS

This paragraph covers the general requirements for equipment general and common characteristics. These should cover at least the following areas:

- **International standards** for supervision structure and communication (such as IEC*, and other local standards), should be supplied only. Proofs of this compliance should be granted at any time. In particular the following ones should be used:
    - CCITT, and IEC standards,
    - Recommendations from normative documents: IEC 60870-2-1 and IEC 60870-2-2 should be enforced,

- Inside substation equipment, it is required to fulfill IEC 61850 normative documents.

- **Regional climate constraints** (desert conditions, tropical areas, humidity, weather stability or instability…) must be taken into account for building and equipment characteristics. In particular, telecom repeaters all along transmission line, to regenerate signal inside optical fibres, should be placed in air-conditioned appropriate shelters, also designed to protect equipment against both climate and forbidden interactions.

  Equipment must withstand bad weather conditions for many years. Consequently the following test must be made, as a minimum.

  - Temperature : 0 to 55 degrees Celsius,
  - Relative humidity : 5 to 95%,
  - Electromagnetic isolations standards and tests to be enforced :
    - operation disturbances : IEC 225.4 et IEC 801.4,
    - electromagnetic protection : IEC 801.2, 801.3, 1000-4.3
    - dielectric tests : 500V at 50 Hz, 10 MΩ resistance.

- **Complementary technical specifications** shall be detailed if a specific agreement between the three participating countries is endorsed for commercial telecommunication. A close collaboration or partnership with telecom companies is recommended

- **Equipment lifetime:** All I.S.O. supervision equipment and software should be chosen to ensure continuous service (nevertheless with periodical partial upgrades) for approximately 20 years. General revamping is estimated by this period. This requires to inquiry about supplier technical products roadmaps, maintenance service and particularly on spare parts availability over this range of time.

- **Control Center and Backup Center architecture:**
  The central processing facility, fully dedicated to ENTRO /I.S.O. operation should have a main operation center and, as an option, a backup center (physically separated from main center building infrastructure). Please refer to the following schemas:
  - Hardware configuration Main System ENTRO 1_2 V2.ppt
  - Hardware configuration Main System ENTRO 2_2 V2.ppt
  - Hardware configuration Backup System ENTRO - V2.ppt

- **Control Center and Backup Center hardware:**
  Each center is constituted of dedicated hardware equipment. The main items should be:

  - Standard SCADA* functionalities: redundancy for critical functions servers, response times, availability rate, switchover performances, etc... Servers should be rack-mounted.
  - Operator consoles: standard equipment (any proprietary equipment prohibited).
  - Maintenance consoles.
  - Dual LAN, using teaming facilities.
  - Protected connection (using firewalls) with backup system and corporate LAN.
  - Redundant archiving system.
  - Video-wall display: a basic 3*2 67” modules device is advised (using retro-projection system).
  - Time synchronizing and frequency measurement devices.
  - Laser type printing devices: both black and white high printing flow and colour A4/A3 formats.
  - Meteorological station (on ISO central system building’s roof): measuring for example temperature, humidity, solar radiation, wind speed, etc…

4 TELECOMMUNICATION FACILITIES FUNCTIONAL DESCRIPTION

4.1.1 TELECOMMUNICATIONS FOR ISO SYSTEM OPERATION ONLY

An entire telecommunication network will be inserted in transmission lines and power infrastructures. Telecommunication devices will follow the best latest state of the art techniques, adapted to energy systems needs. In particular, choice of equipment will implement SDH* and PDH* functionalities.

4.1.1.1 Telecommunication medium

Optical fibres will be used, to create a loop circuit over the whole Interconnector. This will to be implemented to ensure as much as possible redundancy for communications and as much as possible "self repair" capabilities, in case optical fiber loop is broken in one point, to avoid loss of communication links. This faculty is provided inside telecommunication devices, through applications that they are running. Although a single failure will not be visible by usual users, telecommunication system will signal this single failure before one additional happens. This enables to have a high availability of communication data for dispatching center operation.

Nevertheless, as an option satellite communication equipment may be provided to ensure reliable communications (moreover due to important length of transmission lines). This link should only be used under emergency conditions, due, primarily, to important cost of this type of communications.

Telecommunication circuits are essential to proper system operation. Moreover they are at the cross-border to transmission line equipment: optical fiber should use OPGW* technique: insertion inside ground wire on overhead line.

The suggested total number of optical fibres is 48, using monomode technique.

Physical separation of each wing of telecommunication loop should be implemented. Due to ENTRO system topology, three different alternatives may be implemented, each has a different cost against technical advantages brought:

- **Proposal 1**: 2 separate OPGW* cables, each containing 24 optical fibres between Mandaya and Rabak substations, each OPGW cable on a separate power tower (as there are 2 power towers circuits there). Then between Rabak and Nag Hammadi substations, 2 separate OPGW* cables, each containing 24 fibres on the unique power tower.

- **Proposal 2:** 2 separate OPGW* cables, one containing 36 optical fibres and the other 12 optical fibres, on the same power tower, all along the transmission lines, from Mandaya to Nag Hammadi.

- **Proposal 3**: 1 unique OPGW* cable, containing 48 optical fibres all along the transmission lines, from Mandaya to Nag Hammadi.

In order to reduce as much as possible the need of installing signal repeating devices (especially in remote and with difficult physical access areas), "booster" technology should be used. These repeating devices should be installed as much as possible inside already existing infrastructure, such as power substations. Here is a quick comparison:

- **with usual repeaters**: necessity to install a shelter every 100 kms approximately,
- **with terminal equipment using "booster" technology**: necessity to install a shelter only every 200 to 250 kms approximately.

As an option, emergency transmission system may be provided, in order to avoid single mode factor (in case physical transmission medium outage). This emergency telecommunication means can be implemented through microwave or satellite link. We propose it just an option as of today stage.

4.1.1.2 Telecommunication protocol

Standard telecommunication protocols must be used: it is advised to widely use IEC 870-5-101 protocol between local acquisition devices and central supervision facility. Any proprietary protocol and/or equipment is strictly prohibited.

Inside each substation, we strongly advised to use local networks, compliant with IEC 61850 protocol. This protocol is emerging for few years now and is foreseen to develop among substation automation.

Telecommunication circuits for energy system must also transfer voice operation and maintenance phone lines. A private network must be implemented by putting into service appropriate PABX infrastructure.

Provision must be made so that easy extension may be provided in the future, for transmission and distribution network extensions. Design for easy extension must be such so that only additional modules should be added, prohibiting partial or total equipment replacement at time of future extensions. A set of spare telecommunication parts/equipment must be provided along with initial telecom needs.

4.1.2 TELECOMMUNICATIONS BETWEEN ISO AND EACH OF THE THREE PARTICIPATING COUNTRIES, RELATED TO ISO OPERATION:

Communications systems must allow data Interchange between ISO transmission system and the three respective TSO (Egypt, Ethiopia, Sudan): provision should be granted at each SCADA/dispatching levels, reflecting appropriately the organisational decisions undertaken before. To implement such capability, hardware servers must be implemented.

It is advised, to use standard international protocols such as Inter Control Center Protocol (ICCP*), also known as IEC 60870-6/TASE.2. This protocol is intended to be an international standard governing the electronic communication of EMS data between control centers.

In response to this, a provider’s product should be proposed to support a wide range of electronic communication protocols in the control center.

The following sections give a high level functional description of the product requirements.

4.1.2.1 Product requirements overview

Main characteristics that should be achieved through inter-center links are:

1. Data accuracy - No longer are operators reading from, and typing values into the system. While conscientious, invariably mistakes are made.
2. Timeliness - Data is provided to the operator and the EMS system on a regular and scheduled basis. Because of the much higher data rates reachable here, data is usually delivered on time.
3. Completeness - Because transmission of data is modeled in the computer system *all* the data required is transmitted.

Data exchange between control centers will be even more necessary in the future due to the probability of future integration inside a more widely spread electrical power pool, at the Eastern part of Africa.

Basic architecture is to provide a dedicated inter control-center at each communicating dispatching center. This server, hosting ICCP function and utilities, should be totally integrated inside each dispatching local network architecture.

Data exchange should be bidirectional and therefore requires a particular level of coordination between participating TSOs. See also paragraphs below for additional details.

4.1.2.2 Communication product components

To address the needs of utilities to communicate with existing proprietary and standards-based protocols, and new industry-wide standard protocols, the product must be designed in a modular fashion. It is comprised of three principal sub-systems:

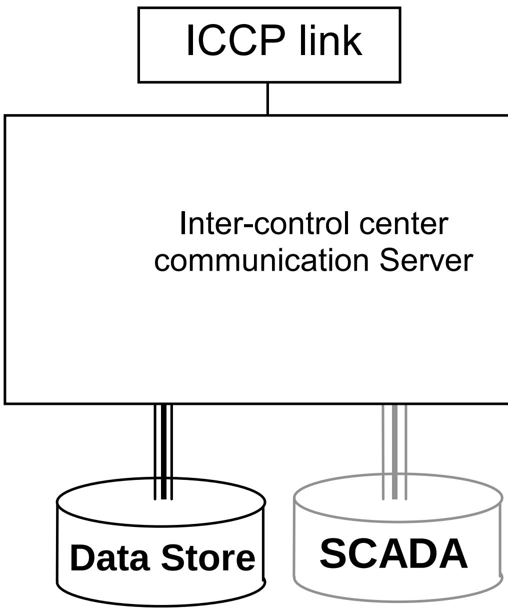


Figure 1 : Storage architecture

ICCP link will handle data communication with counterpart dispatching center. The Inter-control center communication server will integrate software applications for proper data processing (either inward and outward). SCADA database is either the source or destination of exchanged data. Data store provides a means of storing data not directly present in SCADA.

- **Inter-control center communication server:**

The application running on the communication server will coordinate, manage and monitor the communication activities between the control centers.

The inter-control center communication server is the heart of the communication system. It is the component that provides the high-level data modeling, access, and control functions in the system, and can utilize one or more link applications and storage methods.

The communication server will manage the following functions:

- Modelling
- User Interface
- Event Processing
- Data access
- Security
- API Services

The product should enable the local data which should be made available or to be received in the communications system. This includes identification of the data by name (POINT), type (Status w/Quality), location (Local) and storage (SCADA).

It must also be possible to define security information for data that you are the source of. This consists of permissions granted to remote sites so that they may access a particular data item. Because this permission is remote site and data item specific, there is complete control over who may access data.

For data items to be received from remote sites there is a modeling phase. This includes how the data item will be grouped with other data items (data sets) that will be received at the same time and when they will be received (periodically, by exception).

Because different communications protocols and storage methods may represent the same data in different ways, the product must embody a collection of general object formats. These are then used to standardize the communications with the link applications.

Finally, the user interface to the product is handled by the communication server. This eliminates the need for users to deal with separate displays for each link application.

The communication product link applications must provide the protocol specific processing needed in the system. This includes connection management, protocol dialog handling, data transmission, and data conversion.

- **Link Applications:**

Applications that provide the protocol specific processing and communicate with the communication server through a standard API.

The ICCP link will manage the following functionality:

- Protocol handling
- Data conversion
- Com Server API client

The link applications interface with the communication server through an API. This should give all link applications a consistent interface to the configuration information, data, and commands in the system. It is then the link application's responsibility to convert between the protocol specific and communication product general formats. The types and formats of data that can be exchanged with each link application are defined by the particular protocol specification.

Because the link application's only interface is with the communication server and not with any other link applications or the storage methods, any number of them may be supported in the system simultaneously.

- **Storage Methods:**

There are two choices for how inter-center communication stores and accesses local data or application storage.

A means of storing data should be provided in a way that objects are not intrinsically tied to SCADA applications. This method is used primarily on gateway nodes (see below) where SCADA applications are not needed in the system.
These storage methods can be intermixed to provide the exact storage support that is required.

4.1.2.3 Suggested configuration

The gateway configuration is intended to provide protocol conversion and data access support for EMS hosts in a stand-alone, external system. This stand-alone system is known as a *communications network processor* (CNP).

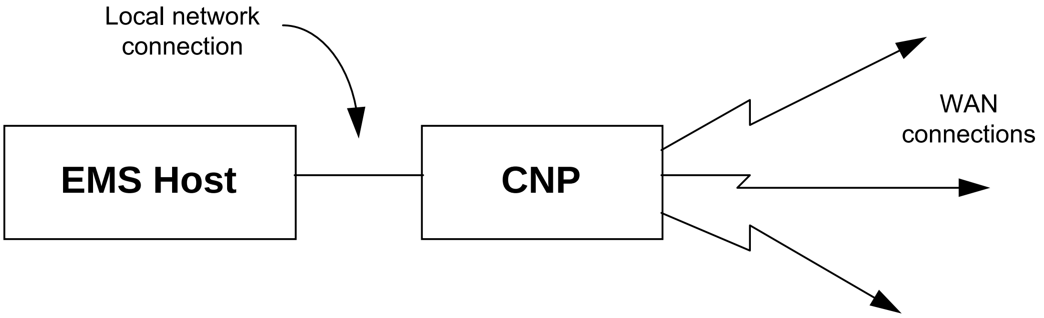


Figure 2 : Connection Network Processor

A CNP consists of a computer running communication product and at least two (2) link applications.

This configuration allows systems with an existing communication protocol to access remote sites that communicate with different protocols. Here, the CNP manages the reception, transmittal, and conversion of data between multiple protocols. This is the use of this corresponding configuration.

4.1.2.4 Exchanged data

Data exchanged will be the one of block 1 and 2 of ICCP protocol:

- Block 1: Basic services (association objects, data value objects, data set objects, transfer set objects, Next transfer set objects)

- Block 2: Extended DS Condition monitoring: Object change, integrity time-out and external events for data set transfer sets.

4.1.3 TELECOMMUNICATIONS FOR NATIONAL UTILITIES TRANSMISSION NEEDS:

Capability may be provided to provide a private dedicated communication capacity allowing each of the 3 utilities to communicate with its neighbouring utilities, separately from ISO-TSO data flow. This capacity, if juridical context allows it, will have an economical benefit for TSO communications

It is also advised, as in paragraph 2.2.1.2 to use standard protocols such as ICCP* protocol, also known as IEC 60870-6/TASE.2.

ENTRO can also forecast to use this transmission capacity for other particular uses, such as hydrology data exchange, flood prevention etc …

4.1.4 TELECOMMUNICATIONS FOR EXTERNAL TELECOM OPERATOR:

Capability may be provided, as an option, to give access to ISO optical fibres backbones, to lease to external telecommunication companies, this separate transfer capacity. This should be taken into account and justified by business economic study: this will be a source of income if juridical context allows it

5 ISO CONTROL AND SUPERVISION FUNCTIONAL DESCRIPTION

This chapter describes necessary functions to be implemented at ISO centralized supervision and monitoring center. These functions are implemented in a dedicated Supervisory Control And Data Acquisition (SCADA) system.

Hereafter follow several chapters, first describing general SCADA system requirements and then more detailed characteristics.

At the time being, there is no particular functional requirement dedicated to electricity market type interchange. Nevertheless, market interchanges may occur in the medium term (5 to 10 years after initial commissioning). Current proposed architecture and functional details described hereafter are compatible to interact with future market applications, nevertheless these are not part of the following description.

5.1 MAIN SCADA SYSTEM FUNCTIONALITIES

- **Monitoring (from local substation to central monitoring system)**

  Basic functionality of centralized computerized system should acquire, as exhaustively as possible, all digital and analog measurements of the ISO transmission system. This covers the following stations: Mandaya Power Station (Ethiopia), Rabak AC/DC station (Sudan), Nag Hammadi AC/DC station (Egypt).

  Particular signals to be acquired: Active Power MW, Reactive MVar, Amperes, Voltage, Frequency, topology status (for all possible disconnecting devices), metering (especially at delivery points to each customer country).

- **Control (from central monitoring system to local substation)**
  The SCADA must have the capacity to transmit controls to:
  - appropriate disconnecting devices. Usual functions such as interlocks (preventing to trigger one action on disconnecting devices under particular conditions), or time out feedback checks (in case of malfunction in operation transmission) must be provided.
  - to adjust active power, voltage, reactive power in critical points of the interconnector to any interconnector DCS system.
  - to enable countries TSO dispatching centers to adjust active power or reactive power transmitted by the Interconnector.

- **Device coordination and protection supervision, in regard of interfaces with:**
  - Transmission lines and power stations protection subsystems
  - HVDC controls systems
  - SVC control systems

  The coordination includes monitoring or remote control, data exchange and interlock capabilities, such subsystem controls are described in other M4 design reports

- **Control Center SCADA and Backup Center functionalities:**
  Each center is constituted of dedicated software capabilities. The main functionalities should be:
  - Standard SCADA* functionalities (monitoring, controlling), feeding archiving system, additional functionalities such as post-mortem review/replay, equipment tagging (maintenance, outages (planned or unplanned), interlocking, information only, …),
  - Advanced functions:
    - Generation related applications: economic dispatch, short, medium and long-term load forecasting, long-term generation scheduling, automatic generation control, unit commitment, …
    - Network analysis functions: network state estimator, contingency analysis, optimal power flow, short circuit analysis, load-shedding, off-line studies
    - Other applications: dispatcher training simulator, maintenance scheduling

    Some of these advanced functions may be optional.
  - Operator consoles: Man-Machine Interface (MMI*: web-based techniques), extension capabilities…
  - Archiving system, fitted with formatted reports editor.
  - Tools/systems (that may be external software interfaced with SCADA system) to ease operation planning, especially taking into account weather forecast impacting power and water constraints (inflows, outflows, agriculture needs, …).
  - Software licences: appropriate sizing estimation should be granted, in order to allow system data base extension, without licence constraints.
  - Equipment maintenance management, automated system, easing maintenance tracking.

5.2 DETAILED REQUIRED SCADA FUNCTIONS:

5.2.1 OVERVIEW

The SCADA subsystem should be an integrated software suite that provides real-time monitoring and control capabilities for distributed industrial applications such as power transmission and generation systems.

Some highlights should be:

- Reliable real-time database which is designed to deal with large volumes of fast-changing data;
- Full graphic interface via which uses state-of-the-art web based technology to present full-graphic interactive views of system data via either local area networks, corporate intranets or the Internet;
- Extensive data acquisition, processing and control capabilities. Data may be collected from many different sources, e.g. field data, inter-site data, manual entry, calculations, applications, etc;
- Complex data calculations, limit and quality checking, alarming, flexible control sequences, interlocking;
- Open interfaces for interconnections to other control centers (via ICCP, etc.) and for access to the databases used by the system (via open API's).
- The following figure illustrates the modular architecture and interconnectivity of the required SCADA system:

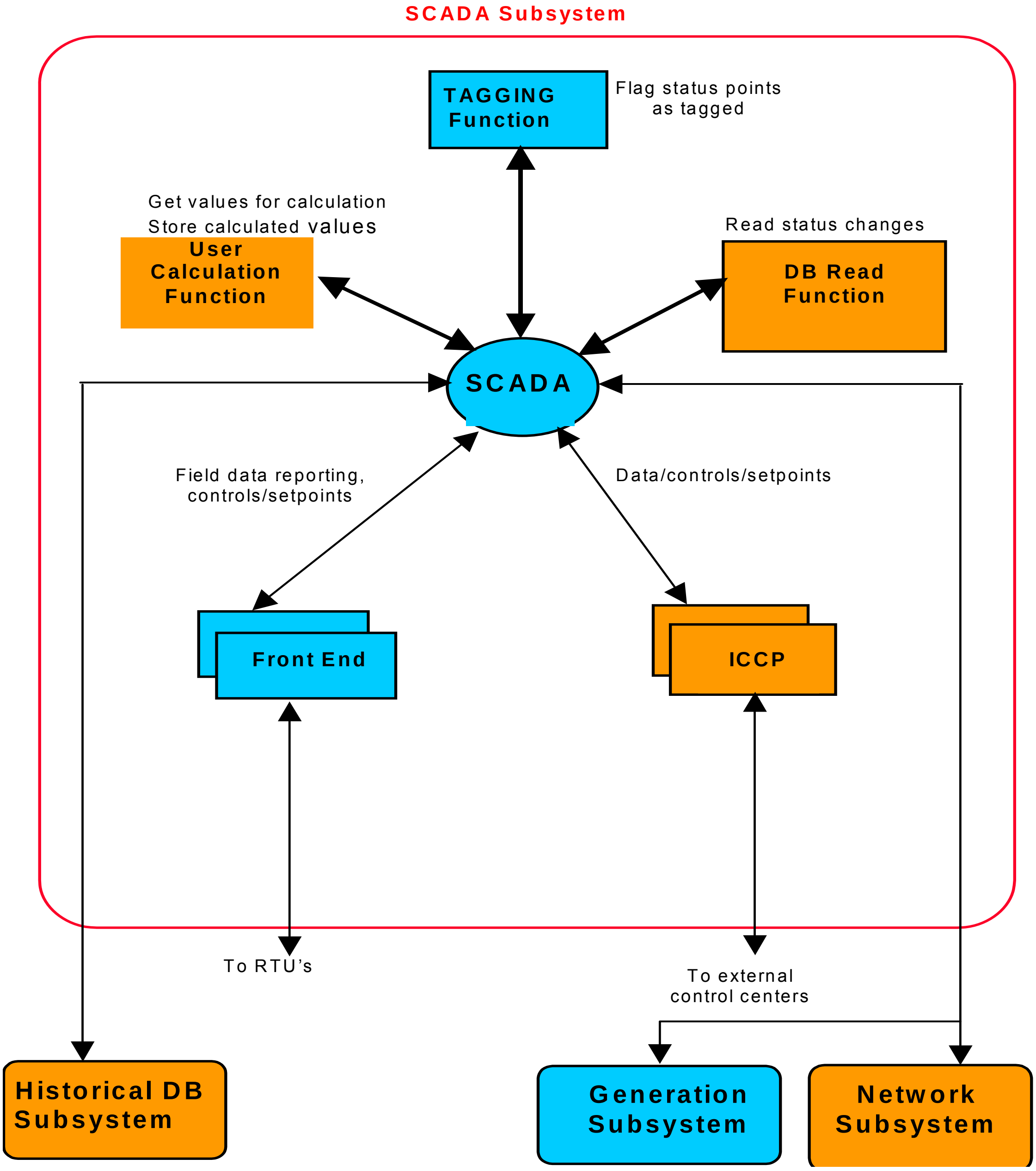


Figure 3 : SCADA Overview

5.2.2 DATA ACQUISITION

Generally speaking, data can be collected from RTUs, Data Concentrators (DCs), Information Nodes, substation and power plant DCS's (Digital Control Systems), other control centers, manual entries, automatic calculations or other applications (via APIs).

5.2.2.1 Data Acquisition via Front Ends Subsystem

This processing software package should be implemented in the SCADA/EMS/FE servers.

5.2.2.2 Communication Monitoring

Each RTU will be connected to the proposed dual servers so as to provide dual access paths to each RTU. Required functionalities should be:

Failure of a single line does not imply a server failover. In the case of a communication line failure, the RTUs connected on the failed line are automatically switched to the second communication line. Communication with other RTUs continues unaffected. In the case of an Information Node failure, the RTUs connected to the failed Information Node are automatically switched to the second Information Node.

Re-transmission logic is implemented in order to recover from communication problems. After "n" poll failures, the offending RTU is placed on a delayed poll list. This causes the RTU to be polled at a reduced rate in order to minimize the effects of protocol retries on other RTUs on the same line. Note that decoupling is designed into the Information Node in order to prevent communication problems and retries on one line from having an effect on other lines.

In such circumstances, the Information Node informs the SCADA subsystem that communications to the RTU have been disrupted. The SCADA subsystem generates a communication failure alarm for the RTU and notes the problem in the communications database and on the communication status displays.

The RTU is restored to the normal polling sequence (and the SCADA subsystem is notified) as soon as communications are re-established by a correct response during the delayed poll sequence. The SCADA subsystem issues a "communications restored" message for the RTU and updates the communications database and related displays.

In addition to the communications messages (alarms), the Information Node should maintain a communication statistics database that keeps a complete record of each communications failure by maintaining counts in a number of categories. Some of those categories should be:

- **No Replies**: These errors are the result of one of two types of failures. The first is a transmission error from the Information Node to the RTU. The second is a failed RTU;
- **Check Code Errors**: This category of errors is generally indicative of transmission errors from the RTU to the Information Node;
- **Other Errors**: The number of errors in this category is normally quite small since transmission errors are the most common form of error. These errors are typically caused by equipment failure or database errors of some type. Notably, it is possible to record error types that are specific to a particular protocol.

One effect of communication failures is that all data belonging to an RTU in a communication failure mode is marked OLD (refer to the description of data quality flags in the Data Processing section). When communications are restored, an initialization scan brings the SCADA and Information Node databases up-to-date and the old quality is replaced by an up-to-date quality representative of the specific measurements.

In order to maximize the availability of the data acquisition subsystem, the failover from one Information Node to the other should be performed on a line-per-line basis.

The operator must have the ability to enable or disable communications with specific RTUs. Any RTUs, which are manually disabled, are identified as "operator removed" on all displays.

5.2.2.3 Data Polling & Scan Groups

A scan group is a set of data points retrieved in a single command to a RTU. Usually, the most important status points and measurements are defined in one scan group and retrieved frequently. Less important status points and measurements may be defined in a different scan group and retrieved less often. SCADA should be able to scan the system in four ways:

Integrity scan: All RTUs and scan groups are scanned to retrieve data for all monitored devices. The integrity scan is always performed when SCADA is started for the first time and following certain failures in the computer and communication systems;

Periodic scan: Each scan group in an RTU is scanned at a rate specified in seconds in the SCADA database. SCADA receives from the Information Node only data for those scan groups being retrieved, and only if the data has changed since the previous scan. Scan groups of status measurements and important analog measurements are scanned the most often so that changes can be quickly detected;

Individual scan: Specific scan groups are scanned collectively at a rate specified in the SCADA database. This allows certain kinds of measurements, such as pulse accumulator counts, to be retrieved as a group at the same rate. Individual scanning also allows certain measurements to be retrieved at a slower-than-normal rate over a long period of time, or a faster-than-normal rate over a short period of time (this latter scan being referred to as "accelerated" scanning);

Demand scan: One or more scan groups can be scanned at the operator's request. Demand scanning can be requested as often as desired.

5.2.2.4 Sequence of Event Data

The SCADA system should have the ability to both synchronize the clocks of RTUs with one another and to acquire and process Sequence of Event (SOE) data from the RTUs. Here are required functions.

Using the standard IEC 870-5-101 protocol, SOE data are not transmitted in a dedicated message since time-stamped change events are returned ordinarily as a result of a normal scan request. Therefore, the reception of a binary-input-change-with-time will trigger both a *status* data exception and an *SOE* data exception (which results in the storage of the event in the SOE log).

SOE data are stored in SOE logs that contain each time-tagged event that has been received. Each log entry contains the point identification, state information, RTU time/date and SCADA time/date for the respective change. SOE data may be sorted, displayed and printed for analysis purposes.

The Information Node may be configured to periodically send a synchronization message to each RTU in order to achieve the synchronization of the RTUs on a regular basis. This message contains the current time (which is generally obtained from a reliable source such as a GPS system). Transmission delays and transmission speeds are accounted for in the setting of the time. RTUs which support time synchronization may mark points with suspect time if a time synchronization is not received within a specified interval.

5.2.3 DATA CONVERSION

The following points describe the data conversions that should apply to the different types of values retrieved from the field:

- **Analog values:**

Raw to engineering conversion is provided for all analogs. A linear or non-linear conversion may be specified for each point. Reasonability limits are also provided for each point. If these limits are exceeded then the data is marked as "unreasonable".
Analogs are numeric values representing the state of variable-state devices, such as power lines, transformers, and pumps. Analog measurements are stored in ANALOG records.

In the monitored system a transducer usually measures a physical variable and the output of the transducer is passed through an analog-to-digital (A/D) converter in the RTU. The A/D converter produces a number that the host computer can process. All analog values are converted to host computer floating point numbers and adjusted by the SCADA Front End to represent the physical measurement in engineering units; that is, megawatts or pounds per square inch. In this form the values are stored in the database and usable for display and calculations.

Each variable-state device in the monitored system is associated with an ANALOG record in the SCADA database. The purpose of the ANALOG record is to identify a single analog data point. Other records subordinate to the ANALOG record describe characteristics of the analog point, such as limits.

Limits are defined by two values that specify a range. For example, a power line may have one pair of limits that define a high limit and a low limit for the line's normal operational state. Outside those limits SCADA would consider the line to be in an abnormal state and could issue an alarm.

The list below describes the different types of limits that can be associated with an analog point:

Normal limits: Define a range of values within which the device is considered to be operating normally.

Reasonability limits: Define a range of values that SCADA uses to determine whether a value retrieved for the analog point is reasonable. If, for example, a value is above the high or below the low reasonability limit, SCADA considers the value unreasonable and ignores it. Instead SCADA uses the last retrieved value for the point.

Forbidden range limits: Define a range of values that SCADA considers violated when the analog point falls within the range. Forbidden range limits are used if there is a range of values within the normal range of limits where operation of the device should be minimized or prevented.

Deadband limits: Applies to the return of an analog value from an abnormal to a normal state. On a pair of normal limits, for example, if the low limit is violated, the value must rise above the low limit by at least the deadband amount before SCADA considers the analog to be back within normal limits.

Rate-of-change limits: Define an acceptable rate at which the analog measurement can change between scans.

As SCADA receives data for an analog point, it should check the limits associated with the point. If the analog's measurement violates any of the limits, SCADA can issue an alarm.
The SCADA operator may inhibit individual limit pairs on an analog point. This prevents SCADA from considering any violation of the inhibited limits to be abnormal or alarmable.
SCADA has the capability of automatically switching between different sets of limits for a given analog, based on such external factors as temperature, season, etc. This function, called Limit Replacement, can also be invoked manually by the operator.

- **Digital values:**

The retrieved digital values must be checked against valid status values and placed in the database.

Status values represent the state of discrete-state devices, such as circuit breakers, tap changers, and valves. SCADA can accept status inputs representing a simple on/off or open/closed input, or a combination of inputs from a three-state device. (An example of a three-state status point is one that has "on" and "off" states and a transition state in between on and off.) All status point values are stored in POINT records in the SCADA database.

Additionally, SCADA should accept status inputs from two- and three-state devices with Momentary Change Detection (MCD). With MCD, SCADA can detect multiple changes that occur between scans.

- **Counter values:**

Pulse Accumulator conversion (in case this option is chosen) differs somewhat from normal analog conversion. The last retrieved accumulator value is subtracted from the current reading and adjusted appropriately if the value is negative (a negative accumulator difference indicates counter wraparound). The difference is then converted to floating point and scaled using a multiplier. If desired, the system may also maintain a running accumulation.

A count measurement is a value from a pulse accumulator. Pulse accumulators are often used to measure the total amount of energy, liquid, or gas that has passed by a specific location in the monitored system. The detection device alternately opens and closes a contact each time a unit of the measured matter passes by it. The pulse accumulator counts the contact changes and passes the count to SCADA which stores the total accumulation of counts since the last time the count was reset.

Like analog values, count values are stored as floating point numbers and adjusted to represent the physical measurement in engineering units such as megawatt-hours (MWH) or cubic feet. In this form the values can be used for display and calculations. Each pulse accumulator or counter being monitored is associated with a record in the SCADA database, which stores the count value.

Some RTUs allow pulse accumulators to be "frozen." This means that at a particular point in time a "freeze" command can be issued to the RTUs to simultaneously capture current running accumulations. The values are stored by the RTU until the various accumulator points throughout the system are scanned. At that point the values are sent to the SCADA Front End.

5.2.4 DATA PROCESSING

There should be five normal sources of SCADA data:

Telemetry;

A remote site;

A calculation;

A manually entry

A host process external to SCADA (State Estimator for example).

The processing of data should be uniform irrespective of the source of the data. All retrieved data undergoes standard processing including limit checking, alarming, quality checking, and calculation triggering. The data is placed in the online database where it becomes available for displays.

There are also three replacement sources from which data may be supplied if the normal source is unavailable:

- Manual entry;
- State Estimator replaced;
- User Calculations replaced.

Any value from any of the normal sources may be manually replaced if the normal source is unavailable. An analog value may be replaced by the State Estimator (not provided in this offer) if the normal source is unavailable. Any value may be replaced by the User Calculation application if the normal source is unavailable.

Points may also be declared Not-in-Service. If a user removes a point from service the point is still received from the RTU, but all further processing of the point is inhibited. When a point is restored to service, it is removed from the Out-of-Service Summary display and the last scanned value becomes the displayed value.

Checks are made to determine whether an alarm is to be generated upon reception of a new value. If desired, alarm processing may be inhibited for any particular point. Inhibited points are shown on the Alarm Inhibit Summary display.

Data quality flags should be associated with each point provide information about the value stored for each status, analog or counter. Data quality flags generally indicate whether the value represents a reliable indication of conditions in the field. Data quality flags are also provided to indicate the source of the data. The User Interface Management System controls the use of the data quality codes in presenting data to the operator. The system designer can prioritize the presentation of the various flags that indicate the state of a point, and can use the data quality codes to alter the presentation of the data (change data color, append flags to data, cause values to blink, etc.).

Several data quality flags should be provided to indicate the source of a value, e.g.:

Value normally reported by an RTU or local input device connected to the system;

Value normally reported to the system by another computer system;

Value normally calculated from other values in the database;

Value normally manually entered by the operator;

Value normally supplied by the State Estimator or some other process external to SCADA;

Value manually replaced (overridden) by the operator on the system;

Value replaced (overridden) by an output from the State Estimator;

Value replaced by an output from a Generalized Calculation.

The normal source flags should be static with only one flag being set for any particular measurement (indicating the normal source for that measurement), e.g.:

Uninitialized value: Nothing has been stored in the record as of yet.

Old value: The value in the record is old for one of three possible reasons:

Upon start-up, all records whose values are produced by scanning are marked as old and remain old until the first scan updates the data;

Bad value: The value in the record is likely incorrect because it came from an RTU whose circuitry has been determined to be malfunctioning. All records receiving data from the affected circuitry have BAD set as soon as the failure is detected. BAD should only be cleared when the circuitry is functioning correctly and a new value is stored in the record;

A/D converter overflow: The value in the record may not be correct since the A/D converter was found to return either the largest or smallest number of which it is capable - meaning that the input could be even larger or smaller;

Not-in-service: This flag is set by the operator to control the updates of a point. If the flag is set by the operator then the corresponding record is not updated from the field, making the value somewhat suspect.

There should be composite data quality flags used to summarize the ones already covered. These composite flags collect the other flags into logical groups, from the standpoint of information that is important to the operator in a real situation. When viewing a display during a system disturbance, the first need for the operator is to be able to quickly tell whether to trust a value completely, treat it with suspicion, or ignore it altogether. From there, analysis of the usable data may proceed in order to solve the problem. Later, the operator may look in more detail at the data quality flags in order to determine why values are not good and to correct any problems.

5.2.5 ALARM MANAGEMENT

An analog point may have one or more limits assigned to it that are checked each time that its value changes. When a limit is violated the analog record is marked as having a violation and an alarm is triggered. In addition, limit bits are set on the analog record in order to identify which limits have been violated. The user may define whether an alarm is to occur when a value returns to normal (between the defined limits).

Alarming can be disabled for the analog as a whole, preventing any alarms but allowing limit checks to continue and their results to be recorded in the analog record. In addition, any given limit record can be disabled - thus preventing the checks on these limits and thereby preventing the occurrence of alarms. Limit records are inserted only in the modeling environment. However, the enabling and disabling of limits (along with the modification of limits) may be performed online by the operator.

Analog alarms may also be delayed for persistence checking. In such case, the alarm tone and associated entry in the alarm list will not be issued unless the analog remains in violation of the limit for a configurable number of seconds.

5.2.5.1 Limit Values

Several pairs of limits may be nested for a given analog point. This allows SCADA to detect several levels of severity when the value is out of limits. For example, one limit pair could specify the limits for normal continuous operation of a device. The next limit pair (surrounding the first) could specify the limits within which the device may operate for only one hour. The subsequent limit pair could specify the limits within which it may operate for only ten minutes. The operator may receive a new alarm as each successive limit pair is exceeded – thus indicating the increasing severity of the situation. The limits must appear in the database in order of increasing severity.

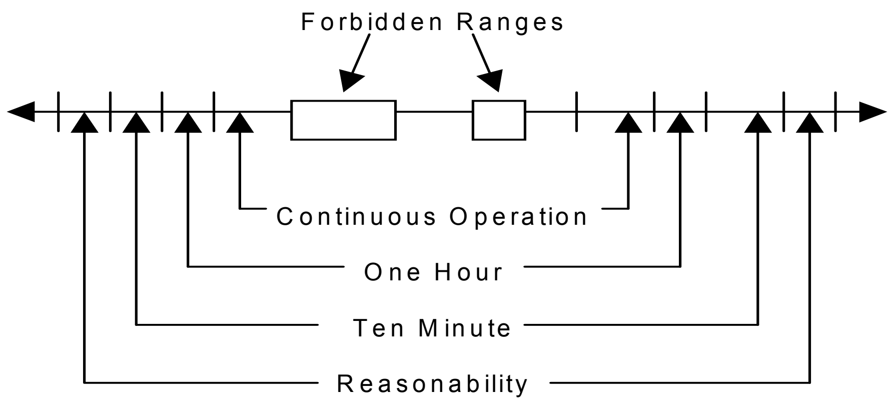


Figure 4 : Limit Values

- **Reasonability Limits**
  A pair of "reasonability limits" is available for each analog value, beyond which no value is acceptable.

- **Forbidden Range Limits**
  An analog may have one or more "forbidden" ranges besides any normal limit pairs that are specified. A forbidden range is a limit pair that is considered violated when the value of the analog falls within the pair.

- **Limit Deadbanding**
  A dead band must be specified on the return of a value to the normal state in order to minimize cycling between error and normal states. E.g. if the low limit is violated on a standard limit pair then the value must go back above the low limit by at least the amount of the dead band before it may be considered to be within limits.

5.3 *RATE OF CHANGE LIMIT*

Rate-of-change limits are those that check the rate at which an analog value changes. That is, a violation is declared if the value of the analog increases or decreases by more than a specified amount in a scan. Positive and negative limits are provided in order to detect excessive rises and falls in the value of the associated analog record.

Status processing detects the existence of status changes and generates alarms accordingly. If an unexpected or unauthorized change is detected then the state of the point in the database is changed and an alarm is generated. The point is also checked for a defined "normal" state. If an abnormal condition has occurred then a new message is added to the abnormal summary. If an abnormal condition was just cleared then the abnormal message is removed from the abnormal summary.

5.4 CALCULATED VALUES PROCESSING

SCADA system should support 2 types of data calculations:

- Calculations defined off-line at database modeling: off-line calculation allows for the definition of a calculation as the normal source of SCADA data (status point, analog, counter). This type of calculation is defined off-line when the database is modeled.

  Examples of supported calculations that should be supported:

Linear combination of two analogs: z = Ax + By + C, where: A, B, and C are constants; x and y are the two input analogs and z is the resulting analog;

Calculation of status values from other status values: z = Axy + Bxy' + Cx'y + Dx'y, where: A, B, C, and D are Boolean constants; x and y are the two input status values; x' and y' are NOT(x) and NOT(y); z is the output status. The calculated status values may generate alarms or may be simply events;

Calculation of MVA and amperes: A variety of functions is provided to calculate these quantities where the necessary analog values exist;

General calculations: A wide variety of general functions can be used directly or combined to form more complex functions: algebraic primitives, maximum value, minimum value, average value, integrated value, conditional value replacement, threshold crossing counters, open-ended summations, and numerous Boolean primitives.

SCADA system should allow the addition of new special processing functions. The new functions are coded in any supported programming language. This facility has been designed so that new functions are very simple to add without requiring any special knowledge.

These calculations could be defined to be performed periodically or automatically whenever any of the input arguments change and the output of a calculation can be used as the input of another calculation.

- Calculations defined on-line by the operator.

  On-line Calculation Definition is supported by a dedicated function of the SCADA System. The detailed operation of the User Calculation subsystem.

5.5 SUPERVISORY CONTROL

Supervisory Control is the SCADA function used to issue control commands to field equipment (digital devices, set points) under the supervision of the RTUs, from the operator or from another application, through a user-callable Application Programming Interface (API).

This allows to operate:

Two state devices, such as switching devices, with associated open/close commands.

Adjustable devices such as transformer tap changer with associated raise/lower commands; and

Power units with set points, with interfacing with the AGC (LFC) function. A set point output involves an analog value being sent to an RTU and henceforth to external equipment. An example of a set point would be the result of an AGC calculation that it sent to a generator. Set points are checked to see that they are within limits before being sent to the RTU.

The man machine interface should allow the following way of controls:

Single control command: with select before operate command (device selection, operation selection, execution) or a direct operate command. Direct operate commands are typically used when inadvertent or erroneous operations have minor or no ill-effects on the operation of the system, while select before operate commands require positive operator verification for security; and

Sequence of control commands. Two mechanisms are provided: defining the sequence of control commands at configuration time (corresponding to usual operations maneuvers) and defining on-line the sequence to be performed.

SCADA should support both dispatcher controls and automatic direct-operate controls governed by other programs.

5.5.1 Alarm and Event Processing

5.5.1.1 General

The Alarm application functions with other applications in the system to provide the following features:

Exception displays of predefined events;

- System central alarm list;
- Chronological event history;
- Audible alarming with multiple tones related to alarm severity;
- Sorting of alarms and exceptions by priority, substation and chronologically;
- Inhibit/enable and acknowledgement of alarms;
- System summary lines of unacknowledged alarms by category and location, or by individual alarms.

The Alarm application should use the above features for notification to operators of significant, unsolicited changes in the system's state and maintains a chronological history of events that have transpired in the operation of the power system. The Alarm application is central to the overall functionality of alarming.

Other software applications contribute significantly, by maintaining displays of their databases that present currently abnormal and/or acknowledgeable conditions and provide support for operator acknowledgement of acknowledgeable conditions, inhibiting of alarm generation, and auto-acknowledgement.

"Alarming" should be distributed, with the Alarm application providing a central summary view of the current state of the system and software applications maintaining more detailed information. Linkages between the summary information contained in the Alarm application and the detailed information contained in other applications are maintained.

The historical recording component of the Alarm utility should provide an event logging function. This logging function records significant events as they are detected by operator applications in a history file and formats the log entries for display and printing.

5.5.1.2 Alarm Area of Responsibility

Each alarm may be associated with an elementary area. Elementary areas should be grouped in areas of responsibility. An area of responsibility is assigned to each console. These associations are used to limit alarm annunciation to each console and alarm acknowledgement from each console.

5.5.1.3 Alarm Priorities

Alarms should be sorted by priority and are filtered according the area of responsibility of each operator console. Up to 8 priorities are available such that most significant alarms can be put in the high priorities and less significant ones in the low priorities. Therefore, in case of simultaneous alarms coming in large quantities, the operator can focus his attention on the high priority alarms before taking care of the low priority ones.

5.5.1.4 Alarm Location & Categories

Exceptions, which contribute to the alarm system, should be assigned to two independent classes: Locations and Categories. Locations represent geographical areas (e.g., substations etc.) at which events occur. Categories represent functional divisions such as a set of related electrical conditions or conditions associated with an application (e.g., 400 KV transmission, major MV distribution, minor MV distribution, SCADA communications etc.)

5.5.1.5 Functions Provided by the Alarm Utility

The Alarm Utility should be provide the following functions:

A method of notification from application programs to operators for significant, unsolicited changes in the system's state. Alarm notification optionally includes audible tones and dedicated display system lines that indicate the presence of unacknowledged state changes. The dedicated display system lines provide linkages to application displays such as abnormal summary displays. The system lines are of two types: (1) a category alarm line and (2) a location alarm line. Alarms are grouped into categories as defined by the requesting application, along with a location (if appropriate) for each alarm. The categories and locations are ordered in the system lines by severity of the alarms in each category and location. Selection of the category on the category system line will cause the appropriate application category exception display to be brought up. Similarly, selection of a location in the location system line will cause the appropriate application display (such as a SCADA one-line display) to be brought up.

Audible tones (such as a horn or alarm bell) may be associated with each category, with levels of severity initiating different audible annunciation. Alternatively, the system lines can be configured to show up to three of the oldest, unacknowledged, highest priority alarms.

A system alarm summary display can be used as a single starting point for deciding what action to take when alarms are generated. Linkages are maintained to displays provided by the applications that contribute to this centralized alarm list. These displays, typically abnormal summary displays or one-line diagrams direct operators to the specific areas that need attention.

Mechanisms for acknowledging new conditions. Alarms may be acknowledged from the application exception displays, one-line diagrams or similar application displays. Alarms may be acknowledged on an individual point or per page basis.

The alarm utility summarizes the current system state in a compact form by maintaining information about abnormal and/or unacknowledged system conditions. Information can be removed from the alarm utility when a condition is no longer abnormal and, optionally, has been acknowledged. An object can be defined to have only one input to the alarm utility, namely its currently abnormal and/or unacknowledged state, whether or not it has repeatedly changed state. Acknowledgement in this case always refers to the current state of the object.

A logging function that records events as they are detected by operator applications maintains the history files and formats the log entries for display and printing. Multiple logs may be formatted, with particular logs for example containing certain categories of alarms.

5.5.1.6 Application Usage of the Alarm Utility

Different applications (Real Time Network, Real Time Generation, SCADA, Contingency Analysis etc.) have different views of the power system and, therefore have supporting databases of considerably different structures. The requirements for the presentation of abnormal conditions and the indication of state changes for different applications vary. Thus, the system state is described by summary displays of the application databases.

The applications, which generate alarms, configure their own summary displays to present abnormal conditions and unacknowledged state changes defined in their own databases. They make their own decisions about whether an object (record) is in an abnormal or unacknowledged condition and must inform the alarm application accordingly. Further, the applications determine their own logging requirements and must ensure that appropriate messages are provided to the alarm application when they generate alarms.

Database integrity of alarms is performed both by Alarm and by functions provided by the applications. The latter functions ensure that the data structures associated with alarm exceptions are always consistently preserved in the event of CPU state changes resulting from failures or other sources. This information includes both the current state and the acknowledge state.

5.5.1.7 Presentation of Alarm and Event Messages

The system exception summary should be maintained by the alarm utility in the alarm application database and is used to summarize the system state. The information for this summary consists of three components:

- System exception summary information, which summarizes the number and nature of exceptions existing in the system but without giving details of the individual exceptions.
- System exception information, which is used to maintain the alarm category and location system lines.
- A list of individual exceptions, which is used to create both optional alarm summary displays and event logs.

Application exception displays provide a major component of the user interface as well. These are maintained by applications and linked to their databases. This section summarizes the components of the user interface that are directly maintained by the alarm utility.

5.5.1.8 System Central Alarm List

The central alarm list should be containing alarms from all applications on the system. These alarms should be sorted by priority and time order. Alarms can be acknowledged and deleted from this display. Alarms can also be acknowledged from the appropriate one-line display. The customer has a great degree of flexibility over how the formatted text for the alarms appears. Many different displays of the alarm list can be constructed without changes to the alarm processing. It is possible to select only alarms of one or more exception type or category. It is also possible to limit the scope of the alarm display to a single location. It is also possible to sort alarms according to
Oldest alarms on top, with unacknowledged before acknowledged, with each priority on a new page.

Newest alarms on top, with unacknowledged and acknowledged intermingled in time order, with each priority on a new page.

The alarm list can be configured such that each alarm event appears in the list independently or such that a new alarm overlays any previous alarm for the same point. There is the capability to mark certain alarms so that operator acknowledgement also deletes the alarm from the list, so that a second step to delete the alarm is not required. Auto-acknowledgement is provided so that a return to normal alarm can acknowledge previous alarms for the same point.

The bottom system view port on each VDU may be dedicated to bringing alarms to the attention of the operator of the system. Typically they display one line of unacknowledged categories and one line of unacknowledged locations. Other options are available, such as two category lines and no location lines. System line entries can be conditionally displayed at each console based upon console permission. Data for the alarm category and location system lines are maintained to provide a central component of the alarm system. This data is maintained separately for each console defined in the Alarm database. The data for each console is formatted according to pictures defined in the console's database.

For each field the record in the Alarm database contains:

- The name of the category (location);
- The name of the display associated with the category (location);
- The priority of the most severe alarm in the category (location);
- A count of the number of exceptions in the category (location);
- A count of the number of unacknowledged exceptions in the category (location).

The usage of dedicated alarm system lines to display one, two, or three individual alarm messages may also be provided.

5.5.1.9 Audible Tones

When an alarm is produced it should have an associated permission area and a severity of tone. This is used with the current console permission area assignments and a tone database to determine which consoles need to be informed of the alarm. Tone severity is assigned on a category basis.

5.5.1.10 Alarm Acknowledgement and Deletion

State changes may require acknowledgement and/or deletion, depending upon application design and Alarm definitions. Application exception displays, one-line diagrams, and similar application displays may be designed to support acknowledgement. Alarm should provide a utility-level capability to support this activity. This function properly maintains the acknowledgement state associated with the Alarm System Lines and application exception displays. Applications that support auto-acknowledgement utilize this Alarms interface as well. Acknowledgement is supported for both individual object and display page acknowledge. An acknowledgement console permission is required.

5.5.1.11 Logging

The system activity logs are maintained by the Alarm application. Each entry is an event; it may or may not have contributed to the generation of an alarm.

A chronological history is kept of what has transpired in the operation of the power system. This history (list of events) contains a number of types of information:

- State changes of power system devices;
- Operator commands to power system devices;
- Operator commands to the control system (tags, inhibits, etc.);
- State changes of the control system;
- Major operator entries to the control system (limit changes, etc.);
- Manual override of device status; and
- Application "alarm" exceptions.

In all cases, the following information should be preserved:

- The time of the occurrence of the event;
- The identity of the associated power (or control) system device;
- The nature of the event (e.g., tripped/closed, etc.); and
- The category of the event.

The Alarm logging function allows system events, which occur during the operation of the power and control systems and are known to different applications in the computer system, to be processed and presented in a common format.

5.5.2 HISTORICAL DATA RECORDING

Historical Data Recording (HDR) functionality should allow the preservation of a complete log of any set of analog, status, and accumulator SCADA measurements, as well as changes to limits on recorded analog measurements. This allows for the recreation of the same preserved log in the SCADA database at any time. The recreated database may be used for a “post-mortem” or after-the-fact analysis of an incident, as well as training, reporting, or other analysis activities.

Because of its recording techniques, HDR can record a significantly larger amount of data than previous techniques. This permits reconstruction of the state of the monitored system at any time.

Any of the points sampled by the data acquisition system can be recorded. This includes such items as boiler turbine pressures, steam flows, fuel flows, and temperatures, in addition to the more common electrical items such as voltages, MW and MVar flows. The former items may be highly useful for analyzing some major disturbances that cause significant frequency deviations and transients internal to power plants. Because this procedure records all changes, it is not necessary to specify triggering conditions that initiate disturbance recording. All status changes and analog changes specified for recording can be recorded whenever they change.

The function should manage the disk space allocated to it so that the operator is informed when the disk is full. The archived data forms a complete historical record of the operation of the system. This machine-readable record may be analyzed off-line at any time to discover statistical patterns or reconstruct the operation of the monitored system.

Reconstruction reviews are conducted to determine the effects on the system of disturbances like the loss of a major transmission line. However, reconstruction reviews represent only one use for the data made available through HDR's capabilities. HDR provides two functions: Data Recording and Reconstruction.

5.5.2.1 Data Recording

Data Recording constantly and automatically records all changes in preselected measurements and status values as SCADA collects or calculates the data. The data items to be recorded are pre-selected during construction of the SCADA database. There is no limit to the number of status or analog points that may be included in this function (however, CPU processing time must be considered when determining how much data to save). The recorded data is a permanent log of the performance of the system.

Initially, Data Recording places recorded data onto ordinary disk files. Each file contains a snapshot of all values, plus a history of all changes to values selected for recording, from the point of the snapshot, forward in time. Each file contains a relatively long period of time (i.e., at least an hour). When the number of HDR files exceeds a specified amount two options are available:

- Automatic deletion of HDR files when the predetermined numbers of files allocated are filled. An automatic backup can be done to another “backup” directory;
- Stop recording HDR files when the predetermined numbers of files allocated are filled.

In either case, an alarm message should be generated to warn the operator that available HDR files are being exhausted.

5.5.2.2 Reconstruction

The Reconstruction function should be used to recreate specific past system configurations through four sub-functions, such as:

- Reconstruct to Time,
- Single-Step-One-Time Scan,
- Playback,
- Build Data History.

The Reconstruct to time should be done for initializations of any review, depending on the current available files. System configurations reconstructed by the Single-Step One-Time Scan and Playback sub-functions can be viewed through the normal SCADA application one-line diagrams and tabular displays. The Single-Step One-Time Scan allows the user to step through data a single scan, instance at a time.

The Playback feature should allow the user to play back the SCADA data at pre-selected time intervals at a predetermined rate, i.e., if database reconstruction were requested ten seconds apart, advancing every thirty seconds, HDR would "playback" reconstruction of the database as it existed at (for instance) 12:00:00, 12:00:10, 12:00:20, and so on, advancing to the next reconstruction every thirty seconds.

The Build Data History sub-function should be creating tables of data about measurements (selected upon dialog), that have changed over a range of time. These tables, or data histories, are viewed on the History display.

Each reconstruction sub-function use data recorded by the Data Recording function. Therefore, all recreated system configurations, whether viewed through diagrams or data histories, show only those data points recorded by Data Recording. Reconstruction should be take place in the SCADA database and to the History database, a separate database within the HDR database.

The reconstruction facility should be rebuild the SCADA database using the initial snapshot, then changes records to represent the database as it existed at the time specified. Of course, only those data points (status or analogs) that were saved can be used in this process. At this point, any of the following functions may be used to analyze the data:

Normal system displays may be used to view the data;

The History display may be used to track the progress of individual data points against others.

In an electric utility system, the reconstruction results may be transferred to the network analysis program for further engineering analysis. The reconstructed system may also be transferred to the Dispatcher Training Simulator (DTS) –not provided in this offer- and used as a starting point for a training scenario.

5.5.3 TAGGING/NOTES FUNCTION

Tagging/Notes should provide the function of constraining and/or restricting the operation of tagged devices, as well as placing notification tags on devices for informational purposes. The tagging function allows placement of inter-site tags which may be sent to other sites when placed on local equipment.

The Tagging application should provide functions for adding, removing and displaying protective or informational tags on power system devices, such as breakers, modeled in the SCADA system.

Tags are normally placed on devices to warn or inform operators of special conditions in the power system and usually prohibit or constrain operation of the device. Tags may also be placed at substations for informational purposes.

When an operator places a tag on a device, Tagging determines the constraints on the device caused by the new tag and any previously placed tags. Likewise, when an operator removes a tag from a device, Tagging determines the constraints on the device caused by any remaining tags.

The Tagging application should be comprised of two major functions, tag definition and tag placement.

The tagging definition function should enable to define the different tag types to be made available in the system. Each of the tag types has a unique "priority", giving it precedence over the other tags, and having one or more of the following characteristics:

- Inhibit opening and/or closing of a device;
- Restrict opening and/or closing of a device (requires operator override);
- Place only on an open or closed device.

The Tagging application should handle the placement of tags on the modeled devices such as circuit breakers as well as substations. Actions taken to both add and remove tags are logged on the System Activity log display. Tagged devices appear on the Tag Summary display, with the date and time the device was tagged.

Tagged devices should also appear on detailed one-lines with a tag annotation next to the device symbol. If an attempt is made to control that device, processing related to the tag type is performed including the display of a message on the console screen from which the command originated, indicating that the device is tagged.

Individual tags may be assigned to a group of tags. For example, when a transmission line segment needs to be electrically isolated, several breakers or switches may need to be opened. Each breaker or switch is tagged. The tags may then be grouped together using a tag group to track the association between the tags.

5.5.4 Work Permit

Display notes, as the name suggests, should be a repository for information and can be placed at an arbitrary location on a display. They may be used to indicate a work permit.

Display notes may be created for informational purposes, but may also be associated with a group of tags. To expand on the example above, a display note may be created and associated with the tag group that references the three-tagged breakers. When the display note is created, a movable picture representing the display note appears on the display that the user can position next to the isolated line segment.

The figure below shows a portion of display with three tagged circuit breakers and one display note.

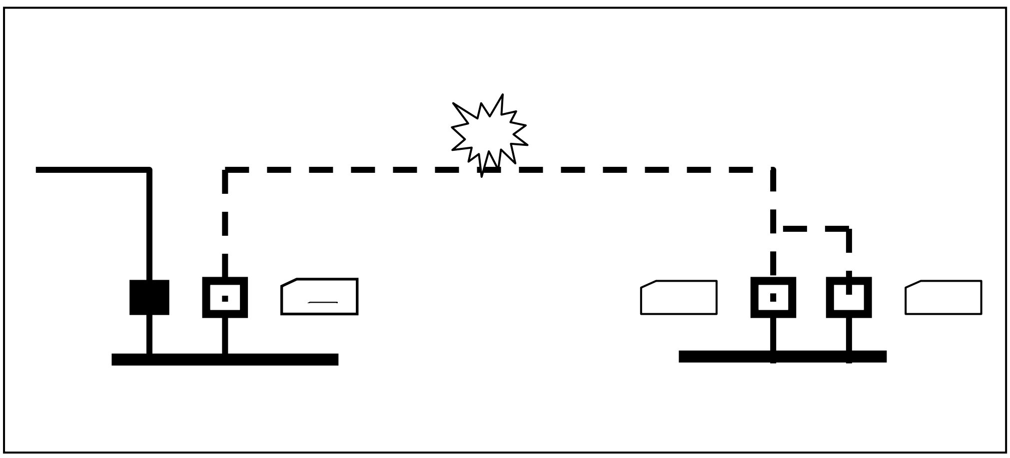


Figure 5: Display example of 3 tagged circuit breakers

5.5.5 DATABASE MANAGEMENT

5.5.5.1 General

A standard tool used to build and moreover maintain databases used in both SCADA and advanced functions, as well as simulator systems.

The data entry is done through easy to use types of files:

- Substation file: One file per substation describing the different devices and measurements of the substation.
- RTU file: One file per RTU describing each I/O card and implements the mapping between the I/O points and the substation measurements.
- Network file: One single file which describe all the network device physical characteristics (line impedance, transformer impedance, loads, and so on).

The filling of the substation files should be made easy thanks to the use of bay templates. Once a bay of each type has been defined, modelling a bay in a substation consists simply to copy the template bay in the new substation file and to enter very few modification thanks to the use of macros.

Once the files are complete, the tool should allow generating the import database files, to load them into an off-line copy of the database installed on the engineer console and to execute the verification of the database against any data coherence, completeness and any miscellaneous checks.

Operators can quickly restore the original database on the operational system by using previous database save cases.

5.5.5.2 Data Entry

Using database management tool should make the data entry procedures very simple by the use of the widely used spreadsheet format. Checks are carried out on data entries to prevent invalid data. Subsequent checks are performed before putting the database on-line to ensure error free operation.

5.5.6 GRAPHIC DISPLAY CONSTRUCTION

5.5.6.1 Display building

A tool used to build the graphic displays should be included. This tool should be activated from the PCs used for maintenance of from the engineer console.

This tool should be interactive that is used for building or modifying full graphic displays. Displays can be built independently of linkages to the application databases.

Full Graphic displays are made of pictures and other elements, such as menus or graphic primitives. Display building has four basic phases:

- Creating sets and accessing editors.
- Defining elements.
- Placing elements on displays.
- Saving and compiling your work.

- **Sets and Editors**

Elements should be the basic building blocks of displays and can be re-used on many displays and in other elements. This reduces maintenance by only having a single place to change a definition. Elements are symbols, pictures, menus, conditional display elements, graphic attributes.

Elements and displays should be defined in a series of editors. Each editor is used to define a specific type of display or element. When needed, each element is assigned to an object in any application database, by defining the key.

The display builder tool should implement each editor by using the NT multi-windowing, where copy / paste functions allow for instance to duplicate a piece of a display into another.

- **Display Definition Language**

The source definitions of the element and display sets of Web Full Graphic should be stored into ASCII files. These ASCII files contain the definitions of all the display information in a documented, structured language for defining the objects that make up the displays. The syntax is patterned after high-level programming language structure definitions.

5.5.6.2 Putting Displays on line

After display building, the files are copied on the data servers, and compiled to establish the true links with the SCADA system databases. Then the displays are simply loaded for each console operator and the updated displays are operational. No data server switch over is necessary.

5.5.7 DATA EXCHANGE FACILITIES

The new LDC should support various data exchange facilities:

- Data exchange via a standard SQL interface to the historical database.
- A dynamic data links application. This application should allow the communication between the Data Servers and most Windows applications such as MS Word, MS Excel, Lotus 123, etc. All the measurements and telesignalisation can be sampled on the main data server and sent to the PC with one of the following mode: on-request, periodic or automatic update
- Export and import application tools should allow import and export of ASCII file from and to SCADA databases under control of a script file.

- Import of geographic display in DXF format, which can be converted into the Full Graphic internal format (static layer), imported and combined with other dynamic layers using FG Editor, and then compiled for being put on-line and available to the operator consoles.

5.5.8 PUTTING DATABASE ON-LINE

This section summarizes the procedures involved in bringing modelling databases on-line in a multi-computer configuration. These procedures should be performed in "Analyst" mode from the engineer console.

During normal operations, real-time functions are resident on the two real-time application servers. One real-time application server is "primary" (or "master"), while the second real-time application server is "secondary" (or "standby"), meaning that it can take over the online duties quickly if the primary machine fails.

When the new database has been verified with success on the engineer console, the database is copied on both data servers in the modelling applications containing off-line copy of the database.

Then the different steps to put the new database on-line are done through a particular on lining application and are represented on the following schema:

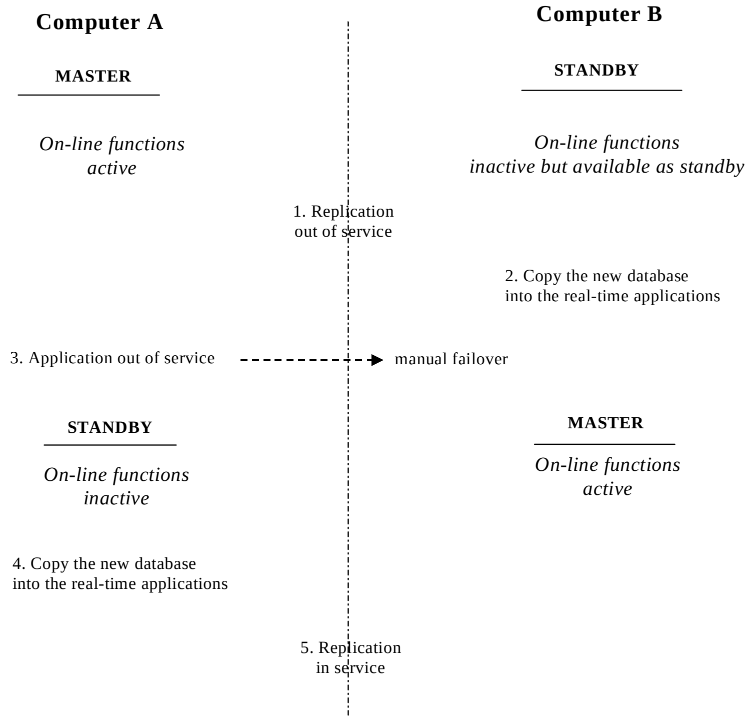


Figure 6 : Replication Management

First, the updating of the standby databases from the master computer is temporarily disabled. This is done by setting replication out of service using a Site Overview display.

Copy the new database into the real-time applications on the stand-by computer. This copy is a "selective" copy that performs a merge of the new configured data with the current parameters such as manual entries that must not be lost.

Up to this point there has been no interference with the on-line functions on the master computer. The on-line functions are still using the old databases on the master computer, while applications on the stand-by computer have the new databases.

Set the application on the master computer out of service in order to perform a manual failover. No host SCADA system is available during this transition failover. However, the telemetry front end continues to scan the RTUs and receive the data that change.

After the failover, the new master computer updates its database with the data coming form the FEs. The system is running using the Computer B updated database. The operator can now check that the changes were made properly. If the new database is not satisfying, the old databases are still available for use on Computer A.

Once the databases are accepted, the new database are copied into the real-time applications on the stand-by computer. eplication is set in service and the database of Computer A (now stand-by computer) is synchronized with those of the now master Computer B.

5.5.9 SYSTEM TIME

SCADA will be provided with a set of GPS-based master clock that broadcasts the standard time (to SCADA and other dispatching servers, as well as to RTUs or DCS) by using the Network Time Protocol (NTP).

All servers will receive the time synchronization signals and adjust their internal time accordingly. Consoles' internal clock will also be synchronized with the servers.

5.5.10 RECOMMENDED SCADA PERFORMANCES

This chapter details the main SCADA system performances that are required for system operation:

Time figures are given sometimes according to different scenarios:

- Normal: usual situation of electrical network
- High: incident situation over the electrical network: many more signals are sent together towards dispatching center.

5.5.10.1 Computer Start Up:

Description	Time Units	Duration
Total time for the start up of a computer, including automatic program load, initialization and database updating = T1	minute	< 10
Complete SCADA/EMS functionality, after a start up or automatic restart = T_2	minute	< 10 (after T_1)
Updating from outstations = T_3	minute	< 10 (after $T_1 + T_2$)

Table 1 : Start up Performance

5.5.10.2 Transfer of Operation:

Description	Time Units	Duration
Unavailability of the operational feature running in the SCADA/EMS server starting from the failure detected by the backup SCADA/EMS server (transfer of operation from one processor to another)	minute	< 2

Table 2 : Start up Performance

5.5.10.3 Display Response Times:

Description	Time Units	Normal	High
Confirmation of point selection on a VDU	second	<6	<10
The time between selection and display of a VDU diagram fully updated from the existing main computer database shall not exceed	second	7	9
Alarm acceptance	second	4	7
Alarm page acceptance	second	4	7
The time between selection of a control function and check back from the outstations shall not exceed	second	5	8
The time between the occurrence of the first change of state/alarm at an outstation and display at the Master Station shall not exceed	second	<25	<30
Hard copy request accept	second	<4	<6

Table 3 : Display Response Performance

5.5.10.4 Event Response Times:

Description	Time Units	Normal	High
The time between the first change of state/alarm receipt at LDC front-end servers and display at the Master Station shall not exceed	second	7	10
The time between the first change of state/alarm receipt at LDC front-end servers and output to logging device at the Master Station shall not exceed	second	7	10
Derived calculations	second	<4	<8
The time between successive updates of the main computer database with analogue measurements shall not exceed:			
a. MW, MVAr, Voltage Measurements	second	20	30
b. Other Measurements	second	30	40

Description	Time Units	Normal	High
The time between successive updates of the main computer database with pulse meter values shall not exceed	minute	30	30

Table 4 : Event Response Performance

5.5.10.5 Execution Periodicity:

Function	Time Units	Periodicity (minimum)
Automatic Generation Control	second	4
Reserve Monitor	second	30

Table 5 : Execution Periodicity Performance

5.5.10.6 Database Update:

Description	Time Units	Duration
Unavailability of Master Station Functions during database update	minute	< 2

Table 6 : Database Update Performance

5.6 DETAILED REQUIRED ADVANCED GENERATION ANALYSIS FUNCTIONS – LOAD FREQUENCY CONTROL:

This chapter describes the Load Frequency Control function as part of strongly advised generation functions to be implemented. It also known as Automatic Generation Control (AGC). As ENTRO system is hydroelectric system, Economic Dispatch function is not implemented (neither required).

5.6.1 OVERVIEW OF THE REAL-TIME GENERATION APPLICATION:

The GENERATION subsystem should include a complete suite of integrated applications for real-time generation control.

Even though a fully integrated package is recommended, it should also be modular.
The present chapter introduces the general characteristics of generation control applications required for ENTRO project and operated by ISO. The subsequent chapters provide more details about the functional capabilities.

The real-time generation application, should encompasses the entire range of real-time generation scheduling, monitoring and control functions. The core function is Automatic Generation Control (AGC), supported by various other auxiliary functions.

The interactions of these functions are illustrated on the next figure.

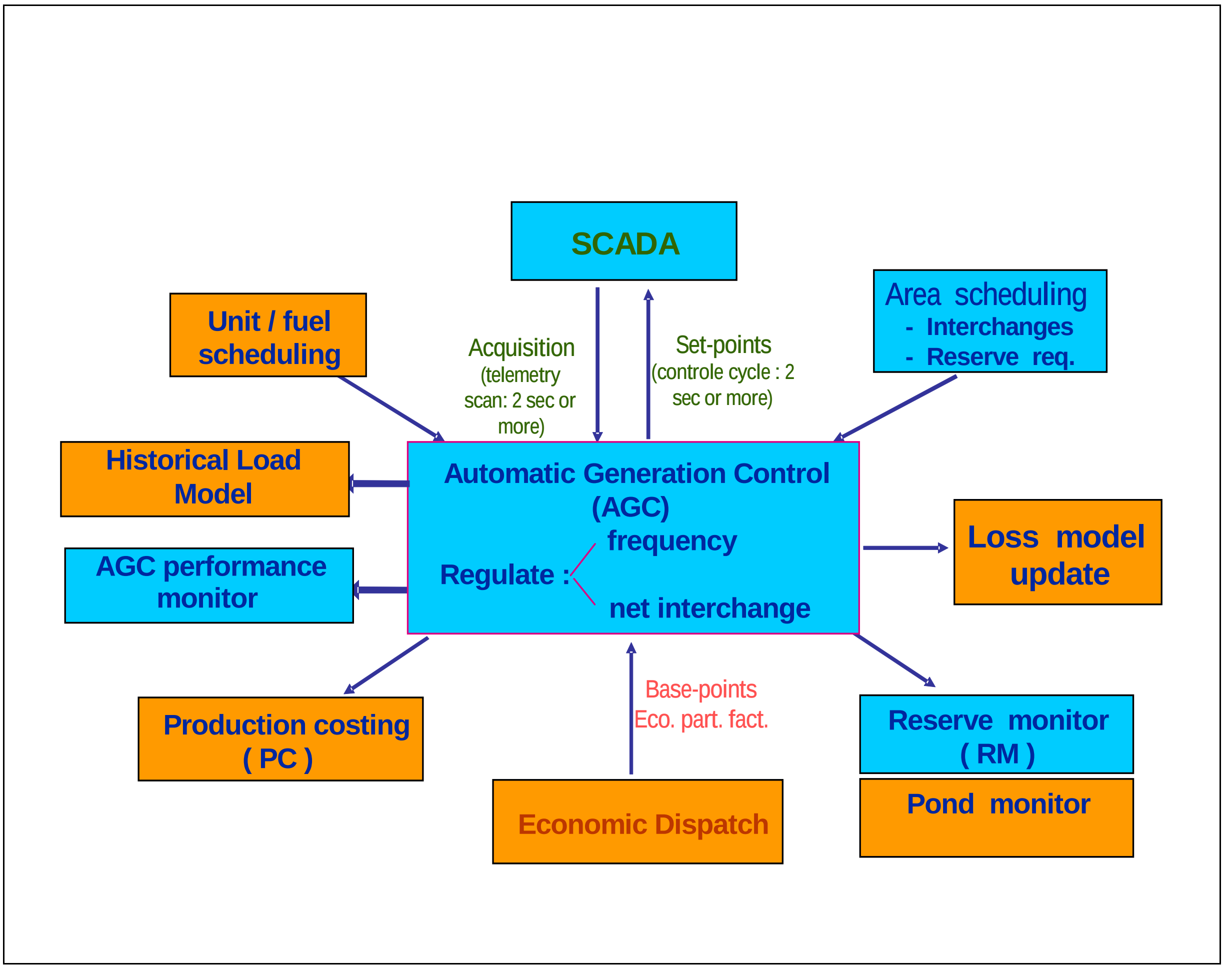


Figure 7 : SCADA General Functions

Main functions are represented in blue color.

5.6.2 AUTOMATIC GENERATION CONTROL (AGC)

Automatic Generation Control is a standard function. Regarding the specificity of this interconnector, AGC will be only use on monitoring mode. No set point will be sent to any generation unit. Nevertheless, this capability will be available for future needs.

The standard AGC should provide all the basic capabilities which are important to the monitoring, dispatching, and controlling of generation, including: operator interface with monitoring, alarming/logging and data-entry capability, economic load following with the units available for control, reliable adaptive area control, error regulation, and smooth control action. AGC uses established techniques of sampled data feedback control design.

5.6.2.1 ACE Calculation Modes

The dispatcher should be able manually set the AGC function to one of the following ACE calculation modes:

- Tie-line Bias Control (TLBC): Both the frequency and interchange components are used to calculate ACE.
- Constant net Interchange Control (CNIC): Only the interchange components are used to calculate ACE.
- Constant Frequency Control (CFC): Only the frequency components are used to calculate ACE.

These modes should be easily selected from a pop-up menu button on the Generation area status display or from the AGC area summary data row at the top of each real time network application display.

5.6.2.2 ACE filtering

In the algorithm that calculates the regulation component for the Plant Controllers (PLC), the inputs are the Area Control Error (ACE) and its integral. Due to the fact that ACE in practice is nonlinear and has random noise, proper filtering of ACE and its integral is required prior to any control actions. A nonlinear, adaptive filter is used.

5.6.2.3 AGC Control Status

The dispatcher can manually set the AGC function to one of the following operating states:

On active control (ON): Real-time data are periodically retrieved and processed from SCADA, calculations are performed and control signals are issued.

Monitoring (MON): Real-time data are retrieved and processed from SCADA, and area calculations are performed, but no control signals are issued.

Off control (OFF): Real-time data are retrieved and processed from SCADA; area calculations are performed, but no control signals are issued. Pause and Suspend states are cleared.

These states are selected from a pop-up menu button on the Generation Area Status display or from the AGC area summary data row at the top of each real time network applicationdisplay.

5.6.2.4 AGC Paused and Suspended States

When in the ‘On control’ status, AGC may enter into a Paused state or Suspended state when certain abnormal conditions occur. When AGC is in the Paused or Suspended state, area calculations are performed but no control signals are issued. When in the Paused state, if the condition that caused AGC to go into the Paused state is corrected within an analyst-adjustable period of time (typically 60 seconds), the AGC function will resume its normal operation. When AGC enters into the Suspended state the dispatcher must reset that state by either selecting the ‘Reset from Suspended’ item in the AGC Status popup menu or setting AGC status to OFF for a couple of AGC cycles.

AGC enters the Paused state when any of the following conditions occurs:

ACE calculation mode is Tie-Line Bias Control (TLBC) or Constant Frequency Control (CFC) and there is no good frequency measurement available.

ACE calculation mode is Tie-Line Bias Control (TLBC) or Constant Net Interchange (CNIC) and at least one tie-line measurement is not available. This includes measurements for the dynamic load ties unless it is a Joint AGC Regulation Requester tie or a Joint AGC Regulation Supplier tie that is inactive. Ties with failed telemetry can be substituted in AGC on the Generation Tie Line Status display. If the flag has been set to honor overridden data in SCADA, the failed telemetry can be substituted on a SCADA display.

MW rate of change for a tie line has exceeded its limit.

ACE calculation mode is Tie-Line Bias Control (TLBC) or Constant Net Interchange (CNIC) and none of the ties is in Telemetry status.

There are no PLCs in Automatic (AUT) control status.

The current value of ACE exceeds the excessive ACE limit. This check can be bypassed by setting the threshold to –1.

In the Paused state, the last good value of the unavailable telemetered data (area frequency or tie-line MW value) is retained and displayed.

AGC enters the Suspended state when any of the following conditions occurs:

AGC is in the Paused state for more than an analyst-adjustable period of time (typically 60 seconds). This transition can be bypassed by setting the time to –1, i.e., AGC will remain in the Paused state until the condition is cleared.

Frequency exceeds the frequency trip limit for two subsequent scans.

In case the center has the state estimator function, and multiple islands in the EMS OPA have been detected by state estimator, AGC should trip for this condition. This option must be enabled or disabled by the dispatcher at both the system and OPA levels. It must be enabled at the system level in order to take effect at an OPA level.

Messages and alarms are issued for the AGC State transitions.

5.6.2.5 Plant Controllers (PLC)

Instead of directly sending control signals to the units, AGC send controls signals to a plant controller (PLC), a device located in power plants. The PLC can control one or more units. If the PLC controls more than one unit, it distributes the received control signal from AGC onto the various units that it controls.

This PLC will be common for all four groups, moreover, this PLC receives an analog value as control variable from dispatching, i.e. analog set point. This analog set point (directly the amount of MW calculated in dispatching, to be produced) is calculated and given by dispatching **for the entire plant**, so we will model our database in this way.

Power regulation from dispatching, via set point control, is only secondary regulation. At all time we advise and assume that local primary regulation will be active, even if the plant and groups are under remote control from dispatching, for security and stability of electric system reasons. To detail: for us primary regulation, is local regulation in PLC or in group, which is effective and can correct group power output in case of important deviations from nominal situation (for example large frequency deviation of electric network nominal frequency (50 Hz)).

Secondary regulation, the one from dispatching calculations, is enabled only when PLC is put in remote status by plant operator, and is dedicated to regulate small or normal deviations in system nominals (frequency and/or exchange of power with foreign countries).

So when large deviations occur, the secondary regulation from dispatching is automatically stopped (standard setting), this is why local primary regulation should be enabled, to take automatically back control of the group locally, to correct plant/group power output, and go back towards nominal situation.

Primary regulation should have, at all time (even if stand-by), higher priority compared to secondary regulation: i.e. even if secondary regulation is active (from dispatching), but electric network system variables trigger primary regulation action, in this case secondary regulation must be ignored and primary regulation must take priority control on the plant/group, automatically.

During the tuning phase, it will be necessary to perform measurements on plant and groups of each power plant.

5.6.2.6 AGC Logic

The desired logic is illustrated on the figure below which shows that the generator desired output, calculated as the sum of the base-point (in the base-point tracking module) and the regulation component (calculated in the area control module), is further processed by the PLC control module for actual implementation by SCADA. Note that neither the Economic Dispatch nor the reserve monitoring function is provided in this project.

AGC offers PID control.

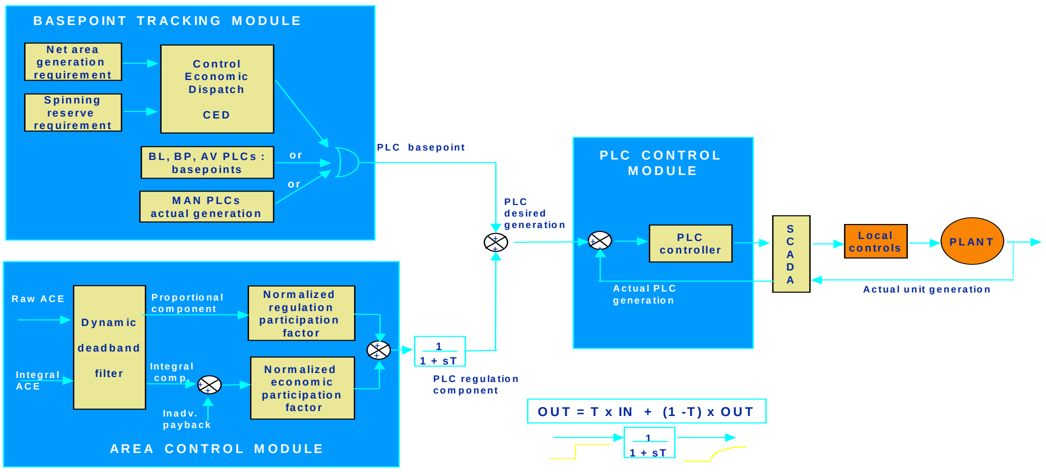


Figure 8 : AGC Functional Modules

5.6.2.7 PLC/Unit Status and Mode

A comprehensive set of PLC/unit control statuses and modes are available to define how the unit is currently interacting with AGC: whether the unit is controlled by AGC or by the plant operator, how the base-point is to be determined, whether and when the unit will regulate.

The unit control statuses are:

- AUTOMATIC - The unit is under automatic generation control from the dispatch center.
- MANUAL - The unit is on-line under plant operator manual control
- OFF - The unit is unavailable for service
- TEST – Used for initial AGC calibration to send set points or series of pulses.

The units under automatic control must have different base-point modes:

- BASE LOAD - Unit basepoint is derived from the basepoint schedules.
- AVERAGE - The unit basepoint is the average of the operator entered unit high and low limits.
- MANUAL - The unit basepoint is manually entered by the operator.
- The control status and the basepoint mode must be easily set by the operator

The operator also specifies **Regulation Priorities** that determine how the units will participate in regulation:

- A regulation priority (any positive integer) can be assigned to each generator. Also, priority thresholds are specified by the user for ACE assist and emergency regions.
- Depending on the current ACE region (dead-band, normal, assist or emergency), all the generators with priorities lower than or equal to the appropriate threshold will be moved first. Other generators will be moved only if regulation from the first set proves insufficient.
- If the priority is zero, the unit does not contribute to ACE correction: it will follow the required basepoint only.

All of the above unit modes are further discriminated in the automatic control logic according to the following conditions (alarms can be sent):

- Unit response is currently being tested.
- Unit is detected by AGC as not tracking.
- Unit has been suspended from control by AGC.
- Unit is assigned normal or slow preference by operator ; slow preference blocks the usage of dynamic short-term rate limits.
- Unit is currently high, low, or rate limited.

Loss of telemetry: a unit/plant on automatic control will be put in the Pause condition when telemetry is lost. If telemetry should resume within a time that can be set in the database (typically 20 seconds), the Pause is automatically lifted ; otherwise, the unit is Suspended and specific operator action is required to put the unit back on control.

AGC reviews the status of telemetry for every generator and external tie line. If the status indicates that a unit or tie is out of service, its analog telemetry will be assumed equal to zero. If telemetry is lost for a unit, its mode will change to "Suspend." If telemetry is lost for a tie, AGC will cease temporarily, but will continue if the condition is corrected or the data is manually overridden within a specified period of time. Each of the above conditions will cause an alarm.

AGC also calculates the instantaneous load and instantaneous net interchange schedule.

5.6.2.8 Regulation component

The generator regulation component represents the unit's share of the area regulation requirement (calculated in the Area Control module and Area & PLC control module).

- The regulation component is the result of a robust PI controller which calculates the area control error ACE and its integrated value ACEINT. Raw ACE is computed conventionally from net interchange and filtered frequency components using one of the three AGC modes:
    - Constant Tie Control,
    - Constant Frequency Control,
    - Tie-Line Bias Control

The ACE frequency component is converted to MW deviation by the Frequency Bias. Variable Frequency Bias (manual or dynamic) calculation is a special technique for calculating the frequency bias dynamically, which is incorporated into the AGC function. The variable frequency bias is computed as a function of the system load and the on-line generation. The components associated with the system load depend on the load response, system load calculated by AGC and other database parameters. The component associated with the on-line generation is a function of all available generator responses in the direction of frequency error. “Available" is defined as units that are not off-line and are not limited in their response to frequency deviation.

Manual and Automatic time error correction, if activated by the operator, are considered in the ACE calculation.

By comparing the current ACE and its integral value ACEINT to various thresholds, the regulation region is determined; this region is 1=deadband, 2=normal, 3=assist, and 4=emergency.

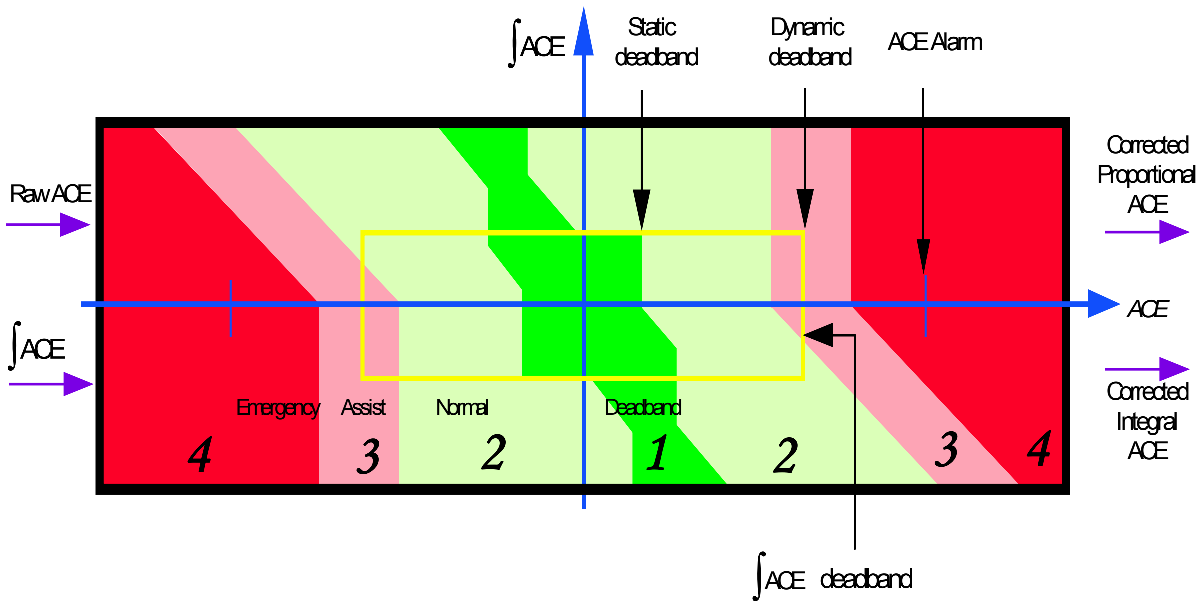


Figure 9 : AGC Functional Modules

Within each region, different gains are applied on the raw and integral ACE. Nonlinear control error filtering is applied in order to remove random load components and contribute to smooth AGC response to sustained load changes. Dynamic filtering is done with deadband logic that adjusts the deadband between minimum and maximum values according to both the magnitude of ACE and the length of time that ACE has exceeded the dynamic deadband threshold. Exponential smoothing is also applied on each regulating unit's component after the ACE allocation, rather than on ACE itself.

Unit participation in the response to ACE and ACEINT is independently assigned via regulation participation factors and economic participation factors. Participation factors are automatically adjusted according to the current unit limit conditions and response capability.

The desired output is restricted to be within the LFCMIN – LFCMAX range :

LFCMIN < desired output = base-point + regulation component < LFCMAX

5.6.2.9 PLC/unit control module

The PLC/unit control module pulses the appropriate units and determines when a unit is no longer responding to sent pulses.

A lead-lag compensator is used whose coefficients are individually tailored to each unit's response capability. A feed-forward control technique is used to eliminate the effect of frequency deviation on the controller output, by simulating the frequency-droop characteristics of each governor. Accumulation of "unsent pulses" is used to provide a means of allowing small unit errors that are within the unit deadband to build until they exceed a minimum pulse threshold. Individually adjustable unit pulse reversal blocking logic is also used to contribute to random error component rejection.

A dynamic rate limit model is used which includes separate sets of rate limits for unit raise and lower pulsing. Each direction includes a normal response rate (maximum sustained rate) and a short-term rate, which allows larger changes for short periods of time. The rate limit model is similar to stored energy based on a recovery factor and unit time constant. With the proper specification of parameters, it can be equivalent to a stored energy rate limit model.

The PLC/unit control module also implements a pulse reversal avoidance logic that prevents change in control direction until a number of seconds has elapsed.

This module also performs the ACE permissive test which prevents controls from being sent to a unit if ACE exceeds a user-defined level and the controls would worsen ACE.

These features result in a reliable PLC/unit controller providing smooth but positive unit response, and ensuring that unit rate and range limits are satisfied.

5.6.2.10 PLC/unit response testing

The PLC/unit controller performs unit response testing to determine if a unit is not responding to its pulses and therefore should be taken off control and alarmed (optionally). The test compares the AGC control with the actual unit generation change which is being fed back to AGC from the RTU of the unit. If the difference is higher than a user-defined tolerance, then further controls to that unit are suspended.

5.6.2.11 AGC-SCADA interface

The AGC-SCADA interface (measurements obtained from and sent to SCADA) is viewed by the operator on the Generation Telemetered Data display. Through this display the operator may :

- Select a different measurement to be used for a record (e.g. select which frequency measurement the operating area will use)
- Ignore a measurement
- Override an input measurement using the not-in-service SCADA functionality
- Change filtering characteristics (filter time constant and filter factor) of a measurement

- Check the quality of the data and its source

The following features should also be provided :

- If a primary measurement is determined to be bad, the alternate measurement, if it exists, will automatically be used.
- An alarm is issued when the absolute difference between an alternate measurement and the primary is greater than a specified percentage of the primary.

Measurements should be grouped together according to their type and are listed in a specific view. The telemetry group proposed are the following :

- OPA DATA FROM SCADA: Operating area input telemetry, such as frequency or time error.
- TIE DATA FROM SCADA: Tie corridor and tie-line input telemetry, such as generation or MWH counts.
- PLANT DATA FROM SCADA: Plant input telemetry, such as hydro plant data.
- PLC DATA FROM SCADA: Plant controller input telemetry, such as auto status.
- UNIT DATA FROM SCADA: Unit input telemetry, such as generation or online status.
- PLC DATA TO SCADA: Plant controller output telemetry, such as or set points.
- UNIT DATA TO SCADA: Unit output telemetry, optionally

5.6.2.12 Scheduling Functions

The scheduling functions are an integral part of all generation applications and thus the user has the same interface.

Schedule definitions and modifications are performed in a workarea so as to allow editing work and validation before the modified schedules can be put online for actual implementation.

5.6.2.13 Transaction Scheduling (TS)

In the context of ENTRO system, the main functionality to be used from a usual generation application is the “Transaction Scheduling” module. Indeed, one of the most important requirement is to have access to a comprehensive set of energy transaction tools. ENTRO should pay a particular high attention to the following functionalities and check that selected software carefully enforce these requirements.

Transaction Scheduling assists the dispatcher in establishing interchange schedules with the external control areas. The basic terms of transactions are pre-arranged by contract and defined as transaction types in the database. Definitions of these contract types are shown on the Transaction Definition display.

Transaction schedules can be initialized with market scheduled values. These values can be available for other applications.

The dispatcher may interactively enter new schedules and modify existing schedules.

5.6.2.13.1 Entering new transaction schedules

With the Transaction Scheduling function, you can specify which type of transaction you want to schedule, the start and end times, the MW level, and, if it is not specified in the database as firm, the price. Defaults are provided as much as possible for quantities not entered by the dispatcher (especially the start and stop ramps for transaction types and the transaction cost). The transaction schedule record consists of a ramping up period, a level period of interchange, and a ramping down period.

The following diagram is a graphic representation of a transaction schedule record.

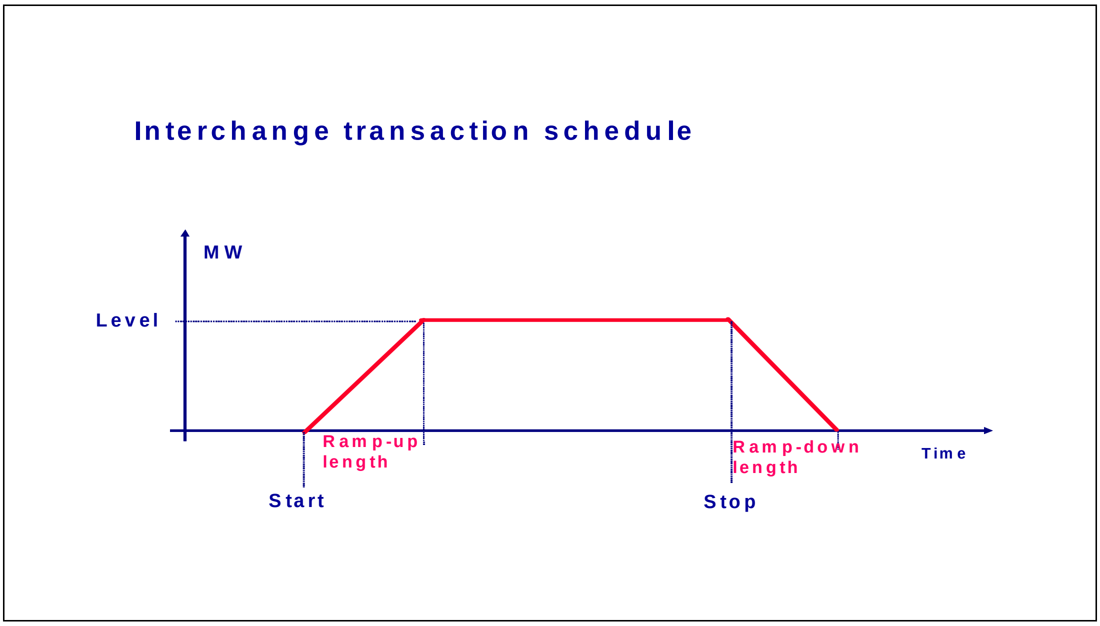


Figure 10 : Transaction Schedule

The specified START TIME of the schedule is at the start of the start ramp. Similarly, the specified STOP TIME is at the start of the end ramp. Toggling a flag in the database would cause the times to be interpreted at the center of the ramps. The operator can specify the length of each ramp, or allow the system to use the default value specified in the database. The end ramp must not begin before the start ramp is completed.

5.6.2.13.2 Modifying an active schedule

Transaction Scheduling will permit the start time to be modified for future schedules. The stop time may be entered or modified for present and future schedules, however, the stop time must remain a future time. The amount may be modified for an active or a future schedule. The modification of a future schedule will simply modify the amount for the entire scheduled period. Modifying the amount for a presently active schedule will modify the amount starting at the present time using an enterable default ramp rate. Any violations of the entry or modification rules will generate error messages. Each Transaction schedule entry will also be automatically logged.

If the user changes the MW level of an active schedule in its level period of interchange, the active schedule is immediately ramped down using the default ramp time. A new schedule is created to reflect the new MW level. The new schedule begins immediately, ramping up in the default ramp time to the new interchange level. The new schedule record is given a new ledger number. These changes are automatically made to the wheeling schedule record, if one exists.

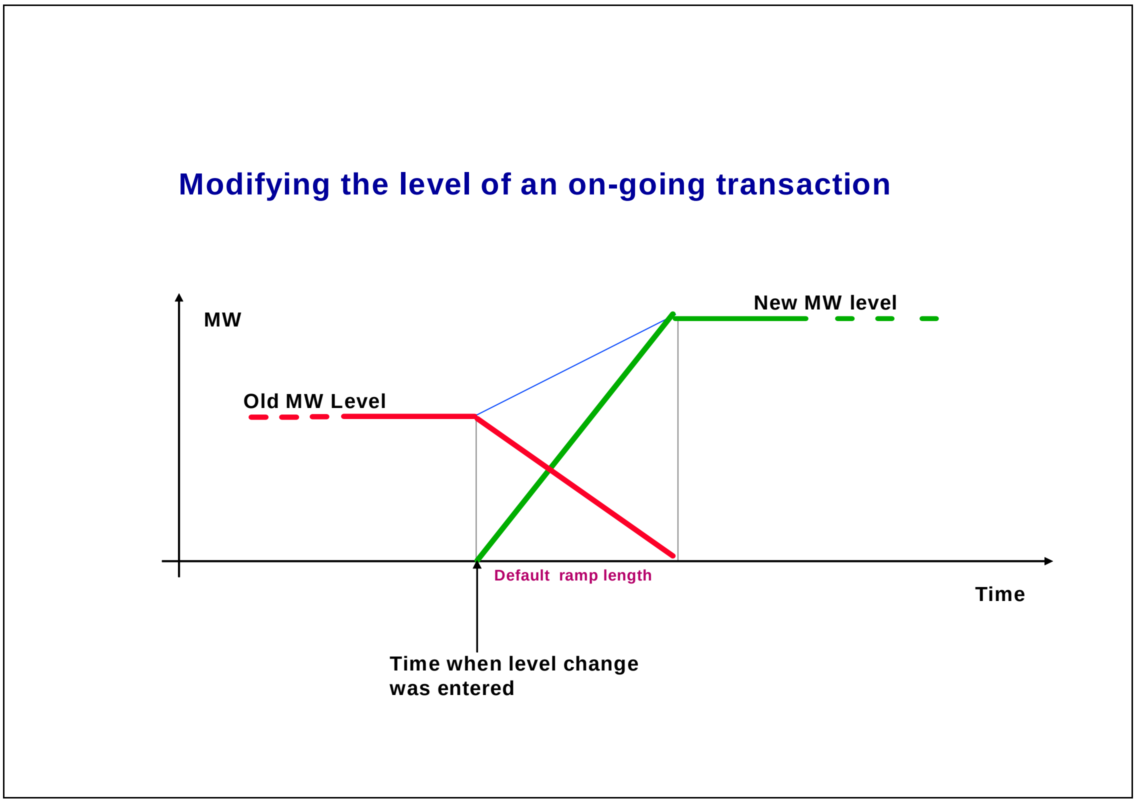


Figure 11 : Transaction Power Overlap

Some changes are allowed to the end ramp time while the schedule is actually ramping down. The user can change the schedule to open-ended. The user can also change the ramp time to any value greater than the ramp time already elapsed. In a case like that, it would be more accurate to enter a new schedule that correctly shows the interchange that has occurred and will occur in the future.

5.6.2.13.3 Viewing the transactions and the interchange schedules

Schedules are all reported ordered by start time. The system will list the transactions into three categories (using color code) ; past, active, and future to assist the dispatcher in readily identifying the active schedules. Past schedules are held in the database for a specified period of time (e.g., 48 hours) so they can be available for copying to historical files and processing by logging/accounting functions. The scheduled transactions file will be purged and reused for new schedules once the specified time period has elapsed.

Transaction schedule records may overlap. The scheduled interchange for an area is the sum of all its transaction schedule records at a given time. Within the generation application, a profile builder executes to provide the short-term net transaction schedule for direct use by AGC. A summary of the transaction balance for each area can be seen in the Grid Summary display.

A single interface via a profile builder eliminates the need for time-consuming lookups by providing a net schedule to AGC. This effectively decouples the AGC algorithm from the form of the transaction scheduling database - an important feature that makes implementation of alternative transaction scheduling interfaces possible with minimum risk.

Alarms can be sent if interchange is not inside the specified limits.

5.6.2.13.4 Overriding the net interchange schedule

The capability to disable the scheduler in the Real Time Network applicationand substitute a single net interchange schedule that will be used by AGC to handle system emergencies is provided.

5.6.3 SUMMARY OF REQUIRED GENERATION FEATURES:

AGC package is state-of-the-art with a full range of modes, coupled with database driven parameters and tuning parameters.

Along with the normal AGC statuses of OFF and ON, AGC provides Monitor mode. In this mode, all the calculations of AGC are performed but no control signals are sent, which is particularly useful when bringing AGC on-line for the first time.

Both short-term load swings and long-term load changes are recognized. The long-term load changes are tracked via changes in the basepoints; while the short-term load swings are handled only by the regulating units. The unit operating mode determines whether a unit participates in short-term regulation and/or basepoint tracking.

Extensive ACE filtering should be provided to prevent temporary jumps of ACE (usually due to tie-line spikes) causing unnecessary AGC actions.

Time error correction: Time error can be acquired from an external source; operator can then ask for a correction schedule to be implemented (either in automatic mode or in manual mode). Operator can stop correction program at any time.

A robust closed loop controller is used to adjust the unit control commands according to the plant dynamics. The controller simulates the plant response to the desired control command and then adjusts the final command to the unit accordingly. Other factors like rate and range limits, pulse accumulation, pulse reversal logic and unit deadbands are also considered to assure that the units smoothly follow the AGC commands and to prevent unnecessary governor actions.

Either the telemetered unit response rates (for units with such telemetry available), or user defined short-term and nominal rates can be used. The use of faster short-term unit response rates allows AGC to make use of the unit stored energy.

Support of backup SCADA measurements.

Flexible tuning parameters permit tuning at the area level as well as at the individual plant controller level. Most of these parameters can be changed on-line, from the AGC analyst displays.

Easy modeling and tuning of future modifications of the Power System, such as new units or new plant controllers.

User interface permits easy modification of AGC parameters, generation scheduling, and allocation of regulation duty.

6 METERING MAIN REQUIREMENTS

6.1 GENERAL CONSIDERATIONS

Metering function is at a central point for I.S.O. interconnector. Indeed, the aim of interconnection is to transmit and therefore electrical energy to participating utilities.

Metering techniques have recently evolved in a great deal. In this chapter are summarized the main technical characteristics that should be required today as the state of the art.

The main purpose of specifying metering devices is to localize as much as possible memory of energy consumption/delivery at metering devices on the field. Therefore, we advise to focus metering functionality at electrical network delivery points to interconnector access points. Consequently, metering values processing should differ from the previously used methods: metering values should be processed by SCADA system as any other analog values rather than pulses management from field metering devices (nevertheless, this pulse management remains in chapters above, in case ISO SCADA may have to interface with older meters).

One important aspect is to consider redundancy of metering devices: at both sides of delivery points. Usually meters will be installed inside substations. Depending the distance between real delivery point and physical location of meters, some correction parameters should be able to be entered to bias appropriately metered values, in order to obtain the best accuracy as possible. This is important because of important energy volumes will be exchanged.

6.2 APPLICABLE INTERNATIONAL STANDARDS

These are the main international standards to which field meters should comply:

- **IEC 62053-22** : Electricity metering equipment for ac currents, particular requirements (Accuracy classes 0,5s-0,2s) ;
- **IEC 62052-11** : calibration and tests for electricity meters
- **IEC 62053-23** : reactive power static meters.

Metered values must of course be transmitted to SCADA system. To perform this task, dedicated communication protocols should be implemented by selected meters. These communication modes should enable to perform the following tasks:

- Remote acquisition of meters values,

- Remote acquisition of instantaneous and short term history measurements,

- Remote programming of meters.

Communication protocol DLMS COSEM :

This protocol handles usual telephone land lines as well as GSM physical layers, as defined in IEC 62056 standard, particularly in 41-42-46-47-51-52-53-61-62 parts.

Communication protocol IEC 62056-21 :

This protocol is used for local optical reading of meters.

Protocole de communication IEC 870-5-104 :

This protocol will be used for communication with SCADA center.

6.3 DETAILED SPECIFICATIONS:

Meters should be of modular and electronic types. They should be compliant to being mounted in air-conditioned areas. No live parts should be accessible. There should be of IP31 protection level as a minimum.

6.3.1 ENERGY METERS - HARDWARE

In addition to be compliant to previously described standards, meters should be compliant to the following requirements:

- Energy metering (both active and reactive) on each of the three phases of power line, in both directions (provided and received energy in the four quadrants. All measured values must be saved within load patterns.
- Meters must be able to measure important quantities of energy, for at least an equipment lifetime of around 20 years, for high voltage power networks.

Meters should be fitted with at least :

- 8 digits displays for each measured values (MWh, Mvarh) using OBIS code IEC 620561-61, signalling voltage on each phase, active tariff, internal battery status, particular mode of meter…
- Two LED showing measurement pulses (imp/kWh et imp/kvarh).
- Self power source in addition to a battery with a capacity of 3 years (equivalent to time without normal power source).
- Frequency : 50 Hz ; Tolerance : 90 – 110%fn.
- Abilities to measure instantaneous variables (voltage, current, power, power factor, frequency …),
- Programmable index retrieval.
- Recording of :
    - power curves with integration periods from 1 to 15 min,
    - status registries.
- Data retrieval (from SCADA system), with a local storage capacity in meter of at least 10 days.
- Multi-tariff abilities (at least 3 time ranges).
- Ability to locally communicate with an external modem (optionally with GPRS).
- « Qualimetry » abilities should also be taken into account :
    - quantities, time length and importance of voltage drops, for each phase,
    - distortions,
- voltage and current for each phases,
- angles between each phases

- Communication interfaces :
  - 1 port RS 232 / RS 485
  - 1 optical port .
- Communication speed : 2400, 4800, 9600bit/s or more.
- Meters should be compliant to be synchronized from SCADA system clock (using NTP* protocol).
- Meters may be compliant to receive (and correct if connection with old equipment is required) signal from voltage and current reduction transformers.

6.3.2 ENERGY METERS - SOFTWARE

As the use of electronic meters is required, the corresponding software for parameter setting should also be provided and fully compatible.

- Remote data retrieval and safe programming (from SCADA place).
- General ease of use.
- Optical port parametering.
- Instantaneous readings.
- Software able to be installed on any current PC device (windows and Vista compliant).
- Remote diagnosis, parametering and repair abilities.
- Permissions protections for parameters setting accesses (passwords, …).
- Communication using RS485 port.
- Reading and analysis of all measured and retrieved values.
- Data archiving abilities, as well as data exports (ASCII format, CSV files …)
- Appropriate documentation should be delivered with each equipment (user's guides, software licence, counter certification (calibration), technical specifications, …)

6.3.3 ENERGY METERS - TRAINING

- Appropriate training should be included by provider. It is estimated to 5 working days for arround 5 engineers. It should cover theoretical and practical activities.
- Meter general overview.
- Meters functionalities presentation and practice.
- Calibration, maintenance and periodic tests methodologies.

6.3.4 ENERGY METERS – SPARE PARTS

The provider should enclose with its proposal, an appropriate list to cover preventive and curative maintenance for an initial period of 5 years.

6.3.5 ENERGY METERS – SPECIAL TOOLS

At least 3 portable PC should be provided, for parametering and maintenance along with meters.

- Portable PC (Processor : mobile Intel Pentium IV (minimum) 2,5 GHz au minimum, RAM : 1 Go, 17 '' TFT screen, DVD device, hard disk : 72 Go minimum, QWERTY keyboard, external interfaces (USB, COM, Ethernet 10/100, Modem V90fax, 2hours autonomy battery + other power accessories, …). Softwares: in English versions Windows X P Pro, Microsoft Office Professional et anti-virus (latest versions) + backup CD s + licences.

- Optical cable for meter connection

TECHNICAL CHARACTERISTICS SUMMARY TABLE				
ENERGY DELIVERY METERS				
N°	Description	Unit	Specified values	Warranted values
1	Provider	-		
1.1	Place of manufacturing	-		
1.2	Type and designation	-		
1.3	Quality check	-		
2	General data:			
2.1	Terminal type			
2.2	Version (hardware and software)			
2.3	International standard applicable	-	CEI 62053 - 21/22/23 CEI 62053-11	
3	**Accuracy**: direct connexion on voltage and current transformers		0,2	
3.1	Active power	-	Class 0,2 S	
3.2	Reactive power	-	Class 1	
4	Auxiliary power		Yes	
4.1	Voltage for meter powering	V		
4.2	Meter internal consumption	W		
5	Frequency	Hz	50 +/-10%	
6	Calibre			
6.1	Voltage	V		
6.2	Direct connexion	A	In 5, Imax 120	
6.3	Direct connexion on voltage and current transformers	A	Ib 1, Imax 10	
7	Display units	-	Yes	
8	Signal LED			
8.1	LED for MWh pulse	-	Yes	
8.2	LED for MVarh pulse	-	Yes	
8.3	LED for alarming	-	Yes	
9	Network connexion	-		
10	Measurement:			
10.1	Bi-directional energy flow		Yes	
10.2	Bi-directional energy flow and 4 quadrants			
10.3	Three phase metering		Yes	
11	Pulses output:			
11.1	Output type			
11.2	Pulse value		Programmable	
12	Multi-tariff compliant		Yes	
13	Communication ports		Yes	
13.1	Protocols		CEI 62056-21; CEI 870;	

TECHNICAL CHARACTERISTICS SUMMARY TABLE				
ENERGY DELIVERY METERS				
			DLMS	
13.2	Interface communication module		RI optical port	
13.3	Interface communication module		RS485	
13.4	Interface communication module		RS232	
13.5	Communication speed	Kbit/s		
14	Remote communication port (connexion to remote SCADA):		Yes	
14.1	Interface communication module		Modem: PSTN / RS232 /GPRS	
14.2	Communication speed	bit/s	2400; 4800; 9600	
14.3	Operation temperature		-20°C to +60°C	
14.4	Storage temperature		-40°C to +70°C	
15	Power cards tropicalization	-	Tropicalized cards	
16	Plugs			
16.1	Direct connexion	-	4 wires (compliant with 3 wires without neutral)	
16.2	Direct connexion on voltage and current transformers	-	3 to 4 wires configuration	
17	Inputs / outputs number	-		
18	Battery	-	Yes	
19	Battery access	-	Yes	
20	Packaging	-	Yes	
21	Live connexion protections	-	Yes	
22	Cover seal	-	Not sealed	
23	Protection slide	-	Yes against common modes	
24	Qualimetry	-	Yes	
25	Meter box		Glass fiber, reinforced carbonate	
26	Dimensions			
	- Length	mm		
	- Width	mm		
	- Heigth	mm		
27	Weight	kg		
28	Protection degree		IP 31 (minimum)	
29	User's guide and other documents	-	Yes	
30	Other characteristics			
31	Software			
31.1	Fonctionnalities			
31.2	Data analysis			
31.3	Data visualization			

Table 7 : Energy meters – summary table

7 CONTROL CENTER LOCATION AND STAFF SKILLS

Main guidances to choose locations for both main and back-up control centers could be the following. The purposes of the present assessments in M4 module are to highlight main requirements to be taken into account for location selection:

- Easy access to fast and reliable commercial communication infrastructures
- Location should be at a central and convenient place for operation issue management.,
- Compatibility with future Electricity Power Pool creation,
- Road access should be as practical as possible, moreover, the study of external factors that could impact road use must also be carefully taken into account

Human resources hired (see M5 Control Center module), should also have specific skills:

- Seniority in electrical network management for management team,
- Equity of nationalities represented operation team, reflecting the common tasks that represent ENTRO initiative,
- Particular schemes could be put in place to professionalize locally hired staff, such as operators or supporting functions staff

8 CONTROL CENTER COST ASSESSMENT

An annex is linked to this document, giving estimate of hardware and software costs for both main and back-up control centers.

These estimates are based on equipment with an offshore origin. Building aspects are for the moment excluded from the above mentioned estimate, main reasons are that civil works will depend on final location of both main and back up control centers, moreover, a significant part of civil works will be provided by local contractors.

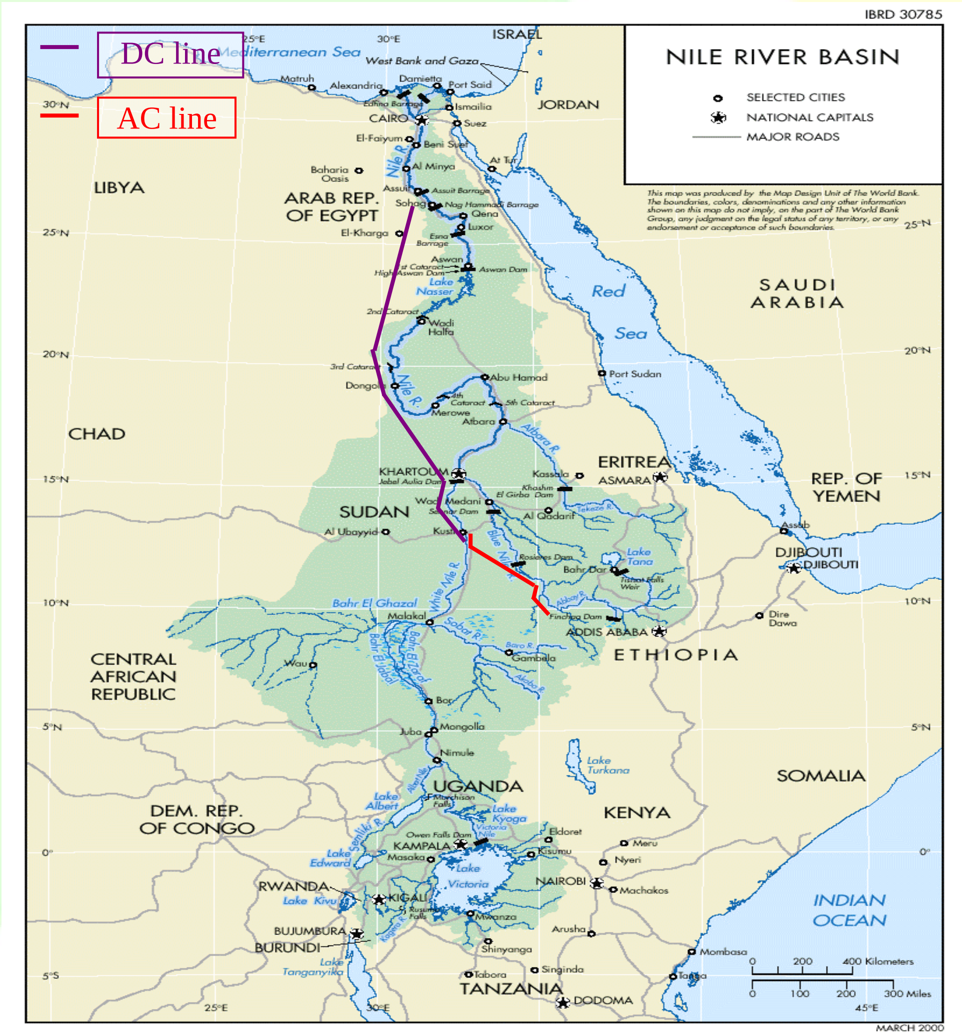
A particular attention should be granted to currency (and its year of reference).

Nile Basin Initiative

Eastern Nile Subsidiary Action Program

Eastern Nile Technical Regional Office

EASTERN NILE POWER TRADE PROGRAM STUDY



M4 - 500 kV AC LINES

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
ACCC	Aluminum conductors composite core
ACCR	Aluminum conductor composite reinforced
ACS	Aluminium Cladded Steel
ACSS	Aluminum conductor steel supported
ASCR	Aluminium Conductor Steel Reinforced
BC	Broken Conditions
BL	Breaking Load
CLINO	Climatological Normals
DC	Direct Current
EDF	Electricité de France
EDS	Every Day Stress
ENTRO	Eastern Nile Technical Regional Office
FOS	Factor Of Safety
GTACSR	Gapped high-temperature aluminum alloy conductor extra high-strength steel reinforced
HV	High Voltage
ICB	International Competitive Bidding
IEC	International Electric Commission
Kr	Roughness Factor (for terrain category)
LID	Light Inject Detect
MES	Guaranteed Minimal Elastic Stress
NBI	Nile Basin Initiative
NC	Normal Conditions
ODTR/OTDR	Optical Time Domain Reflectometer
OPGW	Optical Ground Wire
RIV	Radio Interference Voltage
RMS	Root Mean Square
RSL	Residual Static Load
Vr	Reference Wind Speed
WMO	World Meteorological Organization
ZTACIR	Special zirconium high-temperature aluminum alloy conductor Invar steel reinforced

EXECUTIVE SUMMARY

This document, corresponding to a sub-module of M4 “Preparation of Technical Specifications”, provides particular technical requirements regarding the design of the 500 kV AC overhead transmission lines from MANDAYA (Ethiopia) to KOSTI (Sudan).

In this section, there is no considerations concerning general technical requirements for the construction of the lines.

As stated in the Phase II - Module 1 “Detailed network studies”, two lines 500 kV of double circuit with ACSR DOVE conductors in quad bundle seems to be more relevant for this line.

The technical requirements specified in this document are a compromise between the data collection (National OHL Design Standard) and the latest internationally recognized standard.

A spare part proposition and cost estimate are given at the end of this document.

The different points below will be specified after the data collection on existing overhead line standards in Ethiopia and Sudan.

- Wind reference;
- The Factor of Safety (FOS);
- meteorological conditions (maximum/minimum/mean temperature °C, keraunic level, Humidity (%), etc),
- Specified requirements from national standard (level pollution, tower footing resistance, etc) ;

1 GENERAL REQUIREMENTS

1.1 GENERAL

This section provides general technical considerations regarding the design of the 500 kV AC overhead transmission lines from Mandaya (Ethiopia) to Kosti (Sudan) with a approximate length of the line 544 km.

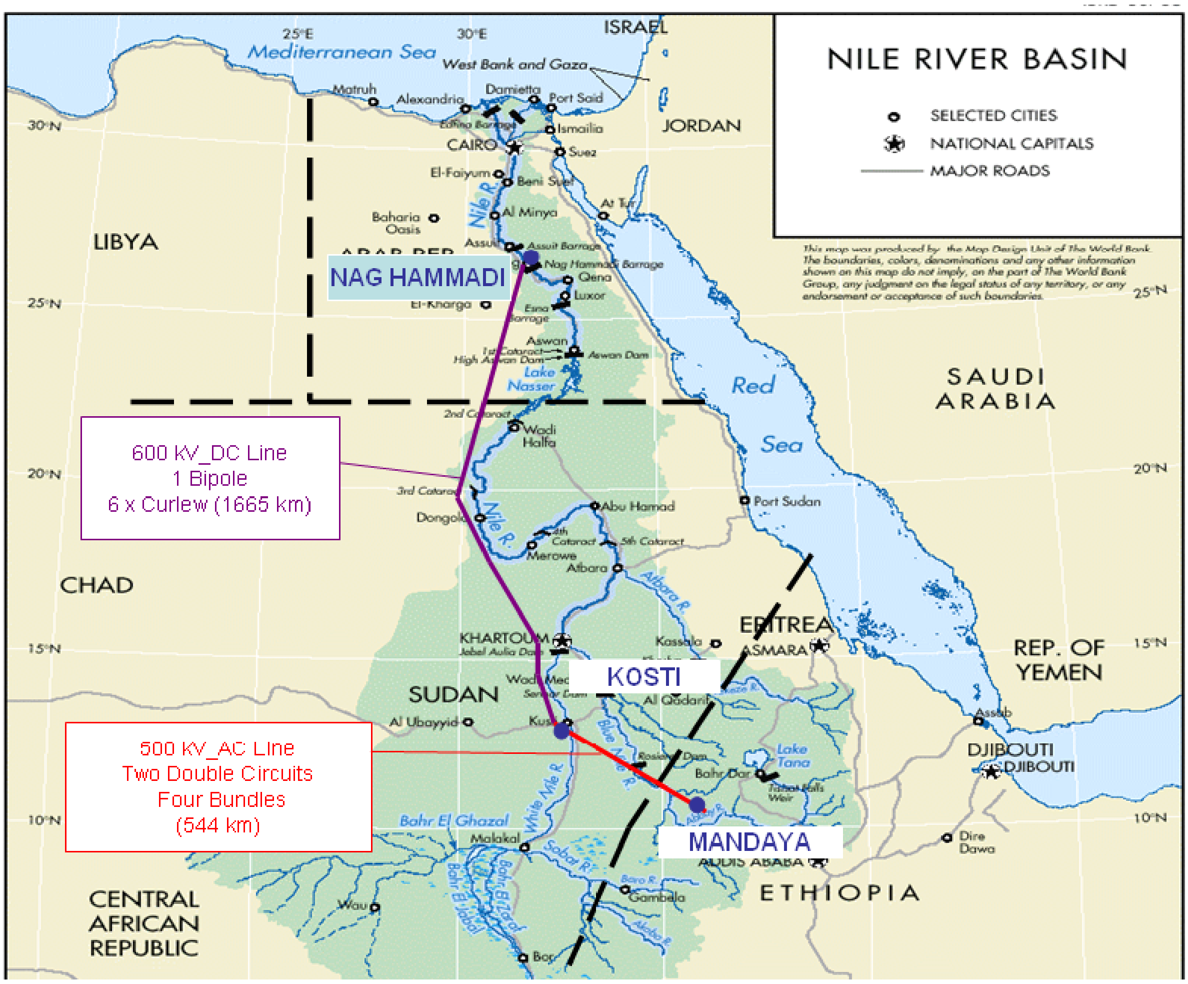


Figure 1 : General view of AC and DC lines

As stated in the Phase II - Module 1"Detailed network studies", two 500 kV AC lines equipped of double circuit quad bundle conductors ACSR DOVE (Aluminium Section=280 mm²) seems to be more relevant for this line.

The technical requirements specified in this document will be the primordial requirements for the design of the lines. However, there are no requirements concerning works for construction such as preliminary works, site preparation, foundations, Tower assembling, Line stringing, Setting, Testing. **These different points should be detailed for the finalization of Technical Specifications.**

A spare part proposition is given at the end of this document.

1.2 SCOPE OF WORK

The Technical Specifications will detail the scope of work that will include :

- Final topographical survey, soil investigation, plotting and picketing,
- Calculation and design of all towers :
  - Terminal towers and Angle towers,
  - Suspension towers.
  - Calculation and design of foundations,
  - Calculation and design of earthing,
- Determination of all equipment and fitting :
  - Insulators,
  - Conductor clamps,
  - Earthwires (optical fiber), conductors and fittings,
  - Accessories as spacers, dampers, clamps, warning signs, etc.
- Calculation of spans and sags,
- Line route profile,
- Supply of all equipment,
- Construction of line :
  - Site preparation,
  - Foundations,
  - Tower assembling,
  - Line stringing,
  - Setting,
  - Testing,
  - Site cleaning.

1.3 TRANSMISSION LINE ROUTES DESCRIPTION

The line routing between Mandaya (Ethiopia) to Kosti (Sudan) is presented in the document "M2 – Line Routing – Final Report"

The approximate length of the line is 544 km and corresponds to Section 1 (Mandaya) to Section 3 (Kosti).

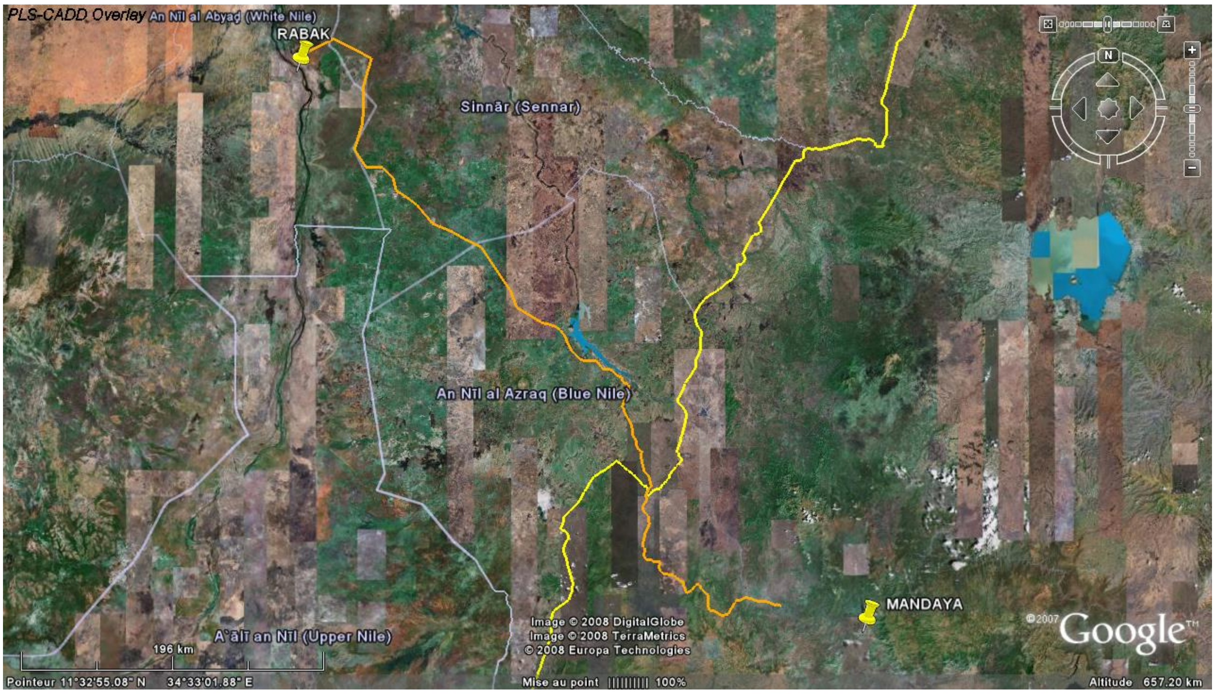


Figure 2: 500 kV AC Line Routing between Mandaya (Ethiopia) and Kosti (Sudan)

1.4 CLIMATE

Climatological information is based on WMO Climatological Normals(CLINO) for the 30-year period 1961-1990 issued from the web site http://www.worldweather.org. Please note that the averaging period for climatological information and the definition of "Mean Number of Precipitation/Rain Days" quoted in this web site may be different for different countries. Hence, care should be taken when city climatologies are compared. In the following tables, "Mean number of precipitation days" = Mean number of days with at least 0.1 mm of precipitation.

1.4.1 *SUDAN WEATHER CONDITIONS*

Weather Information for Khartoum.

Month	Mean Temperature °C		Mean Total Rainfall (mm)	Mean Number of Rain Days
	Daily Minimum	Daily Maximum		
Jan	15.6	30.8	0.0	0.0
Feb	17.0	33.0	0.0	0.0
Mar	20.5	36.8	0.0	0.1
Apr	23.6	40.1	0.4	0.1
May	27.1	41.9	4.0	0.9
Jun	27.3	41.3	5.4	1.2
Jul	25.9	38.4	46.3	4.8
Aug	25.3	37.3	75.2	4.8
Sep	26.0	39.1	25.4	3.2
Oct	25.5	39.3	4.8	1.2
Nov	21.0	35.2	0.7	0.0
Dec	17.1	31.8	0.0	0.0

Table 1: Khartoum Weather Conditions

1.4.2 *ETHIOPIAN WEATHER CONDITIONS*

Weather Information for Bahir Dar.

Month	Mean Temperature °C		Mean Total Rainfall (mm)	Mean Number of Rain Days
	Daily Minimum	Daily Maximum		
Jan	16	24	5	1
Feb	17	25	5	1
Mar	18	25	10	2
Apr	18	25	25	3
May	17	24	85	10
Jun	15	21	185	18
Jul	14	19	430	28
Aug	14	19	375	28
Sep	15	20	305	21
Oct	15	21	90	9
Nov	15	22	25	4
Dec	15	23	5	1

Table 2 : Bahir Dar Weather Conditions

Regarding the above table and the data collection on existing standard in Sudan and Ethiopia, the meteorological conditions for the design should be :

	Ethiopian Part	Sudan Part
Maximum ambient temperature	35 ° C	50 ° C
Minimum ambient temperature	0 ° C	0 ° C
Mean Temperature °C	20 °C	30 ° C
Maximum Conductor temperature	90 °C	90 °C
Minimum Conductor temperature	5 °C	5 °C
Every Day Stress temperature	25 °C	25°C
Maximum wind velocity (gust)	160 km/h	160 km/h
Reference wind speed	110 km/h	110 km/h
Mean annual Rainfall	129 mm	14 mm
Humidity	100 %	100 %

Table 3 : OHL Design Conditions Weather

1.5 POLLUTION LEVEL

1.5.1 GENERALITY

Overhead lines are subjected to conditions that depend on the place in which they are installed. These conditions can vary extensively from a place to another, depending on the characteristics of the region considered. These characteristics make possible that the level of insulation required can vary in a same line, due to the conditions of the pollution are different for all the line. The weather factors influence in a very important way on the growth of the pollution levels in a region.

Due to the line routing in desert areas characterized by no rain for long period and exposed to strong winds carrying sand, a Very Heavy IV pollution level will be considered according to IEC 60 815. The insulators lines will be designed for a minimum nominal specific creepage distance of 31 mm/kV. For the substations, we will consider:

- 20 mm/kV for Mandaya
- 31 mm/kV for Kosti

1.5.2 DESERT ZONES

In some desert zones, the insulators of the electric lines are often subject to the deposition of contaminants substances of the deserts. This can cause a serious reduction in the efficacy of the insulator, having as a result the flashover and the electricity supply lack.

Also the storms of sand must be kept in mind. The type of environmental conditions will affect considerably to the insulators. The predominant elements in this type of pollution are: the sand and the widespread, salty dust in a dry atmosphere. The desert climate is characterized for sand storms and hurricanes that contain particles that move to a high speed. These particles strike to the surface of the insulator causing the material erosion. The storms of sand are an important factor that causes a decrease of reliability in electrical lines.

In this type of pollution the following aspects are relevant:

- The early morning dew represents the greater source of wetting in the desert zones.
- Storms of sand enlarge the pollution problems. The worst conditions occur when the storms are accompanied by a high humidity or rainy weather.
- Pollution layers accumulated on the insulators during the storms are of larger grain and greater content in salt than the layers formed during the normal atmospheric weather of the desert. The pollution contributed by the storms of sand is normally carried by strong winds of distant regions.

The decrease of pollution will depend on: the type of insulator, the maintenance, the increase of the number of elements in the chains of insulators, the increase of the leakage line, a better design of the insulators, the new materials…

1.6 TOWERS, FOUNDATIONS, CONDUCTORS, EARTHWIRES

1.6.1 TOWERS

Lattice steel self supporting towers should be used. The 500 kV tower shape will be designed for vertical arrangement, as illustrated below.

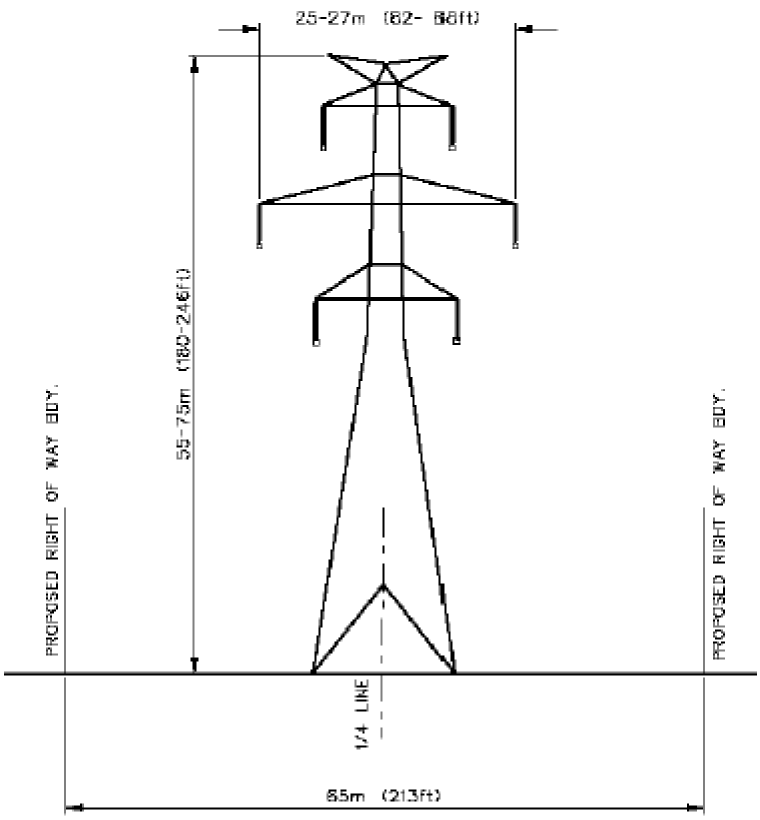


Figure 3 : Tower Outline

The appendices 1 and 2 gives more details on suspension and tension Tower Outline.

1.6.2 RIGHT OF WAY

As it is expected to built a 4x500 kV AC transmission line, the Right Of Way will proposed to be equal to a minimum of 2 x 65 m = 130 m wide, equivalent to 426 ft.

1.6.3 TOWERS FOUNDATIONS

The tower foundations should consist of four independent reinforced concrete blocks.

- Reinforced concrete pad and chimney foundations for normal soil conditions.
- In the areas with submerged and poor soil conditions (like Vertisols area in Sudan) , special foundation design should be considered. The dimension will be determined after the results of soil investigation (bearing capacity, soil density, etc) performed by the Contractor. The minimum requirements will be:
    - Pile foundations or Multi pad foundations with a large base for the stability of foundation under uplift and compression solicitations.
    - The concrete cover of reinforcement is 10 cm
    - The chimney height above the ground must be extended to 1 meters in order to protect the stub from flooding. The specified chimney height will be calculated during the design.

1.7 STANDARDS

It is assumed that the transmission line will be constructed based on International Competitive Bidding (ICB). Hence it is recommended that the principles of the International Electro-technical Commission (IEC) standards 826-1, 2, 3 and 4 for a Security Class I line (50-year return period of ultimate conditions) are adopted for the design of the line (studies, drawings, materials, equipment and tests)

2 CROSS SECTION DETERMINATION

As stated in the Phase II - Module 1_Detailed network studies, the two lines 500 kV of double circuit shall be designed for quad bundle of Aluminium Conductor Steel Reinforced (ACSR) conductor type DOVE per phase, spaced at 400 mm.

The line conductor of ACSR/ACS type is preferable to the AAAC (All Aluminium Alloy Conductor) type due to better behavior in the specific climate area and is selected considering:

- the good performance in polluted areas against corrosion being aluminum cladded (ACS);
- the good performances against wind induced vibrations, due to the self-damping characteristics;
- keeping its mechanical performances in case of long time operation at high temperatures;
- quite same rating capacity as per a similar AAAC conductor type.

Furthermore, all towers shall be self supporting square based and lattice construction. They shall be of a two circuits vertical type arrangement (double triangle geometry type) with 2 earthwires (G1 & G2) at tower top.

3 TECHNICAL REQUIREMENTS

3.1 GENERAL

All material used for the construction will be new of the best quality, and of the most suitable class for working under the specified conditions.

3.2 GALVANIZING

Galvanizing will be in accordance with the requirement of BS 729 or IEC 60383-1 for hot dip process except for earthwire and conductor where BS 443 is applicable.

The minimum mass of zinc coating will be not less than :

- All members 700 g/m^2 of surface
- Bolts, nuts and washers 500 g/m^2 of surface

The galvanizing surface will be treated with chromate process in order to avoid the formation of white rust.

3.3 MECHANICAL DESIGN FOR TOWERS

The determination of climatic loads, wind and associated temperatures will be based on IEC 60826 Standards recommendations and on the existing practices for towers design in each national concerned grid. (Sudanese, Ethiopian).

The unit action of the wind speed on any line component or element (conductors, earthwire, insulator strings, towers) need to be calculated in accordance with IEC 60826 Standard.

Loadings on transmission lines can be separated into three groups: external loads, dead loads and special loads.

- **External loads :** External loads are loads due to wind
- **Dead loads :** Dead loads are loads due to the dead weight of support, conductors and insulator strings. Although they are permanent in nature, dead loads vary from one support to another due to variation of support height and weight span of conductors.
- **Special loads :** Special loads consist of external loads that might occur during line construction and maintenance as well as longitudinal and vertical loads provided as a security measure for the prevention of cascading failures. If the external loads exceeded the limit loads along the total line, or a long section of the line, then the provision of special loads would not prevent cascades to occur in these sections.

The determination of the Vertical, Horizontal and Longitudinal solicitations will depend on theses loadings and the impact of cable tension on the towers (influence of line angle, tension towers, etc).

3.3.1 TERRAIN ROUGHNESS

Wind speed and turbulence depends on the terrain roughness. With increasing terrain roughness, turbulence increases and wind speed decreases near ground level. Four types of terrain categories, with increasing roughness values, are considered in this standard as indicated in the below Table.

Terrain category	Roughness characteristics	K_R
A	Large stretch of water upwind, flat coastal areas	1,08
B	Open country with very few obstacles, for example airports or cultivated fields with few trees or buildings	1,00
C	Terrain with numerous small obstacles of low height (hedges, trees and buildings)	0,85
D	Suburban areas or terrain with many tall trees	D 0,67

Table 4 : Classification of terrain categories

The roughness factor K_R represents a multiplier of the reference wind speed for conversion from one terrain category to another.

Regarding to the line routing of 500 kV lines, the following roughness Category B (K_R= 1,00) is proposed.

3.3.2 REFERENCE WIND SPEED VR

V_R is defined as the reference wind speed (m/s) corresponding to a return period T. V_R can be determined from a statistical analysis of relevant wind speed data at 10 m above ground and with an averaging period of 10 min. Usually V_R is measured in weather stations typical of terrain type B, such as airports. In such cases, V_R is identified as V_{RB}.

The proposed reference wind speed is V_R = 110 km/h (30 m/sec).

The reference wind speed will be confirmed with the data collected on the existing standard overhead line design in Ethiopia and Sudan.

3.3.3 LOAD CASES

The weather conditions that shall be taken into consideration for the calculation of the mechanical resistance of the Works are the least favorable ones that can be met on the Works. In practice, the following load cases need to be checked for each type of tower.

3.3.3.1 Normal Condition

- **Wind** : Maximum Wind at average daily minimum temperature.

The wind velocities defined above for computation shall be considered as occurring at an air temperature equal to the average of the daily conductor temperatures, peculiar to the site. The average daily temperature will be 30°C for Sudan Part and 20° for Ethiopian Part.

- **Cold** : Reduced Wind at the extreme minimum temperature.

The reduced wind speed is equal to the reference wind speed V_R multiplied by a coefficient chosen according to local meteorological conditions. When there is no reliable knowledge of local conditions a value of 0,6 for this coefficient is suggested.

The minimum temperature shall be considered as being equal to the minimum yearly value, having a return period of T years.

The minimum temperature to consider will be 5° C for Sudan and Ethiopian Part.

- **Oblique Wind 45°** (to span)

The wind velocities and conductor temperature will be equal to Wind Condition.

- **Assumption for the construction and maintenance of the Works :** during the construction and maintenance works, the towers should bear the exceptional strengths that may be applied and that will vary depending on the operational methods used. It is necessary to define, with appropriate assumptions, the strengths that shall be taken into consideration during the conception of a tower. The operational methods that will be considered on site should also be conceived in a way that these strengths are not over passed.
- **Construction assumption** : a vertical force of 300 daN corresponding to the weight of two workers and their tools is applied at the middle of all the bars, other than the main legs. These forces will be added to the normal stresses than are withstood by the tower at everyday assumption.

3.3.3.2 Broken Condition

The objective of security measures (breaking assumption for the conductor and for the earth wire) is to minimize probability of uncontrolled propagation of failures (cascades) which might otherwise extend well beyond the failed section, whatever the extent of the initial failure. The loads prescribed below provide conventional lattice structures with the means of minimizing the probability of cascade failures. These requirements are derived from experience on conventional lattice structures. The system stress under these loads shall not exceed the failure limit.

3.3.3.2.1 Torsion Broken Wire

This assumption describes for all the metallic towers a minimal resistance to the necessary torsion to resist the break-up of a combination of broken wires (conductor and earthwire).

At any one ground wire or phase conductor attachment point the relevant, if any, residual static load (RSL) resulting from the release of the tension of a whole phase conductor or of a ground wire in an adjacent span shall be applied.

The RSL for suspension structures shall be calculated for average spans and at sagging tensions, allowance being made for the relaxation of the load resulting from any swing of the insulator strings assemblies, deflection or rotation of the structure, foundations, articulated crossarms or articulated supports, and the interaction with other phases conductors or wires that may influence this load. The value of the RSL may be limited by special devices (slipping clamps, for example), in which case, the minimum security requirements should be adjusted accordingly.

For the Tender, the tensile force of conductor on suspension tower shall be assumed to be reduced by 30%, thus the longitudinal solicitation on the tower will be equal to 0,7 x Horizontal Tension of the considered assumption. The maximum value of this force is however limited to 3 000 daN per cable.

The following broken wires conditions shall be considered minimum.

- Suspension Towers: one conductor is broken on one face of one side of tower **or** earthwire is broken on one face of the tower. For the towers equipped with suspension sets, the longitudinal force due to the break-up of one phase is determined taking into consideration the loosening resulting from the gradient of the set.
- Angle Towers: two conductors are broken on one face of one side of tower **or** one conductor plus earthwire are broken on one face of one side of tower.
- Dead End Tower/Terminal Tower: three conductors are broken on one face of one side of tower.

3.3.3.2.2 Longitudinal Broken Wire Anti Cascade

This specified longitudinal loading corresponds to all broken wires of phase conductors and earthwire attachment points. Longitudinal loads shall be applied simultaneously at all attachment points. This loading concern only the tension tower.

This security loading must be applied to one tower in every 10 km and correspond to insertion of anti-cascading towers at intervals every 20 towers, as recommended by IEC 60826.

3.3.4 SAFETY FACTORS

Safety factors are presented in the table hereafter.

LOAD CASE	ASSUMPTIONS	Temp °C	WIND ON CABLES Pascal	WIND ON TOWER Pascal	Conditions and factor of safety						
					Cables	Hardware	Tower	Foundation <30gr		>30gr	
								comp	uplift	comp	uplift
1 (NC)	Wind	25	720	2000	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5
2 (NC)	Cold	-5	180	300	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5
3 (BC)	Torsion Broken Wire	25	720	2000		R 2/3	MES/1.5	1.5	1.5	1.5	2
4 (BC)	Longitudinal Broken Wire Anti Cascade	25	720	2000		R 2/3	MES/1.5	1.5	1.5	1.5	2
5 (NC)	Oblique Wind 45°	25	450	1000	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5
6 (NC)	No wind Stringing & Maintenance	25	0	0	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5
7 (NC)	Construction	25	0	0	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5

R: Breaking force or stress / MES: guaranteed minimal elastic stress / BL: Breaking Load / NC: NORMAL CONDITION
BC : BROKEN CONDITION

Table 5 : Safety Factors

3.3.5 GEOTECHNICAL DESIGN

Foundation design shall be such that the tower shall be securely supported and unbalanced displacement that may cause harmful effect to the tower shall not be produced. The loads acting on the foundation shall be the maximum loads determined from each tower loading condition and shall take the leg extension of tower into account.

Foundation design loads shall be calculated on the basis of the maximum axial and horizontal tower base reactions exclusive of tower overload factor and further multiplied by the associated factors.

Maximum foundation shear force from any load combination for the download leg will be assumed to act simultaneously with the maximum foundation compression force. Maximum foundation shear force from any load combination for the uplift leg will be assumed to act simultaneously. Undercuts shall be used as much as possible (for fair and good soils).

All combinations of tower and leg extension heights, as stated in the tower design specification, shall be considered in determining the maximum tower base reactions.

In the verification of the stability of foundation, it is stated that, against uplifting forces the following have to be taken into account :

- For pad foundation the weight of the backfill inside the cone shaped volume which top angle is equal to the angle of friction of the soil and which height is equal to the depth of foundation.
- For piles : the friction force all along the depth of the pile which value is equal to the outer surface which depends on the nature of the soil. In any case the safety factor will be : 2 under working loads, 1.5 under broken wire loads.

The different nature of soils are presented in the documents:

- Cooperative Regional Assessment for Watershed Management_Ethiopia
- Cooperative Regional Assessment for Watershed Management_Sudan

3.4 TENSION AND SAG CALCULATION FOR CONDUCTORS

The following conditions should be considered :

- Stress on the conductor at 25°C without wind (Every Day Stress EDS) : 20% of the ultimate strength of the conductor,
- Stress on the conductor will respect the safety factor for the different load case specified in Chapter 6.5.

3.5 ELECTRICAL DESIGN

The line electrical characteristics are assumed as follows:

- Nominal voltage of a three-phase system : 500 kV
- Highest voltage of a three-phase system : 550 kV
- System Design Short Circuit Current: 40 kA
- Rated impulse voltage withstand (peak): 1550 kV
- Rated frequency: 50 Hz
- Maximum operating conductor temperature: 90 ^{o}C

3.6 TOWER OUTLINES DESIGN

The positioning of the conductors and of the earthwires on the tower shall be determined considering the following clearances:

- clearance to ground and obstacles;
- the clearances between tower's live and earthed parts;
- the clearances between the conductors and between conductors and earthwires in midspan and still air;
- the earthwire's shade protection angle;
- clearances between conductors at structures.

3.6.1 CLEARANCES TO GROUND AND OBSTACLES

3.6.1.1 Vertical Clearances

The vertical clearances will be checked at the maximum sag case corresponding to the maximum conductor temperature (90°). The clearances from 500 kV conductors should be :

Vertical Clearance to	Vertical
Rural Area, uncultivated land	11 m
Major Road	14, 50 m
Crossing Navigable River (above max, water surface)	16,00 m
Rail Road track, near substation entrances	16,00 m
Building	Not Permitted
220 kV Lines	6,00 m
110 kV and Telecommunication lines	5,25 m
Distribution Lines 63 kV and less	4,65 m
Shield Wire of others lines	4,00 m
Gas pipe lines	13,00 m
Shield Wire of others lines	4,00 m

Table 6 : Vertical Clearances

Approximately 0.5 m shall be added to the clearance values above to allow for survey and drawing errors.

Where the 500 kV transmission line crosses above or below another transmission line, the respect of clearances shall be obtained in still air with the above temperature:

- 15°C for the phase conductor temperature of the lower transmission line;
- Maximum operating temperature (Repartition 90°) for the phase conductor temperature of the higher transmission line;

The minimum clearances specified below between the lowest conductor (phase or earth) of the higher transmission line should be respected.

3.6.1.2 Horizontal Clearances

The horizontal clearances will be checked at the Light wind climatic condition (25°, 360 Pa).

Horizontal Clearance to	Horizontal
State, Major Highways	75 m
Rail Roads	65 m
Country Roads	55 m
Farm lanes, District road, tracks	25 m
Canals	20 m
Buildings	35 m
Transmission Lines 220 kV	50 m
Transmission and Distribution lines 110 kV and less	40 m
Gas Pipe Lines	45 m

Table 7 : Horizontal Clearances

3.6.2 CLEARANCES BETWEEN TOWER'S LIVE AND EARTHED PARTS

The clearances between live and earthed parts have to be considered as follows:

For suspension towers, the following electrical clearances have to be observed, as a function of the insulator set swing angle under wind as follows:

Everyday climatic condition (25°, no wind)	3,80 m
Light wind climatic condition (25°, 360 Pa)	2,50 m
Full wind climatic condition (25°, 800 Pa)	0,90 m

Table 8 : Suspension Clearances between Tower's live and earthed parts

For tension towers (insulator sets and jumpers), as a function of the jumper loop swing angle under wind:

Everyday climatic condition (25°, no wind)	3,80m
Light wind climatic condition (25°, 360 Pa)	2,50 m

Table 9 : Tension Clearances between Tower's live and earthed parts

The electrical clearances specified are to be considered as minimum dimensions to be provided between the outermost tower steel parts (outstanding web angles, step bolts) to the nearest point of the line conductor, insulator set live hardware or conductor accessory.

3.6.3 CLEARANCES BETWEEN THE CABLE (CONDUCTORS, EARTHWIRE)

The condition between conductors (Phase to phase distance) in mid span and still air should take account the asynchrony oscillation phenomena and geometry spacer (400 mm) .The minimal distance D_{pp} between conductors is 3,20 m.

$c = k \cdot \sqrt{f_{\max} + l_i} + 0.75 \cdot D_{pp} + 0.40$ but not less than 7.00m

The condition between conductor and earthwire (Phase to earthwire) distance in mid span should take account the asynchrony oscillation phenomena and geometry spacer (400 mm).The minimal distance D_{el} between conductors and earthwire is 2,80 m.

$c = k \cdot \sqrt{f_{\max} + l_i} + 0.75 \cdot D_{el} + 0.40/2$ but not less than 9.00m, measured vertically.

in which is:

k: factor according to EN 50341/2001

l_i: length of suspension insulator set [m]

f_{max}: maximum sag of the biggest span [m] with the “Light Wind” Condition (25°, 360 Pa).

D_{el}: min. earthwire – phase clearance

0.40: sub-conductor spacing in bundle

3.6.4 EARTHWIRE’S SHADE PROTECTION ANGLE

A shade protection angle of the earth wires of 0 degree to the vertical of the upper phase conductors shall be considered and not higher than 30° for lower conductors.

The sag of the earthwire shall be at 35°C, 10% less than the sag of conductor for the basic spans of 500m.

The dimensions of the crossarms of the angle-tension towers shall be such to ensure that horizontal spacing between conductors in a plan normal to the conductors are not less than that at normal suspension towers. The earth wire support positions must also ensure the corresponding spacing between earth wires as well as the assumed shielding angle.

For the angle towers having line deviation angles of 60 or 90 deg., rectangular crossarms may be used so that live metal clearances are maintained with or without the use of jumper suspension insulator strings.

The crossarms of suspension towers shall be designed to allow the attachment of double insulator strings.

The crossarms of tension towers shall be designed to allow the attachment of double insulator strings and an attachment for maintenance purpose.

The tower designer shall design the attachment points to have insulator strings in parallel position for the line angle equal with the media between maximum and minimum tower design angles.

3.6.5 CLEARANCES BETWEEN CONDUCTORS AT STRUCTURES

At angle towers between the jumper of one phase and the other phase or at gantries, the phase to phase distance have to be minimum 5.00m.

4 STEEL TOWERS

4.1 GENERAL

Steel structure will be of self supporting types, and designed to carry line conductor sets, overhead earthwires and all fitting under the conditions and with the safety factors which are specified in these technical specifications.

The minimum clearances phase earth (suspension and tension) previously defined will be followed to design the tower. The appendix 1 present the general tower outline.

The design of the lattice tower will be in accordance with the ASCE 10-97 : Design of Latticed Steel Transmission Structures.

The tower design should be based on three-dimensional indeterminate stiffness method. The computer program to be used shall be developed or tested by a recognized institute such as PLSCADD/TOWER from Power line Systems Inc., another recognized design method proved to be accurate.

Painting used as Aircraft Warning system shall meet requirements of International Standards and Recommended Practices issued by the International Civil Aviation Organization.

4.2 TYPE OF TOWERS

Tower Family to be designed, supplied and erected shall be as follows:

Tower Type	Application	Line Angle (Degree)	Wind Span (m)	Weight Span (m)
LAS	Light Angle Suspension	0-5	540	675
MAS	Medium Angle Suspension	5-10	540	675
HAS	Heavy Angle Suspension	10-15	540	675
LAT	Light Angle Tension	15-30	540	675
MAT	Medium Angle Tension	30-45	540	675
HAT	Heavy Angle Tension	45-60	540	675
T	Terminal	Complete dead end	270	340
		Dead end with 0-90° slack span	400	500
SRC	Special River Crossing	0-5	540	675

Table 10 : Family Type of Tower

The term basic span length is the horizontal distance between centers of adjacent supports on level ground from which the height standard supports is derived with the specified conductor clearance to ground in still air at maximum temperature.

The term wind span shall mean half the sum of adjacent horizontal span lengths supported on any one tower.

The term weight span shall mean the equivalent length of the weight of conductor supported at any one tower at minimum temperature in still air and it is the horizontal distance between the lowest point of Conductors, on the two spans adjacent to the tower. At suspension positions, the minimum weight of conductor supported shall not be more than 25 percent of the total weight of conductor in the two adjacent spans.

4.3 EXTENDED TOWERS

The height of each type of tower will increase or decrease by fixed steps of three meters according to the lay-out of the routing by means of appropriate body-extensions.

Following standard tower heights and leg extensions lengths have been defined :

- Standard tower heights -3m, +0m, +3m, +6m
- Leg extensions length +1m, +2m

The shape of the legs will be the same for different body sections of each tower type and towers will be symmetrical about both transverse and longitudinal center planes.

4.4 MATERIALS FOR LATTICE TOWER

Material that are used in towers manufacturing are those defined in the following requirement list or at least those equivalent to them :

- High tensile steel : steel quality reference E 36 - 2 according to the French standard NF A 35 - 501 or better or equivalent international standards.

Description	Unit	Minimum Data
High Strength Steel		
Tensile Strength	N/mm²	520
Yield Point	N/mm²	360
Normal Working Load	N/mm²	240

Table 11 : High tensile steel characteristics

- Standard steel : steel quality reference E 24 - 1 according to the French standard NF A 35 - 501 or better or equivalent international standards.

Description	Unit	Minimum Data
Structural Steel		
Tensile Strength	N/mm²	370
Yield Point	N/mm²	240
Normal Working Load	N/mm²	160

Table 12 : Standard steel characteristics

- Nuts and bolts : steel quality according to the calls 4.6 of the French standard NF E 27 - 005 or equivalent. Screw threads : ISO dimensions according to the French standards NF E 03 - 014 and NF E 03 - 053 with the possibility of substituting UNC dimensions (ANSI B 1 - 1) to ISO dimensions or better or equivalent international standards.

Description	Unit	Minimum Data
High Strength Steel Bolts		
Tensile Strength	N/mm²	500
Yield Point	N/mm²	300
Normal Working Load	N/mm²	200

Table 13 : Nuts and Bolts characteristics

- Washers : according to the French standard NF E 27 - 611 or better or equivalent international standards.
- Galvanizing : hot dipped galvanized coating according to the British Standards BS 729 or better or equivalent international standards.

4.4.1 MINIMUM SIZES

Description	Unit	Minimum Data
Calculated members	mm	45 x 45 x 5
Redundant members	mm	35 x 35 x 4
Thickness of legs, members in crossarms and in earthwire peak	mm	6
Secondary members Thickness	mm	4
Secondary unstressed members Thickness		3
Diameter of bolts for members carrying stress	mm	16
Diameter of bolts for redundant members without calculated stress	mm	12
Gusset plates	mm	6
Stub angles	mm	8

Table 14 : Minimum size Tower characteristics

The following maximum allowable slenderness ratios (L/R) shall not be exceeded:

1. Tower legs, main compression members in cross arms, and earthwire peak 150
2. Other compression members carrying calculated stresses 200
3. Redundant members without calculated stresses 250
4. The tension members of crossarm hangers 350
5. All other tension members 500

For tensile members of towers the design stress will not exceed the yield point of materials, the stress will be calculated by division of total load in the member by net area, that is to say cross section of the member minus the section of the hole.

4.4.2 BOLT, NUTS AND WASHERS

All bolts and nuts used will be hexagonal - round - hexagonal and comply with ISO Metric thread standards.

All bolts and washers will be efficiency galvanized no more than three sizes of bolts will be allowed for each type of tower.

4.4.3 CONNECTION

All connections on all the tower body will be bolted with Anti-vandalism tower bolt.

4.4.4 *TOWER DESIGNATION AND MARKING*

All members of the structure will be stamped with letter in relation with the piece marks shown on erection drawings.

4.4.5 *CLIMBING STEPS*

Each leg will be fitted with an anti climbing device. The climbing device will be installed on two legs by means of step bolts.

4.4.6 *DANGER PLATE - PHASE PLATES*

All towers will be provided with danger plates, phases plates with associated tower number.

4.4.7 *TOWER EARTHING*

The tower footing resistance (without the installed earthwire) shall not exceed 20 ohms. In proximity to the substations (1.5 km), the footing resistance shall be of maximum 15 ohms.

Furthermore, the earthing will be made with anti-vandalism device.

At tower sites in urban areas often frequented by people an additional protective earthing should be carried out aimed at less than 10 Ohms.

As theft of ground wire could be a problem, it is recommended that the grounding be designed with depressed copper rods connected to the steel grillage foundation.

Earthing	Material
Ground electrode	Galvanized steel pipes 60 mm or 35 x 35 x 5 mm steel angles, 2 m long
Ground strip	Galvanized steel wire, 70 mm^2
Connection of ground electrode with stub angle	Galvanised steel wire, 70 mm^2
Connection of reinforcement to stub angle	Galvanised steel wire, 70 mm^2 and parallel groove clamp

Table 15 : Tower Earthing Characteristics

5 FOUNDATIONS

5.1 GENERAL

The foundation of each tower consist of four independent reinforced concrete blocks.

For the Tendering , the Geotechnical Report Study will allow the Contractor to make a preliminary design for different types of foundations and a cost estimates.

The responsibility for proving the adequacy of the dimensions and type of foundation at each location shall remain to the Contractor according to the results of soil investigation performed by the Contractor.

Soil Classification

The soil has been classified into five classes as follows:

Soil Class	Description	Density kg/m^3	Angle of Repose	Ultimate Bearing Capacity MPa
I	Very Soft	900	0	<0.1
II	Soft	1,000	5	0.15
III	Fair	1,200	15	0.3
IV	Good	1,700	20	0.5
V	Hard	2000	30	0.75

Table 16 : Soil Classification

Soil class I, II and III are submerged. Disintegrated rock shall be classified as soil class V.

Foundation Type

Foundation type for each soil class shall be as follows:

Soil Class	Foundation Type
I	Long Pile
II	Short Pile or pad
III, IV, V	Pad

Table 17 : Foundation Type

The foundation for towers shall be:

- In the areas with submerged and poor soil conditions, the use of pile foundations is proposed to be used.
- Reinforced concrete pad and chimney foundations for normal soil conditions.

The Contractor shall propose undercuts for soils class III, IV and V.

5.2 TYPES OF FOUNDATION

5.2.1 PAD FOUNDATION (CLASS II TO V)

Three types of foundation will be designed to meet the soil site existing condition which will depend of the bearing capacity of soil encountered along the line :

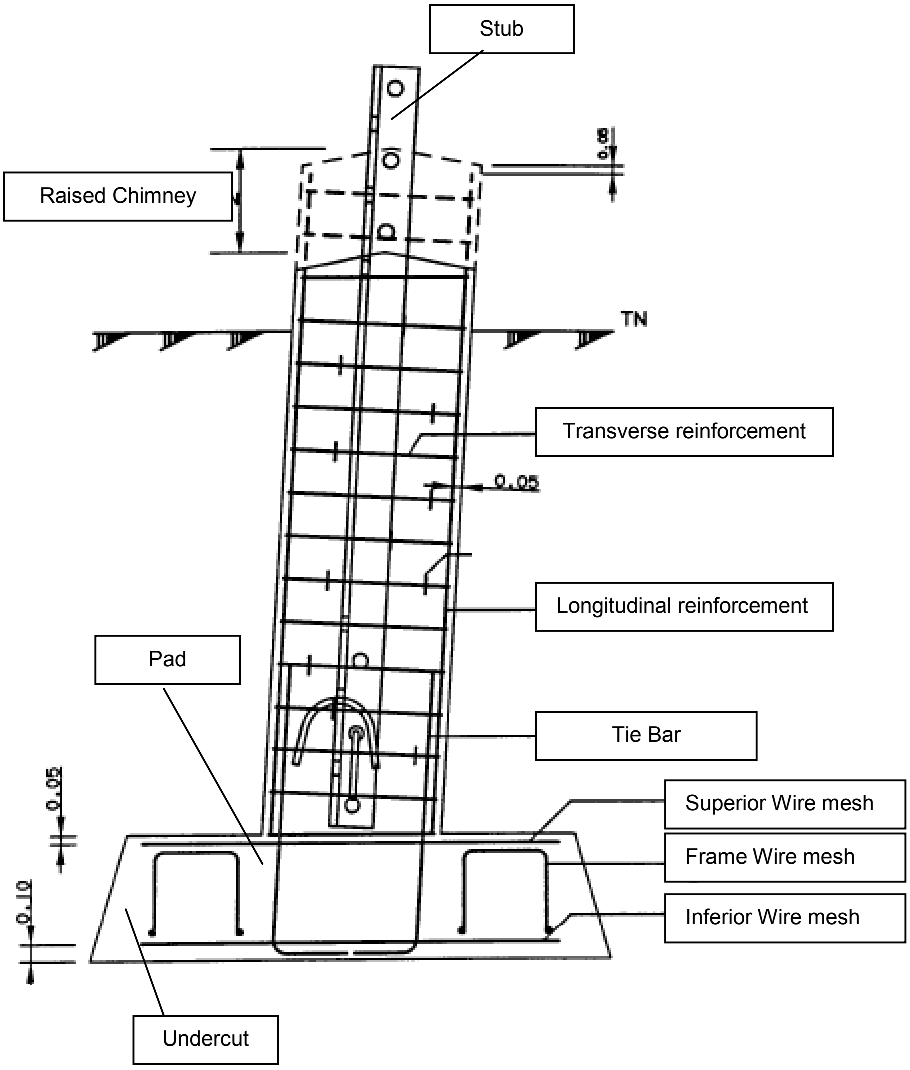


Figure 4: Pad Foundations

5.2.2 PILE FOUNDATION (CLASS I TO II)

In case of very low resistance soils, when the recession of phreatic line involve high equipment cost, pile foundation will be used.

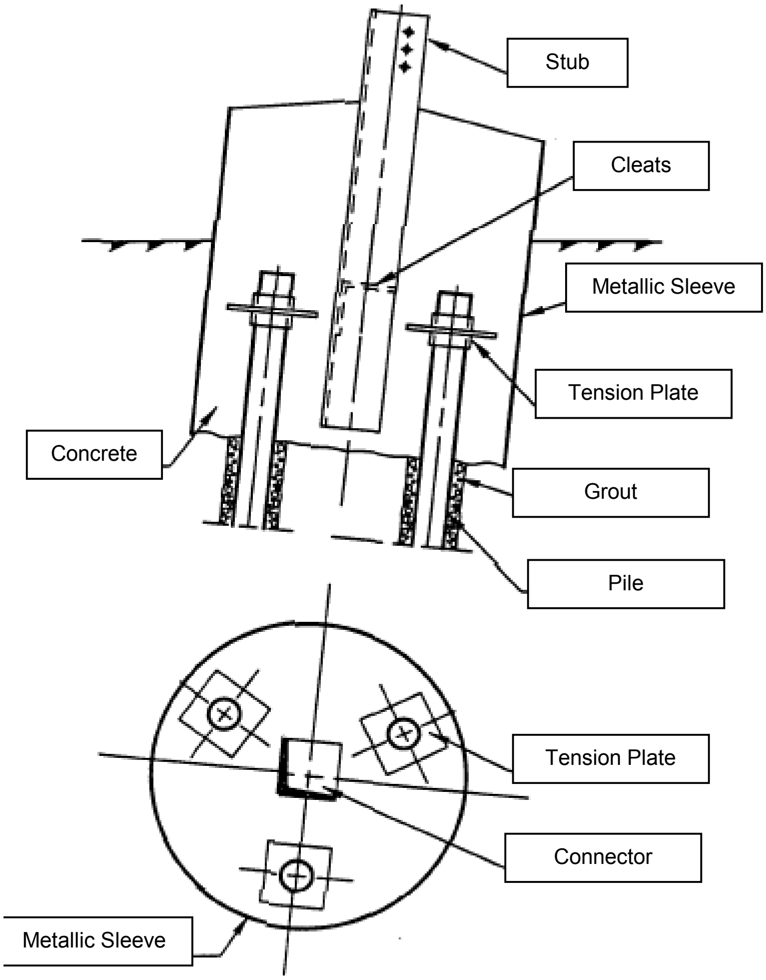


Figure 5: Pile Foundations

5.2.3 MATERIALS FOR FOUNDATION

- Concrete with characteristic strength of 250 kg/cm2 (28 days),
- Steel reinforcement : deformed steel bars with yield strength fy = 4200 kg/cm2
- Cement : Portland type II
- Concrete cover of reinforcement is 7.5 cm

6 CONDUCTOR AND EARTHWIRES

6.1 LINE CONDUCTOR

The line conductors selected on this study are aluminum conductors steel reinforced (ACSR) DOVE with the following characteristics.

Specification		Conductor
Material		ACSR DOVE
Conductor designation		DOVE
Cross-section	mm^2 Aluminium (mm²) Steel (mm²)	328,5 282,6 45,9
Overall diameter	mm	23,55
Stranding Aluminium	No x mm	26 x 3,72
Stranding Steel	No x mm	7 x 2,89
Weight	kg/m	1,141
Rated Strength	kN	100,39
Rated DC resistance at 20 °C	Ω/km	0,10218
Standard		DIN 48204

Table 18 : ACSR DOVE Characteristics

The conductors shall be subjected to type, sample and routine tests according to IEC 61089 and ISO 9001 to 9003.

An alternative of using new type of conductor should be studied before the implementation of the transmission lines; like as.

- Aluminum conductor steel supported (ACSS) and a variation of this construction where the aluminum strands are formed to produce a trapezoidal shape (ACSS/TW).
- Special zirconium high-temperature aluminum alloy conductor Invar steel reinforced (ZTACIR).
- Gapped high-temperature aluminum alloy conductor extra high-strength steel reinforced (GTACSR).
- Aluminum conductor composite reinforced (ACCR).

- Aluminum stranded conductors reinforced with fiberglass and graphite composites (ACCC).

The cable change and the impact on design of the towers will be a good option if :

- the total cost is reduced
- the reliability experience feed back of these new conductor is good
- this cable is compatible for 500 KV AC design.

Nowadays, GTASCR (Gap Type Aluminum Conductors Steel Reinforced) is the less expensive between theses new conductors. GTASCR conductor is capable to carry double the power of the equivalent ACSR. The Gap type conductor has a unique structure. The aluminum wires in the internal layer, closest to the core, has a trapezoidal cross section which creates a gap between the steel core and the aluminum layers. The GTACSR construction, designed for operation at 150°C, uses trapezoidal-shaped high-temperature aluminum alloy strands with a grease-filled gap over the steel core. Commercially available from Japan, there has been limited field experience at National Grid installations in England, Korea and Japan. Extensive laboratory data and detailed installation instructions are available. The installation of this conductor is more complex and labor intensive than ACSR, requiring special semi-strain-type suspension fittings for long lines.

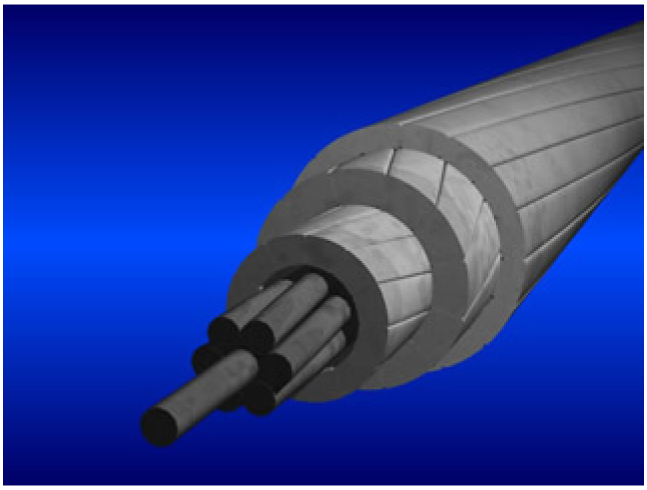


Figure 6: GTASCR Conductor

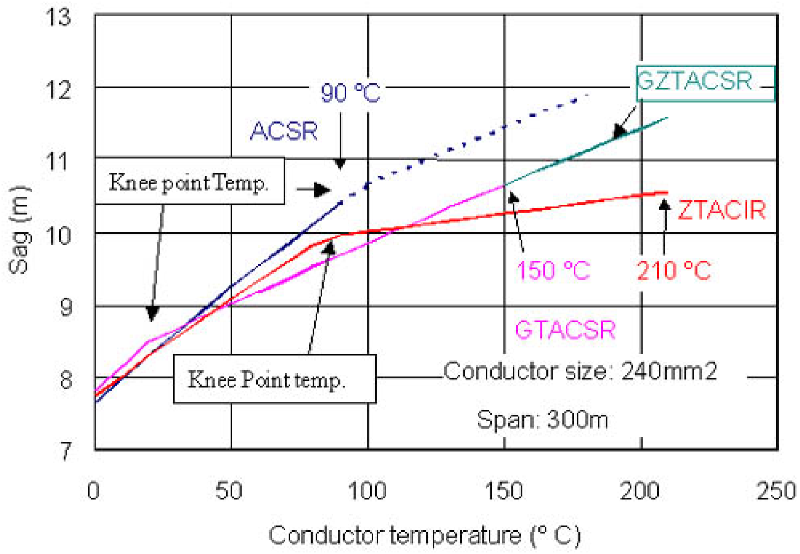


Figure 7: Sag Curve for GTASCR Conductor

On the other hand, GTASCAR price is unfortunately still high (twice more expensive than ACSR) and the savings in the tower design will not be significant nowadays. But on the future, the evolution prices for this type of conductor will be decisive in the configuration conductor choice.

6.2 EARTHWIRES

All towers shall be self supporting square based and lattice construction. They shall be equipped with 2 earthwires (G1 & G2) at tower top consisting in :

- One Optical Ground Wire (OPGW) with 48 fibers. The OPGW installed could be routed through substations as « Line-in-line-out connection ».
- One classic ACSR earthwire

Composite Fiber Optic Overhead Ground Wire (OPGW) shall be used to serve dual function as optical fiber communication link and shielding wire.

6.2.1 CLASSIC EARTHWIRE

The second earthwire should be “Alluminium Conductors Steel Reinforced” (ACSR) 210/50 and the main characteristics are:

Code Name	ACSR 210/50
Standard	ASTM B232, BS215_Part II
Sectional Area	261,6 mm²
Overall diameter	21 mm
Stranding Aluminium Steel	 30x3,00 7x3,00
Weight	0,973 kg/m
Rated Tensile Strength	92,23 kN
Rated DC resistant at 20 °C	0,1363 Ohm/km

Table 19 : ACSR 210/50 Characteristics

ACSR 210/50 shall comply with the requirements of IEC 61089 and EN 50182 and the cables shall be greased in accordance with the IEC 61394.

6.2.2 OPGW

The earthwire should be OPGW. It shall be a slotted core structure or steel tube construction for 48 optical fibers. The OPGW will be designed and comply with the following standards:

- IEC 60794 Part 1-1 : Optical fibre cables –Generic specification – General
- IEC 60794 Part 1-2 : Optical fibre cables –Generic specification –Basic optical cable test procedures
- IEC 60794 Part 2 : Optical fibre cables –Indoor cables –Sectional specification
- IEC 60794 Part 3 : Optical fibre cables –Sectional specification –Outdoor cables
- IEC 60794 Part 4 : Optical fibre cables –Sectional specification –Aerial optical cables along electrical power lines

The optical fiber earthwire shall be of design and construction as to ensure long service with high economy and low maintenance costs. It shall be suitable in every respect for continuous operation at nominal parameters as well as in transient operating conditions, under the climatic conditions peculiar to the Site.

The standards and regulations mentioned above shall be observed in the design, construction and manufacture.

6.2.2.1 OPGW characteristics

The main requirement characteristics of the selected OPGW are:

- Aluminum alloy – steel type
- OPGW shall incorporate 48 optical fibers
- OPGW should be designed for a short cut current of 40 kA
- Mean conductor length on drum 5000 meters

The Contractor will give the above characteristics of the selected OPGW:

- nominal cross section (mm²)
- Overall Diameter (mm)
- Linear Weight (k/m)
- telecommunication tube diameter (mm)
- calculated diameter (mm)
- conductor structure: (mm) aluminum alloy / (mm) steel
- Minimum ultimate strength (kN)
- Max DC resistance at 20°C (Ohm/km)
- Electrical and Optical characteristics in accordance with IEC 60794 (1 to 4)

6.2.2.2 OPGW Compositions

6.2.2.2.1 Optical Core design

The OPGW shall incorporate 48 optical fibers. They shall be greased in accordance with the Standards. Individual optical fibers or groups of fibers shall be contained in protective tubes. These tubes shall form the fibers' secondary protection (the coating being the primary protection).

The function of loose tube and water screen may be covered the same physical component. The optical core design shall prevent longitudinal fiber transport in the loose tubes.

A water block shall prevent longitudinal water penetration of the optical core and individual tubes. A metallic water screen shall prevent transversal water penetration of the optical core.

6.2.2.2.2 Loose Tube

The loose tube shall be made of PE (polyethylene) or metal. Elongation of the tube caused by cable elongation shall be in proportion to such cable elongation.

The tube shall not deform and shall continue to fulfill its function when subjected to the following:

- The electrical, thermal and mechanical loads stated in this generic specification
- The high-frequency (>1 Hz) and low-frequency (<1 Hz) vibrations occurring in the high-voltage line

- Use with the prescribed suspension and tensioning equipment and vibration dampers
- All regular and permissible conductor assembly processes

Non-circularity of the tube shall be ≤ 5%.

6.2.2.2.3 Water Screen

In case the water screen and loose tube are physically not the same, the relevant requirements stated above apply.

The water screen shall consist of a welded or extruded metallic tube.

In case of stainless steel tubes, aluminum cladding shall be applied in order to prevent corrosion.

OPGW types, manufactured with Water Screen of plastic tube are not accepted.

6.2.2.2.4 Fiber coating

The optical fibers are to be coated with a tight outer UV-hardened acrylate protective coating having a nominal diameter of 250 μm ± 15 μm.

The coating shall be mechanically easily removed over a length of up to 50 mm for the purpose of cleaning, cleaving and fusion splicing.

Each fiber is to be color coded in order to facilitate fiber identification. These coatings are to be colored fast, and shall not degrade the optical cladding/core neither mechanically nor optically.

The optical fiber coating material shall not generate H2 gas around the optical fibers that will increase the optical loss as specified above over the designed life span of the optical fiber. The Contractor shall supply details of the methods employed to minimize the generation of H2 gas.

All coatings/colors are to be compatible with fusion splices utilizing the light inject detect (LID) method and profile alignment method.

6.2.2.3 Optical fiber parameter , performance and Tests

The following characteristics of each optical fiber shall be applied for OPGW:

- transmission rate: 2.0 to 155.0 Mbit/sec
- transmission wavelength: 1310 nm and 1550 nm
- mode field diameter: 9.0 ± 1 micrometers (μm), including tolerances
- mode field concentricity error: < 1 μm
- optical cladding diameter: 125 μm ± 2.4%
- Cut off wavelength: <1270 Nm
- cable attenuation: not greater than 0.4 dB/km for every fiber in every drum at optical wavelength of 1310 nm; and not greater than 0.25 dB/km for every fiber in every drum at optical wavelength of 1550 nm.
- joint attenuation: not greater than 0.10 dB at optical wavelength of 1310 nm or at 1550 nm for every fiber, measured on the fully installed joint
- core numerical aperture: less than 0.23

- life span: greater than 30 years

No joints shall be allowed in any fiber in any drum length.

Discontinuities will be acceptable if:

- less than 0.10 dB in magnitude measured at 1310 nm, and
- ODTR traces from both ends of the cable at 1310 and 1550 nm wavelength show a difference of less than 0.05 dB/km for every fiber in every drum.

Tests nominated by the Contractor shall include but not be limited to:

- tensile test with indicated over length of fiber and simultaneously measured attenuation at 1310 nm and 1550 nm
- bending test
- repeated bending test
- crush test
- aging test
- water penetration test (tube)
- temperature test
- short circuit test
- lightning test
- stress-strain test
- creep test
- tests to verify the mechanical and optical performances of the optical fibers including OTDR (optical time domain reflectometer) tests.

The length of the optical fibers shall be subjected to a proof test at a minimum strain of 1.1 % on duration of at least 0.2 seconds. Only fibers, which pass this strain level, will be accepted. The Contractor shall supply details of the test method and references to any standards used, including a copy of the applied standards.

6.2.3 PACKING, SHIPPING, TRANSPORT

After the arrival of the conductors and/or OPGW at site, they will be inspected and shall pass to the satisfaction of the Employer / Project Manager such of the tests set out above or the Standardization Rules as he may deem necessary to satisfy himself that the conductors and OPGW supplied conform to the Technical Specification, including Guaranteed Performances and Characteristics.

Conductors and OPGW which do not pass the tests satisfactorily may be rejected forthwith and shall be replaced at the Contractor's expense.

The conductors and OPGW required for incorporation in the transmission line project shall be supplied on timber drums. The OPGW shall be shipped in continuous lengths. The packing for the corresponding spare parts shall comply with the requirements specified for long time storing.

The following requirements apply for packing and shipping:

The conductors and OPGW shall be delivered and shipped on stoutly constructed timber or steel drums as specified and lapped with protective covering across the whole width of the drum. All drums with conductors and OPGW shall have a layer of waterproof wax paper or plastic sheet which must be safe against chemical reactions laid around the barrel under the conductors or OPGW and another one laid over them and under the lapping. Drums shall be securely fastened around the perimeter and shall be suitable for rolling on the flanges without causing damage to the conductors or OPGW.

The disposal of all empty drums shall be the responsibility of the Contractor.

The following information shall be clearly written in indelible paint on both flanges of each drum:

- contract title and reference number;
- manufacturer's name;
- lifting instructions and limitations;
- direction of rolling.

An aluminum or painted metallic marking plate shall be fixed to each drum clearly showing the following data:

- type and size;
- length;
- gross and net weight;
- batch and drum numbers;
- stranding date;
- main dimensions of the drum;
- correct direction of rolling.

Contractor shall submit a sketch or drawings showing the full details of drum design and the details of the proposed method of impregnation and lagging the inner drum surfaces with approved tarred paper or equivalent material. The minimum length of the conductor and earth wire in a drum is subject to the Project Manager 's approval.

The disposal / surpluses of materials ..etc should be delivered to the Employer store.

7 INSULATORS

7.1 GENERAL

The insulators set design will comply in all aspects with the requirements of IEC recommendations.

- IEC 60815 : Guide for the selection of insulators in respect of polluted conditions.
- IEC 60383-1 : Insulators for overhead lines with a nominal voltage above 1000 V - Part 1: Ceramic or glass insulator units for AC systems - Definitions, test methods and acceptance criteria
- IEC 60383-2 : Insulators for overhead lines with a nominal voltage above 1000 V - Part 2: Insulator strings and insulator sets for AC systems - Definitions, test methods and acceptance criteria
- IEC 60471 : Dimensions of Clevis and Tongue Couplings of String Insulator Units
- IEC 60120 : Dimensions of Ball and Socket Couplings of String Insulator Units
- IEC 60305 : Characteristics of string insulator units of the cap and pin type
- IEC 60372 : Locking devices for ball and socket couplings of string insulator units _ Dimensions and test

The insulators sets should preferably be made of composite insulators :

- IEC 61952 : Insulators for overhead lines – Composite line post insulators for alternative current with a nominal voltage >1 000 V
- IEC 61466-1 : Composite string insulator units for overhead lines with a nominal voltage greater than 1000 V. Part 1: Standard strength classes and end fittings.
- IEC 61466-2 : Composite string insulator units for overhead lines with a nominal voltage greater than 1000 V. Part 2: Dimensional and electrical characteristics.
- IEC 61109: Composite Insulators for AC overhead lines with a nominal voltage greater than 1000V - Definitions, test methods and acceptance criteria.
- IEC 60433 : Characteristics of string insulator units of the long rod type
- IEC 60433 : Insulators for overhead lines with a nominal voltage above 1 000 V –Ceramic insulators for AC systems – Characteristics of insulator units of the long rod type

Complete insulator sets consisting of composite insulator units and assembling fittings as well as fittings for phase conductors and OPGW are required as described below. Specification requirements for individual composite insulators and fittings are listed in the following sections.

The suspension towers will be equipped with suspension insulator sets. The tension towers (angle-tension and dead-end towers) and gantries will be equipped with tension insulator sets. The insulator sets shall be designed for quad bundle of ACSR/ACS conductor type "Dove" per phase, spaced at 400 mm. The single suspension insulator set shall be used as standard set on suspension towers.

Double sets will be use for :

- Double suspension insulator sets shall be generally provided at all Highway Crossings, Residential areas, Power and Communication line crossings etc., Special attention has to be paid to ensure that by breakage of an insulator string of a double set, the remaining string shall withstand the resulting static and dynamic stress.
- Double tension insulator sets shall be generally provided at tension and terminal towers.

Between the terminal towers and gantries, upright and inverted low duty tension sets will be installed having the same creepage distance based on maximum phase to phase voltage. In order to avoid the insulators columns twisting, the upright tensions sets shall have two columns (i.e. double tension sets).The upright double tension sets will be installed at the terminal tower on the slack span. The single low duty (inverted) tension sets will be installed at the Substation gantries.

The single suspension insulator set shall be installed as jumper suspension sets on the tension and terminal towers, where clearance requirements so demand.

Spacing between double strings shall be sufficient to assure good behavior of insulators and good performance of guarding rings. The insulator set attachments to the tower crossarms are of special importance due to the overhead transmission lines and main roads to be crossed, so for the twin suspension and tension insulator sets, two independent fixing to the tower is specified.

Suitable adjustment, in case of tension sets, has to be done for the different line angles in order to assure equal repartition of the loads to the insulator strings of the set. Attachments are to be secure connection such as with swivels. Hooks are not acceptable.

All insulator sets including their clamps and fittings shall be in fair weather, free from visible corona discharges. The freedom from corona shall be proven by design tests in the workshop or laboratories in accordance with the tests described below.

The live part of all insulator sets shall be conceived and shielded in such a way, that there shall be no visible corona in fair weather condition.

All insulator sets shall be provided with the necessary guarding devices in order to keep their radio and television noise as low as possible. The radio interference (RI) performance of the insulator sets has to be proven by design tests in the workshop or laboratories in accordance with the tests described below. A noise level less than 46 dB above 1 micro-volt shall be ensured under standard laboratory conditions.

By means of adequate fittings (guarding rings), an optimized potential distribution along the insulator strings shall be ensured. All insulator sets shall be designed to withstand the single-phase fault currents. This performance shall be proven by design tests in the workshop or laboratories in accordance with the tests described below. The upper and lower horns and guard rings shall be installed on the insulator assemblies as recommended by the fittings manufacturer and confirmed by electrical tests.

All insulators shall be designed with a view of service in an area subject to sand storms and must be designed for the short curt current of 40 kA. An example of double suspension is given here after.

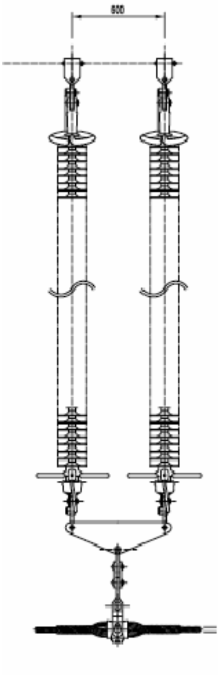


Figure 8 : Double composite suspension set

7.2 TYPE OF INSULATOR

The suspension and tension string insulator units shall be of the composite long-rod type. The composite insulator is made of two insulating materials, a load bearing core able to fulfil the electrical insulation and an external elastomeric housing whose main function is to protect the core from any environmental attack and to provide the best efficiency of the leakage distance. When required, grading rings are added to reduce excessive electric stress conditions.

- **Core:** The core shall be made of fibreglass of "electrical" grade *(type E)* positioned in an epoxy resin matrix having high electrical, mechanical and thermal performances.
- **Housing and Sheds:** The fibreglass/epoxy resin core of the composite insulator shall be protected by a silicone housing. The housing shall be perfectly bonded to the core and to the fittings. High pressure/ high temperature direct injection moulding is recommended.
- **Metal Fittings :** The metal end fittings should be made of forged steel or cast iron *(malleable or ductile)* and hot dip galvanized standards. The minimum mass of zinc should be in accordance with the clause 26.2.2 of IEC 60383-1 standard (min. thickness of 120 μm). The end fittings shall be attached to the core through a compression crimping process. The crimping process shall be controlled by a specific method to ensure that there is no damage to the core during the compression crimping operation. The gap between fitting and core housing shall be sealed permanently against the ingress of moisture. Sealing by compression only is not regarded to be permanently waterproof. Covering the cap, even partly, with housing material is unacceptable due to electrical reasons. The material shall adhere to the surface of the metal cap, as well as to the housing.

The insulators shall be of sufficient length to provide the required electrical performance in one single unit. In-line coupling of two or more units is not acceptable. The minimal Rated Strength requirement of the insulators shall be as follows:

- 210 kN for suspension insulators
- 310 kN for tension insulators

The minimum safety factors required for the different load cases are given in the table of § 2.3.

The minimum creepage path of composite strings, based on phase to phase maximum operating phase, shall be not less than :

- 16 mm/kV for Ethiopian Part
- 31 mm/kV for Sudan Part

The design should be in accordance with the specified standards and the electrical requirements. The coupling device will be determined according IEC 60120. The design of insulators and fittings shall be such as to avoid local corona formation and no significant radio interference shall be exhibited.

All insulators shall be designed to facilitate cleaning and insulators and shall have the minimum practical number of sheds and grooves. All grooves shall be so proportioned that any dust deposits can be removed without difficulty either by wiping with a cloth or by remote washing under live-line conditions.

The composite insulator must be designed, manufactured and tested according to the following standards: IEC 61952, IEC 61466-1, IEC 61466-2, IEC 61109, IEC 60471, IEC 60120.

Each insulators shall be marked (on the insulating component or on a metal part) with the name or trade mark of the manufacturer and the year of manufacture. In addition, each string insulator unit shall be marked with the specified electromechanical or mechanical failing load whichever is applicable. These markings shall be legible and indelible. The designations included in IEC 60305 and IEC 60433 may be used.

8 CLAMPS AND FITTING FOR CONDUCTORS AND OPGW

8.1 GENERAL

The design of these material will be suitable for all the material indicated in these technical specification. They shall be suitable for :

- four ACSR/ACS "Dove" conductor type per phase (quad bundle)
- OPGW type earthwire
- ACSR 210/50 type earthwire

The design of clamp, vibration dampers, spacers will avoid sharp corners on projection which could produce high electrical stress during operation.

All hardware components for line conductor groundwire and insulator strings will be so fabricated that no electrolytic action will occur between the accessories and the conductor and between the components. All ferrous parts of insulator and conductor fittings component elements shall be fully hot dip galvanized with a minimum zinc weight (§2.2). All bolt, nuts and cotter pins will be locked in order to prevent dislocation.

The ultimate strength of the hardware for suspension and tension insulation strings will be not less than :

- 210 kN for suspension insulators
- 310 kN for tension insulators

8.2 SUSPENSION CLAMPS

Suspension clamps shall be designed to meet the following requirements:

- so that the effects of vibration both on the conductors, or the earthwire and on the clamp themselves are minimized;
- to avoid localized pressure or damage to the conductor or earthwire, and shall have sufficient contact surface to avoid damage by fault currents;
- shall be free to pivot in the vertical plane of the conductor / earthwire and shall have a minimum range of movement of plus or minus 30 degrees;
- shall have a slipping capacity between specified minimum and maximum slipping loads;
- suspension clamp assemblies shall have sufficient strength and durability to prevent deterioration in service;
- the mouth of the suspension clamp shall be rounded and slightly flared, with a minimum radius of curvature in the vertical plane of 150 mm.

Suspension clamps for conductor :

Suspension clamps to be used shall be suitable for the conductor. The material of the suspension clamp shall be made of malleable iron or aluminum alloy which will be hot dip galvanized. The suspension clamp will be used with preformed armor rods and will be as light as possible.

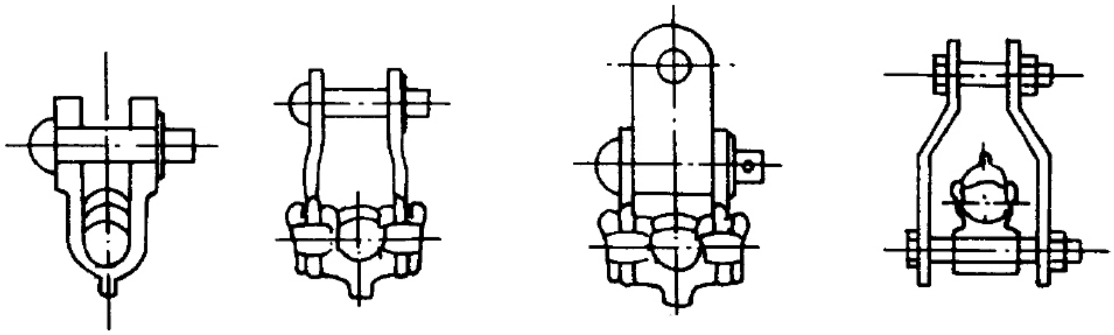


Figure 9 : Typical suspension clamps

Suspension clamps for earthwire :

The material of the suspension clamps will be made of malleable iron or forged steel which will be hot dip galvanized.

8.3 TENSION CLAMPS

All tension clamps and joints for conductor and ACSR earthwire will be of the compression type made by hydraulic compression. All aluminum parts of tension clamps and joints will be of at least 99.5% pure aluminum.

The tension clamps and joints will not permit slipping off or cause damage, or failure of the conductor at a load less than 95% of the ultimate strength of the corresponding conduction. The electrical conductivity and current carrying capacity of each joint and tension clamp will not by less than that of an equal length of unjointed conductor.

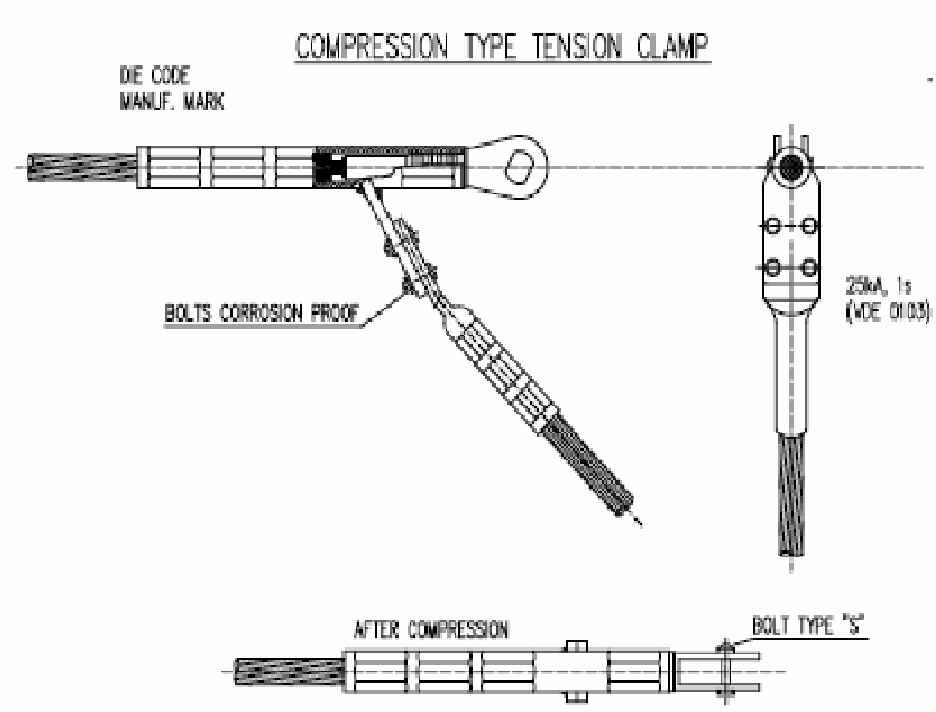


Figure 10 : Compression Type Tension Clamp

8.4 REPAIR SLEEVES FOR CONDUCTOR

Repair sleeves of the compression type or preformed type, will be used in case of local damage to the outer strands of the conductors during erection.

The joint sleeves shall consist of aluminum compression sleeve. The aluminum compression sleeves shall be of aluminum alloy conforming to the specification in IEC 60889 standard.

8.5 DAMPERS

Antivibration Dampers shall be installed on conductors and earthwire. The design and tests of antivibration Dampers shall be conducted according with IEC 61897 : Overhead lines – Requirements and tests for Stockbridge type aeolian vibration dampers

Dampers for conductor :

All conductors will be fitted with dampers of the Stockbridge type. The number and position of these dampers will be specified by the Contractor together with a calculation note justifying number, location and type of proposed dampers. A sufficient clamping surface with adequate curvature at the clamp mouth will be provided. All bolts will be locked.

Dampers for earthwire :

Earthwire will be fitted with dampers of the Stockbridge type. The number of these dampers will be specified by the Contractor together with a calculation note justifying number and type of proposed dampers.

The clamps body and keeper of these dampers will be of malleable cast iron or other approved ferrous material.

8.6 SPACERS

Bundle conductor shall be provided with spacer dampers. The spacer-dampers shall be designed to meet the following requirements.

- The spacer-damper shall be designed so that during operation, the conductor is not damaged by its movements.
- The spacer-damper shall be capable of being installed and easily removed without completely separating components. In addition, the clamp shall be capable of being removed and reinstalled on the conductor at the design torque.
- Where elastomers or other non-metallic materials are used, they shall be capable of withstanding conductor temperatures of up to 90°C without permanent loss of essential properties. The energy absorbing assembly shall be designed to provide effective damping throughout a temperature range of 0° C to 75° C.
- The elastomer or other energy absorbing assembly shall have adequate resistance to the effects of ozone, ultra violet radiation and other atmospheric contaminants over the entire temperature range.
- Clamp bolts shall be galvanized steel with steel nuts and washers and shall be furnished with a locking system. The clamp shall be designed to permit ease of installation and removal.
- The energy absorbing assembly shall be electrically conductive.
- The spacer-damper shall maintain the proper subconductor spacing in the span under everyday conditions and prevent contact between subconductors during conditions of wind up to 30 meters per second. The spacer-damper must also control wind-induced subconductor oscillation and aeolian vibration to the extent that damage to the spacer-damper, conductor or insulator and hardware assemblies will be prevented. The bending strain along the spans shall not exceed 200 microstrain peak to peak for aeolian vibration control and shall not exceed 600 microstrain peak to peak for subspan oscillation control. Spacing of spacer dampers shall be staggered to provide optimum control of wake-induced subspan oscillation.

The Contractor shall specify the location of spacer-dampers within the various span lengths and the limit of the longest subspan that will enable the system to meet the requirements of this Specification. This data shall be for suspension to suspension, suspension to dead-end and dead-end to dead-end spans. The Contractor shall furnish all necessary information to show that its recommendation regarding type, the number, and the position, of spacer dampers is based on solid experimental and analytical data.

Bundle rigid spacers used to maintain the configuration of jumper loops shall be capable of being installed and easily removed without completely separating components. In addition, the clamp shall be capable of being removed and reinstalled on the conductors at the design torque. Rigid spacer bolted clamps shall be furnished with a locking system acceptable to the Employer.

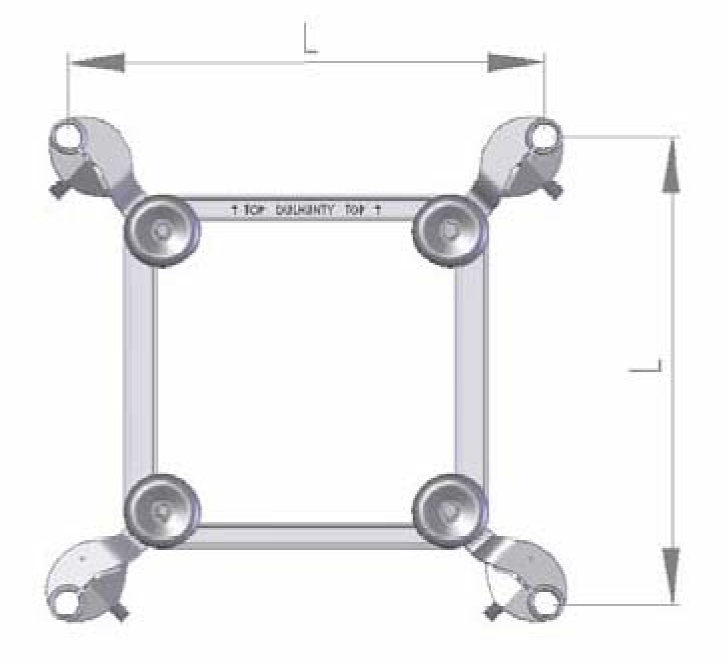


Figure 11 : Spacer

The Contractor shall perform the following laboratory and field tests to verify that the spacer-dampers and rigid spacers will perform acceptably during service. All cost of tests shall be borne by the Contractor.

- Laboratory Test : Laboratory test qualifications shall be based on the testing of five samples of spacer-dampers and two samples of rigid spacers. The samples will be tested individually and wherever possible, the same spacer-damper or rigid spacer will be used in all test. Conductor samples used for all tests shall be supplied by the Contractor. Laboratory testing costs shall be borne by the Contractor and shall be included in the cost of the spacer-dampers and rigid spacers.
- Corona and RIV Test.
- Longitudinal Deflection Test.
- Vertical Deflection Test: Three clamps of one of the spacer dampers that have successfully passed the longitudinal deflection test shall be attached to lengths of conductor that have been tensioned to 3,000 kg. The conductor will be subject to a vibration of 2.5 millimeters amplitude above and below a plane parallel to the conductors at a frequency of approximately 20 Hertz for 10^7 cycles. The conductors shall not be damaged at the clamp and the spacer-damper components shall not show any sign of deterioration.
- Transverse (Torsional) Deflection Test: One of the spacer-dampers that have successfully passed the longitudinal deflection test shall be subject to a reciprocating load of ± 30 kilograms. The load shall be applied between the upper pair of clamps and normal to the vertical axis of the spacer-damper. After 10^7 cycles of approximately 2 hertz, the spacer-damper should show no visible sign of damage or fatigue.
- Clamp Slip Test: One rigid spacer and separately, one of the spacer dampers that have successfully passed the longitudinal and vertical deflection tests of (2) and (4) above,

should be installed, with bolts tightened to their design torque, on three lengths of conductor tensioned to 3,000 kilograms. The clamps shall withstand, without slipping, a minimum axial load of 200 kilograms.

- Mechanical Strength (Short Circuit) Test: The spacer-damper and rigid spacer shall be capable of withstanding short circuit currents of 40,000 amperes RMS for a minimum of 6 cycles at 50 hertz without damage to the spacer-damper or subconductors. Upon removal of short circuit forces it shall restore all wires to normal spacing. A mechanical test may be used to satisfy this test requirement. Each sample shall be subject to 1,000 kilograms compression and 1,000 kilograms tension applied between diagonally opposite and then adjacent clamps. All compression and tension loads are to be held for a minimum of one minute.
- Elastomer Properties Test : The stiffness characteristics of elastomer damping pads shall be tested in accordance with ASTM D1043.
- Waked-Induced Oscillation Tests: The Contractor shall furnish previously performed conclusive and detailed test reports demonstrating the effectiveness of his staggered spacing selection methods for spacer dampers in limiting the magnitude and degree of wave propagation to adjacent subspans due to wake-induced oscillation.
- Sample Tests: Sample tests shall be made on each lot of dampers, spacer-dampers and rigid spacers offered for acceptance.
    - Verification of Dimensions
    - Galvanizing Test
    - Marking: Each damper, spacer-damper and rigid spacer shall be permanently marked by casting or die-stamping to indicate the following : type and nominal cross-sectional area of the conductor or shield wire on which it is to be installed, manufacturer’s name.

Dampers, spacer-dampers and rigid spacers shall be packed in sturdy wooden cases, suitable for both ocean and inland transportation and shall be clearly marked with the following information :

- Description of the items.
- Number of pieces.
- Net weight and gross weight.
- Contract number
- Project name
- Destination

Detail drawings of the dampers and spacer-dampers and all component parts shall include the following information :

- Dimensions and tolerances for all parts and the assembly.
- Material fabrication details including any weld detail, and any specified finishes and coating.
- Catalog or part numbers for each component part and the total assembly.

- Assembly drawing shall include : Installation instructions, Design installation torque recommended for the bolt, Withstand torque that may be applied to the bolt without failure of component parts, Weight of assembly.

8.7 ARMOR RODS

At all suspension clamps, the conductor will be fitted with armor rods. Armor rods to be attached to the conductor will be of the preformed type, made of aluminum alloy and will be smooth.

The direction of the armor rod lay shall be equal to the direction of the outermost wire lay of the conductor. The suspension clamps offered for the phase conductors shall accommodate the increased diameter resulting from armor rods. The ends of the armor rod wires shall be well rounded, without sharp edges, to avoid an increase in corona level.

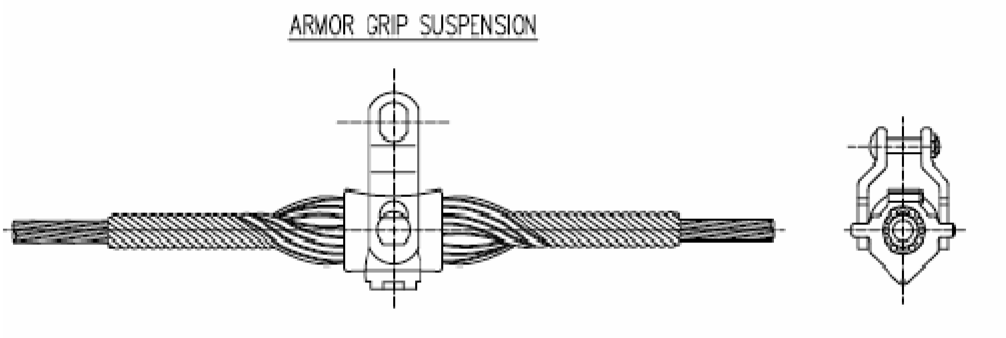


Figure 12 : Armor Rods

8.8 GUARD RINGS

The guard rings of the insulator sets must fulfill simultaneously the functions of arcing rings, corona shield and potential distribution devices.

As arcing device, the guard rings shall be designed to protect insulators and conductors when flashover occurs. The arcing fittings shall be made of hot dip galvanized steel and must have the capability to withstand a short circuit current of 40kA for 1 second. The arcing fittings must be designed so that in case of flashover the arc will be led to the end burning spot. They may reach a final temperature not exceeding 600°C during the short-circuit. The function of arcing protection must not be greatly altered by the power arc.

As corona shield devices, the guard rings shall be designed to ensure under fair weather and under the specific site conditions a corona-free insulator set line end as well as the specified insulator set radio noise performance. As shown on the drawing, the tension insulator strings shall be equipped with additional guard rings for corona purposes.

As potential distribution devices, the guard rings must be designed to insure a uniform distribution of the potential along the insulator string.

The design of the guard rings shall consider and optimize simultaneously all the functions required.

The rings shall be strong enough to support a weight of 90 kg without permanent deformation. The ring attachment shall be via bolted connections to the hardware assembly.

8.9 COUNTERWEIGHTS

When counterweights are considered necessary they will be of 50 kg and 80 kg types. All material will be hot dip galvanized. The specified counterweights shall either be fitted below the suspension clamp by extension of the clamp keeper retaining bolts by attachment to the yoke plate.

The suspension assembly with counterweights must be designed to respect the distances to the towers.

8.10 WARNING DEVICES

Warning devices shall be in installed in accordance with Aeronautic regulations (to be confirmed at a later stage). The design and positions of air navigation warning lights shall be approved by the appropriate Authorities.

Aircraft warning system

Warning spheres shall be fitted on shield wire of the transmission line in height restricted areas in the vicinity of air fields. The warning spheres shall be 600 mm diameter and shall be colored white and red which will not fade when subjected to the direct rays of the sun.

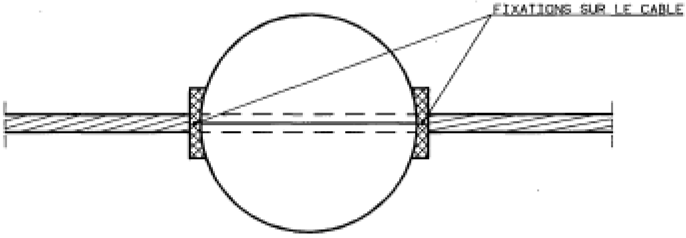


Figure 13 : Warning Devices

Air Navigation Warning lights

Air navigation warning lights shall be fitted to the conductors of the transmission line.

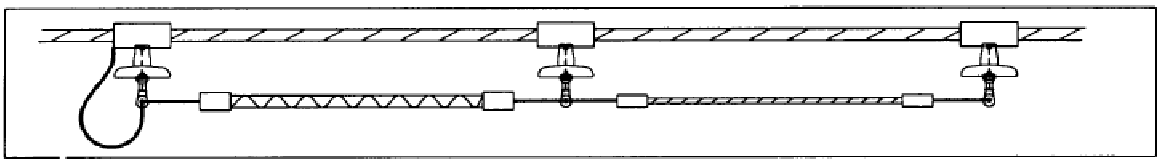


Figure 14 : Air Navigation Warning Lights

8.11 FAUNA MITIGATING MEASURES

The mitigating measures related to protection of wetlands and birds could be implemented by the installation of bird devices on the conductor and cable.

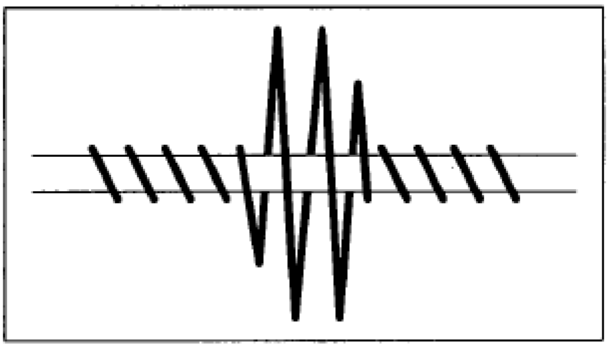


Figure 15 : Bird Devices

8.12 OPGW FITTINGS

8.12.1 SUSPENSION ASSEMBLIES

Armor grip suspension clamps shall be used for OPGW. The clamp body shall be of high-tensile corrosion-resistant aluminum alloy and shall be preferably forged. The spiral wires shall also be of aluminum alloy and shall not have diameters less than 4 mm.

The neoprene or other non-metallic material shall have good resistance to aging and be capable of withstanding temperatures between +0 deg.C and +90 deg.C without changing of essential properties. The material shall have adequate resistance to the effects of ultra-violet radiation, ozone or pollution factors.

The clamp body shall be able to pivot up to 45 degrees above and below the horizontal line. The Contractor shall ensure by appropriate design a suitable performance of the clamp-conductor assembly by wind induced vibration. The clamp body shall have provision for connecting the OPGW to the tower.

In addition to the suspension clamp, several other fittings are required for a suitable mechanical and electrical connection to tower and the Contractor is responsible to supply the complete set of the suspension assembly.

8.12.2 TENSION ASSEMBLIES

The OPGW attachments to tower shall be of helical grip type consisting of two helical parts (fittings), one for OPGW protection and the other one as actual dead-end fitting, as shown on the drawings. Preformed helical dead-ends shall have "cabled loop" eyes. The material of the spiral wires shall be high-tensile aluminum clad steel. The protection part is defined to protect the earth wire against radial forces in the OPGW produced by the high longitudinal tensions during operation. The protection part must be laid in the opposite direction of the outer layer of the OPGW and the dead-end part must be laid in opposite direction to the protection part. The grip strength shall be at least 95 % of the ultimate tensile strength of the OPGW.

The tension attachment devices must correspond to the OPGW type and dimensions. The protection part must be longer than the tension (dead-end) part and must be sufficient to install vibration dampers. The number and diameter of the spiral wires of the two parts are generally different but must be coordinated to meet the operational requirements.

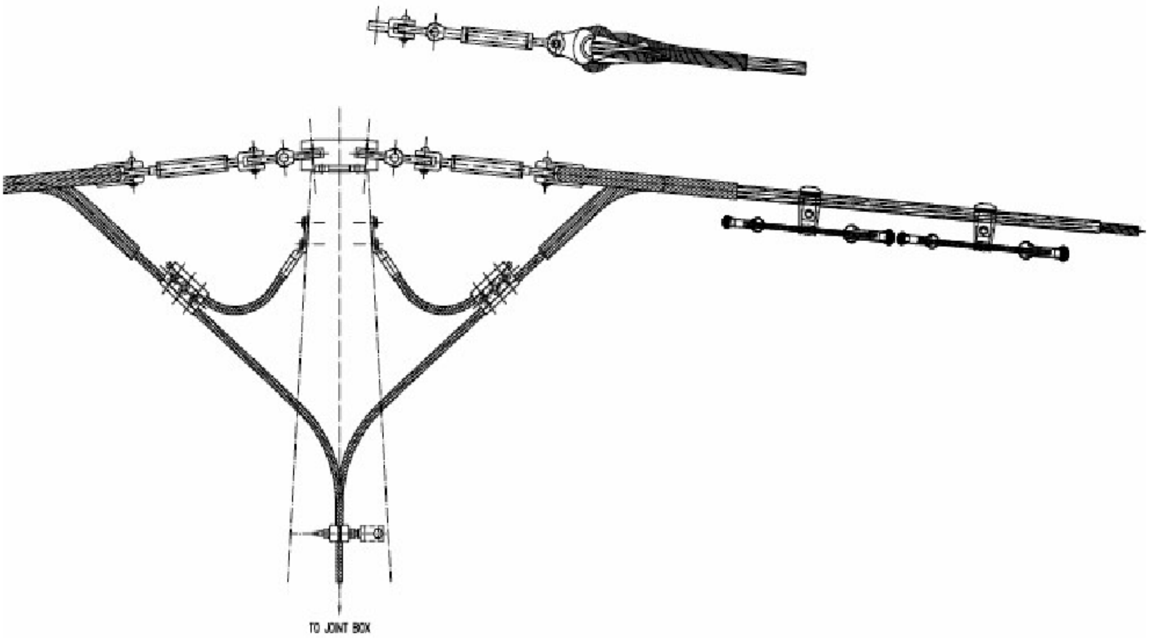


Figure 16: Double Tension Set for OPGW

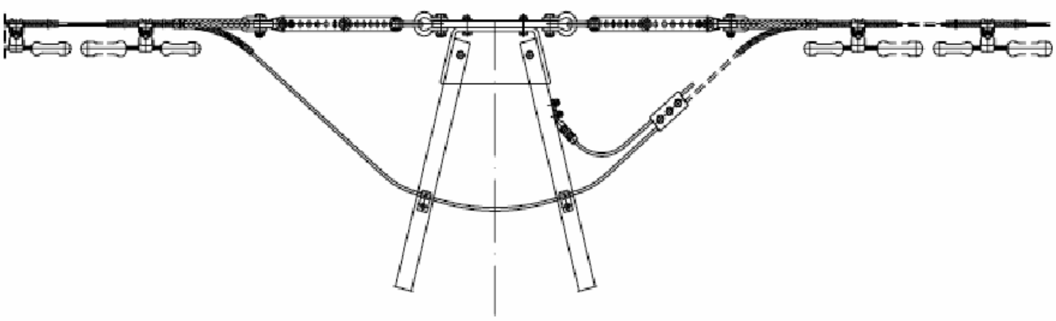


Figure 17: Single Tension Set for OPGW

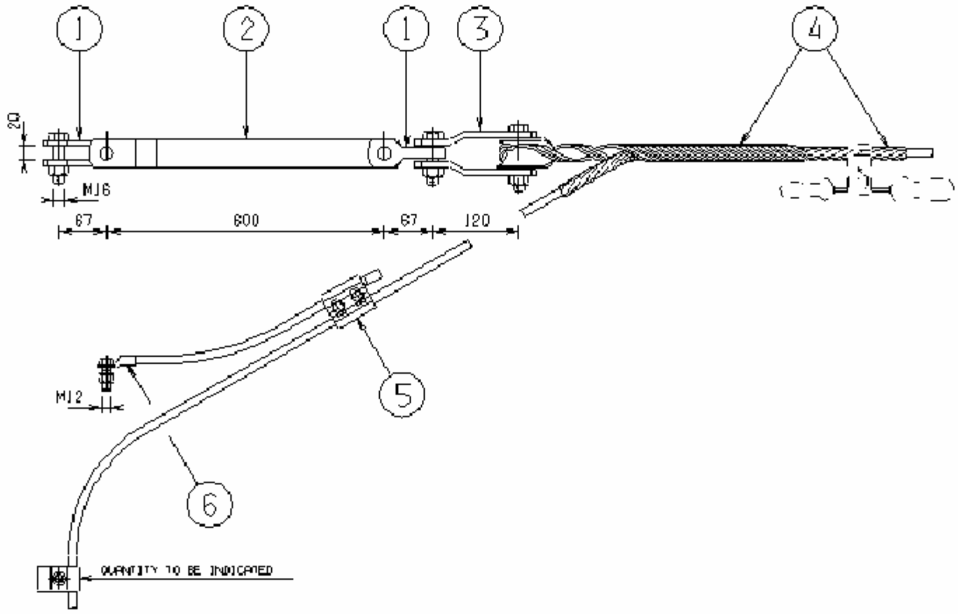


Figure 18: Single Tension Set for OPGW details

8.12.3 *MID SPAN JOINTS FOR OPGW*

The OPGW shall not be jointed in the spans.

8.12.4 *OPGW SPLICING*

On the Substation gantries and at every 5 km on tension towers, connections between OPGW Drum's shall be realized by means of joints in Joint Boxes.

The joints will be located in a suitable enclosure and the OPGW access to the enclosure should be via entry ports in the base, properly sealed to prevent moisture ingress. The joints or joint enclosures connecting OPGW are installed at + 6 … + 9 m above ground level where a covered waterproof working platform can be accommodated. Locking facilities shall be provided for every joint box.

Weatherproof units shall be provided for the joint boxes (enclosures). The joint boxes shall include all necessary hardware to terminate, protect and fix the spliced fibers. Each splice shall have a spare length of fiber of approximately 1 m or more. A finished splice shall be supported within the joint box by suitable clips or restraints. It shall be possible to remove and replace the splice in the support device without risk of damage to the splice or fiber.

The inlets of the joint boxes shall be sealed with thermofit plastics. These inlets shall be possible to match necessary branches. The outer material of the box shall be oil resistant and metallic, preferably aluminum.

The fusion splice tray shall not have any sharp edges or protrusions which may damage the optical fiber. An encapsulant shall not be used. The enclosure is to be re-enterable and re-sealable without detriment to the integrity of the enclosure and optical fibers. Enclosure re-entering and sealing shall not require power tools and use a minimum number of special tools.

9 SPARE PARTS

For maintenance, the proposed spare parts will be included for conductors, OPGW and materials.

Designation	Quantity
Conductors DOVE	100 km
Earthwire OPGW (48 fibers)	35 km
Single Suspension Sets	240 units
Double Suspension Sets	180 units
Double Tension Sets	180 units
Mid-span joints for conductor	300 units
Compression Dead End for conductor	70 units
Bolts for lattice tower	1% of each type
Suspension Clamps	72 units
Spacers	400 units
Jumper Spacer	72 units
Clevis Tongue Couplings	72 units
Preformed Armor Rod	240 units
Earthing Material	32 units
Warning Sphere	(to be confirmed)
Cleats for OPGW	240units
OPGW Box	10 units
Insulator Vibration Damper (stockbridge)	150 units

Table 20 : Proposal Spare Parts

10 SITE TESTS

During the erection the following tests shall be carried out by the Contractor in the presence of the Employer/Engineer.

10.1 TOWER FOOTING RESISTANCE

The resistance to earth of the complete foundation of individual structures shall be measured in an approved manner before the earth conductors are erected. The placing of the test electrodes shall normally be along the center line of the route in such direction as to ensure the lowest resistance to earth is recorded, and a note shall be made of the direction in the test log. The schedule used for recording earth resistance test shall contain in addition to the measured ohmic values, date of measurement, details of the surface soils and general ground conditions at the time of test.

10.2 MEASUREMENT OF GALVANIZING AND PAINT THICKNESS

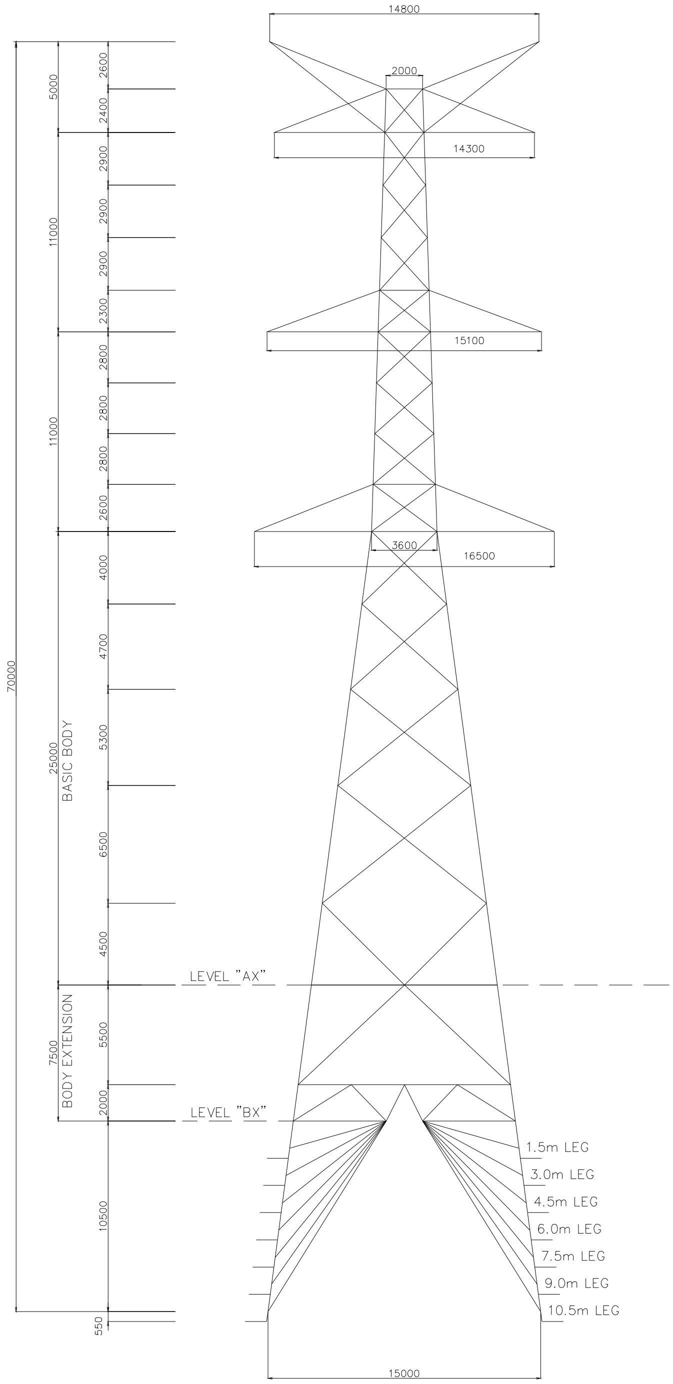
The Contractor shall have available on site for the Employer's/Engineer's use an instrument suitable for the accurate checking of painted coats and galvanizing thickness. The gauge shall be available from the time of arrival of the first consignment of steel work until the issue of the final acceptance certificate. The cost of the gauge and other operating expenses are deemed to be included in the contract price and the gauge will remain the property of the Contractor.

10.3 CLEARANCE MEASUREMENTS

Measurement at qualified crossing spans or other spans defined by Employer/Engineer to ground and/or obstacles

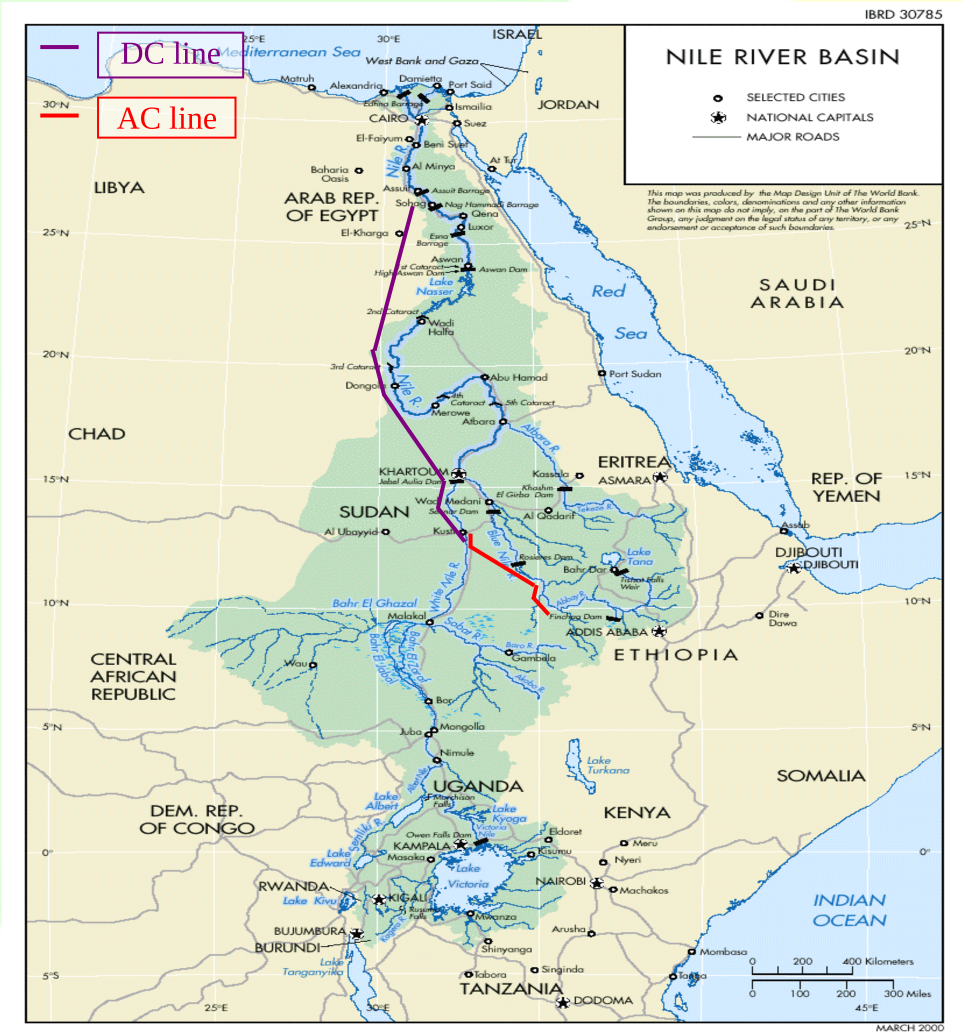
Appendix 1 : Tower Outline

ENTRO Project
500 kV AC line _ Tower
Mandaya (Ethiopia) _ Rabak (Sudan)



Nile Basin Initiative
Eastern Nile Subsidiary Action Program
Eastern Nile Technical Regional Office

EASTERN NILE POWER TRADE PROGRAM STUDY



M4 – 600 kV DC LINES

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
ACCC	Aluminum conductors composite core
ACCR	Aluminum conductor composite reinforced
ACSS	Aluminum conductor steel supported
ASCR	Aluminium Conductor Steel Reinforced
BC	Broken Conditions
BL	Breaking Load
CLINO	Climatological Normals
DC	Direct Current
EDF	Electricité de France
EDS	Every Day Stress
ESIA	Environmental and Social Impact Assessment
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
GTACSR	Gapped high-temperature aluminum alloy conductor extra high-strength steel reinforced
HV	High Voltage
HVDC	High Voltage Direct Current
ICB	International Competitive Bidding
IEC	International Electric Commission
MES	Guaranteed Minimal Elastic Stress
NBI	Nile Basin Initiative
NC	Normal Conditions
O&M	Operations and Maintenance
OPGW	Optical Ground Wire
RMS	Root Mean Square
RT	Routine Test
SVC	Static Voltage Compensator
ST	Sample Test
TT	Type Test
WMO	World Meteorological Organization
ZTACIR	Special zirconium high-temperature aluminum alloy conductor Invar steel reinforced

EXECUTIVE SUMMARY

This document, corresponding to the final report for a part of Module 4 “Preparation of Technical Specifications”, provides with particular technical requirements regarding the design of the 600 kV DC overhead transmission lines from KOSTI (Sudan) to NAG HAMMADI (Egypt).

In this section, there is no consideration concerning general technical requirements for the construction of the lines.

As stated in the Phase II - Module 1 “Detailed network studies”, one bipolar line with ACSR CURLEW conductors seems to be more relevant for this line. Each pole will have six sub-conductors.

The technical requirements specified in this document are a compromise on the latest internationally recognized standard for DC lines.

DC Transmission lines are mechanically designed as in the same way with AC transmission lines; the main differences are:

- conductor configuration
- electric field requirements
- insulation design

For DC Transmission lines, the correct insulation design is the most essential topic for undisturbed operation. The general layout of insulation is based on the recommendations of IEC 60815. This IEC is a standard for AC lines and the creepage distances recommended are based on the phase to phase voltage. When applying these creepage distances recommended by IEC 60815 to a DC line, the DC voltage is considered as a peak voltage pole to ground value. Therefore these creepage distances have to be multiplied by the factor $\sqrt{3}$.

1 GENERAL REQUIREMENTS

1.1 GENERAL

This section provides general technical considerations regarding the design of the 600 kV DC overhead transmission line from Kosti (Sudan) to Nag Hammadi (Egypt) with a approximate length of the line 1665 km.

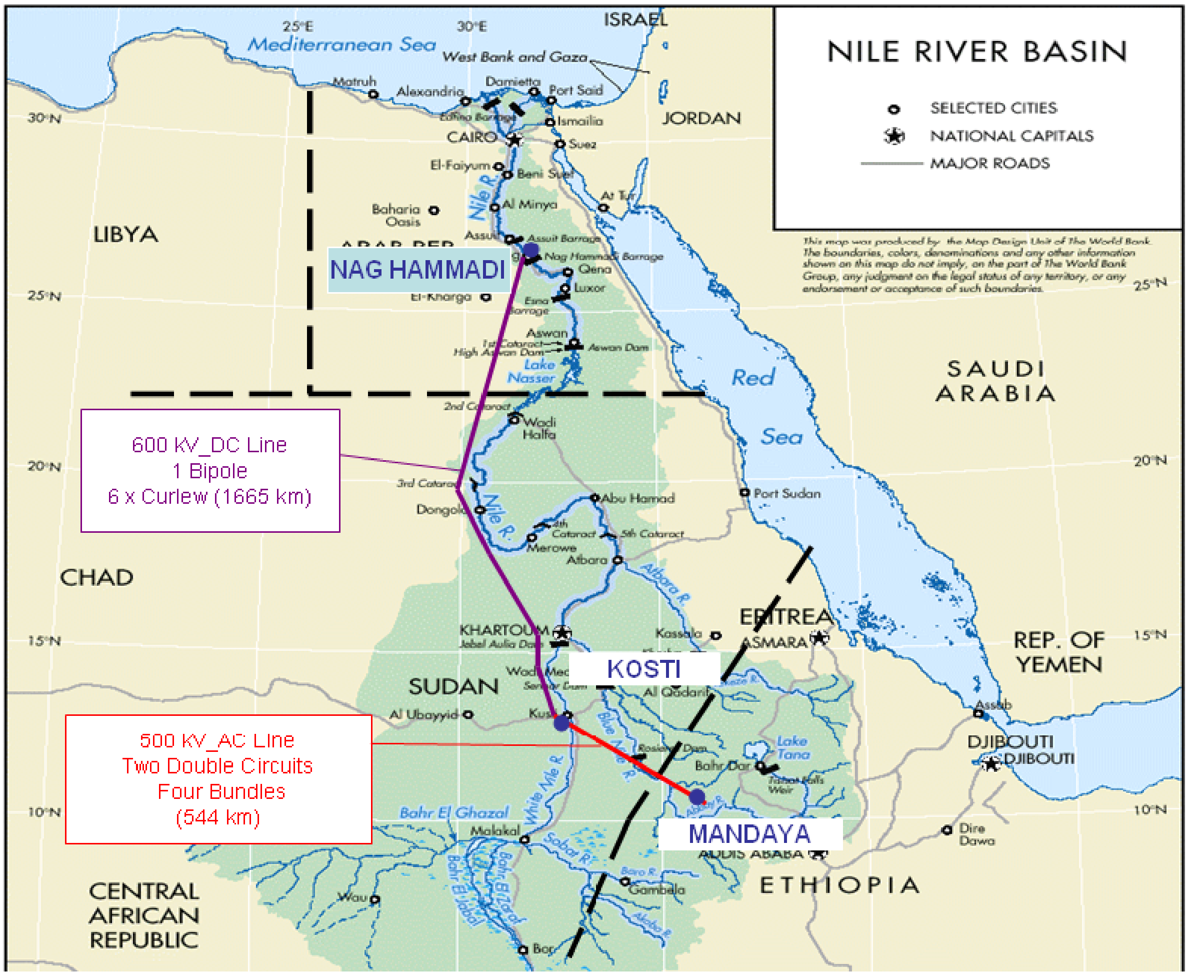


Figure 1 : General View of AC and DC Lines

As stated in the report Phase II - Module 1"Detailed network studies", one bipolar line 600 kV lines equipped of six boundless conductors ACSR CURLEW 593 mm² seems to be more relevant for this line.

The particular technical comments specified in this document will be the primordial requirements for the design of the lines. However, there are no requirements concerning works for construction such as preliminary works, site preparation, foundations, tower assembling, line stringing, setting, testing. **These different points shall be detailed for the finalization of Technical Specifications.**

1.2 SCOPE OF WORK

The scope of work will include :

Final topographical survey, soil investigation, plotting and picketing,

- Calculation and design of all towers :
  - Terminal towers,
  - Angle towers,
  - Suspension towers.
  - Calculation and design of foundations,
  - Calculation and design of earthing,
- Determination of all equipment and fitting :
  - Insulators,
  - Conductor clamps,
  - Earthwires (optical fiber), conductors and fittings,
  - Accessories as spacers, dampers, clamps, warning signs, etc.
- Calculation of spans and sags,
- Line route profile,
- Supply of all equipment,
- Construction of line :
  - Site preparation,
  - Foundations,
  - Tower assembling,
  - Line stringing,
  - Setting,
  - Testing,
  - Site cleaning.

1.3 TRANSMISSION LINE ROUTES DESCRIPTION

The line routing between Kosti (Sudan) and Nag Hammadi (Egypt) is presented in the document “M2- Line Routing – Final Report”.

The approximate length of the line is 1665 km and corresponds to Section 4 (Kosti) to Section 7 (Nag Hammadi).

Figure 2: ± 600 kV DC Line Routing between Kosti (Sudan) and Nag Hammadi (Egypt)

1.4 CLIMATE

Climatological information is based on WMO Climatological Normals (CLINO) for the 30 years period 1961-1990 issued from the web site http://www.worldweather.org. Please note that the averaging period for climatological information and the definition of "Mean Number of Precipitation/Rain Days" quoted in this web site may be different for different countries. Hence, care should be taken when city climatologies are compared. In the following tables, “Mean number of precipitation days” = Mean number of days with at least 0.1 mm of precipitation.

1.4.1 *SUDAN CONDITIONS WEATHER*

Weather Information for Khartoum.

Month	Mean Temperature °C		Mean Total Rainfall (mm)	Mean Number of Rain Days
	Daily Minimum	Daily Maximum		
Jan	15.6	30.8	0.0	0.0
Feb	17.0	33.0	0.0	0.0
Mar	20.5	36.8	0.0	0.1
Apr	23.6	40.1	0.4	0.1
May	27.1	41.9	4.0	0.9
Jun	27.3	41.3	5.4	1.2
Jul	25.9	38.4	46.3	4.8
Aug	25.3	37.3	75.2	4.8
Sep	26.0	39.1	25.4	3.2
Oct	25.5	39.3	4.8	1.2
Nov	21.0	35.2	0.7	0.0
Dec	17.1	31.8	0.0	0.0

Table 1: Khartoum Weather Conditions

1.4.2 *EGYPTIAN CONDITIONS WEATHER*

Weather Information for Aswan.

Month	Mean Temperature °C		Mean Total Rainfall (mm)	Mean Number of Rain Days
	Daily Minimum	Daily Maximum		
Jan	8.7	22.9	TR	0.0
Feb	10.2	25.2	TR	0.0
Mar	13.8	29.5	TR	0.0
Apr	18.9	34.9	TR	0.0
May	23.0	38.9	0.1	0.1
Jun	25.2	41.4	0.0	0.0
Jul	26.0	41.1	0.0	0.0
Aug	25.8	40.9	0.7	0.5
Sep	24.0	39.3	TR	0.0
Oct	20.6	35.9	0.6	0.25
Nov	15.0	29.1	TR	0.0
Dec	10.5	24.3	TR	0.0

Table 2 : Aswan Weather Conditions

Regarding the above table and the data collection on existing standard in Sudan and Egypt, the meteorological conditions for the design should be :

	Egyptian Part	Sudan Part
Maximum ambient temperature	50 ° C	50 ° C
Minimum ambient temperature	0 ° C	0 ° C
Mean Temperature °C	30 °C	30 ° C
Maximum Conductor temperature	80 °C	80 °C
Minimum Conductor temperature	5 °C	5 °C
Every Day Stress temperature	25 °C	25°C
Maximum wind velocity (gust)	160 km/h	160 km/h
Reference wind speed	110 km/h	110 km/h
Mean annual Rainfall	0 mm	14 mm
Humidity	100 %	100 %

Table 3 : OHL Design Weather Conditions

1.5 LEVEL POLLUTION

1.5.1 GENERALITY

Overhead lines are subjected to conditions that depend on the place in which they are installed. These conditions can vary extensively from a place to another, depending on the characteristics of the region considered. These characteristics make possible that the level of insulation required can vary in a same line, due to the conditions of the pollution are different for all the line. The weather factors influence in a very important way on the growth of the pollution levels in a region.

Due to the line routing in desert areas characterized by no rain for long period and exposed to strong winds carrying sand, a very high pollution level will be considered according to IEC 60 815. The insulators will be designed for a minimum nominal specific creepage distance of 40 mm/kV for Egyptian and Sudan Parts.

For the substations, we will consider a minimum nominal specific creepage distance of :

- 31 mm/kV for Kosti/Rabak Substation
- 40 mm/kV for Nag Hammadi Substation

1.5.2 DESERT ZONES

In some desert zones, the insulators of the electric lines are often subject to the deposition of contaminants substances of the deserts. This can cause a serious reduction in the efficacy of the insulator, having as a result the flashover and the electricity supply lack.

Also the storms of sand must be kept in mind. The type of environmental conditions will affect considerably to the insulators. The predominant elements in this type of pollution are: the sand and the widespread, salty dust in a dry atmosphere. The desert climate is characterized for sand storms and hurricanes that contain particles that move to a high speed. These particles strike to the surface of the insulator causing the material erosion. The storms of sand are an important factor that causes a decrease of reliability in electrical lines.

In this type of pollution the following aspects are relevant:

- The early morning dew represents the greater source of wetting in the desert zones.
- Storms of sand enlarge the pollution problems. The worst conditions occur when the storms are accompanied by a high humidity or rainy weather.
- Pollution layers accumulated on the insulators during the storms are of larger grain and greater content in salt than the layers formed during the normal atmospheric weather of the desert. The pollution contributed by the storms of sand is normally carried by strong winds of distant regions.

The decrease of pollution will depend on: the type of insulator, the maintenance, the increase of the number of elements in the chains of insulators, the increase of the leakage line, a better design of the insulators, the new materials…

1.6 TOWERS, FOUNDATIONS, CONDUCTORS, EARTHWIRES

1.6.1 TOWERS

Lattice steel self supporting towers should be used.

The ± 600 kV tower shape is presented in appendix 1.

For Tension Tower, the shape will differ by a cross arm more longer. The length of cross arm will depend from the value of line angle associated at each tower type (Table 8).

1.6.2 RIGHT OF WAY

As it is expected to built a 600 kV DC transmission line, the Right Of Way will proposed to be equal to a minimum of 70 m wide.

1.6.3 TOWERS FOUNDATIONS

The tower foundations should consist of four independent reinforced concrete blocks.

- Reinforced concrete pad and chimney foundations for normal soil conditions.
- In the areas with submerged and poor soil conditions, special foundation design should be considered. The dimension will be determined after the results of soil investigation (bearing capacity, soil density, etc) performed by the Contractor. The minimum requirements will be
    - Pile foundations or Multi pad foundations with a large base for the stability of foundation under uplift and compression solicitations.
    - The concrete cover of reinforcement is 10 cm
    - The chimney height above the ground must be extended in order to protect the stub from flooding. The specified chimney height will be calculated during the design.

1.7 STANDARDS

It is assumed that the transmission line will be constructed based on International Competitive Bidding (ICB). Hence it is recommended that the principles of the International Electro-technical Commission (IEC) standards 826-1, 2, 3 and 4 for a Security Class I line (50-year return period of ultimate conditions) are adopted for the design of the line (studies, drawings, materials, equipment and tests)

2 CROSS SECTION DETERMINATION

As stated in the Phase II - Module 1"Detailed network studies", the 600 kV DC bipole line shall be designed for six bundle of Aluminium Conductor Steel Reinforced (ACSR) conductor type CURLEW per phase, spaced at 240 mm.

The line conductor of ACSR/ACS type is preferable to the AAAC (All Aluminium Alloy Conductor) type due to better behavior in the specific climate area and is selected considering:

- the good performance in polluted areas against corrosion being aluminum cladded (ACS);
- the good performances against wind induced vibrations, due to the self-damping characteristics;
- keeping its mechanical performances in case of long time operation at high temperatures;
- quite same rating capacity as per a similar AAAC conductor type.

Furthermore, all towers shall be self supporting square based and lattice construction with 1 earthwire OPGW at tower top.

3 TECHNICAL REQUIREMENTS

3.1 *General*

All material used for the construction will be new of the best quality, and of the most suitable class for working under the specified conditions.

3.2 *Galvanizing*

Galvanizing will be in accordance with the requirement of BS 729 for hot dip process except for earthwire and conductor where BS 443 is applicable.

The minimum mass of zinc coating will be not less than :

- All members 700 g/m^2 of surface
- Bolts, nuts and washers 500 g/m^2 of surface

The galvanizing surface will be treated with chromate process in order to avoid the formation of white rust.

3.3 *Mechanical Design for Towers*

3.3.1 *Load Cases*

The weather conditions that shall be taken into consideration for the calculation of mechanical resistance of the Works are the least favorable ones that can be met on the Works. The different load cases are to be verified for each type of tower.

- **Wind** (Normal Condition)
- **Cold** (Normal Condition)
- **Oblique Wind 45°**(Normal Condition)
- **Assumption for the construction and maintenance of the Works** (Normal Condition): during construction and maintenance works, the towers should bear the exceptional strengths that may be applied and that will vary depending on the operational methods used. It is necessary to define, with appropriate assumptions, the strengths that shall be taken into consideration during the conception of a tower. The operational methods that will be considered on site should also be conceived in a way that these strengths are not over passed.
- **Construction assumption** (Normal Condition): a vertical force of 300 daN corresponding to the weight of two workers and their tools is applied at the middle of all the bars, other than the main legs. These forces will be added to the normal stresses than are withstood by the tower at everyday assumption.

- **Breaking assumption for the Conductor and for the earth wire** (Broken Condition):
  - **Torsion Broken Wire**: this assumption describes for all the metallic towers a minimal resistance to the necessary torsion to resist the break-up of a combination of broken wires (conductor and earthwire). The following broken wires conditions shall be considered minimum.
    - Suspension Towers: one conductor is broken on one face of one side of tower **or** earthwire is broken on one face of the tower. For the towers equipped with suspension sets, the longitudinal force due to the break-up of one phase is determined taking into consideration the loosening resulting from the gradient of the set.
    - Angle Towers: two conductors are broken on one face of one side of tower **or** one conductor plus earthwire are broken on one face of one side of tower.
    - Dead End Tower/Terminal Tower: three conductors are broken on one face of one side of tower.
  - **Longitudinal Broken Wire Anti Cascade**: this specified longitudinal loading corresponds to all broken wires of phase conductors and earthwire attachment points simultaneously. This security loading must be applied to one tower in every 10 towers and/or one tower every the 5 km. This loading concern only the tension tower.

3.3.2 Safety Factors

Safety factors are given in the table hereafter.

LOAD CASE	ASSUMPTIONS	Temp °C	WIND ON CABLES Pascal	WIND ON TOWER Pascal	Conditions and factor of safety						
					Cables	Hardware	Tower	Foundation <30gr		>30gr	
								comp	uplift	comp	uplift
1 (NC)	Wind	25	720	2000	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5
2 (NC)	Cold	-5	180	300	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5
3 (BC)	Torsion Broken Wire	25	720	2000		R 2/3	MES/1.5	1.5	1.5	1.5	2
4 (BC)	Longitudinal Broken Wire Anti Cascade	25	720	2000		R 2/3	MES/1.5	1.5	1.5	1.5	2
5 (NC)	Oblique Wind 45°	25	450	1000	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5
6 (NC)	No wind Stringing & Maintenance	25	0	0	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5
7 (NC)	Construction	25	0	0	0.95*BL/3	R/3	MES/2,5	2	2	2	2.5

R: Breaking force or stress / MES: guaranteed minimal elastic stress / BL: Breaking Load / NC: NORMAL CONDITION
BC : BROKEN CONDITION

Table 4 : Factor of safety

3.3.3 *NILE CROSSING*

Between Kosti substation and Khartoum agglomeration, the line routing of 600 kV DC line will cross the Nile River. The Nile River crossing facilities in general consists of two tension towers, two or three suspension towers located on each bank and one intermediate suspension towers located in the small island on the Nile river. The conceptual profile of this portion is as shown on the drawings.

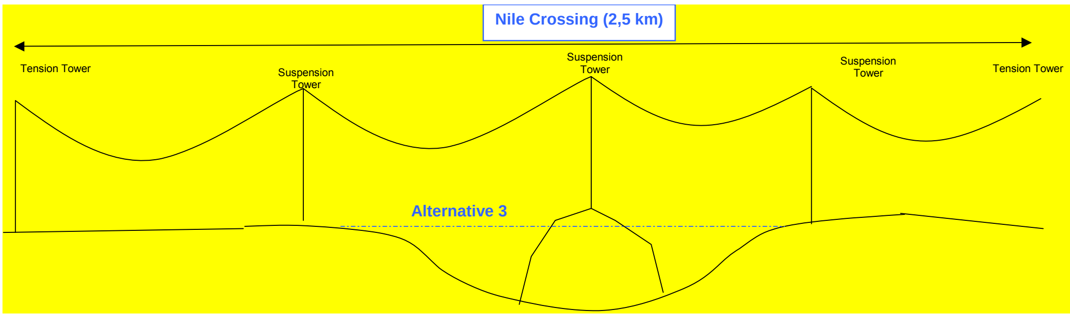


Figure 3: Nile Crossing

All of the requirements for the design, supply and construction shall conform to the aforementioned specification unless otherwise specified hereafter and shown on the drawings.

Tower family shall be as follows :

Tower Type	Application	Line Angle (Degree)	Wind Span (m)	Weight Span (m)
NRS	Suspension	0 – 3°	550	600
NRT	Tension	Dead end with 0 – 45^0	550	600

Table 5 : Tower Design for Nile Crossing

Foundation design criteria shall be the same as that for in land foundation. However the intermediate suspension tower and eventual pier foundation structure shall be designed to withstand all forces associated with the foundation structure located in the river, including stream flow, and earthquake.

For seismic loads, the Peak Ground Acceleration (Horizontal) to consider will be

- Operating Basis Earthquake 0.3 m/s²
- Maximum Credible Earthquake 0.4 m/s²

Vertical acceleration for pseudo static acceleration shall be 20% of the peak horizontal ground acceleration defined above. ACCELERATIONS SHALL BE APPLIED SIMULTANEOUSLY.

Seismic activity for RABAK and NAG HAMMADI

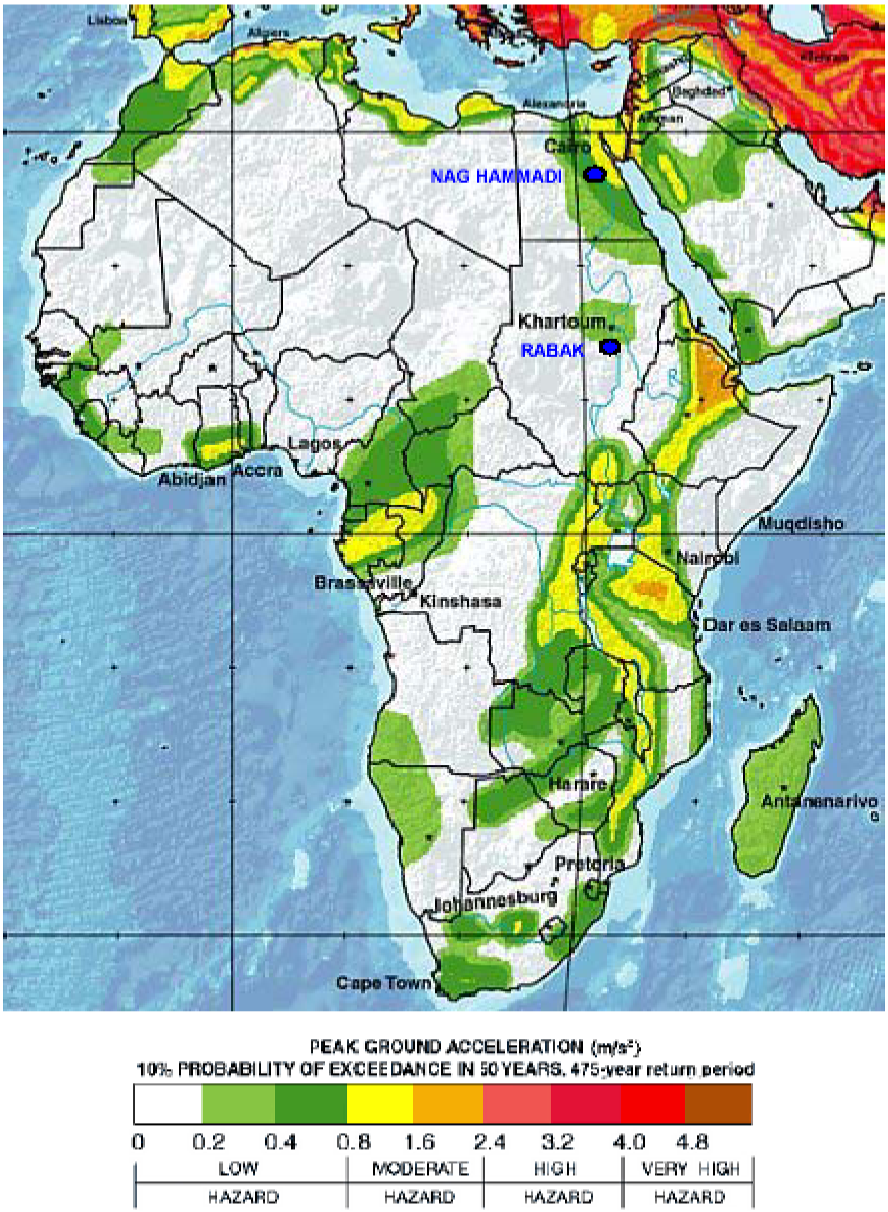


Figure 4: Seismic Activity

3.3.4 GEOTECHNICAL DESIGN

Foundation design shall be such that the tower shall be securely supported and unbalanced displacement that may cause harmful effect to the tower shall not be produced. The loads acting on the foundation shall be the maximum loads determined from each tower loading condition and shall take the leg extension of tower into account.

Foundation design loads shall be calculated on the basis of the maximum axial and horizontal tower base reactions exclusive of tower overload factor and further multiplied by the associated factors.

Maximum foundation shear force from any load combination for the download leg will be assumed to act simultaneously with the maximum foundation compression force. Maximum foundation shear force from any load combination for the uplift leg will be assumed to act simultaneously. Undercuts shall be used as much as possible (for fair and good soils).

All combinations of tower and leg extension heights, as stated in the tower design specification, shall be considered in determining the maximum tower base reactions.

In the verification of the stability of foundation, it is stated that, against uplifting forces the following have to be taken into account :

- For pad foundation the weight of the backfill inside the cone shaped volume which top angle is equal to the angle of friction of the soil and which height is equal to the depth of foundation.
- For piles : the friction force all along the depth of the pile which value is equal to the outer surface which depends on the nature of the soil. In any case the safety factor will be : 2 under working loads, 1.5 under broken wire loads.

3.4 TENSION AND SAG CALCULATION FOR CONDUCTORS

The following conditions should be considered :

- Stress on the conductor at 25°C without wind (Every Day Stress EDS) : 20% of the ultimate strength of the conductor,
- Stress on the conductor will respect the safety factor for the different load case specified in Chapter 6.5.

3.5 DC ELECTRICAL DESIGN

The line electrical characteristics are assumed as follows:

- Nominal voltage (bipolar) : ± 600 kV
- Maximum Line Load: MW
- Line Voltage range (kV) at maximum load: kV
- Maximum operating conductor temperature: 90 °C

3.6 TOWER OUTLINES DESIGN

The positioning of the conductors and of the earthwires on the tower shall be determined considering the following clearances:

- clearance to ground and obstacles;
- the clearances between tower's live and earthed parts;
- the earthwire's shade protection angle;
- clearances between conductors at structures.

3.6.1 CLEARANCES TO GROUND AND OBSTACLES

3.6.1.1 Vertical Clearances

The vertical clearances will be checked at the maximum sag case corresponding to the maximum conductor temperature (90°). The clearances from 600 kV conductors should be :

Vertical Clearance to	Vertical 600 kV
Rural Area, uncultivated land	13 m
Major Road	16,50 m
Crossing Navigable River (above max, water surface)	18,00 m
Rail Road track, near substation entrances	18,00 m
Building	Not Permitted
220 kV Lines	8,00 m
110 kV and Telecommunication lines	7,25 m
Distribution Lines 63 kV and less	6,65 m
Shield Wire of others lines	6,00 m
Gas pipe lines	15,00 m
Shield Wire of others lines	6,00 m

Table 6 : Vertical Clearances

Approximately 0.5 m shall be added to the clearance values above to allow for survey and drawing errors.

Where the DC 600 kV transmission line crosses above another transmission line, the respect of clearances shall be obtained in still air with the above temperature:

- 15°C for the phase conductor temperature of the lower transmission line;
- Maximum operating temperature (Repartition 90°) for the phase conductor temperature of the higher transmission line;

The minimum clearances specified below between the lowest conductor (phase or earth) of the higher transmission line should be respected.

3.6.1.2 Horizontal Clearances

The horizontal clearances will be checked at the Light wind climatic condition (25°, 360 Pa).

Horizontal Clearance to	Vertical
State, Major Highways	75 m
Rail Roads	65 m
Country Roads	55 m
Farm lanes, District road, tracks	25 m
Canals	20 m
Buildings	35 m
Transmission Lines 220 kV	50 m
Transmission and Distribution lines 110 kV and less	40 m
Gas Pipe Lines	45 m

Table 7 : Horizontal Clearances

3.6.2 CLEARANCES BETWEEN TOWER'S LIVE AND EARTHED PARTS

Insulation coordination is the total design of the insulation air gap system to achieve a desired reliability with appropriate allowance for safety, switching-surge and isokeraunic levels, altitude variations, contamination, weather variables and maintenance requirements.

According the design practices presented in the "Transmission Line Reference Book HVDC to ± 600 kV", the basic requirement for clearance between conductor and supporting structure is determined by the following equation:

$$D = 0{,}08 + (V_{L-L} - 8{,}7)x0{,}0051 + 0{,}3 \text{ m}$$

Where

V_{L-L} corresponds to the line voltage in kV rms

The "0,3 m" is an additional distance to allow inspection.

The nominal DC line to ground voltage of 600 kV is considered equivalent to AC peak and is converted to line to line rms:

$$\frac{\sqrt{3}}{\sqrt{2}} x600 = 734{,}9 \text{ kV}$$

so

D = 4,1m for 600 kV

The required clearance will be checked with an insulator swing of 45° from the vertical point.

The electrical clearances specified are to be considered as minimum dimensions to be provided between the outermost tower steel parts (outstanding web angles, step bolts) to the nearest point of the line conductor, insulator set live hardware or conductor accessory.

3.6.3 EARTHWIRE'S SHADE PROTECTION ANGLE

A shade protection angle of the earth wires of 0 degree to the vertical of the upper phase conductors shall be considered and not higher than 30° for lower conductors.

The sag of the earthwire shall be at 35°C, 10% less than the sag of conductor for the basic spans of 500m.

The dimensions of the crossarms of the angle-tension towers shall be such to ensure that horizontal spacing between conductors in a plan normal to the conductors are not less than that at normal suspension towers. The earth wire support positions must also ensure the corresponding spacing between earth wires as well as the assumed shielding angle.

For the angle towers having line deviation angles of 60 or 90 deg., rectangular crossarms may be used so that live metal clearances are maintained with or without the use of jumper suspension insulator strings.

The crossarms of suspension towers shall be designed to allow the attachment of double insulator strings.

The crossarms of tension towers shall be designed to allow the attachment of double insulator strings and an attachment for maintenance purpose.

The tower designer shall design the attachment points to have insulator strings in parallel position for the line angle equal with the media between maximum and minimum tower design angles.

3.6.4 CLEARANCES BETWEEN CONDUCTORS AT STRUCTURES

At angle towers between the jumper of one phase and the other phase or at gantries, the phase to phase distance have to be minimum 5.00m.

4 STEEL TOWERS

4.1 GENERAL

Steel structure will be of self supporting types, and designed to carry line conductor sets, overhead earthwires and all fitting under the conditions and with the safety factors which are specified in these technical specifications.

The minimum clearances phase earth (suspension and tension) previously defined will be followed to design the tower. The appendix 1 present the general tower outline.

The design of the lattice tower will be in accordance with the ASCE 10-97 : Design of Latticed Steel Transmission Structures.

The tower design should be based on three-dimensional indeterminate stiffness method. The computer program to be used shall be developed or tested by a recognized institute such as PLSCADD/TOWER from Power line Systems Inc., another recognized design method proved to be accurate.

Painting used as Aircraft Warning system shall meet requirements of International Standards and Recommended Practices issued by the International Civil Aviation Organization.

4.2 TYPE OF TOWERS

Tower Family to be designed, supplied and erected shall be as follows:

Tower Type	Application	Line Angle (Degree)	Wind Span (m)	Weight Span (m)
LAS	Light Angle Suspension	0-5	540	675
MAS	Medium Angle Suspension	5-10	540	675
HAS	Heavy Angle Suspension	10-15	540	675
LAT	Light Angle Tension	15-30	540	675
MAT	Medium Angle Tension	30-45	540	675
HAT	Heavy Angle Tension	45-60	540	675
T	Terminal	Complete dead end	270	340
		Dead end with 0-90° slack span	400	500
SRC	Special River Crossing	0-5	540	675

Table 8 : Family Type of Tower

The term basic span length is the horizontal distance between centers of adjacent supports on level ground from which the height standard supports is derived with the specified conductor clearance to ground in still air at maximum temperature.

The term wind span shall mean half the sum of adjacent horizontal span lengths supported on any one tower.

The term weight span shall mean the equivalent length of the weight of conductor supported at any one tower at minimum temperature in still air and it is the horizontal distance between the lowest point of Conductors, on the two spans adjacent to the tower. At suspension positions, the minimum weight of conductor supported shall not be more than 25 percent of the total weight of conductor in the two adjacent spans.

4.3 EXTENDED TOWERS

The height of each type of tower will increase or decrease by fixed steps of three meters according to the lay-out of the routing by means of appropriate body-extensions.

Following standard tower heights and leg extensions lengths have been defined :

- Standard tower heights -3m, +0m, +3m, +6m
- Leg extensions length +1m, +2m

The shape of the legs will be the same for different body sections of each tower type and towers will be symmetrical about both transverse and longitudinal center planes.

4.4 MATERIALS

Material that are used in towers manufacturing are those defined in the following requirement list or at least those equivalent to them :

- High tensile steel : steel quality reference E 36 - 2 according to the French standard NF A 35 - 501 or better or equivalent international standards.

Description	Unit	Minimum Data
High Strength Steel		
Tensile Strength	N/mm²	520
Yield Point	N/mm²	360
Normal Working Load	N/mm²	240

Table 9 : High tensile steel characteristics

- Standard steel : steel quality reference E 24 - 1 according to the French standard NF A 35 - 501 or better or equivalent international standards.

Description	Unit	Minimum Data
Structural Steel		
Tensile Strength	N/mm²	370
Yield Point	N/mm²	240
Normal Working Load	N/mm²	160

Table 10 : Standard steel characteristics

- Nuts and bolts : steel quality according to the calls 4.6 of the French standard NF E 27 - 005 or equivalent. Screw threads : ISO dimensions according to the French standards NF E 03 - 014 and NF E 03 - 053 with the possibility of substituting UNC dimensions (ANSI B 1 - 1) to ISO dimensions or better or equivalent international standards.

Description	Unit	Minimum Data
High Strength Steel Bolts		
Tensile Strength	N/mm²	500
Yield Point	N/mm²	300
Normal Working Load	N/mm²	200

Table 11 : Nuts and Bolts characteristics

- Washers : according to the French standard NF E 27 - 611 or better or equivalent international standards.
- Galvanizing : hot dipped galvanized coating according to the British Standards BS 729 or better or equivalent international standards.

4.4.1 MINIMUM SIZES

Description	Unit	Minimum Data
Calculated members	mm	45 x 45 x 5
Redundant members	mm	35 x 35 x 4
Thickness of legs, members in crossarms and in earthwire peak	mm	6
Secondary members Thickness	mm	4
Secondary unstressed members Thickness		3
Diameter of bolts for members carrying stress	mm	16
Diameter of bolts for redundant members without calculated stress	mm	12
Gusset plates	mm	6
Stub angles	mm	8

Table 12 : Minimum size Tower characteristics

The following maximum allowable slenderness ratios (L/R) shall not be exceeded:

1. Tower legs, main compression members in cross arms, and earthwire peak 150
2. Other compression members carrying calculated stresses 200
3. Redundant members without calculated stresses 250
4. The tension members of crossarm hangers 350
5. All other tension members 500

For tensile members of towers the design stress will not exceed the yield point of materials, the stress will be calculated by division of total load in the member by net area, that is to say cross section of the member minus the section of the hole.

4.4.2 BOLT, NUTS AND WASHERS

All bolts and nuts used will be hexagonal - round - hexagonal and comply with ISO Metric thread standards.

All bolts and washers will be efficiency galvanized no more than three sizes of bolts will be allowed for each type of tower.

4.4.3 CONNECTION

All connections on all the tower body will be bolted with Anti-vandalism tower bolt.

4.4.4 *TOWER DESIGNATION AND MARKING*

All members of the structure will be stamped with letter in relation with the piece marks shown on erection drawings.

4.4.5 *CLIMBING STEPS*

Each leg will be fitted with an anti climbing device. The climbing device will be installed on two legs by means of step bolts.

4.4.6 *DANGER PLATE - PHASE PLATES*

All towers will be provided with danger plates, phases plates with associated tower number.

4.4.7 *TOWER EARTHING*

The tower footing resistance (without the installed earthwire) shall not exceed 20 ohms. In proximity to the substations (1.5 km), the footing resistance shall be of maximum 15 ohms.

Furthermore, the earthing will be made with anti-vandalism device.

At tower sites in urban areas often frequented by people an additional protective earthing should be carried out aimed at less than 10 Ohms.

As theft of ground wire could be a problem, it is recommended that the grounding be designed with depressed copper rods connected to the steel grillage foundation.

Earthing	Material
Ground electrode	Galvanized steel pipes 60 mm or 35 x 35 x 5 mm steel angles, 2 m long
Ground strip	Galvanized steel wire, 70 mm²
Connection of ground electrode with stub angle	Galvanised steel wire, 70 mm²
Connection of reinforcement to stub angle	Galvanised steel wire, 70 mm² and parallel groove clamp

Table 13 : Tower Earthing Characteristics

5 FOUNDATIONS

5.1 GENERAL

The foundation of each tower consist of four independent reinforced concrete blocks.

For the tendering, the Geotechnical Report Study will allow the Contractor to make a preliminary design for different types of foundations and a cost estimates.

The responsibility for proving the adequacy of the dimensions and type of foundation at each location shall remain to the Contractor according to the results of soil investigation performed by the Contractor.

Soil Classification

The soil has been classified into five classes as follows:

Soil Class	Description	Density kg/m^3	Angle of Repose	Ultimate Bearing Capacity MPa
I	Very Soft	900	0	<0.1
II	Soft	1,000	5	0.15
III	Fair	1,200	15	0.3
IV	Good	1,700	20	0.5
V	Hard	2000	30	0.75

Table 14 : Soil Classification

Soil class I, II and III are submerged. Disintegrated rock shall be classified as soil class V.

Foundation Type

Foundation type for each soil class shall be as follows:

Soil Class	Foundation Type
I	Long Pile
II	Short Pile or pad
III, IV, V	Pad

Table 15 : Foundation Type

The foundation for towers shall be:

- In the areas with submerged and poor soil conditions, the use of pile foundations is proposed to be used.
- Reinforced concrete pad and chimney foundations for normal soil conditions.

The Contractor shall propose undercuts for soil class III, IV and V.

5.2 TYPES OF FOUNDATION

5.2.1 PAD FOUNDATION (CLASS II TO V)

Three types of foundation will be designed to meet the soil site existing condition which will depend of the bearing capacity of soil encountered along the line :

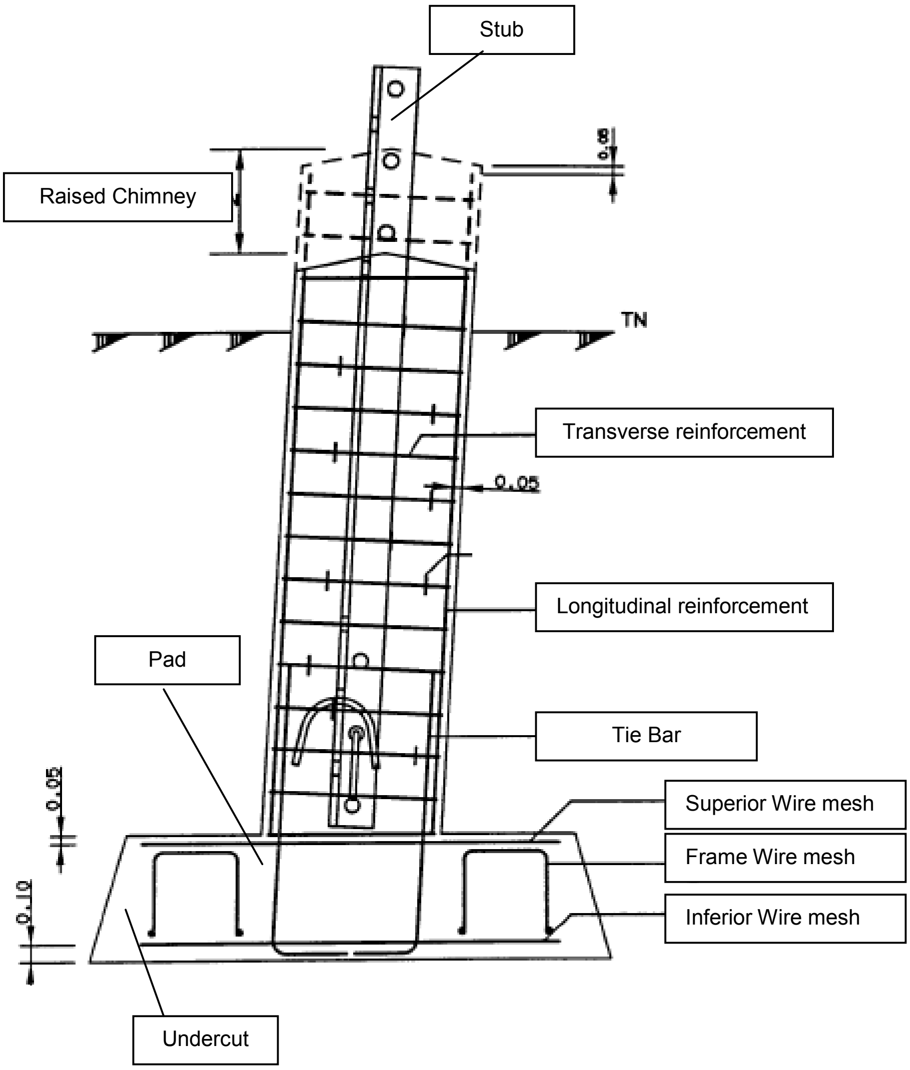


Figure 5: Pad Foundations

5.2.2 PILE FOUNDATION (CLASS I TO II)

In case of very low resistance soils, when the recession of phreatic line involve high equipment cost, pile foundation will be used.

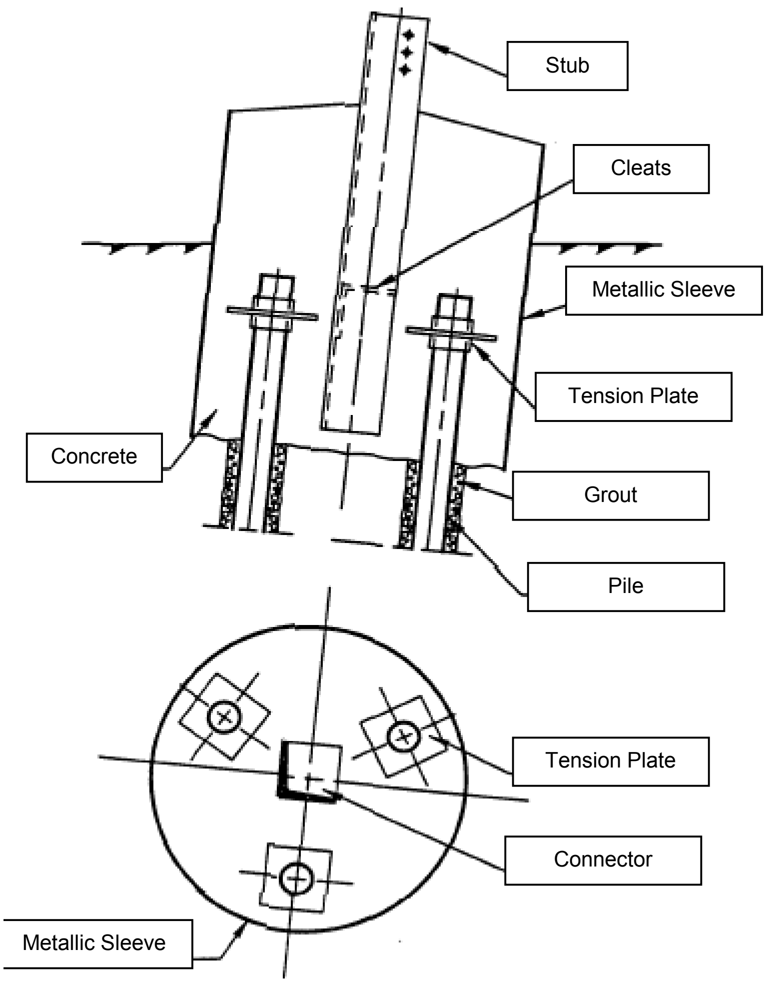


Figure 6: Pile Foundations

5.2.3 MATERIALS FOR FOUNDATION

- Concrete with characteristic strength of 250 kg/cm2 (28 days),
- Steel reinforcement : deformed steel bars with yield strength fy = 4200 kg/cm2
- Cement : Portland type II
- Concrete cover of reinforcement is 7.5 cm

6 CONDUCTORS AND EARTHWIRES

6.1 LINE CONDUCTOR

The line conductors selected on this study are aluminum conductors steel reinforced (ACSR) CURLEW with the following characteristics.

Specification		Conductor
Material		ACSR
Conductor designation		CURLEW
Cross-section	mm^2	591.5
	Aluminium (mm²)	523.7
	Steel (mm²)	67.85
Overall diameter	mm	31.62
Stranding Aluminium	No x mm	54 x 3.513
Stranding Steel	No x mm	7 x 3.513
Weight	kg/m	1.899 kg/m
Rated Strength	kN	161.99
Rated DC resistance at 20 °C	Ω/km	0.05302
Standard		DIN 48204

Table 16 : ACSR CURLEW Characteristics

The conductors shall be subjected to type, sample and routine tests according to IEC 61089 and ISO 9001 to 9003.

An alternative of using new type of conductor should be studied before the implementation of the transmission lines; like as.

- Aluminum conductor steel supported (ACSS) and a variation of this construction where the aluminum strands are formed to produce a trapezoidal shape (ACSS/TW).
- Special zirconium high-temperature aluminum alloy conductor Invar steel reinforced (ZTACIR).
- Gapped high-temperature aluminum alloy conductor extra high-strength steel reinforced (GTACSR).
- Aluminum conductor composite reinforced (ACCR).
- Aluminum stranded conductors reinforced with fiberglass and graphite composites (ACCC).

The cable change and the impact on design of the towers will be a good option if :

- the total cost is reduced
- the reliability experience feed back of these new conductor is good
- this cable is compatible for 600 KV DC design.

Nowadays, GTASCR (Gap Type Aluminum Conductors Steel Reinforced) is the less expensive between theses new conductors. GTASCR conductor is capable to carry double the power of the equivalent ACSR. The Gap type conductor has a unique structure. The aluminum wires in the internal layer, closest to the core, has a trapezoidal cross section which creates a gap between the steel core and the aluminum layers. The GTACSR construction, designed for operation at 150°C, uses trapezoidal-shaped high-temperature aluminum alloy strands with a grease-filled gap over the steel core. Commercially available from Japan, there has been limited field experience at National Grid installations in England, Korea and Japan. Extensive laboratory data and detailed installation instructions are available. The installation of this conductor is more complex and labor intensive than ACSR, requiring special semi-strain-type suspension fittings for long lines.

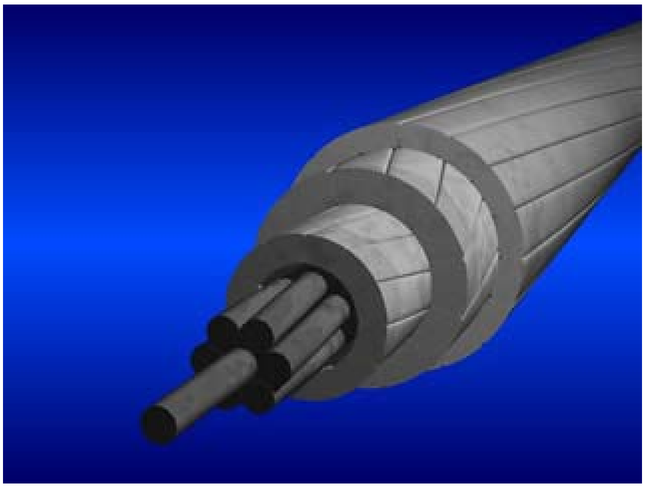


Figure 7: GTASCR Conductor

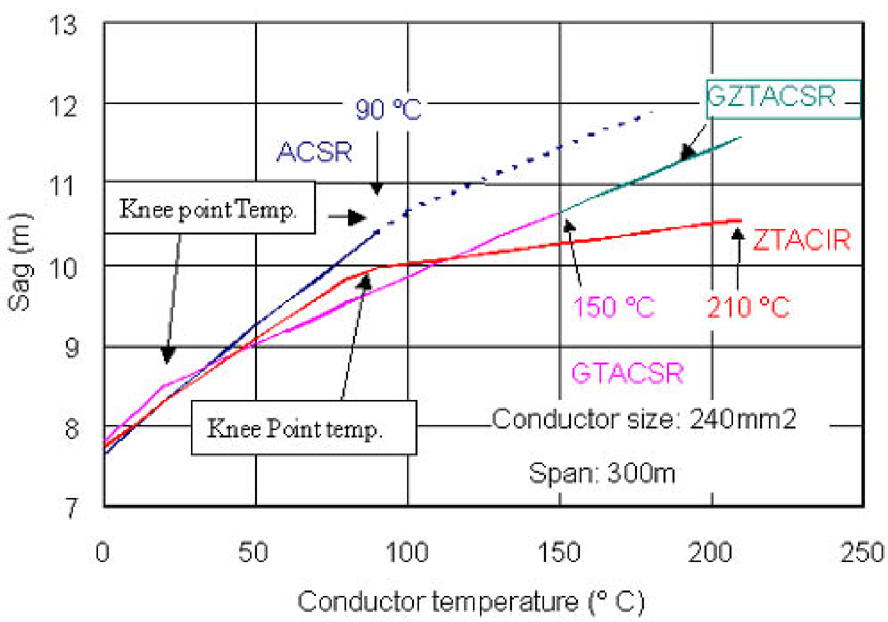


Figure 8: Sag Curve for GTASCR Conductor

On the other hand, GTASCAR price is unfortunately still high (twice more expensive than ACSR) and the savings in the tower design will not be significant nowadays. But on the future, the evolution prices for this type of conductor will be decisive in the configuration conductor choice.

6.2 EARTHWIRE

The earthwire should be OPGW. It shall be a slotted core structure or steel tube construction for 48 optical fibers. The OPGW will be designed and comply with the following standards:

- IEC 60794 Part 1-1 : Optical fiber cables –Generic specification – General
- IEC 60794 Part 1-2 : Optical fiber cables –Generic specification –Basic optical cable test procedures
- IEC 60794 Part 2 : Optical fiber cables –Indoor cables –Sectional specification
- IEC 60794 Part 3 : Optical fiber cables –Sectional specification –Outdoor cables
- IEC 60794 Part 4 : Optical fiber cables –Sectional specification –Aerial optical cables along electrical power lines

The optical fiber earthwire shall be of design and construction as to ensure long service with high economy and low maintenance costs. It shall be suitable in every respect for continuous operation at nominal parameters as well as in transient operating conditions, under the climatic conditions peculiar to the Site.

The standards and regulations mentioned above shall be observed in the design, construction and manufacture.

6.2.1.1 OPGW Characteristics

The main requirement characteristics of the selected OPGW are:

- Aluminum alloy – steel type
- OPGW shall incorporate 48 optical fibers
- OPGW should be designed for a short cut current of 40 kA
- Mean conductor length on drum 5000 meters

The Contractor will give the above characteristics of the selected OPGW:

- nominal cross section (mm²)
- Overall Diameter (mm)
- Linear Weight (k/m)
- telecommunication tube diameter (mm)
- calculated diameter (mm)
- conductor structure: (mm) aluminum alloy / (mm) steel
- Minimum ultimate strength (kN)
- Max DC resistance at 20°C (Ohm/km)
- Electrical and Optical characteristics in accordance with IEC 60794 (1 to 4)

6.2.1.2 OPGW Compositions

6.2.1.2.1 Optical Core design

The OPGW shall incorporate 48 optical fibers. They shall be greased in accordance with the Standards. Individual optical fibers or groups of fibers shall be contained in protective tubes. These tubes shall form the fibers' secondary protection (the coating being the primary protection).

The function of loose tube and water screen may be covered the same physical component. The optical core design shall prevent longitudinal fiber transport in the loose tubes.

A water block shall prevent longitudinal water penetration of the optical core and individual tubes. A metallic water screen shall prevent transversal water penetration of the optical core.

6.2.1.2.2 Loose Tube

The loose tube shall be made of polyethylene PE or metal. Elongation of the tube caused by cable elongation shall be in proportion to such cable elongation.

The tube shall not deform and shall continue to fulfill its function when subjected to the following:

- The electrical, thermal and mechanical loads stated in this generic specification
- The high-frequency (>1 Hz) and low-frequency (<1 Hz) vibrations occurring in the high-voltage line
- Use with the prescribed suspension and tensioning equipment and vibration dampers
- All regular and permissible conductor assembly processes

Non-circularity of the tube shall be ≤ 5%.

6.2.1.2.3 Water Screen

In case the water screen and loose tube are physically not the same, the relevant requirements stated above apply.

The water screen shall consist of a welded or extruded metallic tube.

In case of stainless steel tubes, aluminum cladding shall be applied in order to prevent corrosion.

OPGW types, manufactured with Water Screen of plastic tube are not accepted.

6.2.1.2.4 Fiber coating

The optical fibers are to be coated with a tight outer UV-hardened acrylate protective coating having a nominal diameter of 250 μm ± 15 μm. The coating shall be mechanically easily removed over a length of up to 50 mm for the purpose of cleaning, cleaving and fusion splicing.

Each fiber is to be color coded in order to facilitate fiber identification. These coatings are to be colored fast, and shall not degrade the optical cladding/core neither mechanically nor optically.

The optical fiber coating material shall not generate H_2 gas around the optical fibers that will increase the optical loss as specified above over the designed life span of the optical fiber. The Contractor shall supply details of the methods employed to minimize the generation of H_2 gas.

All coatings/colors are to be compatible with fusion splices utilizing the light inject detect (LID) method and profile alignment method.

6.2.1.3 Optical fiber parameter , performance and Tests

The following characteristics of each optical fiber shall be applied for OPGW:

- transmission rate: 2.0 to 155.0 Mbit/sec
- transmission wavelength: 1310 nm and 1550 nm
- mode field diameter: 9.0 ± 1 micrometers (μm), including tolerances
- mode field concentricity error: < 1 μm
- optical cladding diameter: 125 μm ± 2.4%
- cut off wavelength: <1270 Nm
- cable attenuation: not greater than 0.4 dB/km for every fiber in every drum at optical wavelength of 1310 nm; and not greater than 0.25 dB/km for every fiber in every drum at optical wavelength of 1550 nm.
- joint attenuation: not greater than 0.10 dB at optical wavelength of 1310 nm or at 1550 nm for every fiber, measured on the fully installed joint
- core numerical aperture: less than 0.23
- life span: greater than 30 years

No joints shall be allowed in any fiber in any drum length.

Discontinuities will be acceptable if:

- less than 0.10 dB in magnitude measured at 1310 nm, and
- ODTR traces from both ends of the cable at 1310 and 1550 nm wavelength show a difference of less than 0.05 dB/km for every fiber in every drum.

Tests nominated by the Contractor shall include but not be limited to:

- tensile test with indicated over length of fiber and simultaneously measured attenuation at 1310 nm and 1550 nm
- bending test
- repeated bending test
- crush test
- aging test
- water penetration test (tube)
- temperature test
- short circuit test
- lightning test
- stress-strain test
- creep test
- tests to verify the mechanical and optical performances of the optical fibers including OTDR (optical time domain reflectometer) tests.

The length of the optical fibers shall be subjected to a proof test at a minimum strain of 1.1 % on duration of at least 0.2 seconds. Only fibers, which pass this strain level, will be accepted. The Contractor shall supply details of the test method and references to any standards used, including a copy of the applied standards.

6.2.2 PACKING, SHIPPING, TRANSPORT

After the arrival of the conductors and/or OPGW at site, they will be inspected and shall pass to the satisfaction of the Employer / Project Manager such of the tests set out above or the Standardization Rules as he may deem necessary to satisfy himself that the conductors and OPGW supplied conform to the Technical Specification, including Guaranteed Performances and Characteristics.

Conductors and OPGW which do not pass the tests satisfactorily may be rejected forthwith and shall be replaced at the Contractor's expense.

The conductors and OPGW required for incorporation in the transmission line project shall be supplied on timber drums. The OPGW shall be shipped in continuous lengths. The packing for the corresponding spare parts shall comply with the requirements specified for long time storing.

The following requirements apply for packing and shipping:

The conductors and OPGW shall be delivered and shipped on stoutly constructed timber or steel drums as specified and lapped with protective covering across the whole width of the drum. All drums with conductors and OPGW shall have a layer of waterproof wax paper or plastic sheet which must be safe against chemical reactions laid around the barrel under the conductors or OPGW and another one laid over them and under the lapping. Drums shall be securely fastened around the perimeter and shall be suitable for rolling on the flanges without causing damage to the conductors or OPGW.

The disposal of all empty drums shall be the responsibility of the Contractor.

The following information shall be clearly written in indelible paint on both flanges of each drum:

- contract title and reference number;
- manufacturer's name;
- lifting instructions and limitations;
- direction of rolling.

An aluminum or painted metallic marking plate shall be fixed to each drum clearly showing the following data:

- type and size;
- length;
- gross and net weight;
- batch and drum numbers;
- stranding date;
- main dimensions of the drum;
- correct direction of rolling.

Contractor shall submit a sketch or drawings showing the full details of drum design and the details of the proposed method of impregnation and lagging the inner drum surfaces with approved tarred paper or equivalent material. The minimum length of the conductor and earth wire in a drum is subject to the Project Manager 's approval.

The disposal / surpluses of materials ..etc should be delivered to the Employer store.

7 INSULATORS

7.1 IEC STANDARDS FOR DC INSULATORS

The insulators set design will comply in all aspects with the requirements of IEC recommendations.

- IEC 60815 : Guide for the selection of insulators in respect of polluted conditions.
- IEC 60471 : Dimensions of Clevis and Tongue Couplings of String Insulator Units
- IEC 60120 : Dimensions of Ball and Socket Couplings of String Insulator Units
- IEC 60305 : Characteristics of string insulator units of the cap and pin type
- IEC 60372 : Locking devices for ball and socket couplings of string insulator units _ Dimensions and test
- IEC 61325 : Insulators for overhead lines with a nominal voltage above 100V – Ceramic or glass insulator units for D.C. Systems _ Definitions, tests methods and acceptance criteria
- IEC 61245 : Artificial pollution tests on high voltage insulators to be used in D.C. Systems

7.2 DC INSULATORS CHOICES

Regarding to existing DC Line , there are 3 different types of insulators applicable for DC Transmission lines:

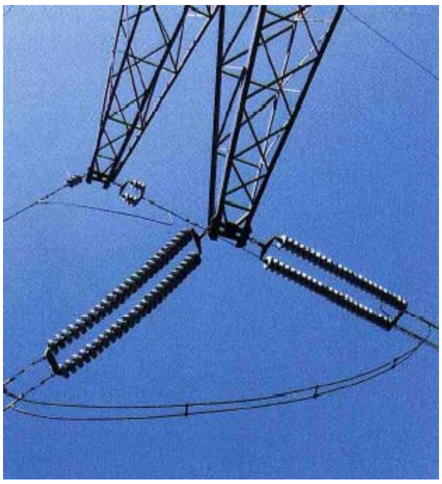


Figure 9: Cap and pin type

Figure 10: Long-rod porcelain type

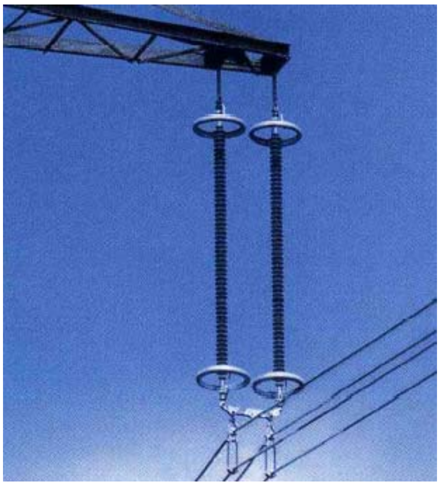


Figure 11: Composite long-rod type

	Cap and pin	**Long-Rod Porcelain**	**Composite Long-rod**
Insulator string length	5270 mm 31 insulators	5418 mm 4 insulators	4450 mm 1 insulator
Creepage per unit	570 mm	4402 mm	17640 mm
Weight of string	332 kg	200 kg	28 kg
Breaking load	160 kN	160 kN	160 kN

Table 17 : Comparison of Insulator Application for a 400 kV Transmission Line

Types of Insulators	Positive Aspect	Negative Aspect
Cap and pin	▪ Long-term experience/track record ▪ Good-mechanical strength ▪ Vandalism proof ▪ Flexibility within the insulator string	▪ Very heavy strings ▪ Insulator not puncture-proof ▪ Poor self-cleaning ability ▪ Loss of strength/reliability due to corrosion of pin in polluted areas caused by high track current density ▪ Many intermediate metal parts ▪ High RIV and corona level ▪ Special shed design and porcelain material ▪ Very expensive
Long-Rod Porcelain	▪ Long-term experience/track record ▪ Good mechanical strength ▪ Puncture-proof ▪ Good self-cleaning ability ▪ Less intermediate metal parts ▪ Due to caps on both insulator ends not subjected to pin corrosion because of low track current density ▪ Moderate price	▪ Heavy strings ▪ String not very flexible ▪ Under extreme vandalism failure of string possible
Composite Long-rod	▪ Small number of insulators in one string ▪ Up to 400 kV per unit possible ▪ Good mechanical strength, no chipping of sheds possible ▪ Very light-easy handling during construction and maintenance, logistical advantages in areas with poor access. ▪ Puncture-proof ▪ Good self cleaning behaviour-hydrophobicity of surface which offers advantages of less creepage distance up to pollution class II ▪ Very good RIV and corona behaviour ▪ Good resistance against vandalism ▪ Shorter insulator string length ▪ Very Competitive price	▪ Relativity short track record in DC application (since 1985 first major application in USA) ▪ Less tracking resistance against flash-over (can be improved by means of corona rings)

Table 18 : Type of DC Insulators

7.3 TYPE OF INSULATOR

Regarding the above considerations , Composite Long-Rod Insulator seems to be more economic for this DC 600 kV line. However, the relativity short track record in DC application concerning composite insulators should be taking account. Indeed, the existing IEC 61245 are at the moment only applicable to ceramic and glass insulators. For IEC 61245, the insulating materials of D.C overhead line insulators are:

- Ceramic material, porcelain;
- Toughened glass, being glass in which controlled mechanical stresses have been induced by thermal treatment.

The insulators sets should preferably be :

- Class A (as long rod insulators with external fittings) : insulator unit in which the length of the shortest puncture path trough solid insulating material is at least equal to half the arcing distance.
- Class B (as cap and pin insulator) : insulator unit in which the length of the shortest puncture path trough solid insulating material is less than half the arcing distance.

The specific insulating materials and design are necessary for DC applications since special features are required for satisfactory insulator performance.

Corrosion problems due to unidirectional current flow in contaminated conditions make the use of a zinc sleeve mandatory on the pin of cap and pin insulators. For some applications enhanced corrosion protection of the cap (zinc collar) may be used.

7.4 CHARACTERISTICS OF ±600 KV DC INSULATORS

All insulators unit for use on DC lines will be characterized by the following values:

- Specified significant dimensions, including the creepage distance
- Specified dry lightning impulse withstand voltage determined on a short standard string
- Specified positive dry D.C withstand voltage value of a single unit
- Specified electromechanical failing load for Suspension Set 300 kN
- Specified electromechanical failing load for Tension Set 600 kN

For class B insulators only:

- Specified positive D.C puncture withstand voltage in SF6
- Specified impulse overvoltage puncture withstand voltage
- Electrical body resistance

In addition the insulator unit shall be capable of passing the following special tests: ion migration, thermal runaway, test on the zinc sleeve of the pin (class B insulators only).

Each insulators shall be marked (on the insulating component or on a metal part) with the name or trade mark of the manufacturer and the year of manufacture. In addition, each string insulator unit shall be marked with the specified electromechanical or mechanical failing load whichever is applicable. These markings shall be legible and indelible. The designations included in IEC 60305 and IEC 60433 may be used.

The rules for insulator types and uses will be:

- Double suspension sets as required at suspension towers as illustrated below;

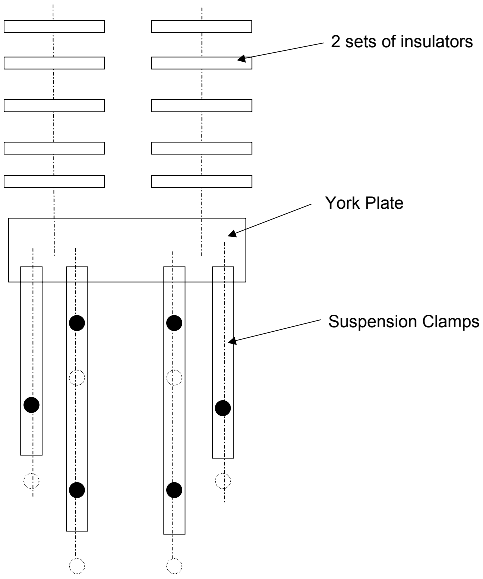


Figure 12: Double Suspension Sets

- Triple tension insulator sets shall be generally provided at tension towers.

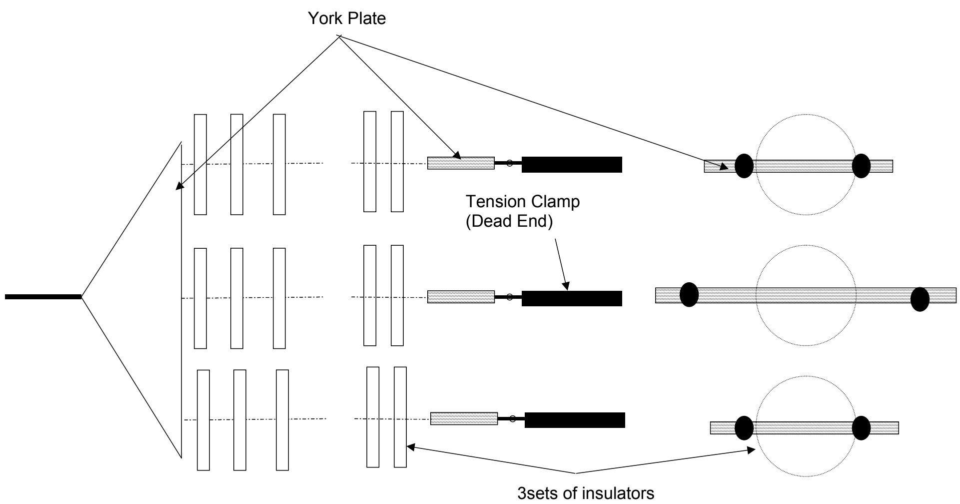


Figure 13: Triple Tension Sets

7.5 SAFETY FACTORS

The minimum safety factors required for the different load cases are given in the table of § 3.3.2.

7.6 TESTS

The test procedure and requirements for electrical testing of the different types of insulators are prescribed in IEC 61325. The insulators should be verified on type tests (TT), sample tests (ST) and routine tests (RT). The list of tests is :

- Verification of the dimensions (TT and ST);
- Dry Lightning impulse withstand test (TT);
- Dry DC withstand voltage test (TT);
- Electromechanical failing load test (TT and ST);
- Mechanical failing load test (TT);
- Ion migration test (TT);
- Impulse overvoltage test (TT and ST);
- Thermal runaway test (TT),
- SF6 puncture test (TT)
- Zinc sleeve test (TT and ST)
- Zinc collar test (TT and ST);
- Residual mechanical strength test (TT and ST)
- Thermal-mechanical performance test (TT)
- Body Resistance test (ST)
- Verification of the displacements (ST)
- Verification of the locking system (ST)
- Temperature cycle test (ST)
- Thermal shock test (ST)
- Porosity test (ST)
- Routine visual inspection (RT)
- Routine mechanical test (RT)
- Routine electrical test (RT)

Artificial pollution testing of DC insulators is covered by IEC 61245.

7.7 BALL, SOCKET, AND COTTER PINS

The socket will be of galvanized malleable cast iron and the pin ball of galvanized steel. The zinc coating will be smooth, clean, of uniform thickness and free from defects and not less of 99.7% of pure zinc.

Ball and socket connections will be provided with special designed cotter pins which effectively lock the connection against accidental uncoupling.

The cotter pin will be of phosphorous bronze. The design will be such as to permit easy removal for replacement of insulator units. All ferrous metal part will be hot dipped galvanized.

The ball socket and cotter pins will be designed according the standard recommendation IEC 60372 “Locking Devices for Ball and Socket Couplings of String Insulator Units: Dimensions and Tests”.

8 FITTING (CONDUCTOR, EARTHWIRE)

8.1 GENERAL

The design of these material will be suitable for all the material indicated in these technical specification.

The design of conductor, vibration dampers, spacers will avoid sharp corners on projection which could produce high electrical stress during operation.

All hardware components for line conductor groundwire and insulator strings will be so fabricated that no electrolytic action will occur between the accessories and the conductor and between the components.

All ferrous parts of insulator and conductor fittings component elements shall be fully hot dip galvanized with a minimum zinc weight (§2.2).

All bolt, nuts and cotter pins will be locked in order to prevent dislocation.

The ultimate strength of the hardware for suspension and tension insulation strings will be not less than 160 kN for single and double string respectively.

8.2 SUSPENSION CLAMPS

The suspension clamps illustrated in Chapter 7.4 shall be designed to meet the following requirements:

- so that the effects of vibration both on the conductors, or the earthwire and on the clamp themselves are minimized;
- to avoid localized pressure or damage to the conductor or earthwire, and shall have sufficient contact surface to avoid damage by fault currents;
- shall be free to pivot in the vertical plane of the conductor / earthwire and shall have a minimum range of movement of plus or minus 30 degrees;
- shall have a slipping capacity between specified minimum and maximum slipping loads;
- suspension clamp assemblies shall have sufficient strength and durability to prevent deterioration in service;
- the mouth of the suspension clamp shall be rounded and slightly flared, with a minimum radius of curvature in the vertical plane of 150 mm.

Suspension clamps for conductor :

Suspension clamps to be used shall be suitable for the conductor. The material of the suspension clamp shall be made of malleable iron or aluminum alloy which will be hot dip galvanized. The suspension clamp will be used with preformed armor rods and will be as light as possible.

Suspension clamps for earthwire :

The material of the suspension clamps will be made of malleable iron or forged steel which will be hot dip galvanized.

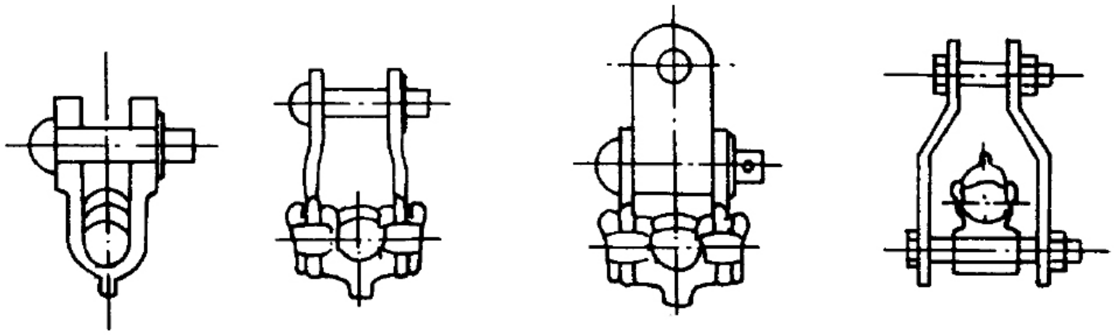


Figure 14 : Typical suspension clamps

8.3 TENSION CLAMPS

All tension clamps and joints for conductor will be of the compression type made by hydraulic compression. All aluminum parts of tension clamps and joints will be of at least 99.5% pure aluminum.

The tension clamps and joints will not permit slipping off or cause damage, or failure of the conductor at a load less than 95% of the ultimate strength of the corresponding conduction. The electrical conductivity and current carrying capacity of each joint and tension clamp will not by less than that of an equal length of non-jointed conductor.

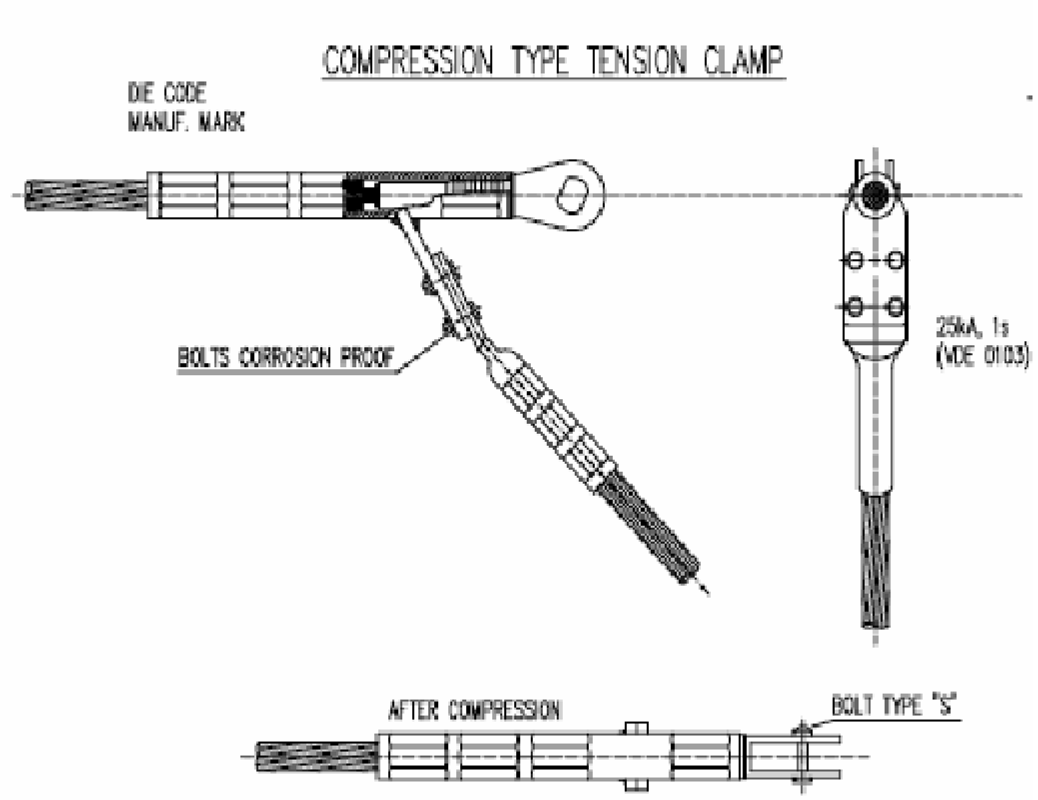


Figure 15 : Compression Type Tension Clamp

8.4 REPAIR SLEEVES FOR CONDUCTOR

Repair sleeves of the compression type or preformed type, will be used in case of local damage to the outer strands of the conductors during erection.

The joint sleeves shall consist of aluminum compression sleeve. The aluminum compression sleeves shall be of aluminum alloy conforming to the specification in IEC 60889 standard.

8.5 DAMPERS

Anti-vibration Dampers shall be installed on conductors and earthwire. The design and tests of anti-vibration Dampers shall be conducted according with IEC 61897 : Overhead lines – Requirements and tests for Stockbridge type aeolian vibration dampers

Dampers for conductor :

All conductors will be fitted with dampers of the Stockbridge type. The number and position of these dampers will be specified by the Contractor together with a calculation note justifying number, location and type of proposed dampers. A sufficient clamping surface with adequate curvature at the clamp mouth will be provided. All bolts will be locked.

Dampers for earthwire :

Earthwire will be fitted with dampers of the Stockbridge type. The number of these dampers will be specified by the Contractor together with a calculation note justifying number and type of proposed dampers.

The clamps body and keeper of these dampers will be of malleable cast iron or other approved ferrous material.

8.6 SPACERS

Six bundle spacer - dampers are used to :

- control vibration and conductor oscillation;
- maintain conductor spacing;
- restore conductor spacing after a short circuit occurs.

The material composition of spacer will be :

- Frame, arm & keeper - Aluminium alloy
- Bolt & nut - Galvanized steel
- Damping Element - EPDM rubber

These fittings will be designed and supplied to IEC standards.

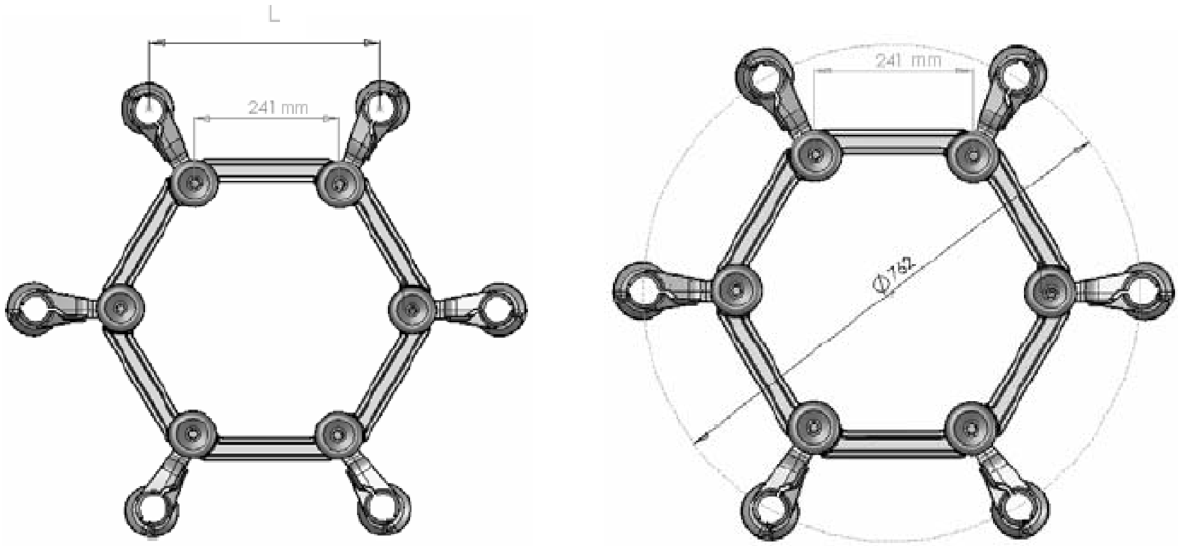


Figure 16 : Spacer Dampers for 6 bundle

8.7 ARMOR RODS

At all suspension clamps, the conductor will be fitted with armor rods. Armor rods to be attached to the conductor will be of the preformed type, made of aluminum alloy and will be smooth.

The direction of the armor rod lay shall be equal to the direction of the outermost wire lay of the conductor. The suspension clamps offered for the phase conductors shall accommodate the increased diameter resulting from armor rods. The ends of the armor rod wires shall be well rounded, without sharp edges, to avoid an increase in corona level.

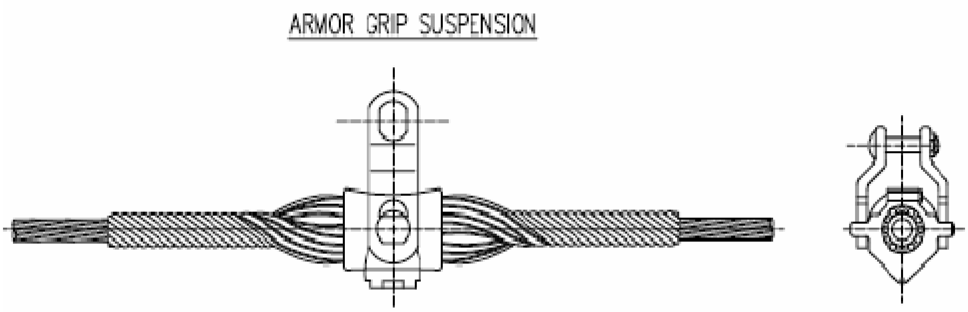


Figure 17 : Armor Rods

8.8 COUNTERWEIGHTS

When counterweights are considered necessary they will be of 50 kg and 80 kg types. All material will be hot dip galvanized. The specified counterweights shall either be fitted below the suspension clamp by extension of the clamp keeper retaining bolts by attachment to the yoke plate.

The suspension assembly with counterweights must be designed to respect the distances to the towers.

8.9 WARNING DEVICES

Warning devices shall be in installed in accordance with Aeronautic regulations (to be confirmed at a later stage). The design and positions of air navigation warning lights shall be approved by the appropriate Authorities.

Aircraft warning system

Warning spheres shall be fitted on shield wire of the transmission line in height restricted areas in the vicinity of air fields. The warning spheres shall be 600 mm diameter and shall be colored white and red which will not fade when subjected to the direct rays of the sun.

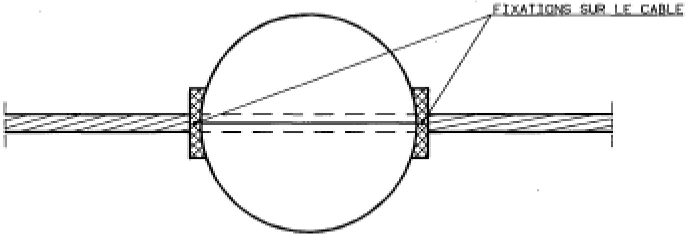


Figure 18 : Warning Devices

Air navigation warning lights shall be fitted to the conductors of the transmission line.

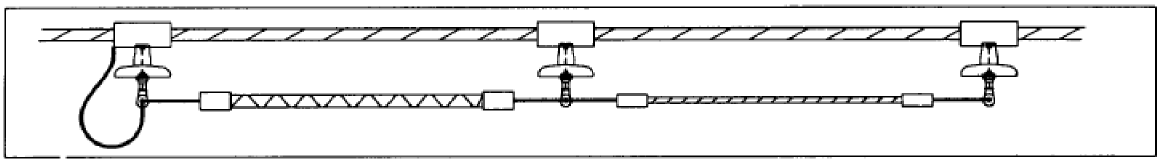


Figure 19 : Air Navigation Warning Lights

8.10 FAUNA MITIGATING MEASURES

In the vicinity of Dondo the transmission line passes over the lower Pungue floodplains that comprise around 4500 km2 of wetlands. This is an important area for rare and globally threatened birds.

The mitigating measures related to protection of wetlands and birds must be implemented by the installation of bird devices on the conductor and cable.

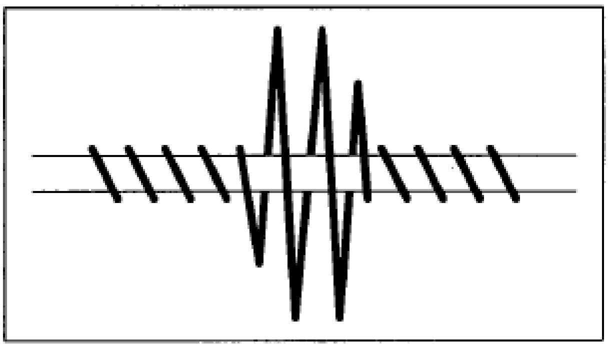


Figure 20 : Bird Devices

8.11 OPGW FITTINGS

8.11.1 SUSPENSION ASSEMBLIES

Armor grip suspension clamps shall be used for OPGW. The clamp body shall be of high-tensile corrosion-resistant aluminum alloy and shall be preferably forged. The spiral wires shall also be of aluminum alloy and shall not have diameters less than 4 mm.

The neoprene or other non-metallic material shall have good resistance to aging and be capable of withstanding temperatures between +0 °C and +90 °C without changing of essential properties. The material shall have adequate resistance to the effects of ultra-violet radiation, ozone or pollution factors.

The clamp body shall be able to pivot up to 45 degrees above and below the horizontal line. The Contractor shall ensure by appropriate design a suitable performance of the clamp-conductor assembly by wind induced vibration. The clamp body shall have provision for connecting the OPGW to the tower.

In addition to the suspension clamp, several other fittings are required for a suitable mechanical and electrical connection to tower and the Contractor is responsible to supply the complete set of the suspension assembly.

8.11.2 TENSION ASSEMBLIES

The OPGW attachments to tower shall be of helical grip type consisting of two helical parts (fittings), one for OPGW protection and the other one as actual dead-end fitting, as shown on the drawings. Preformed helical dead-ends shall have "cabled loop" eyes. The material of the spiral wires shall be high-tensile aluminum clad steel. The protection part is defined to protect the earth wire against radial forces in the OPGW produced by the high longitudinal tensions during operation. The protection part must be laid in the opposite direction of the outer layer of the OPGW and the dead-end part must be laid in opposite direction to the protection part. The grip strength shall be at least 95 % of the ultimate tensile strength of the OPGW.

The tension attachment devices must correspond to the OPGW type and dimensions. The protection part must be longer than the tension (dead-end) part and must be sufficient to install vibration dampers. The number and diameter of the spiral wires of the two parts are generally different but must be coordinated to meet the operational requirements.

Tension Set for OPGW

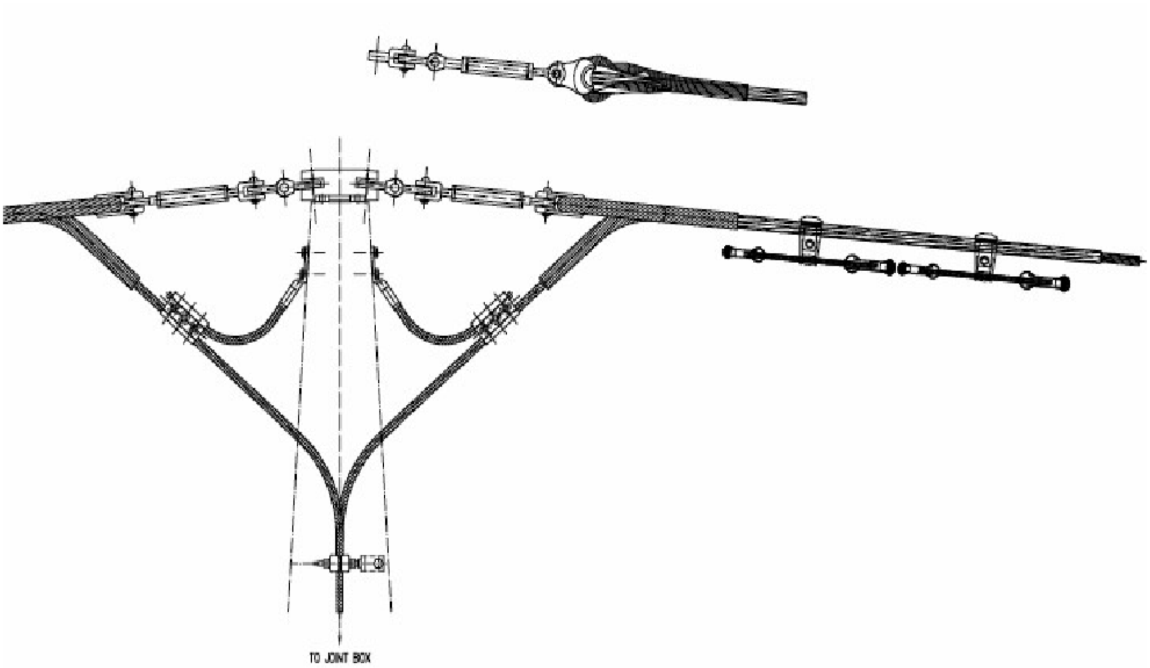


Figure 21: Double Tension Set for OPGW

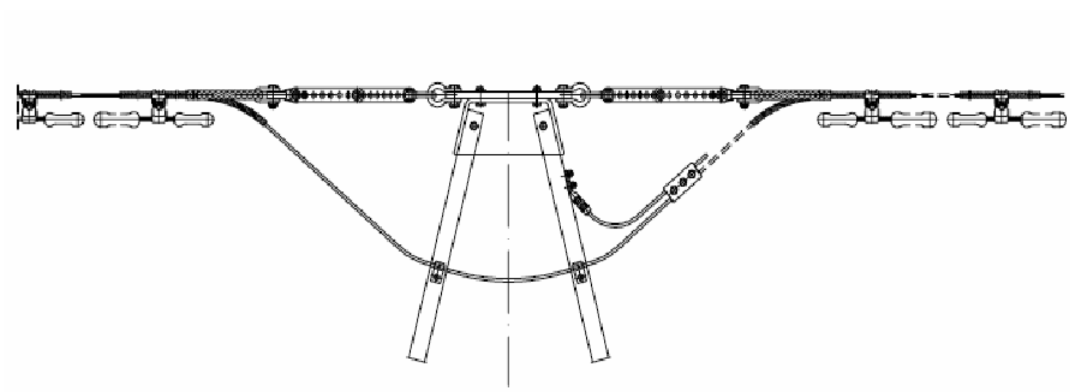


Figure 22: Single Tension Set for OPGW

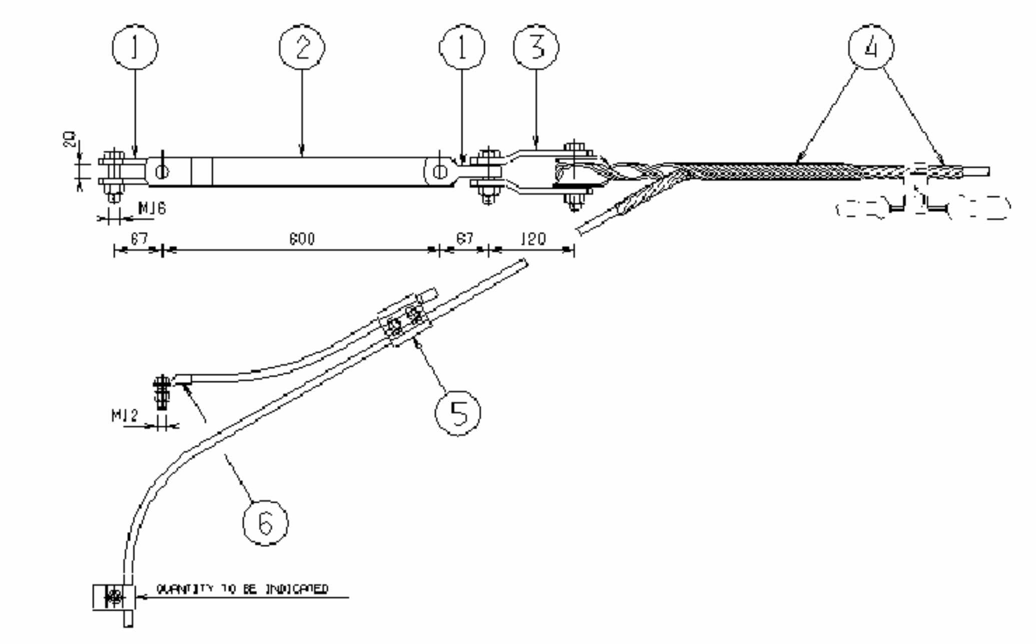


Figure 23: Single Tension Set for OPGW details

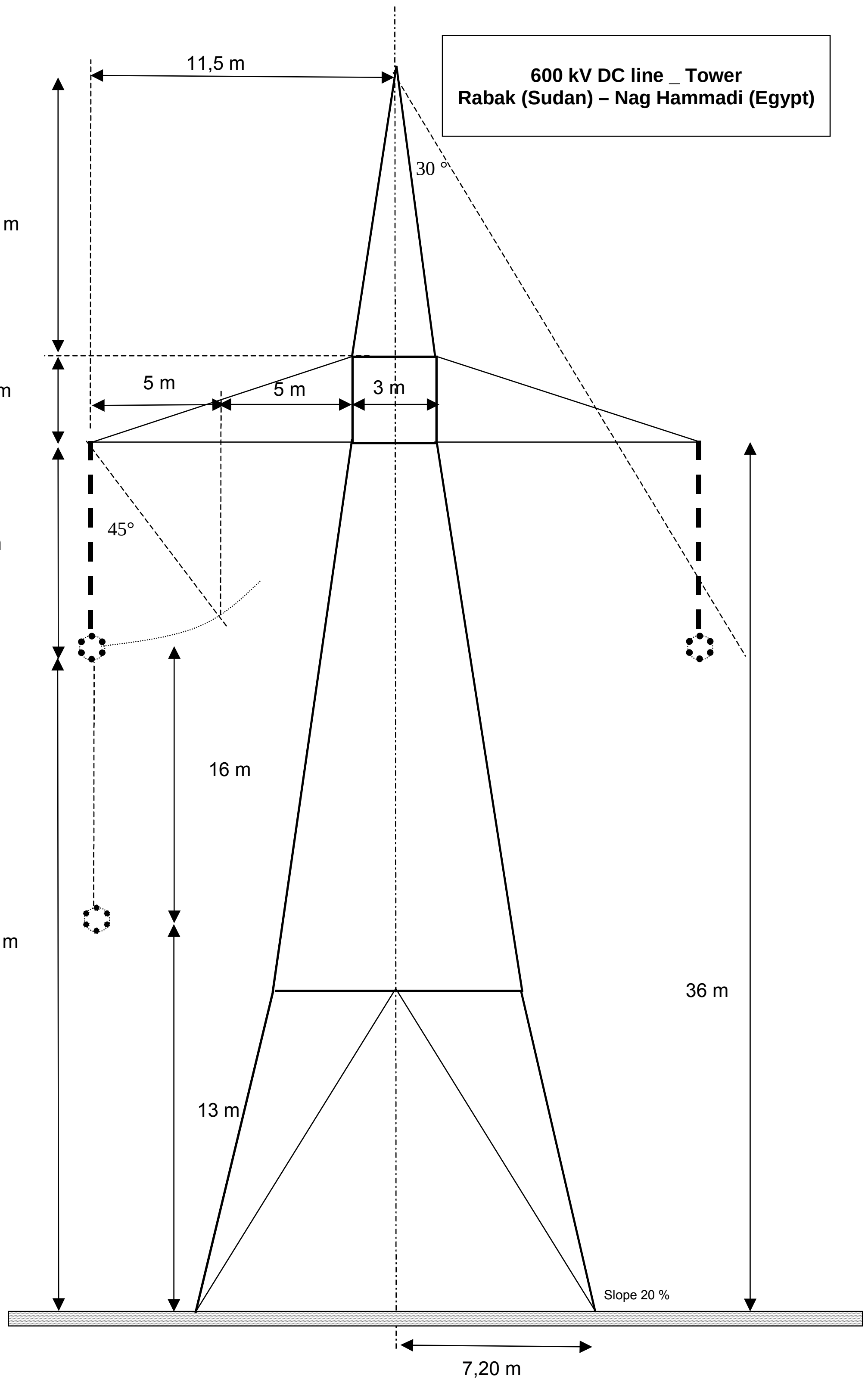
9 SPARE PARTS

For maintenance, the proposed spare parts will be included for conductors, OPGW and materials.

Designation	Quantity
Conductors ACSR CURLEW	70 km
Earthwire OPGW	25 km
Single Suspension Sets	180 units
Double Suspension Sets	130 units
Double Tension Sets	130 units
Mid-span joints for conductor	210 units
Compression Dead End for conductor	50 units
Bolts for lattice tower	1% of each type
Suspension Clamps	50 units
Spacers	290 units
Jumper Spacer	50 units
Clevis Tongue Couplings	50 units
Preformed Armor Rod	180 units
Earthing Material	30 units
Warning Sphere	(to be confirmed)
Cleats for OPGW	240 units
OPGW Box	10 units
Insulator Vibration Damper (stockbridge)	110 units

Table 19 : Proposed Spare Parts

Appendix 1 : Tower Outline

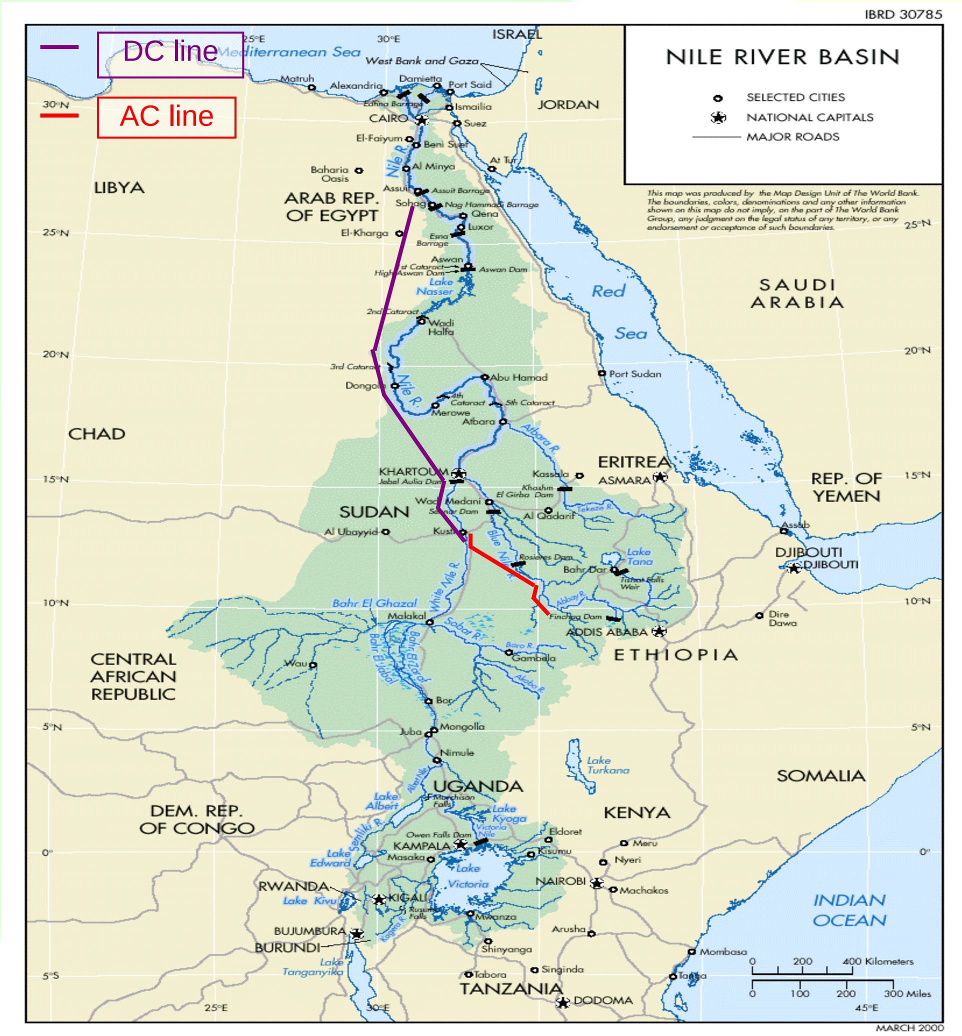


Nile Basin Initiative

Eastern Nile Subsidiary Action Program

Eastern Nile Technical Regional Office

EASTERN NILE POWER TRADE PROGRAM STUDY



M4 – HVDC MAIN EQUIPMENTS DESCRIPTION

EDF
Scott Wilson
TCE
EPS Electrical Power Systems Engineering Company

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
AIS	Air Insulated Switch
BIL	Basic Impulse Level
CVD	Capacitive Voltage Divider
CT	Current Transformer
CVT	Capacity Voltage Transformer
DC	Direct Current
EDF	Electricité de France
EFOR	Equivalent Forced Outage Rate
EHV	Extra High Voltage
ENTRO	Eastern Nile Technical Regional Office
GIS	Gas Insulate Switch
GPR	General Purpose Reagent
GRP	Glass Reinforced Protection
HMI	Human Machine Interface
HV	High Voltage
HVDC	High Voltage Direct Current
IEC	International Electrotechnical Commission
LAN	Local Area Network
NBI	Nile Basin Initiative
ODAF	Oil forced Directed-flow and Air Flow
OFAF	Oil Forced non-directed-flow and Air Flow
OHL	Overhead Lines
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SOE	Sequence Of Event
SVC	Static Voltage Compensator
UPS	Uninterruptible Power Supply
VBE	Valve Base Electronic
VBO	Voltage BreakOver
VDU	Visual Display Unit

EXECUTIVE SUMMARY

This document is a part of module M4 – technical specification.

It provides use full information concerning the main equipments of a HVDC station, typical HVDC losses, and a typical layout for KOSTI and NAG HAMMADI HVDC Stations

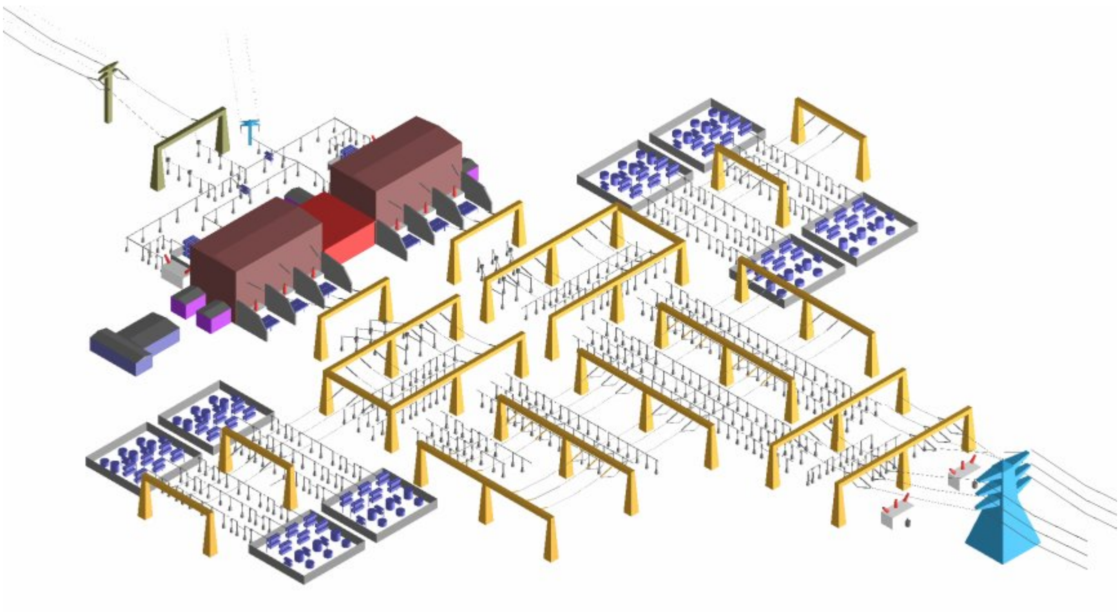


Figure 1 : Overview of HVDC Converter Stations

1 INTRODUCTION

There are six main electrical equipments installed in an HVDC Converter Station, these are:

- HVDC Valves
- HVDC Control System
- HVDC Cooling System
- HVDC Converter Transformers
- DC Smoothing reactor
- Harmonic Filters

A short description of these components is given in this document.

The document also shows typical losses of a HVDC Station, and the arrangement of the HVDC Stations (KOSTI and NAG HAMMADI).

2 HVDC VALVES

2.1 INTRODUCTION

Figure 2 below shows a typical HVDC converter valve arrangement.

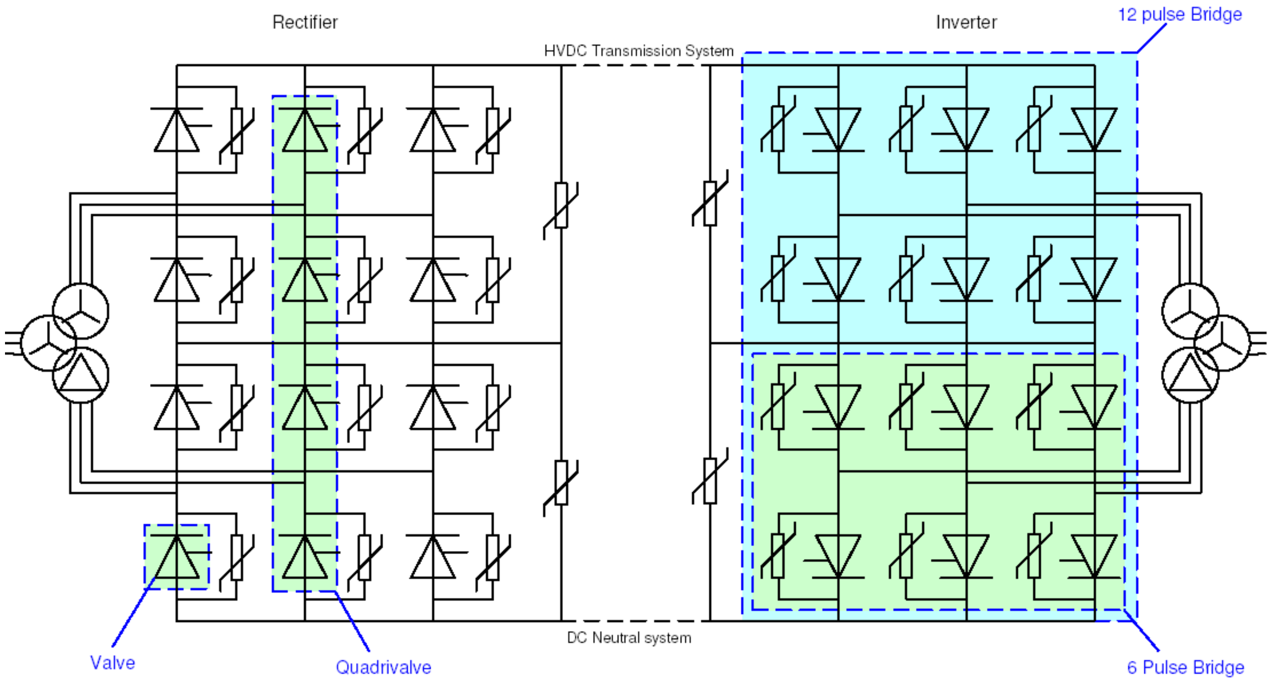


Figure 2 : Single Line Diagram of a typical Transmission Scheme

2.2 VALVE MECHANICAL ARRANGEMENT

Although electrically the valve is split into valve sections, mechanically each valve consists of a number of interconnected valve modules. Each module conveniently houses two valve sections, as shown in Figure 10. The layout of the components is not simply for aesthetics or electrical configuration, but is a result of careful consideration to many complexly related factors. These include for example: creepage, clearances, interference, stray inductance and capacitance, hydraulic requirements, weight distribution, ease of assembly, maintenance and testing. Also the materials of construction and design of equipment have been carefully considered in order to provide high reliability, long service life and to minimise the risk of a valve fire. The mechanical supports within the module are provided by flame retardant GRP beams and aluminium end frames. The end frames also serve as the main power connections to the module. This modular design approach simplifies the mechanical design of the valve since it removes the need for a separate valve structure.

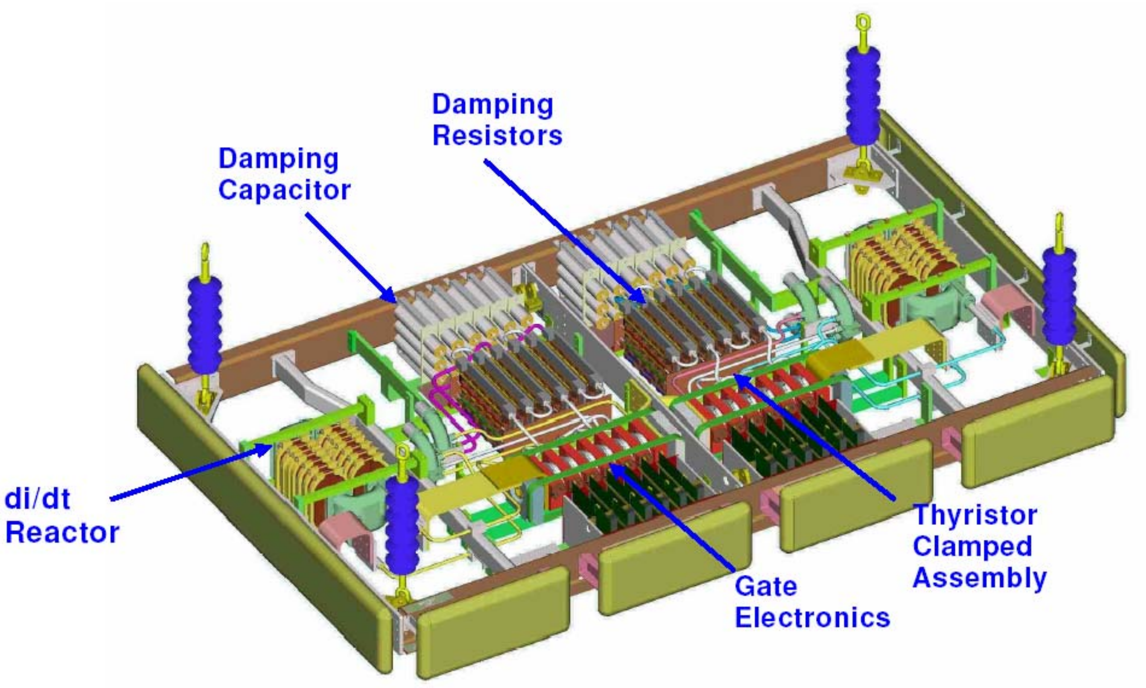


Figure 3 : Mechanical Valve Module Housing Two Electrical Valve Sections

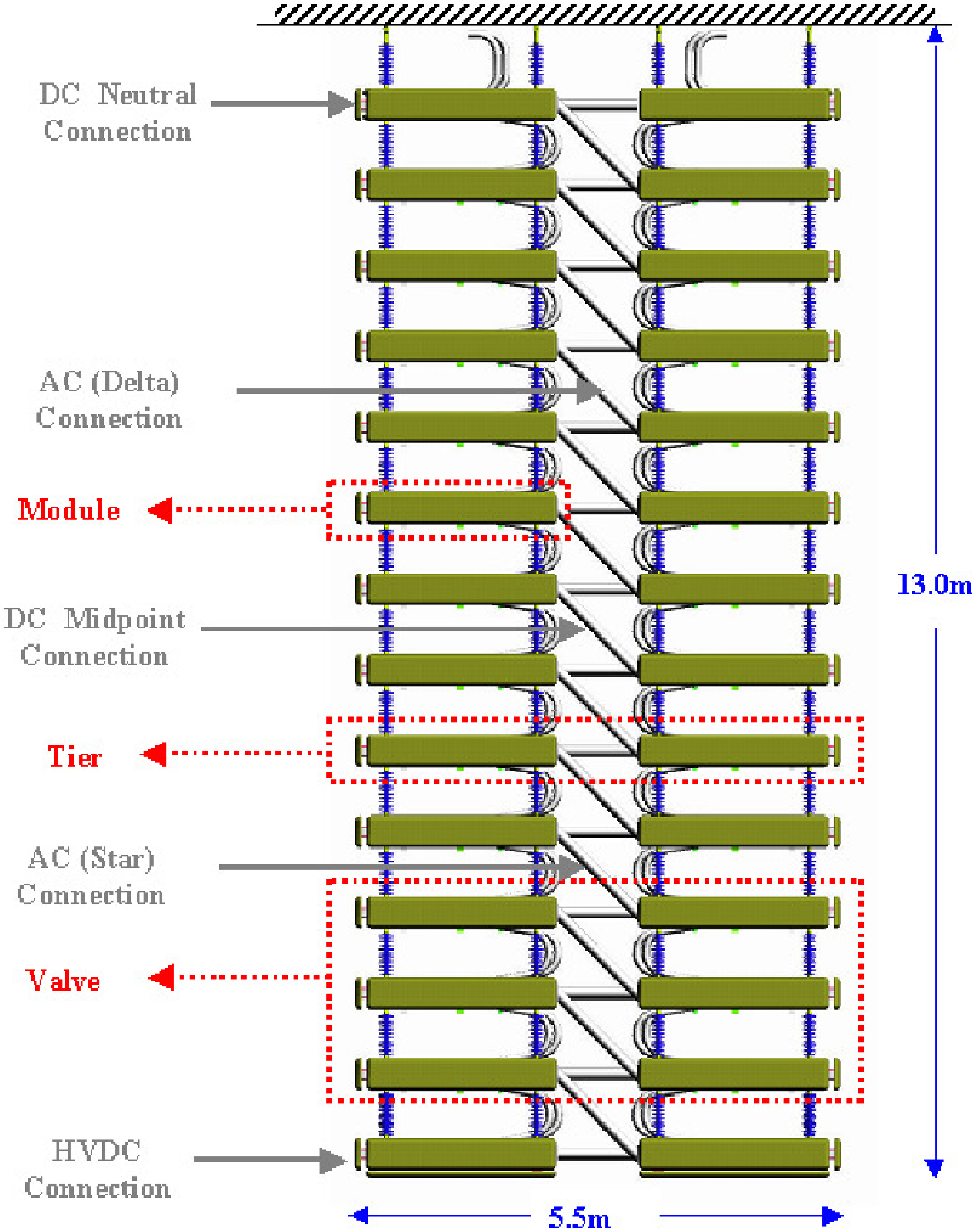


Figure 4 : Typical 600kV Quadrivalve Arrangement

2.3 VALVE PROTECTIION

Each valve has a surge arrester connected between its terminals to provide protection against overvoltages. For voltages applied in the reverse direction, the surge arrester is typically selected to give a margin of at least 15% between its protective level and the withstand level of the valve. For voltages in the forward direction, each thyristor is protected by voltage breakover (VBO) protection (at least 15% margin between maximum over voltage limitation and withstand level of the valve)

The valve is designed to withstand the inrush current which results if it turns on whilst the surge arrester is conducting. The effective VBO threshold for the complete valve is coordinated with the arrester protective level for switching impulses. For steep front and lightning impulse voltage transients in the forward direction, the electronic dv/dt protection provided may trigger the thyristor before the VBO level is reached. The damping resistors and other components in the valve are rated for continuous operation with VBO firing taking place each cycle.

The gating electronics is mounted adjacent to each level, and the layout and component placement are carefully selected to achieve high reliability and good interference immunity. In addition to the electronic dv/dt protection mentioned above, forward recovery protection is included in the gating electronics to re-trigger the thyristors if the thyristor voltage becomes positive too soon or too quickly after the thyristors have stopped conducting. The sensitivity of this protection is continuously adjusted to reflect the variation of thyristor parameters with junction temperature, and is therefore self adapting to all ambient temperature and prior loading conditions.

2.4 FLAMMABILITY CONSIDERATIONS

All exposed materials and components in the valve with individual masses greater than 25g, are self-extinguishing and fire retardant to the Underwriters Laboratory standard: UL94V-0. The damping capacitors are of oil-free construction.

Careful attention has also been paid to possible fire initiation processes. All components are generously rated, both thermally (to minimise the risk of overheating) and electrically (all other components in parallel with the thyristor are specified with voltage ratings in excess of those of the best thyristor which could be encountered). Hence the potential spread of a fire throughout the valve can be virtually dismissed by the materials and components used.

As an additional security measure, high-sensitivity smoke detection apparatus and/or optical arc detection equipment may be specified.

2.5 ROUTINE TESTING

Every thyristor valve supplied is subject to a comprehensive series of routine tests. Individual valve modules are subjected to stringent hydraulic, thermal and electrical tests. Typically the tests are designed to check:

- Level damping and grading component impedance
- Electronics power supply
- Thyristor firing
- Forward recovery protection
- Impulse test
- AC voltage withstand
- Hydraulic pressure and flow
- Thermal heat-run

Routine tests are defined in the relevant IEC standards

2.6 VALVE MAINTENANCE

No routine maintenance of the HVDC valve is prescribed, other than inspection and external cleaning at a maximum recommended interval of six years.

However, given the normal need to shut down for maintenance of other equipment, it is usual to carry out inspections at more frequent intervals and to spread the cleaning across several shutdowns over a six year period.

Provision of 2% redundant thyristor levels will usually allow at least two years between shutdowns, for replacement of failed thyristors, although this is dependent on the operating voltage and number of levels per valve. Replacement of any failed thyristors at an earlier occasion to suit scheme operation will ensure the greatest reliability.

3 HVDC CONTROL SYSTEMS

3.1 *FUNCTIONAL DESCRIPTION OF THE SERIES V HVDC CONTROL SYSTEM*

The Control System provides all of the functionality needed to control and protect the HVDC equipment and ensure safe stable real and reactive power flow through the converter and into the connected power systems. The control system controls the valve firing, filter switching, tap changer operation, cooling plant operation, and provides protection for the thyristor valves and other related DC equipment including the HVDC transmission lines and/or cables. The control system has been designed for use in both manned and unmanned stations.

The hierarchy of the complete control system is designed in accordance with IEC60633:1998 and is shown in Figure 5.

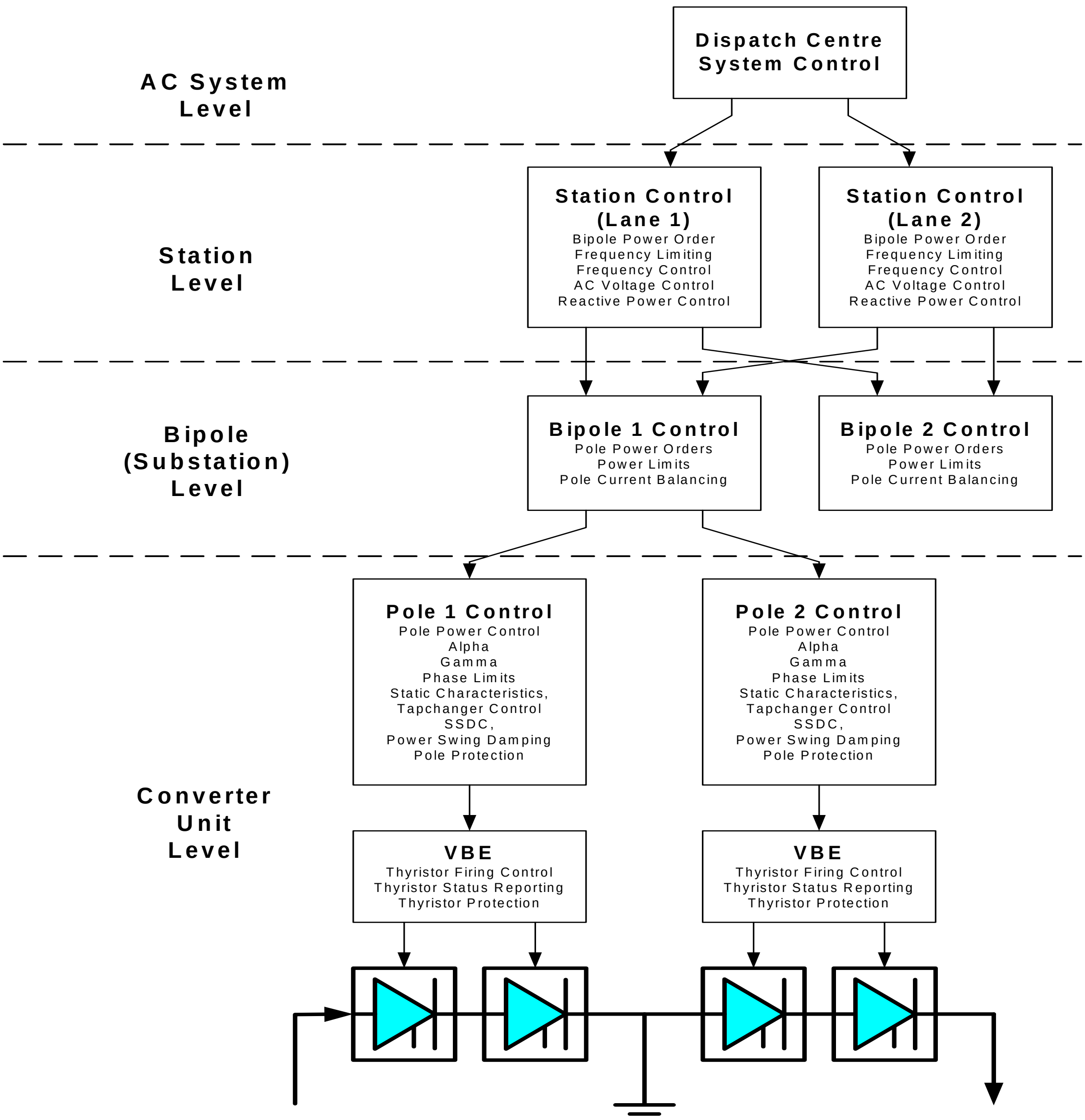


Figure 5 : Control System Hierarchy

3.2 PHYSICAL IMPLEMENTATION

The control systems for each "pole end" of a HVDC scheme are normally identical. Each pole end has two independent dual redundant control and protection lanes, a plant interface sub-system, one VBE sub system and one high reliability change over module. A block of the equipment for one pole end of a typical dual redundant system is shown below.

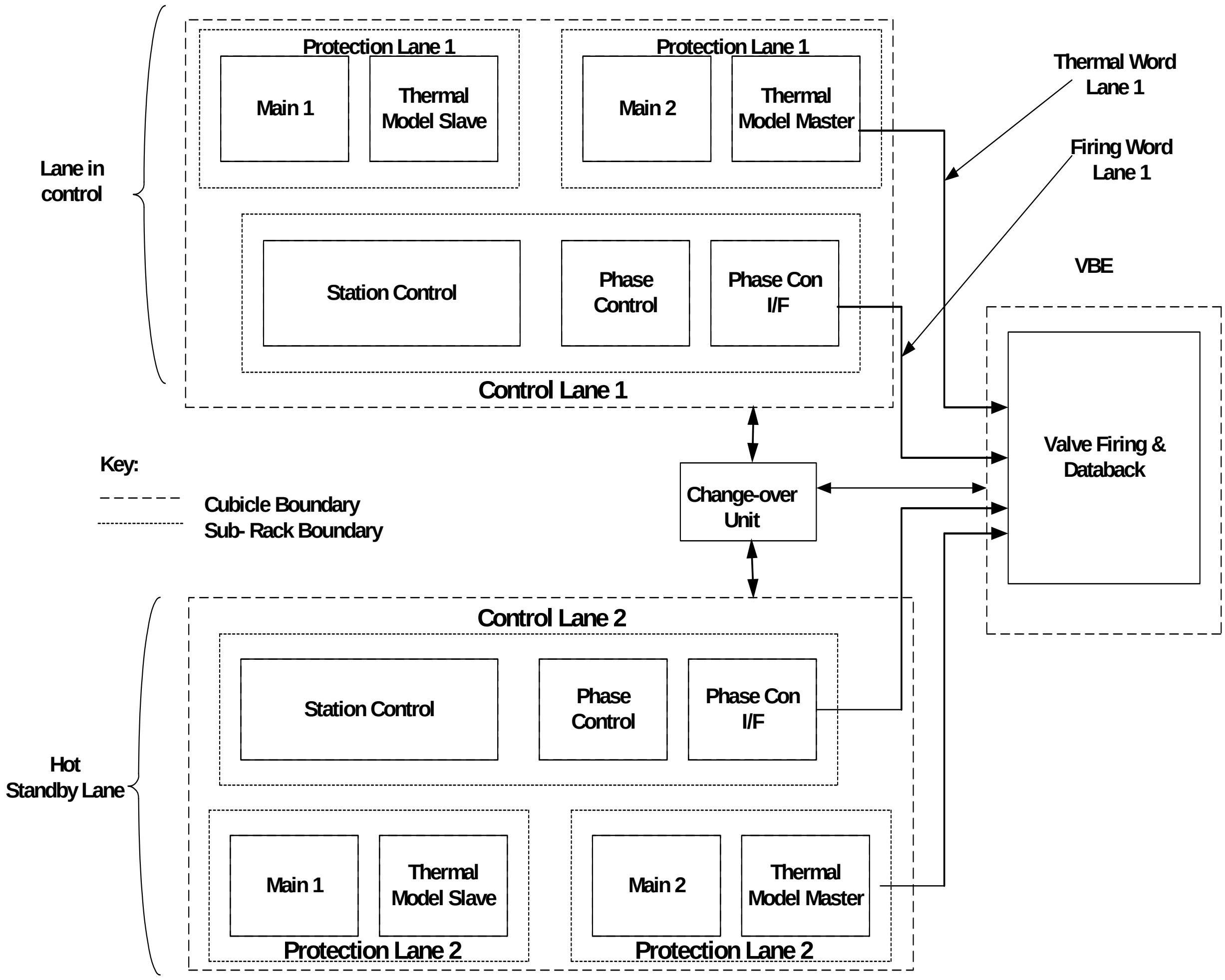


Figure 6 : Physical Implementation

3.3 HMI AND OPERATOR INTERFACE

The operator control and monitoring facilities for the HVDC Interconnection are provided by a HMI (Human Machine Interface) system.

A typical HMI system architecture is shown in at the end of this section.

The HMI system permits the scheme to be controlled from any one of the control points located within the converter station or remote control centers.

3.3.1 THE HMI SYSTEM FACILITIES

The HMI system provides facilities for:

- Control of HVDC converters allowing selection of operating mode, setting of control demand /target values, and initiation of the start/stop sequences.
- Control, positional indication and operational interlocking of AC and DC switchgear.
- Monitoring/display of analogue measurements (including trends) in AC switchyard, DC switchyard yard, valve cooling systems, auxiliary power equipment, building services equipment etc.
- Monitoring/display of status and alarm indications of station equipment including audible alarm annunciation.
- Sequence of Event recording (1ms resolution) for station equipment.
- Logging, printing, archiving, retrieval and transfer of captured data.

The HMI system normally has either direct or indirect interfaces with the following equipment within the converter stations. The type and number of interfaces is application specific:

- The Series V HVDC control system
- AC and DC switchgear
- AC protection equipment
- DC protection equipment
- Converter transformers and AC filters
- Shunt and series reactors
- AC and DC measurement devices (CT's and VT's).
- Converter valve cooling systems
- Building management and fire protection systems
- Communication systems to other local/remote control centre locations.

The Series V Control System at the converter station supervises the operator control commands and provides alarms, inhibits and interlocks to ensure safe operation of the converter stations whilst automatically controlling the converters and power transfer across the HVDC link. Transfer of operator control between the control points is managed by the HMI and Series V Control systems to ensure that there is only one active control point at any time.

3.3.2 ARCHITECTURE

Though the exact system required is specific to each application, the HMI equipment at the converter station may comprise of:

- Dual redundant Server computers
- Operator/engineer workstations for local control points
- Associated printers
- Communications interfaces for remote control points

- Dual redundant Ethernet LAN connecting Server computers to workstations and remote communications interfaces
- Remote Terminal Units (RTU) outstations with redundant communications processors, redundant power supply units and non duplicated input/output modules
- Communication links with dual redundant Series V HVDC control system and the converter valve cooling controllers
- GPS clock

The HMI system incorporates extensive redundancy to ensure a high degree of availability. The Server computer, RTU outstation processors, communications interfaces and system communication networks are duplicated. In the case of duplicated items, one equipment is in service whilst the redundant equipment is in 'hot standby'.

3.3.3 HMI SERVER COMPUTERS

Two high quality industry standard PCs operate as dual redundant servers processing all the data received from the various interfaces with the converter station equipment, workstations and dispatch centers. Data is collected by the on line server, processed to detect changes/alarms and stored in a real time database. Time registered event information is sorted into chronological order. The database is used to produce the workstation displays, event/alarm lists and trend records. The off line server database is kept updated to ensure that it can take over should the on line server fail.

The Server computers communicate with the local operator workstations and the remote communications interfaces within the converter station via a dual redundant Ethernet LAN. The RTU outstations are star connected to both Server Station computers. Control and monitoring data is exchanged with the dual redundant Series V HVDC control system and valve cooling controllers via industry standard serial interfaces. The Server computers are powered from either an Uninterruptible Power Supply (UPS) or the station batteries.

3.3.4 WORKSTATIONS AND PRINTERS

The workstations are industry standard PCs each with high resolution color VDUs, mouse and keyboard. They are connected to both server computers via the dual redundant Ethernet LAN. It is possible to blank the VDU completely from the keyboard when a workstation is not in use.

The workstations provide an intuitive user friendly human machine interface with the converter control systems and the other electrical equipment at the converter stations. Access to HMI functions is password protected by the HMI system with different levels of privilege assigned to the operator or engineer. It is possible to display images, lists and reports. The graphic presentation uses windowing techniques and displays, which give clear indication using format, color and video attributes to enhance the information displayed. Animated mimics are used to display areas of plant and highlight changes of state or alarm conditions as a change of color. The keyboard and/or mouse are use to navigate between mimics. A hierarchical structure is used for the mimics. Control operations are performed by means of operator dialogue boxes in a three stage select, command and execute sequence.

The workstation will include display pages such as the following:

- Operator/engineer log on
- Main Power Circuit mimic
- Detailed sub-sets of the main power circuit mimic (AC switchyard, DC switchyard, converter valves and transformer).
- Converter Cooling System mimic.
- Operator command/display screens for HVDC control mode selection and HVDC control parameter setting.
- Equipment status.
- Sequence of events (SOE) listing.
- Active alarm list (grouped and individual alarms).
- Trend records.
- Internal HMI system diagnostics.

It is possible to display grouped alarm and individual equipment alarm pages with indication of whether the alarm is still valid, acknowledged or not acknowledged. SOE information can be displayed and sorted according to various criteria such as by date, time or by equipment etc. All SOE data including alarm data is reported to a dedicated printer.

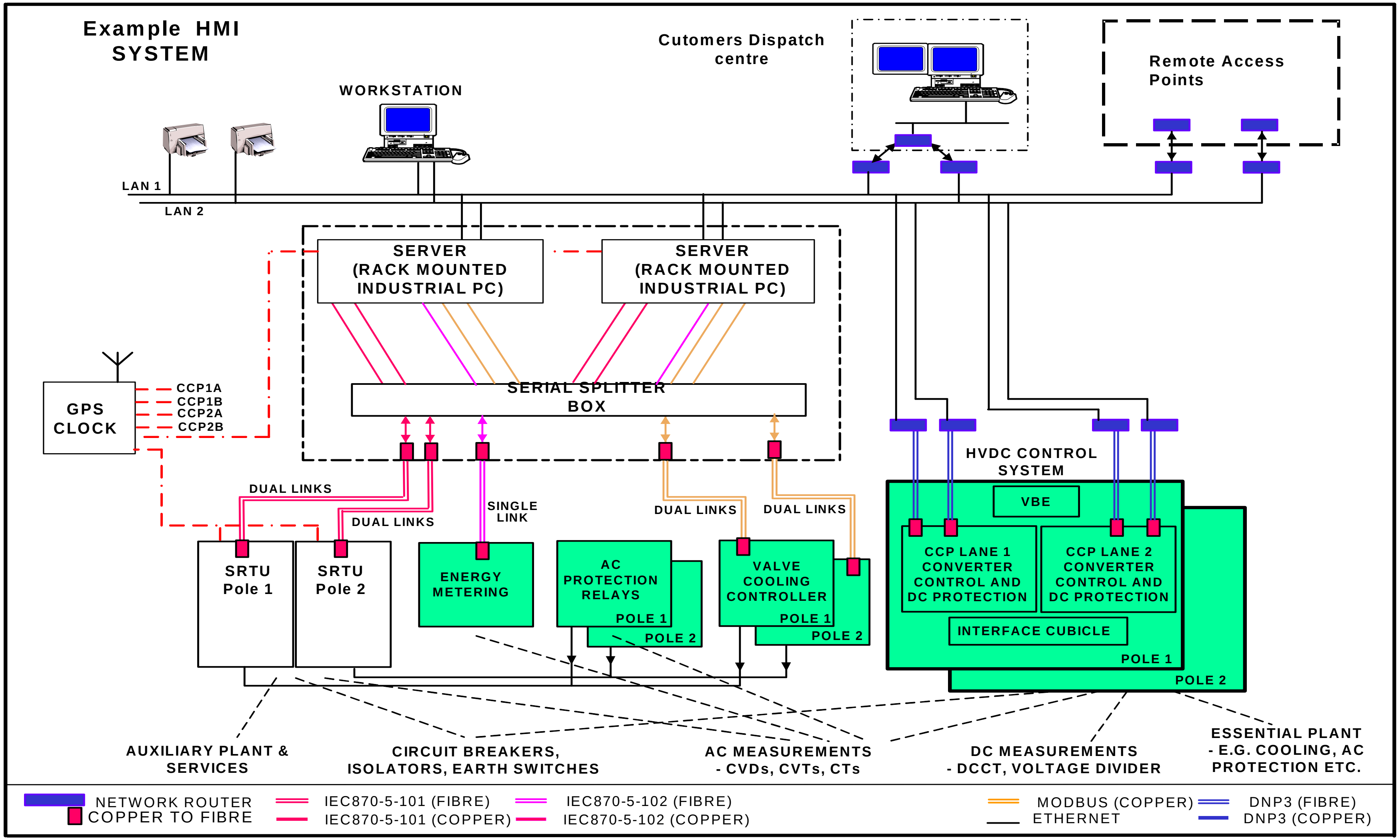


Figure 6 : Example of HMI System

4 HVDC COOLING SYSTEM

4.1 INTRODUCTION

A typical flow diagram of a single-circuit cooling plant used for HVDC thyristor valves is detailed in Figure below. It shows the location of all key components in the cooling circuit between the connection of the valves to the coolers. Some items in this diagram might be simplified or omitted in certain cases.

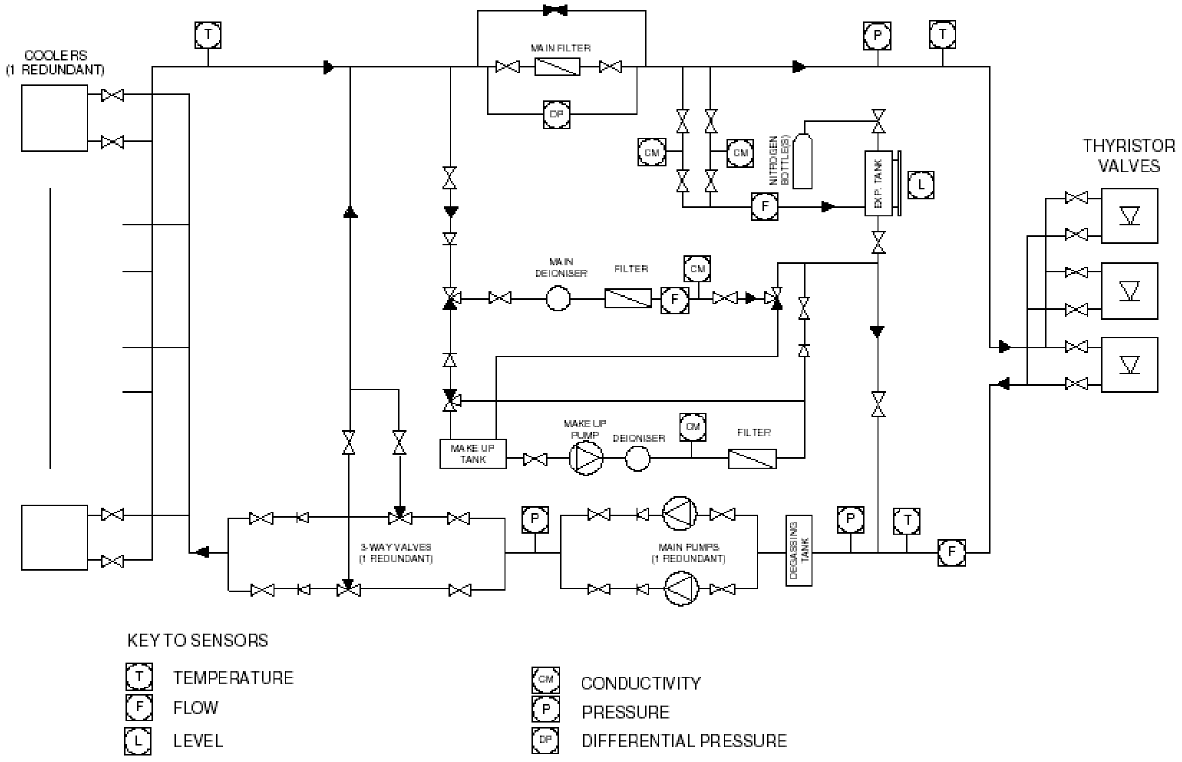


Figure 7 : Typical Flow Diagram

4.2 COOLING PLANT DESCRIPTION

The detailed design of the cooling plant varies from project to project, depending on environmental conditions and special requirements. However, typical characteristics of some of the main components are described below.

4.2.1 COOLANT

The cooling system generally uses pure de-ionised water for the coolant. However, if the specified minimum outdoor ambient temperature is below 0°C then depending upon project requirements ethylene glycol may be added to prevent the coolant from freezing. General purpose reagent grade (GPR) Ethylene Glycol is specified with no additives. It also has a very low conductivity (0.3 µS/cm or better) and a very low level of impurities (1% or less).

4.2.2 FILTERING

A full flow filter is typically included in the main cooling circuit before the thyristor valves, to prevent debris trapped in the system from entering the thyristor valves. The filter may be fitted with a full flow bypass circuit to allow the replacement/cleaning of the filter basket while the system is in operation. A differential pressure switch positioned across the filter will indicate a blockage in the filter basket.

4.2.3 DE-IONISATION

The main deioniser system is typically a secondary circuit off the main circuit. Thus a small percentage of the main flow is passed through the main deioniser cylinder to maintain the conductivity of the coolant below a set limit. This circuit also contains a fine filter on the outlet side, a flow detection sensor and conductivity meter to monitor the coolant leaving the deioniser system before it re-enters the main system.

4.2.4 MAIN PUMPS

The main coolant circulation pumps generally consist of a duty pump and a standby pump. They are normally hydraulically connected in parallel and are arranged such that maintenance work can be carried out on one pump while the other pump is in operation. Usually the duty pump function is cycled between the two main pumps to even out the average service hours. A non-return valve is positioned at the outlet of each pump to prevent reverse flow through the standby pump.

4.2.5 WAY VALVE

The coolant from the cooler bank circuit may be diverted to the cooler bank bypass circuit by using a 3-way valve. The 3-way valve is used to limit the minimum coolant temperature entering the thyristor valves and to prevent condensation forming within the thyristor valves when the thyristor valve inlet temperature is low and the scheme power transfer level is low. The 3-way valve may be controlled for example by electrical actuators.

Note: A 3-way valve is only required in areas that experience low minimum ambient air temperatures. Therefore in locations with high minimum ambient conditions a 3-way valve is unnecessary. Instead only a bypass with shutoff valve is used to quickly increase the coolant temperature.

4.2.6 COOLERS

Outlets from the cooling pumps pass outdoors to the cooler units. These coolers are generally a dry type air blast unit, although other types may be used such as water to water coolers. In areas of high ambient temperatures, adiabatic or evaporative coolers may be used as an alternative. The choice of coolers will depend on the amount of heat that needs to be exchanged for a given scheme.

4.2.7 EXPANSION TANK

The expansion tank accommodates the normal variation in volume of the coolant due to expansion over the full working range of temperature. The expansion tank has a pressurised nitrogen blanket to maintain the static pressure required in the cooling system. Hence the expansion tank may also be used as a combined gassing tank. A restricted flow of coolant from the main circuit is passed through the expansion tank to keep the coolant in the tank in prime condition. Level switches are included on the expansion tank to provide make-up control signals in the event of a minor coolant leak and alarm and trip signal in the event of a major system leak.

5 HVDC CONVERTER TRANSFORMERS

The converter transformer design is a special design of a conventional HV AC transformer, the main differences are that its parameters must be designed in conjunction with the HVDC valves and AC Filters – to give the most efficient and economical overall converter station design.

The location of the converter transformer is shown in the simplified schematic below :

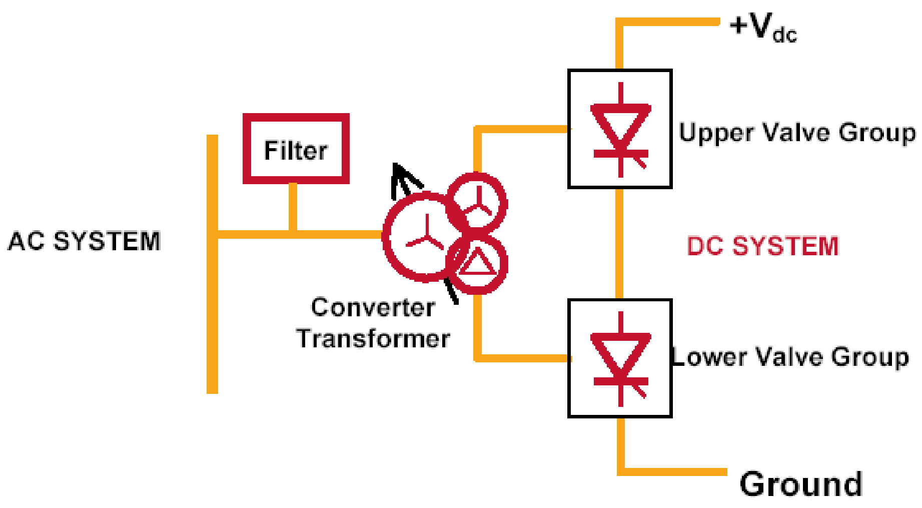


Figure 8 : Position of the Converter Transformer in a Pole of HVDC Station

The other specialties are that the transformer has to be able to withstand DC components of current in its winding, which leads to extra bracing and insulation materials. Additionally, the secondary winding bushing will normally protrude from the side of the transformer tank and pass directly through the wall of the Valve hall.

As the converter valves will be connected in a 12-pulse configuration, a converter transformer will use star and delta windings. This may be within one transformer, or by the use of multiple transformers – depending on MVA rating and transport limitations.

The transformer will be fitted with an on-load tapchanger, with the number and size of the steps determined during system design to ensure correct operation over the desired AC voltage range, DC voltage range and the reactive power exchange.

BIL of the transformers shall be determined by the insulation coordination study. A minimum BIL shall be specified for the primary windings, in accordance with the utility practice (see M4 - HVDC Converter Stations - Preparation of Specifications)

Typically, the converter transformers will be mounted on a rail system so that they can easily be removed and a spare installed and should the need arise.

The rating is based on OFAF/ODAF cooling.

Fire walls will always be installed between transformers. Each transformer will be equipped with a fire detection and fire fighting system.

As converter transformers are the largest and heaviest single item to transport to site, they usually dictate the configuration (3 phase/3 winding through to single phase/two winding) and often will dictate the width of the valve hall building.

The transformers will also normally be fitted with redundant cooling; hence a steady-state overload capability of 10% is typically achievable with a maximum overload of up to 50%.

Converter transformers will always be fitted with on-line continuous monitoring equipment, this equipment becomes integrated into the HVDC SCADA system.

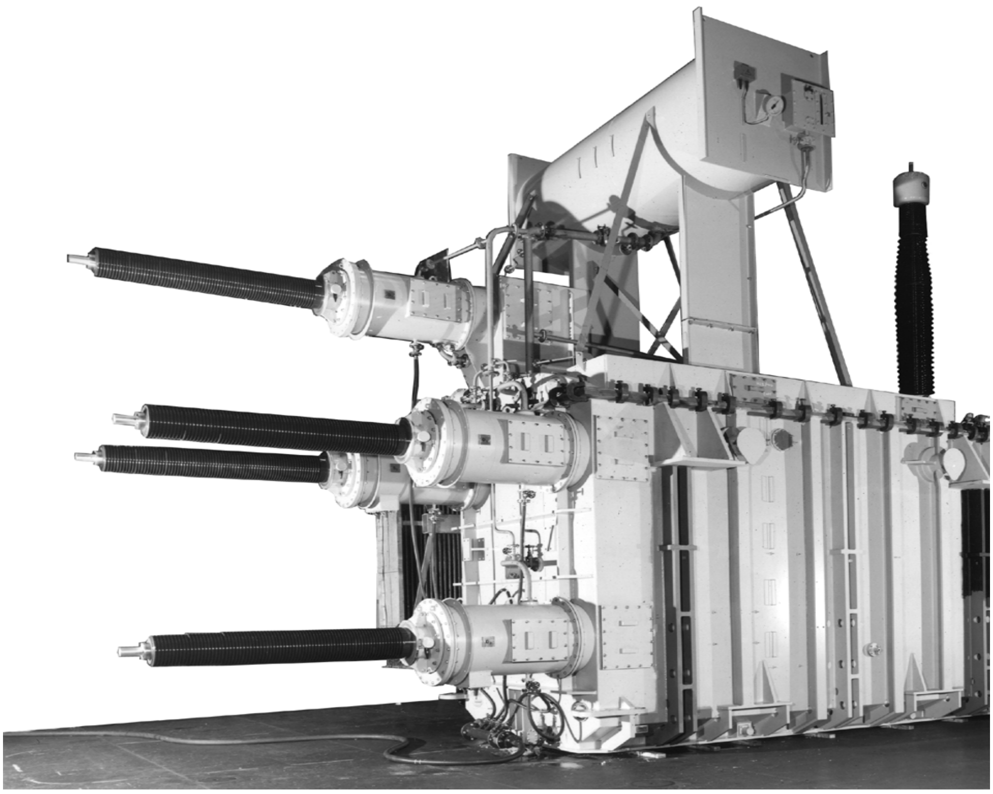


Figure 9 : Single Phase 3 Windings Transformer for HVDC Applications (Y y d)

6 DC SMOOTHNG REACTOR

The DC reactor (often called the Smoothing reactor) is primarily designed to limit the rate of rise of DC current during inverter voltage collapse, for smoothing the dc current ripple and to prevent resonance phenomena.

They have to be designed to withstand the electrical and mechanical stresses resulting from harmonics and surge currents and are rated to satisfy the specified performance requirements.

DC smoothing reactors are air insulated.

The smoothing reactors will be equipped with a fire detection system. Some fire walls can be used between reactors, in order to limit collateral damages in case of fire.

BIL shall be determined by the insulation coordination study.

The figure below gives an example of a smoothing reactor, air insulated.

Figure 10 : Typical Smoothing Reactor

7 HARMONIC FILTERS

The close control of the power transmitted across the DC link, along with the requirement to limit the amount of reactive power exchange with the system to which it is connected, results in the need to connect shunt capacitors to offset the reactive power absorbed by the converter.

The planning limits of voltage distortion as defined in IEC 61000-3-6 and EA Engineering Recommendation G5/4 for the harmonics, which typically have the major impact on HVDC filter design, are shown in Table 1.

The IEC 61000-3-6 limits apply only up to 230 kV; beyond this level national limits will often apply. G5/4, and the limits shown apply to 275kV/400kV systems. Generally, limits similar to those of G5/4 are specified for an HVDC scheme.

These limits mean that it is often necessary to configure the shunt capacitor elements as filters to attenuate the characteristic harmonics (and some non-characteristic ones resulting from system unbalance) associated with HVDC schemes.

The design of filters must be such that as they are switched – in accordance with the reactive power exchange limits defined by the customer – they always ensure compliance with the relevant harmonic distortion limits.

Harmonic	IEC 61000-3-6 planning limit	G5/4 planning limit
3	2.0	1.5
5	2.0	2.0
7	2.0	1.5
11	1.5	1.0
13	1.5	1.0
23	0.7	0.5
25	0.7	0.5
35	0.56	0.41
37	0.54	0.40
47	0.47	0.36
49	0.46	0.35

Table 1- Planning Levels of Harmonics Taken from IEC 61000-3-6 and EA Engineering Recommendation G5/4

8 OTHER EQUIPMENTS

All other equipments are created using standard AC transmission network products, these include:

- AC switchgear (Circuit breakers, Disconnectors/Isolators, Grounding switches, etc): normally Air Insulated Switchgear (AIS) is used, but Gas Insulated Switchgear (GIS) is sometimes considered in certain installation environments. They will be configured to meet Utility standards.
- Instrument Transformers, used for the precision measurement of voltages and currents at the appropriate points in the converter station electrical circuit. The outputs of the instrument transformers are used by the Converter Control System and also the traditional AC protection electronic relays.
- AC filters, created using appropriately rated linear shunt capacitors, reactors and, if necessary, resistors connected to the AC busbar using conventional AC switchgear. Several banks, each tuned to different frequencies will normally be used. The AC filters also play a role in providing the reactive power exchange requirements with the AC network.
- DC filters, created using appropriately rated linear shunt capacitors, reactors and, if necessary, resistors
- Surge Arresters, both DC and AC surge arresters are used to provide protection of the converter station equipment.

9 TYPICAL LOSSES

The typical losses curve of a bipolar converter or (inverter) is given below (losses are is given in percent of the power flux).

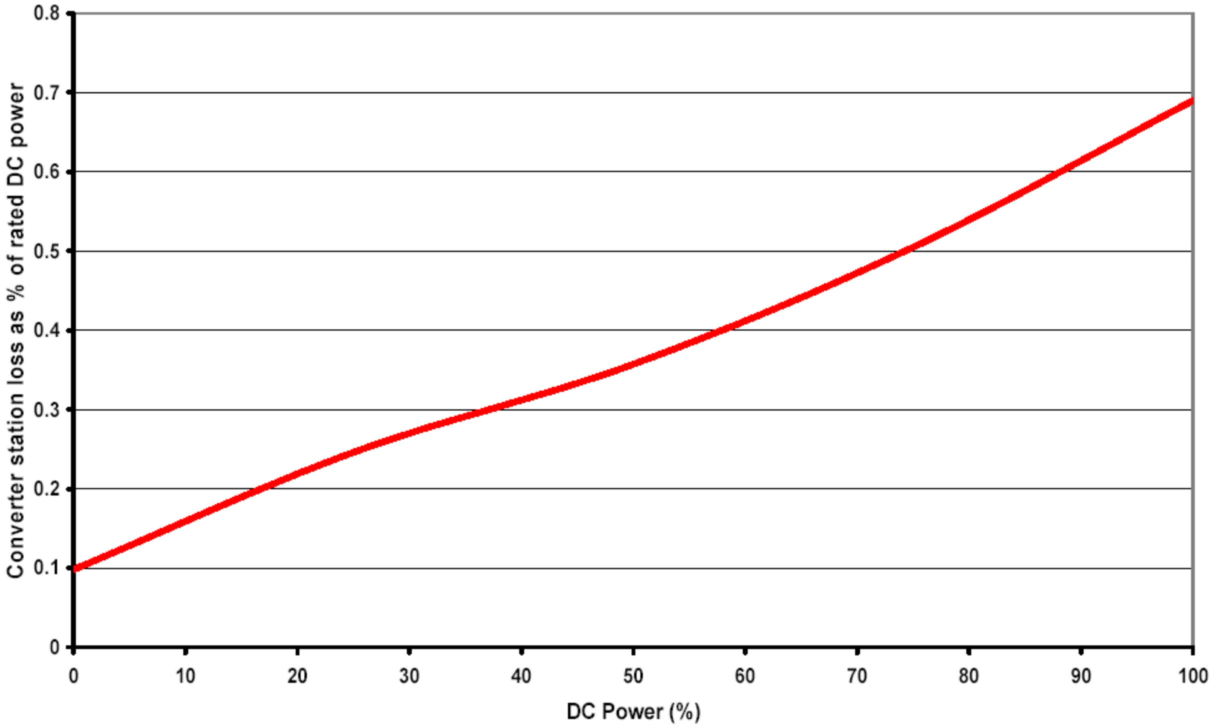


Figure 11 : Losses in a HVDC Station (for one station)

10 LAND ELECTRODE STATION

The ground electrode station design depend on soil characteristics. They are located in separate areas from the HVDC stations (typically 10 to 15 km).

The schematic below shows the arrangement of electrode stations for a bipolar scheme, with OHL transmission :

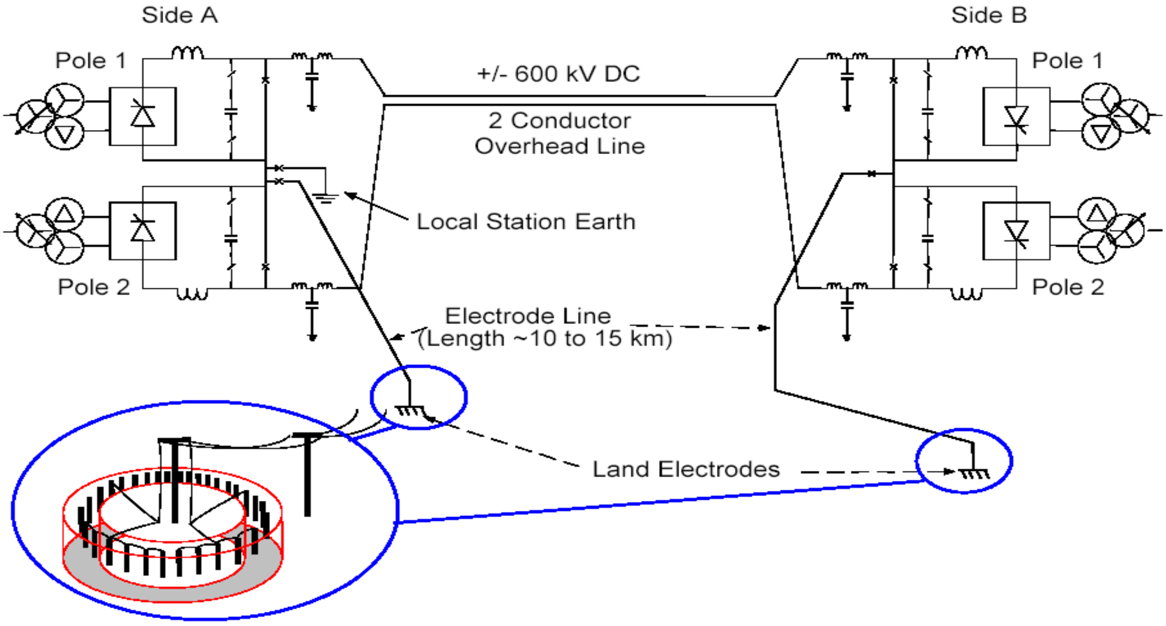


Figure 12 : Schematic of Land Electrode

Figure 13 : Picture of Land Electrode

11 TYPICAL LAYOUT FOR KOSTI AND NAG HAMMADI HVDC STATIONS

Typical layout and isometric view are given hereafter.

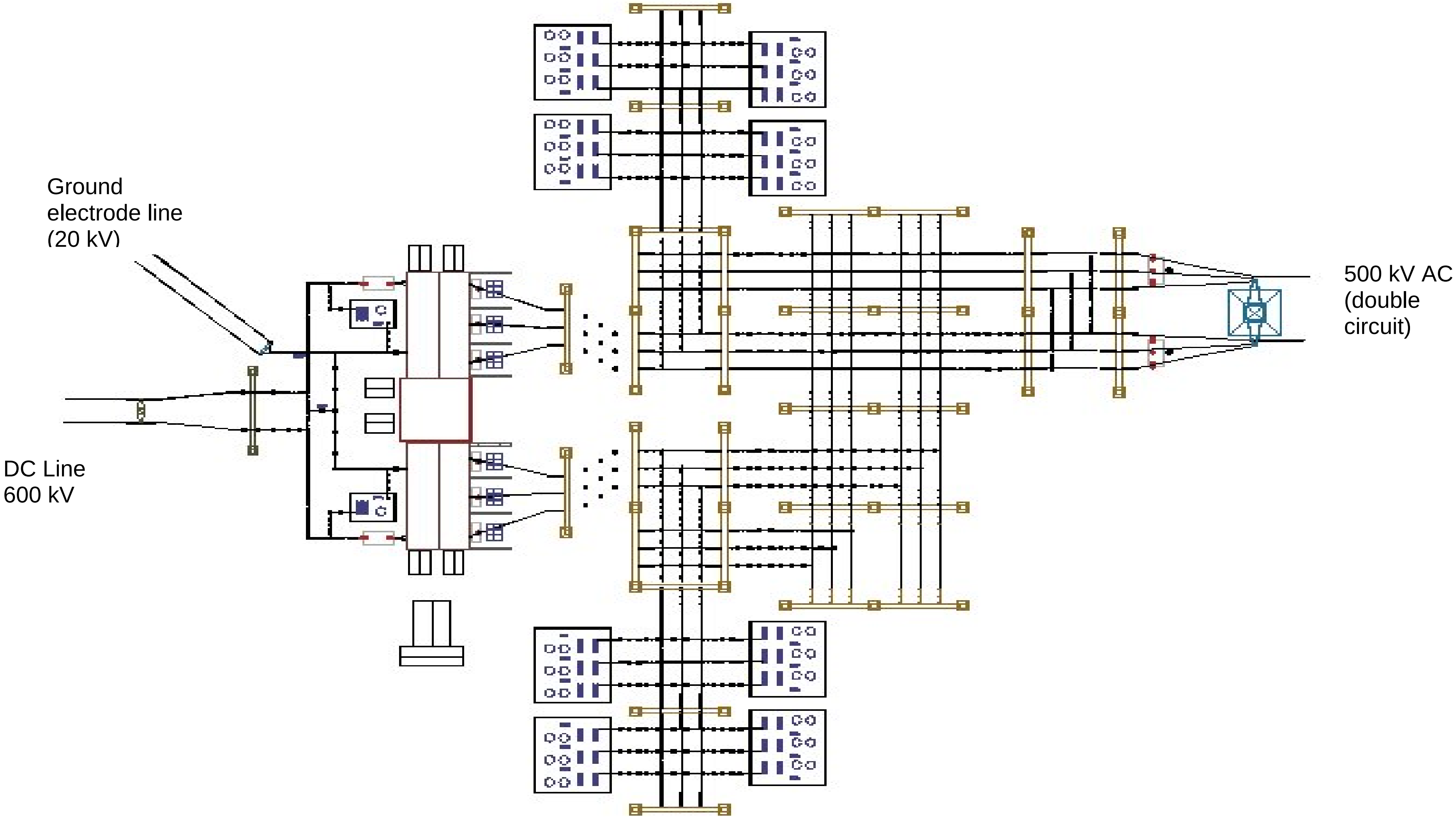


Figure 14 : Typical Layout for the KOSTI and NAG HAMMADI Bipolar HVDC Stations

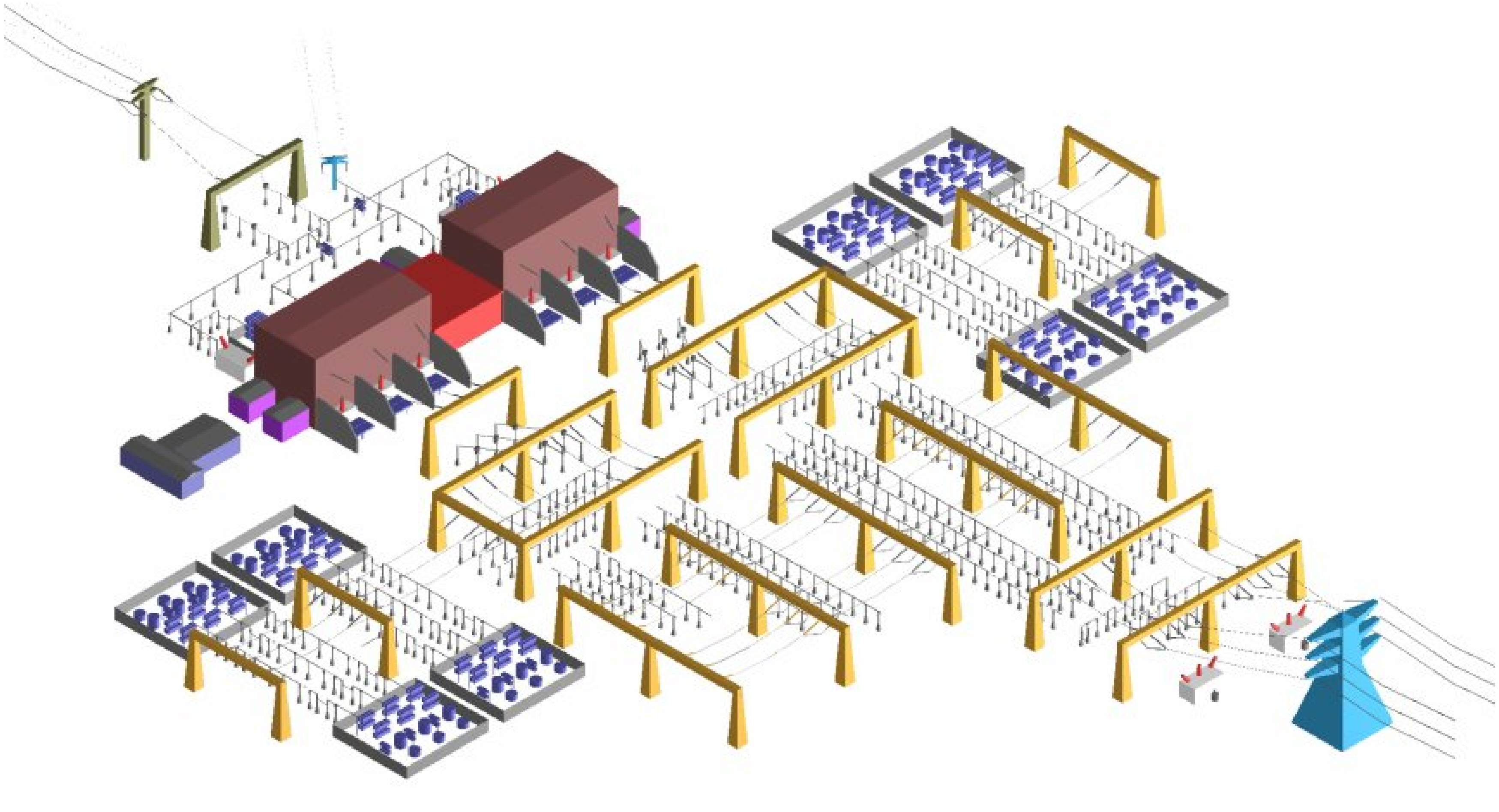
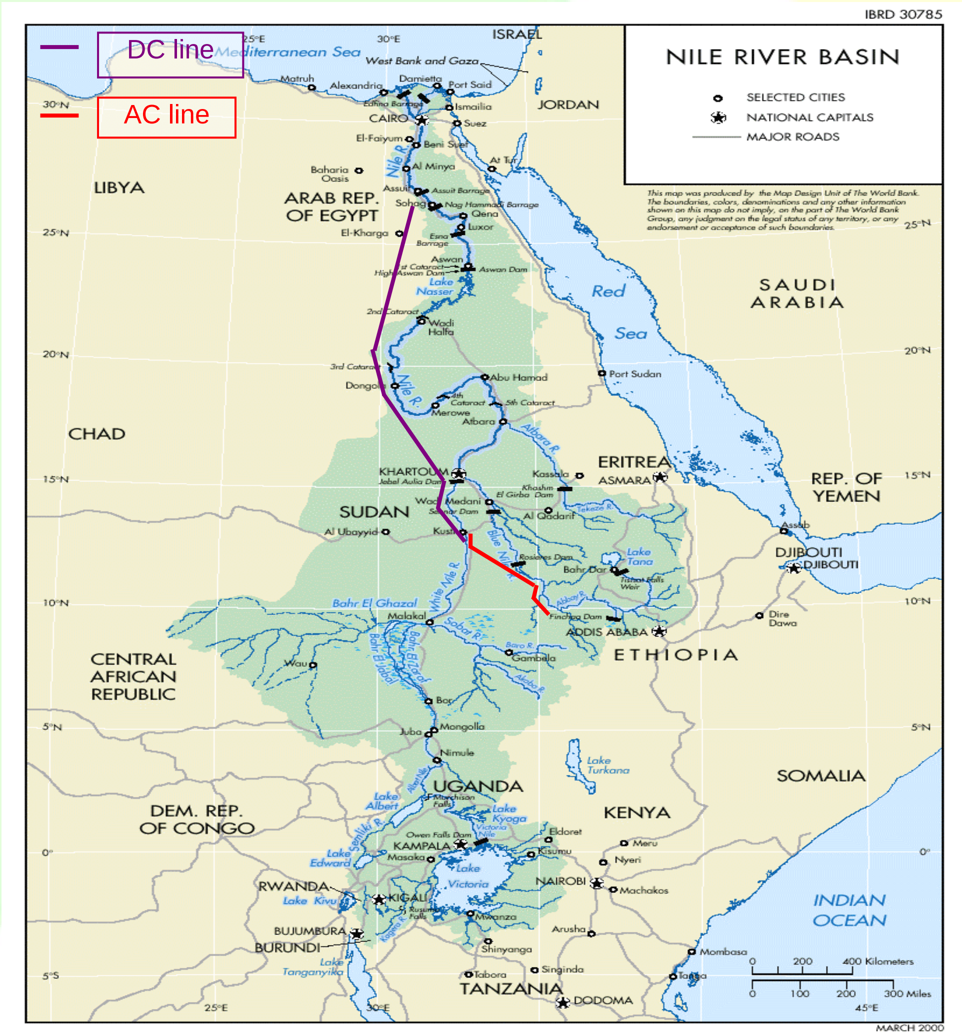


Figure 15 : Isometric View of the KOSTI and NAG HAMMADI HVDC Stations

Nile Basin Initiative

Eastern Nile Subsidiary Action Program
Eastern Nile Technical Regional Office

EASTERN NILE POWER TRADE PROGRAM STUDY



M4 – HVDC PREPARATION OF SPECIFICATIONS

EDF
Scott Wilson
EPS Electrical Power Systems Engineering Company

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
AF	Availability Factor
AH	Available Hours
AIS	Air Insulated Switch
ANSI	American National Standards Institute
BIL	Basic Impulse Level
CIGRE	International Council on Large Electric Systems
CVD	Capacitive Voltage Divider
CT	Current Transformer
CVT	Capacitive Voltage Transformer
DC	Direct Current
DE	Derating Extension
EA	Energy Availability
EA	Equivalent Availability (only in appendix)
EFDH	Equivalent Forced Derated Hours
EFOR	Equivalent Forced Outage Rate
EHV	Extra High Voltage
EMC	Electro-Magnetic Compatibility
ENTRO	Eastern Nile Technical Regional Office
EPDH	Equivalent Planned Derated Hours
ESDH	Equivalent Scheduled Derated Hours
ESEDH	Equivalent Seasonal Derated Hours
EUDH	Equivalent Unplanned Derated Hours
FDH	Forced Derated Hours
FFTOV	Fundamental Frequency Transient Over-Voltage
FO	Forced Outage
FOF	Forced Outage Factor
FOH	Forced Outage Hours
FOR	Forced Outage Rate
GAC	Gross Available Capacity
GAG	Gross Actual Generation (MWh)
GCF	Gross Capacity Factor

GOF	Gross Output Factor
GDC	Gross Dependable Capacity
GEA	Guarantee for Energy Availability
GEFOR	Guarantee for Equivalent Forced Outage Rate
GIS	Gas Insulate Switch
GMC	Gross Maximum Capacity
GPR	General Purpose Reagent
GRP	Glass Reinforced Protection
GVP	Guarantee Verification Period
HF	High Frequency
HMI	Human Machine Interface
HV	High Voltage
HVDC	High Voltage Direct Current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for standardization
LAN	Local Area Network
LOWS	Local Operator Workstation
MDC	Maximum Dependable Capacity
MDH	Maintenance Derated Hours
MO	Maintenance Outage
MOH	Maintenance Outage Hours
MTBF	Mean Time Between Failures
NAC	Net Availability Capacity
NAG	Net Actual Generation (MWh)
NBI	Nile Basin Initiative
NCF	Net Capacity Factor
NDC	Net Dependable Capacity
NMC	Net Maximum Capacity
NOF	Net Output Factor
OFAF	Oil Forced non-directed-flow and Air Flow
OHL	Overhead Lines
PCB	Poly Chlorinated Biphenyl

PD	Planned Derating
PDH	Planned Derated Hours
PH	Period Hours
PO	Planned Outage
POH	Planned Outage Hours
PSS/E	Power System Simulator for Engineering
p.u	Per Unit
RAM	Reliability Availability and Maintainability
RS	Reserve Shutdown
RSH	Reserve Shutdown Hours
RTDS	Real Time Digital Simulator
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SCL	Short Circuit Levels
SDH	Scheduled Derated Hours
SE	Scheduled Outage Extension
SF	Startup Failure
SH	Service Hours
SOE	Sequence Of Event
SOEH	Scheduled Outage Extension Hours
SOF	Scheduled Outage Factor
SOH	Scheduled Outage Hours
SSO	Sub-Synchronous Oscillation
SVC	Static Voltage Compensator
UH	Unavailable Hours
UDH	Unplanned Derated Hours
UOH	Unplanned Outage Hours
UPS	Uninterruptible Power Supply
VBE	Valve Base Electronic
VBO	Voltage BreakOver
VDU	Visual Display Unit
VME bus	Versa Module Eurocard bus
VTE	Valve Test Equipment

EXECUTIVE SUMMARY

The present document gives the guidelines for the preparation of technical specifications for the two HVDC converter stations located in KOSTI and NAG HAMMADI, including the ground electrod stations for each end.

1 INTRODUCTION

This section provides general description on the two HVDC stations involved by the regional interconnection project between Ethiopia, Sudan and Egypt. These two substations are:

- KOSTI, connected to KOSTI 500 kV substation through two double 500kV AC circuits (about 2 km)
- NAG HAMMADI, connected to NAG HAMMADI 500 kV substation (on the bus bar)

The schedule and interconnection scheme is given here after.

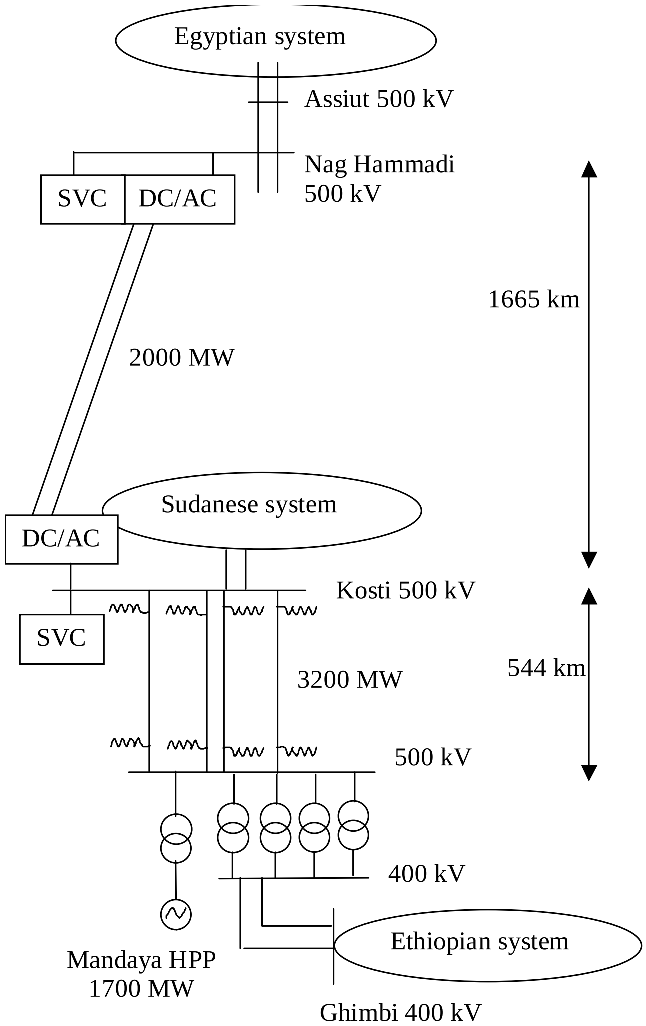


Figure 1 : Interconnection scheme

The particular technical characteristics listed hereafter are the basic requirements for the design of the HVDC Stations.

A list of the mandatory spare parts is proposed in section 10.

2 STANDARD TO BE APPLIED FOR THE DESIGN AND TEST

Description:	Standard:
Metric Standards	ISO 1000:1992
Quality Assurance	ISO 9001:2008
Hot-dip Galvanizing	ISO 1459:1999 ISO 1461:1999
High Voltage Test Techniques	IEC 60060:1989
Insulation Coordination	IEC 60071-1:2006 ;-2:1996
Tests on Post Insulators	IEC 60168:2001
Testing of Semiconductor Valves for HVDC Power Transmission	IEC 60700-1:2008
Semiconductor Devices	IEC 60747:2006
Power Transformers	IEC 60076:2000
Converter Transformers: Transformers for HVDC	IEC 61378-2:2001
On load tap changers	IEC 60214-2:2004
Shunt Capacitors (AC and DC)	IEC 600871-1;-4:2005
Reactors (AC and DC)	IEC 60076-6:2007
Voltage Transformers	IEC 60044-2 :2003
Capacitive Voltage Transformers	IEC 60044-5 :2004
Current Transformers	IEC 60044-1:2003
Bushings	IEC 60137:2008
Bushings for DC Applications	IEC 62199:2004
Selection of insulators	IEC 60815:2008
Disconnectors and Earthing Switches	CEI 62271-102:2001
High Voltage Circuit Breakers	IEC 62271–100:2008
High Voltage Switches	IEC 60265:1998
Surge Arresters	IEC 60099-4:2006
Transducers for Electrical Measurements	IEC 60688 :2002
Optical Fibre Cables	IEC 60794:2003
Insulating Oil for Transformers and Switchgear	IEC 60296:2003
Common clauses for HV switchgear and controls	IEC 60694:2001
Low voltage switchgear/controlgear assemblies	IEC 60439:2004
Electrical Protective Relays	IEC 60255:2008
Control Systems EMC (immunity)	IEC 61000-4-2:2006,-3:2008,-4, -5:2008
Determination of Losses in HVDC Converter Stations	IEC 61803:1999

Table 1 : Applicable standards

3 SCOPE OF SUPPLY

3.1 EQUIPMENT, MATERIAL AND SERVICES TO BE FURNISHED BY THE SUPPLIER

The works carried out under this Contract shall include the design, supply, construction, installation and commissioning of the following permanent plants:

- Converter station “A” in KOSTI
- Converter station “B” in NAG HAMMADI
- Complete electrode station in KOSTI
- Complete electrode station in NAG HAMMADI

The Contractor shall design, produce material, manufacture, test at the factory, transport and deliver to the sites, install, test, commission, put into operation and guarantee the attainment of certain performance criteria with respect to the plants as described in this Specification and/or shown in the drawings.

The Contractor shall deliver to each converter station one complete set of special maintenance equipment and tools together with necessary measuring and testing equipment, which are needed for a proper maintenance of the converter stations. These special tools and maintenance equipment include all the equipment that is only available from the Contractor and his sub-suppliers.

The maintenance, measuring and testing equipment may be used during installation, but any such tool or device which is damaged by the Contractor shall be refinished, repaired or replaced by the Contractor at no extra cost to the Owner.

The Contractor shall organize and conduct, as part of the Scope of Supply, training programs and courses for operation and maintenance personnel prior to the test on site.

Trainees' travel and living expenses will be born by the Owner.

3.2 SPARE PARTS

The Scope of Supply shall include all spare parts necessary for safe operation and maintenance within the stated availability and reliability limits, and for scheduled maintenance of the two converter stations for the first **5 years** of operation.

If a spare part must be used during the Defects Liability Period it shall be replaced at the Contractor's expense.

If during the Defects Liability Period an item should fail, and if no such spare part item was recommended to be kept in stock, the Contractor shall replace this faulty item at his expense, and in addition provide another item to the Owner.

4 GENERAL TECHNICAL SPECIFICATION

4.1 ENVIRONMENT

Environmental conditions are given below for both KOSTI stations :

Maximum ambient temperature	50 ° C
Minimum ambient temperature	0 ° C
Mean Temperature °C	30 ° C
Reference wind speed (gust)	34 m/s
Mean annual Rainfall	14 mm
Humidity	100 %
Pollution	31 mm/kV (class IV)
Keraunic level (thunderstorm day per year):	18
Altitude	<1000m

Table 2 : Climatic and Environmental Conditions - KOSTI

Environmental conditions are given below for both NAG HAMMADI stations :

Maximum ambient temperature	50 ° C
Minimum ambient temperature	0 ° C
Mean Temperature °C	30 ° C
Reference wind speed	34m/s
Mean annual Rainfall	14 mm
Humidity	100 %
Pollution	31 mm/kV (class IV)
Keraunic level (thunderstorm day per year)	
Altitude	<1000m

Table 3 : Climatic and Environmental Conditions – NAG HAMMADI

Special climatic and environmental conditions

Due to the location of the substation (desert zone in vicinity), special attention shall be taken on the design of the insulators. Sand together with humidity can affect the dielectric withstand of the electrical equipment. Pollution class and material (porcelain or synthetic) shall be fixed as a result of the feed back from the Sudanese network.

4.1.1 SEISMIC REQUIREMENTS

The peak ground acceleration to be used are :

- KOSTI substation : 0,4 m/s².
- NAG HAMMADI substation : 0,8 m/s²

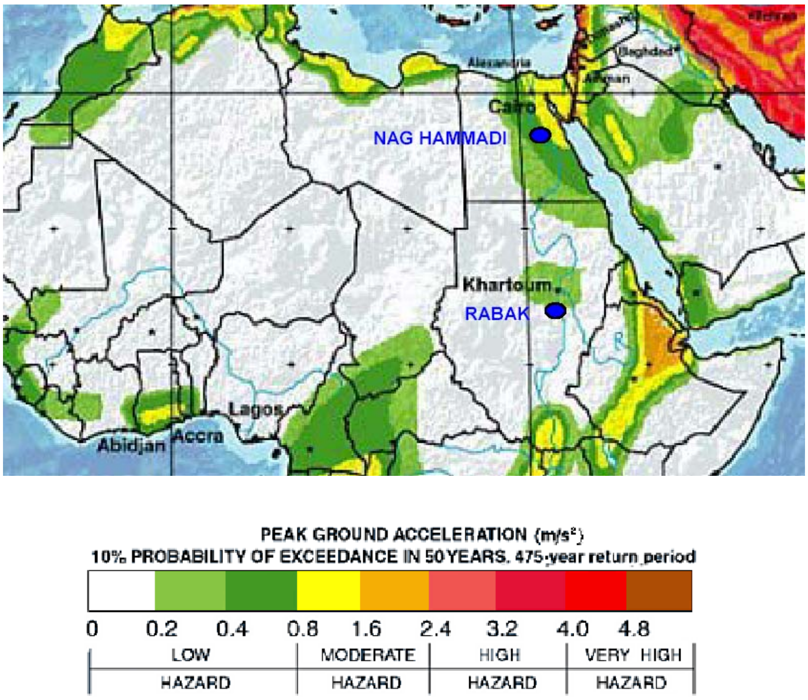


Figure 2. Seismic Activity

4.2 AC SYSTEM CHARACTERISTICS

The provisional applicable data for both stations (KOSTI and NAG HAMMADI) are given below. These data shall be up dated for the final specification (after measurements on site) :

- Nominal voltage is **500** kV (1.0 pu) phase to phase.
- Minimum continuous voltage of **475** kV.
- Maximum continuous voltage of **525** kV.
- Maximum temporary voltage of **650** kV for **5** sec.
- Max negative sequence voltage during normal operation of **1** %.
- Maximum phase to phase voltage unbalance of **2** %.
- Normal base frequency of **50** Hz. Minimum continuous frequency of **49,5** Hz. Maximum continuous frequency of **50,5** Hz.
- Minimum temporary frequency of **49** Hz for **1** hour, **47** Hz for **10** min maximum temporary frequency of **51** Hz for **1** hour, **52** Hz for **10** min.

4.2.1 A.C. SYSTEM FAULT CLEARING

The following clearing times are anticipated for faults in the both **500** kV system (station A and B) :

Initiating relaying	Time
➢ Primary Line	**120 ms**.
➢ Back-up Line	**500 ms**.
➢ Breaker Failure	**1 s**

4.2.2 SHORT-CIRCUIT CHARACTERISTICS

Short Circuit Power	**KOSTI**	**NAG HAMMADI**
Strong System	8 GVA	10 GVA
Weak System	6 GVA	6 GVA

Table 4: Short-Circuit Characteristics

4.2.3

The existing individual harmonic voltage distortion shall need a specific study and site measurements for final specification.

Typical existing distortion in the AC system are proposed below

Maximum steady state harmonic distortion:	**Unit**	**System A**	**System B**
5th harmonic	**[%]**	1	1
7th harmonic	**[%]**	1	1
Maximum temporary harmonic distortion:	**Unit**	**System A**	**System B**
5th harmonic/duration	**[%]/[s]**	1.5 / Steady state (for equipment rating)	1.5 / Steady state (for equipment rating)
7th harmonic/duration	**[%]/[s]**	1.5 / Steady state (for equipment rating)	1.5 / Steady state (for equipment rating)

Table 5: System Voltage Distortions

4.3 HVDC LINE CHARACTERISTICS

4.3.1 OVERHEAD LINE

The DC line, which interconnects the two converter stations, consists of a bipolar overhead line with a steel tower structure.

The line configuration is according to Figure 1.

The line data is:

Characteristics	Unit	Values
Length	**km**	1665
Rated DC voltage	**kV**	600
Lightning impulse withstand level	**kV**	1550
Switching impulse withstand level	**kV**	1300
Line resistance at 2000MW	**Ohm**	15,2 (at 20°C), 17,6 (at 60°C)
Tower footing resistance	**Ohm**	15

Table 6: OHL Characteristics

4.3.2 ELECTRODE LINES AND STATIONS

The required data for electrode lines and stations are given below.

A specific study will be necessary on site to define each parameter for the final specification

Typical values are given below :

Characteristics	Unit	Station A	Station B
Length	**km**	5 to 10	5 to 10
Rated DC voltage	**kV**	20 to 30	20 to 30
Lightning impulse withstand level	**kV**	750	750
Cross section	**mm^2**	1000	1000
Electrode resistance	**Ohm**	**< 0,5**	**< 0,5**

Table 7: Electrode Lines and stations Characteristics

4.4 TELECOMMUNICATION SYSTEM

For the transmission of control signals between the converter terminals an optical system provided by the Owner is foreseen. The terminal equipment at each converter station is to be included.

The transmission shall consist of two channels used for the redundant high speed data exchange of control and protection signals and a data transmission rate of at least 64kBit/s.

A multi-channel telecommunication system will be provided between the converter stations and the regional control center

This telecommunication system will be used for remote control and data acquisition via the remote terminal units (RTUs) at the converter stations.

4.5 DOCUMENTATION

The Contractor shall submit the main design documents for review by the Owner. The review period is maximum 14 calendar days from receipt of documents. Any request for changes from the Owner given outside the review period shall be considered but may be subject to time/price adjustment.

The Contractor shall resubmit the revised documents within 21 calendar days from receipt of the comments from the Owner.

The main design documents to be sent for review are:

- Single line diagram
- Switchyard layouts
- General layout and architecture of the building(s) (if any)
- Maintenance and service plan
- Operation guidelines for the HVDC plant
- Locking and interlocking
- Nameplate drawings for main circuit apparatus

The Contractor shall submit the following documents for information:

- Type test reports
- Routine test reports
- Technical reports
- Equipment specifications for main circuit apparatus
- Dimension drawings for main circuit apparatus
- Main circuit parameters
- One copy of the related standards (IEC, ISO, IEEE…)
- Experience list

The instruction books for the equipment shall contain all information needed for operation and maintenance of the converter station.

The "as-built" plant documentation shall be delivered in a structured fashion no later than three months after start of commercial operation.

4.6 TRAINING OF PERSONNEL

The Contractor shall organize and conduct, as part of the Scope of Supply, thorough training programs for :

- technical and design studies understanding
- operating and maintenance personnel prior to the commercial operation date. Trainee's travel and living expenses will be born by the Owner.

The courses shall also include training in the factory during the testing of the complete HVDC control system, Factory System Test.

The training program shall run for such period of time as is required to enable the trainees to familiarize themselves with the operation and maintenance of the converter station. Appropriate training documentation shall be included.

It is also anticipated that the technical and maintenance personnel take part in the installation and testing work in cooperation with the Contractor's personnel for training purposes. The Contractor is, however, to be responsible for the work.

The participating persons shall have basic knowledge about switchgears and control system and basic computer know-how and have future participation in the plant's operation and/or maintenance.

The participating persons in the training program shall also participate in the commissioning activities.

5 PERFORMANCE GUARANTEES

The Contractor shall fulfill the following guaranteed performance.

5.1 POWER TRANSMISSION CAPACITY

The Contractor shall guarantee the specified transmission capacity, see Section 6.1.

5.2 LOSSES

5.2.1 GUARANTEED LOSSES

The Contractor shall state values for the no-load losses, and load losses at nominal operation. The Contractor shall guarantee the equivalent total losses (P_E), which shall be calculated as follows:

$$P_E = P_0 + P_L$$

where: P_0 *are the no-load losses*
P_L *are the load losses*

The no-load losses are defined as the losses in stand-by operation with the transformers energized and the converter valves blocked.

The load losses to be guaranteed are defined as the total losses at nominal power, nominal ac voltage and frequency, nominal firing angle and at 20 ^oC ambient temperature, minus the no-load losses.

5.2.2 LOSSES CAPITALIZATION

For the final specification, the cost of capitalized losses shall be indicated.

The Vendor shall optimize the losses of its design, in order to be the most competitive for the total cost of the station.

The total cost is given by :

$$C_T = C_I + C_L$$

where : C_I = cost of investment (station cost)
C_L = cost of losses, capitalized on 25 years.

The cost of losses shall be established with :

- The MWh cost for losses at the contract time
- The actualization coefficient

5.2.3 LOSSES TO BE INCLUDED

The losses of the entire main circuit equipment in the Contractor's supply shall be included for the determination of station losses. Furthermore, the Contractor's total active auxiliary power load for equipment cooling and control shall be included.

5.2.4 VERIFICATION OF LOSSES

For main circuit equipment for which the losses that are established at factory test conditions can be considered equivalent to the losses in actual operation, the factory test results shall be used in the listing of station losses.

For equipment where the operational conditions differ from the factory test conditions (which is the case where harmonics influence the losses), the losses shall be calculated. The guidelines given in IEEE Std. 1158-1991 "IEEE Recommended practice for determination of power losses in HVDC converter stations" shall be followed.

The losses shall be determined for Station A operating as rectifier and Station B as inverter.

5.3 AVAILABILITY AND RELIABILITY

The Contractor shall guarantee values for Energy Availability (EA) and Equivalent Forced Outage Rate (EFOR) for the equipment within his Scope of Supply. The guarantee values will be GEA for EA and GEFOR for EFOR.

A definition of EA and EFOR is given in appendix 1.

These guaranteed values shall satisfy the following:

GEA	**= 98 %**
GEFOR	**= 10 (typical value for a bipolar transmission)**

These guaranteed values shall be verified by operational follow-up during a Guarantee Verification Period (GVP) as stipulated below:

The GVP shall begin after a burn-in period of 6 months, beginning when the system has been taken over by the Owner. The verification period shall be 3 years.

If at the end of the GVP the mean value for EA, or EFOR is better than or equal to the guaranteed value, the guarantee for this value is fulfilled.

If at the end of the GVP the mean value for one of EA, or EFOR does not fulfill its guaranteed value, the GVP for this particular value shall be extended by 1 (one) year. If at the end of this extension the best mean value over 3 years, disregarding any 12 consecutive months in the 4 year period, is better than or equal to the guaranteed value, the guarantee is fulfilled for this value.

If at the end of the extended GVP the mean value for one of EA, or EFOR still does not fulfill its guaranteed value, the Contractor shall propose and, after approval by the Owner, make necessary improvements. After the implementation of these improvements the GVP shall be extended by 1 (one) year and the best 3 year mean value, disregarding any 2 years of the 5 year GVP, shall be calculated. If this value is better than the guaranteed value the guarantee is fulfilled.

6 SYSTEM PERFORMANCE

The Contractor shall fulfill the requirements for the overall performance of the system, as defined herein. Fulfillment of the requirements will be demonstrated by acceptance tests, as specified in Section 6.4.

6.1 POWER TRANSMISSION CAPACITY

The transmission capacity stated below refers to the DC line terminal at Station B.

It shall apply to power transfer from Station A to Station B at the rated DC transmission voltage, with the AC network voltage and frequency within their steady state limits and at maximum ambient temperature.

The transmission capacity during power transfer from Station B to Station A shall be the same as Station A to station B (the interconnection shall be completely reversible).

Rated power transmission capacity P_N	2000 MW at the delivery point.
Minimum transmission capacity of converter unit	10 %

6.2 RATED TRANSMISSION VOLTAGE

The rated DC transmission voltage shall be **600 kV**.

6.3 FILTERING AND REACTIVE POWER COMPENSATION

6.3.1 REACTIVE POWER COMPENSATION

6.3.1.1 Station A

The reactive power shall be supplied by capacitor banks, commutation capacitors or AC filters. The reactive power generation shall be determined by the following requirements:

1. The HVDC link shall be self-supporting as regards reactive power load at rated power transmission capacity and at normal operating AC voltage.

2. The reactive power unbalance with the AC network during normal operating conditions shall be minimized.

   - o the maximum size of a single switchable filter bank or shunt capacitor bank shall not exceed **140 MVAr.**

   - o the maximum reactive power exchange with the AC system shall not exceed **140 MVAr**.

The Contractor shall by calculations show the voltage change caused by switching of any of the individual capacitor or filter banks.

6.3.1.2 Station B

The reactive power shall be supplied by capacitor banks, commutation capacitors or ac filters. The reactive power generation shall be determined by the following requirements:

1. The HVDC link shall be self-supporting as regards reactive power load at rated power transmission capacity and at normal operating AC voltage.

2. The reactive power unbalance with the AC network during normal operating conditions shall be minimized.

   o the maximum size of a single switchable filter bank or shunt capacitor bank shall not exceed **140 MVAr**.

   o the maximum reactive power exchange with the AC system shall not exceed **140 MVAr.**

The Contractor shall by calculations show the voltage change caused by switching of any of the individual capacitor or filter banks.

6.3.2 AC FILTERING

The supplier shall consider all characteristic harmonic currents up to order m = 50 and all non-characteristic harmonic currents up to order m = 20.

The supplier shall consider the limits given in table below to design the filters of the stations :

Harmonic	G5/4 planning limit
3	1.5
5	2.0
7	1.5
11	1.0
13	1.0
23	0.5
25	0.5
35	0.41
37	0.40
47	0.36
49	0.35

Table 8 : Harmonic levels

6.3.3 DC FILTERING

DC harmonic filters shall be designed to reduce telephone interference from the DC overhead line and electrode line.

6.4 CONVERTER CONTROL

6.4.1 GENERAL

Each converter shall be equipped with a control system that has been designed to operate satisfactorily under normal as well as abnormal system conditions.

The HVDC system must be stable in all situations, for all AC network configurations specified, and the system must be self-protecting.

The control system shall not contribute with negative damping of sub-synchronous oscillations (SSO) in the AC system.

The control system shall be designed to permit transmission of power in both directions. Fast reversal of power shall be possible. The amount of power transmitted shall be adjustable from 10 percent of rated power to full overload capacity.

Power transmission shall be determined and measured at the DC terminal. The power corresponding to the true physical power exchange at this point shall be displayed.

The power transmission sign shall be positive when the power transfer is from System KOSTI to System NAG HAMMADI.

The control system shall be designed to minimize the tolerance in equidistance of firing the valves in steady state operation, so that the converter station generates a minimum of non-characteristic harmonics.

Local control from the local control room and remote control from the regional dispatch center shall be possible.

6.4.2 REDUNDANCY

All essential parts of the control equipment shall be designed as duplicated systems acting as active or hot standby. At any time only one of the two control systems shall be active, controlling the converter and associated equipment.

The other control system, the standby system, shall be in operation, but the “outputs” from that system shall be disabled. If a fault is detected in the active system, the standby system will take over the control, becoming the new active system. The faulty system (the previously active system) shall not return to operation as a standby system, unless the fault is cleared.

6.4.3 SELF-SUPERVISION

The control equipment shall, as far as possible, be built to avoid periodic maintenance and provide shortest possible repair times. The maintenance of the control equipment shall (due to the redundant design) not require any periodic shut down of any main circuit equipment.

Maintenance shall be minimized by the use of self-supervision built into all microprocessor- based electronic units and the possibility to check all measured values during operation without disturbing the operation of the transmission link.

The microprocessor-based systems shall include internal supervision functions below :

- Auxiliary power supervision
- Program execution supervision (stall alarm)
- Memory test (both program and data memory)

The operation of possible field busses shall be monitored by a supervisory function in the control and protection systems, continuously reading from each individual node of the system.

Any detected faults shall generate an event record and shall initiate a switchover to the standby system.

Integrated self-supervision of the high-voltage switchgear control units shall also be included to detect the following:

- Failure of the output circuits to the breaker
- Ground faults of the close/trip lines to the breaker
- Close/trip coil failure of the breaker

6.4.4 POWER CONTROL

Power control shall be the normal mode of control.

Changes in the amount of power transmitted shall be carried out automatically at a constant rate after a new power order and rate of change (in MW/minute) have been set and initiated.

The control commands shall be absolute values and shall comprise:

- Sign of order value (+ for power transfer from System KOSTI to System NAG HAMMADI)
- Order value, resolution 2 MW
- Rate of change, resolution 2 MW/min
- Initiation command
- Stop regulation command

Power control commands shall be given as one of the following alternatives:

- power control command from the local control room (local control)
- power control command from the remote dispatch center (remote control)

6.4.5 RECOVERY AFTER A.C. NETWORK FAULTS

The design target for the control system shall be to restore the power transfer to 90 percent of the pre-fault power within **200 ms** after clearing a single-phase or three-phase AC fault at the rectifier side, and within **200 ms** after clearing a fault at the inverter side.

6.5 SYSTEM PROTECTION

6.5.1 GENERAL

All protection equipments shall be suitably restrained or stabilized to prevent incorrect operation of the protections during system transients and AC system fault conditions. The protections shall be arranged so that suitable redundancy is obtained. Loss of one auxiliary power source shall not result in loss of the protection system.

If suitable, protections should have selectivity between switchover order and trip and block order. The selectivity between switchover order and trip and block orders from a protection can be accomplished by setting a lower level criteria and a shorter pick-up delay for the switchover order.

Special protection requirements for the equipment are specified in Section 7.

The protective equipment shall include, but not be limited to, the following:

- Commutation failure protection
- Short-circuit protection
- DC line harmonic protection for the detection of the fundamental and the second harmonic in the DC line voltage.
- DC line ground-fault protection. This shall have an automatic restart feature with provision for selection of 0, 1, 2, or 3 restart attempts prior to the final tripping. The time for arc clearing shall be adjustable.
- DC bus differential protection for detection of ground faults in the DC yard.
- DC overcurrent protection

The protections shall be arranged so that suitable redundancy and backup are obtained.

6.6 INSULATION COORDINATION

The converter stations shall be protected by surge arresters as per Section 5.8. The arresters shall be selected as outlined in the CIGRE WG 33/14.05 report "Guidelines for the application of metal oxide arresters without gaps for HVDC converter stations".

For the lightning study, multiple strokes shall be assumed as normal occurrence. As for multiple strokes, see Electra No. 69, March 1980, p. 65-102.

The following insulation margins shall be selected for impulse voltages:

Thyristor valves, excluding redundant thyristors	10 %	for all stresses
Oil insulation	15 %	for switching surges
	20 %	for lightning surges
Other	15 %	for switching surges
	20 %	for lightning surges

6.7 ACOUSTIC NOISE

Acoustic noise from the installations given as the equivalent, constant and corrected dB(A) L_{eq} noise pressure level, shall not exceed the recommended emission values at typical locations provided in the table below.

The level of audible noise inside the SVC building should not exceed 80 dB(A) in areas where personnel are permitted during HVDC operation. Audible sound shall be further limited to not exceed 50 dB(A) in the control room.

Typical Requirements:

Location	Noise pressure level , L_{eq} ; [dB(A)]
Inside Station	$\leq$ 90
At the fence boundary line	$\leq$ 65
150 m from equipment boundary line	$\leq$ 55
In the control room	$\leq$ 50

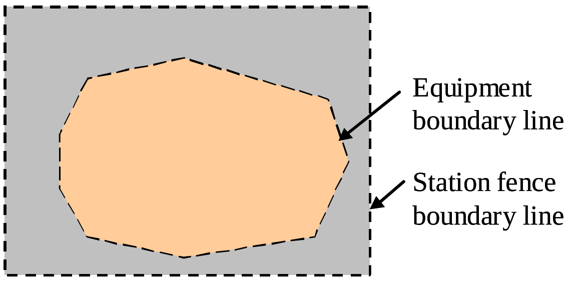


Table 9 : Acoustic Noise Typical Requirements

7 EQUIPMENT AND SUB-SYSTEMS

7.1 GENERAL REQUIREMENTS

The Contractor undertakes to fulfill the following general requirements in the design of apparatus and sub-systems.

Components containing PCB or similar materials will not be accepted.

All electrical and electronic switchboards and cabinets shall be made of metal, and they shall be reliably grounded. If junction and terminal boxes are metal-enclosed, they shall be reliably grounded.

Apparatus tests shall demonstrate that the equipment fulfills the specified requirements and has the ability to perform as intended.

7.2 FILTER BANKS

7.2.1 AC FILTERS

7.2.1.1 Component rating

The mechanical and thermal design of the filter components shall be such that no constraints are imposed on the operation of the plant in the voltage and frequency range.

7.2.1.2 Protection

Adequate protection with alarm and trip levels shall be provided for the filter components. The protection system shall include capacitor unbalance protection and thermal overload protection.

7.2.2 DC FILTERS

7.2.2.1 Component rating

The mechanical and thermal design of the filter components shall be such that no constraints are imposed on the operation of the plant in the voltage and frequency range given in Section 2.3.

7.2.2.2 Protection

An adequate thermal overload protection with alarm and trip levels shall be provided for filter reactors and resistors.

It is foreseen that element failures in the DC filter capacitor are detected by capacitance measurement during the maintenance stops. An adequate interval for these measurements shall be given.

7.3 CONVERTER TRANSFORMERS

7.3.1 TRANSFORMER DESIGN REQUIREMENTS

The transformers shall be of oil-immersed type with cooling method OFAF and temperature Class A according to IEC 76.

The rated exact power shall be determined by the main components ratings study (made by the Vendor).

On-load tap changers shall be incorporated on the a.c. network (line) side of the transformers. The range of regulation shall be determined by the Vendor studies, according to the performances specified for the HVDC Station.

The transformers shall be single phased type, with 2 or 3 windings (1 primary and 1 or 2 secondaries). A spare part shall be provide for each station. This spare can be used for both poles of the bipolar station.

The line side windings shall be connected in star and directly grounded. The secondary windings shall be connected in star for one , and in delta for the other one.

Insulation withstand voltages on the AC line side of the transformers shall be equal to or exceed those given in the Table below:

Insulation Level / Primary Winding	
Power frequency withstand voltage (lines/neutral)	680/275 kV
Lightning impulse level (lines/neutral)	1550/650 kV
Switching impulse level	1300 kV

Table 10 : Insulation Levels for Converter Transformers

On the valve side of the converter transformers, the Contractor shall select appropriate insulation levels in accordance with his insulation coordination design with due consideration to the minimum insulation margins provided in Section 4.8. The test voltages for the valve side shall be in accordance with Electra No. 46, May 1976 "Voltage tests on transformers and smoothing reactors for HVDC transmission".

The valve side windings shall be connected in delta and star to form the 12-pulse operating condition with the converter unit. Bushings of the same voltage and current rating shall be interchangeable for all transformers.

The transformers shall be provided with the necessary instrumentation and at least the following protections:

- Gas detection relays
- Oil and winding temperature contact thermometers
- High speed restrained differential protection
- Overcurrent protection
- Oil level gauge

7.3.2 TRANSFORMER INSTALLATION

Each transformer shall be mounted on wheels, in order to change with a spare in the shortest time.

The spares shall be totally mounted, and oil treated (ready for use). The auxiliary cubicles shall be heated just like the main transformer.

Fire protection walls shall separate each transformer.

7.3.3 TRANSFORMER TRANSPORTATION

The maximum size of transformer shall be determined by the Owner for the final edition of the specification. The aim is ensure the transportation possibilities (bridges limits, railway limits, road transportation limits, etc…).

For information : The typical dimensions of the single phased converter transformers of a 1000 MW pole are given below :

Transportation size for ingle phased converter transformers		
	3 windings type	**2 windings type**
Rated power	≈ 390 MVA	≈ 195 MVA
Length	≈ 9 m	≈ 6 m
Width	≈ 4 m	≈ 3 m
High	≈ 5 m	≈ 5 m
Weight	≈ 280 tons	≈160 tons
Oil	≈ 50 tons	≈ 30 tons

Table 11 : Transformer Transportation

7.4 CONVERTER VALVES

The thyristor valves shall be designed to ensure satisfactory operation according to the overall performance requirements for the HVDC transmission system. The valves shall be air insulated, water-cooled and of indoor design.

The minimum time between maintenance periods shall be at least one year.

The valves shall be provided with all necessary protection devices.

7.5 DC SMOOTHING REACTOR

The DC smoothing reactor shall be designed to ensure satisfactory operation according to the overall performance requirements for the HVDC transmission system.

The design of the reactor shall consider any disturbances in the transmission system, which may cause transient overvoltage or overcurrent stresses on the reactor.

The DC smoothing reactor shall preferably be of air-core dry-type design according to IEC 85.

The reactor shall be complete with all necessary instrumentation.

7.6 DISCONNECTORS, GROUNDING SWITCHES AND INTERLOCKING

All disconnectors and grounding switches shall be designed to ensure satisfactory operation and maintenance.

All disconnectors shall be motor-operated, but with provision for manual operation.

All disconnectors and grounding switches shall have a clearly visible position-indicating device.

An interlocking scheme shall prevent unpermitted operation. The interlocking system shall include:

- The AC disconnectors and grounding switches for the converter transformers.
- All disconnectors, grounding switches etc., within the Scope of Supply.
- Doors in the valve hall, if any.
- Valve service platform.

7.7 INSULATORS AND BUSHINGS

All bushings and insulators shall be ceramic type.

Creepage distances, based on crest terminal-to-flange voltage, shall be as follows:

Outdoor/indoor insulators and bushings are subjected requirements summarizing in the following table :

Outdoor	**Unit**	**Values**
Type		Ceramic
AC voltage	minimum, mm/kV	31
DC voltage	minimum, mm/kV	40
DC with AC component	minimum, mm/kV	40
Indoor	**Unit**	**Values**
DC & AC voltage	minimum mm/kV	14

Table 12 : Outdoor/Indoor insulators and bushings

7.8 SURGE ARRESTERS

Only arresters of metal-oxide type will be accepted.

The protective characteristics of the arresters shall be selected by the Contractor to coordinate system protection, subject to approval by the Owner.

7.9 AUXILIARY POWER SYSTEM

The auxiliary power system shall be designed to fulfill the following requirements:

- Operation of the converters shall not be affected by loss of one source of the main AC auxiliary supplies, i.e. the auxiliary power system shall be able to overlap the time required for switching all loads over from the failing supply to the operating supply.
- With loss of the entire AC auxiliary power system, automatically controlled shut-down of the converters shall take place. Immediately after recovery of the auxiliary power supply, start-up of the converters shall be possible.

7.10 COOLING SYSTEMS

The cooling system for the valves shall be capable of cooling all the heat produced by the valves in any specified mode of operation.

All fine water circuit components, i.e. piping, valves, heat exchangers, filters etc., shall be made of stainless steel of quality as ANSI 304 L or ANSI 316 L.

The control system for operating and monitoring of the cooling plant shall be included in the delivery. It shall be possible to operate and monitor the cooling process from the control room.

Each converter pole shall be supplied with its own fully independent cooling system.

7.11 FIRE PROTECTION SYSTEM

In the event of a fire being discovered, a fire alarm signal is to be transmitted:

- locally in all buildings
- to the remote control center
- to the local fire brigade

The fire alarm device shall be designed in such a way that:

- it operates automatically, i.e. itself discovers and indicates an incipient fire.
- it is self-monitoring, i.e. important functions are monitored in such a way that a fault affecting the function of the installation triggers off a fault alarm, which is indicated locally and in the monitoring center.
- ventilation etc. shall be designed and controlled to minimize the spread of fire and smoke to fire cells not directly affected by the fire.

For buildings the fire protection shall follow the local regulations.

7.12 CONTROL, PROTECTION AND MEASURING EQUIPMENT

7.12.1 GENERAL REQUIREMENTS

The design of the control system shall be flexible enough to enable changes required by application development. A computer based control system will be preferred.

A high degree of control system hardware and software reliability is required. The control system shall be duplicated and shall be designed so that the control system not in use can be tested and serviced during normal operation of the HVDC converter station.

The control and protection systems shall be designed so that loss of one auxiliary power source does not result in loss of the control or protection systems. Two Owners will provide two independent auxiliary power supplies.

Terminal blocks and other components for connection of external cables shall be located in the lower part of the control system cabinets, or in separate termination cabinets.

All control cables shall be shielded. All cabling for converging low level analogue signals shall use individually shielded and twisted pairs in overall shielded cables. The shielding of signal cables shall be insulated when taken through junction boxes.

7.12.2 OPERATING FACILITIES

The control system shall be designed to permit control and monitoring of the HVDC Back-to-Back converter stations either from a local control room within each station or from a remote dispatch center. A local operator workstation (LOWS) shall be located at both converter stations. Any change in control settings carried out from the dispatch center shall be monitored in the LOWS at the concerned converter station and vice versa. Switching between local and remote control shall be made from the LOWS.

The local control room shall be equipped with monitoring facilities so that the operator can easily survey the state of the converter station. It shall be possible to initiate all control actions necessary for the daily operation, including shutdown and start-up of the converter station, locally as well as from the remote dispatch center, if any.

In the operator workstation environment all necessary tools for configuration and operation shall be included.

The LOWS shall be provided with, but not be limited to, the following functions.

- Logon/logoff
- Control window
- Event recorder
- Alarm and Fault list
- Trend window

Different users with different access levels shall be able to logon to the LOWS.

The Event recorder shall store all events generated in the HVDC Back-to-Back station and have possibilities to show events as they appear and for a specified historical time span.

The Alarm list shall show all alarms generated in the station and it shall be possible to acknowledge the alarms one by one or all at once. The Fault list shall show the actual status of the station with all present alarms.

It shall be possible to see variations in specified signals in a real time Trend window. It shall also be possible to store information regarding specified signals and view them later, or export the data to a file center.

7.12.3 FAULT RECORDING

To facilitate the analysis of malfunctions and system disturbances, the Contractor shall provide equipment for high speed, analogue and digital fault recording of significant quantities, i.e. DC and AC voltages, currents, and selected control and protection signals.

Measuring and event indication devices suitable for cooperation with the fault recorder, and devices for starting the fault recorder in the event of faults and major disturbances shall be provided.

Transmission of the recorded digital data to a remote control center shall be possible.

The fault recorders shall be equipped with a clock. It shall be possible to synchronize this clock from a central time source

8 TESTING AND TRIAL OPERATION

8.1 GENERAL REQUIREMENTS

All equipment within the Scope of Supply of the Contractor shall be comprehensively tested in order to demonstrate that they meet the specified requirements and fulfill the guarantees.

The Contractor is responsible for the performance of the tests required in these Specifications.

The tests shall be divided into three main groups:

1. Factory tests

   To the extent possible, equipment shall be assembled in large units or sub-systems in the Contractor's factory and be tested prior to shipping.

   The test reports shall be forwarded to the Owner immediately upon completion of the tests. The Owner's acceptance shall be obtained prior to shipping of the equipment.

2. Sub-system and component tests after mounting and installation.

   This test program shall include verification tests of components and sub-systems that can be carried out prior to the final testing of the complete Scope of Supply.

3. System and acceptance tests.

   This test program shall be carried out after sub-system and component tests, and be performed according to the Contractor's proposed test program.

The Contractor shall submit a list of tests with a preliminary time schedule for system tests and acceptance tests with his Tender. The test programs shall be approved by the Owner.

Two months before the start of the system test period, the Contractor shall provide a test time schedule and final test program for the tests. The test program shall indicate the need for power supply, connection of main circuits, and other information necessary for the system planning and operation.

The Owner reserves the right, in collaboration with the Contractor, to make alterations in the test program.

8.2 EQUIPMENT TESTS

All individual components shall, without any additional cost to the Owner, be subjected to manufacturing tests according to:

1. Specifications in this Section
2. "Voltage tests on transformers and smoothing reactors for HVDC transmission", Electra No. 46, May 1976.
3. Applicable IEC (or ANSI) standards

4. IEC 700 for testing of thyristor valves.

5. CIGRE report 33-14-1986: "Stresses on metal-oxide arresters in HVAC and HVDC systems by temporary and transient overvoltages and related tests."

Type tests shall be performed on one unit of each design with the specific design and rating used for this project. Type tests proved by certified test reports on tests previously performed on a component with similar design and rating may be accepted as type tests.

All type and routine tests to be carried out shall be witnessed by an authorized inspecting engineer, unless permission to proceed with the test in his absence has been given by the Owner.

8.3 SYSTEM TESTS

Prior to trial operation there shall be a testing period. The purpose of this test period is to permit:

- Equipment inspection and verification at the site (on site equipment test).
- Functional tests and final adjustment of sub-systems and systems.
- Tests at rated voltage
- Tests at rated current and specified overload

During the high voltage energization and on load testing period, normal operating procedures shall be followed regarding switching, power dispatching and access to high voltage areas. The staff necessary for performing these tasks will be provided by the Owner. When the high voltage energization tests have started, all temporary connections or similar arrangements in the high voltage circuiting are to be performed by the Owner's personnel.

8.4 TRIAL OPERATION AND ACCEPTANCE TESTS

As soon as commissioning and system tests are completed, the Contractor shall advise the Owner in writing that the equipment is ready for service.

From the time the Contractor has stated in writing that the equipment is ready for service, trial operation shall start and last for a minimum of one month, to confirm to the Owner that the system is working satisfactorily.

During the trial operation, the Contractor shall on his own account provide sufficient supervising engineers and service personnel on site.

The Contractor's engineers shall supervise the equipment on site and instruct the Owner's operating personnel, and at the same time assist the Owner in testing etc.

9 LIST OF STUDIES

The List of Technical Studies to be done by HVDC system vendor is given below :

9.1 STATION ENGINNERING

- Audible noise

9.2 SYSTEM VERIFICATION

- Load Flows & Short Circuit Levels (SCL)
- Equivalent Networks for AC Systems
- Fundamental Frequency Transient Over-Voltage FFTOV
- Power System Transient Stability using PSS/E
- Dynamic Interaction Study using PSS/E
- Dynamic Performance using EMTDC
- Performance Studies using Real Time Digital Simulator (RTDS)
- Sub-Synchronous Oscillation (SSO) Study

9.3 SYSTEM DESIGN

- Main circuit design and parameters
- Reactive Power Management
- Power circuit arrangement
- Thermal ratings of key equipment
- Insulation co-ordination
- Transient overvoltage study
- Filter design (AC, DC, HF as applicable)
- Loss calculation
- Reliability Availability and Maintainability (RAM)
- Electromagnetic Interference
- Ground electrode stations design

10 TYPICAL MANDATORY SPARE PARTS

The appropriate list of spare parts shall be defined by the Contractor.

The Contractor shall demonstrate in the Reliability Availability and Maintainability study (RAM) that the guaranteed value of availability of the total scheme is fulfilled, based on MTBF of components and the appropriate spare parts list.

The list given below is assumed to be the minimum list for a 2000 MW scheme, with high availability.

Typical Availability Spare Parts (minimum)	Quantity Station A	Quantity Station B
Converter Transformer pole (each type in case of 2 windings design)	1	1
Thyristor Valve Spares	1 set	1 set
Converter Control / SCADA Spares	1 set	1 set
Converter Transformer Spares	1 set	1 set
AC Filter Spares	1 set	1 set
Cooling Plant Spares	1 set	1 set
Surge Arresters Spares	1 set	1 set
Protection Relays	1 set	1 set
LV Cables	1 set	1 set
Auxiliary power transformer	1	1
Individual Thyristors	10	10
Reactor (for Valve Module)	1	1
Firing pulse transmitter	2	2
1 of each type of valve arrester	1 set	1 set
Complete circuit breaker (3 poles)	1	1
Complete disconnector switch (3 poles)	1	1
Disconnector switch motor mechanism	1	1

1 of each type of capacitor	1 set	1 set
1 of each type of filter inductor	1 set	1 set
1 of each type of filter resistor	1 set	1 set
1 of each type of filter CT	1 set	1 set
1 of each type of surge arrester	1 set	1 set
1 of each type of support insulator	1 set	1 set
1 off each main circuit VT and CT	1 set	1 set
Valve cooling heat exchanger fan + motor	1	1
Valve cooling circulating pump + motor	1	1
1 of each type of protection Relay	1 set	1 set
1 of each type of printed circuit board	1 set	1 set
Transducers for valve cooling system	1 set	1 set

Table 13 : Typical Mandatory Spare Parts

The typical list of test equipment, tools and fixture is given below :

Test equipment, special tools, and fixtures	Quantity Station A	Quantity Station B
VTE Calibration unit	1	1
Valve Hall Maintenance Platform	1	1
Thyristor Replacement Tool	1	1
Voltage Divider Calibration Tool	1	1
VME extender Card	1	1
Firmware Update Tool	1	1

Table 14 : Typical Test Equipments

APPENDIX 1 : OPERATION AND OUTAGE STATES DEFINITION

Operation and outage states

Actual Unit Starts

Number of times the unit was actually synchronized

Attempted Unit Starts

Number of attempts to synchronize the unit after being shutdown. Repeated failures to start for the same cause, without attempting corrective action, are considered a single attempt.

Available

State in which a unit is capable of providing service, whether or not it is actually in service, regardless of the capacity level that can be provided.

Forced Derating (D1, D2, D3)

An unplanned component failure (immediate, delayed, postponed) or other condition that requires the load on the unit be reduced immediately or before the next weekend.

Forced Outage (U1, U2, U3, SF)

An unplanned component failure (immediate, delayed, postponed, startup failure) or other condition that requires the unit be removed from service immediately or before the next weekend.

Maintenance Derating (D4)

The removal of a component for scheduled repairs that can be deferred beyond the end of the next weekend, but requires a reduction of capacity before the next planned outage.

Maintenance Outage (MO)

The removal of a unit from service to perform work on specific components that can be deferred beyond the end of the next weekend, but requires the unit be removed from service before the next planned outage. Typically, a MO may occur anytime during the year, have flexible start dates, and may or may not have a predetermined duration.

Planned Derating (PD)

The removal of a component for repairs that is scheduled well in advance and has a predetermined duration.

Planned Outage (PO)

The removal of a unit from service to perform work on specific components that is scheduled well in advance and has a predetermined duration (e.g., annual overhaul, inspections, testing).

Reserve Shutdown (RS)

A state in which a unit is available but not in service for economic reasons.

Scheduled Deratings (D4, PD)

Scheduled deratings are a combination of maintenance and planned deratings.

Scheduled Derating Extension (DE)

The extension of a maintenance or planned derating.

Scheduled Outages (MO, PO)

Scheduled outages are a combination of maintenance and planned outages.

Scheduled Outage Extension (SE)

The extension of a maintenance or planned outage.

Unavailable

State in which a unit is not capable of operation because of the failure of a component, external restriction, testing, work being performed, or some adverse condition.

Time

Available Hours (AH)

a. Sum of all Service Hours (SH), Reserve Shutdown Hours (RSH), Pumping Hours, and Synchronous Condensing Hours, or;

b. Period Hours (PH) less Planned Outage Hours (POH), Forced Outage Hours (FOH), and Maintenance Outage Hours (MOH).

Equivalent Forced Derated Hours (EFDH)*

The product of the Forced Derated Hours (FDH) and the Size of Reduction, divided by the Net Maximum Capacity (NMC).

Equivalent Forced Derated Hours During

Reserve Shutdowns (EFDHRS)*

The product of the Forced Derated Hours (FDH) (during Reserve Shutdowns (RS) only) and the Size of Reduction, divided by the Net Maximum Capacity (NMC).

Equivalent Planned Derated Hours (EPDH)*

The product of the Planned Derated Hours (PDH) and the Size of Reduction, divided by the Net Maximum Capacity (NMC).

Equivalent Scheduled Derated Hours (ESDH)*

The product of the Scheduled Derated Hours (SDH) and the Size of Reduction, divided by the Net Maximum Capacity (NMC).

Equivalent Seasonal Derated Hours (ESEDH)*

Net Maximum Capacity (NMC) less the Net Dependable Capacity (NDC), multiplied by the Available Hours (AH) and divided by the Net Maximum Capacity (NMC).

Equivalent Unplanned Derated Hours (EUDH)*

The product of the Unplanned Derated Hours (UDH) and the Size of Reduction, divided by the Net Maximum Capacity (NMC).

Forced Derated Hours (FDH)

Sum of all hours experienced during Forced Deratings (D1, D2, D3).

Forced Outage Hours (FOH)

Sum of all hours experienced during Forced Outages (U1, U2, U3, SF).

Maintenance Derated Hours (MDH)

Sum of all hours experienced during Maintenance Deratings (D4) and Scheduled Derating Extensions (DE) of any Maintenance Deratings (D4).

Maintenance Outage Hours (MOH)

Sum of all hours experienced during Maintenance Outages (MO) and Scheduled Outage Extensions (SE) of any Maintenance Outages (MO).

Period Hours (PH)

Number of hours a unit was in the active state.

Planned Derated Hours (PDH)

Sum of all hours experienced during Planned Deratings (PD) and Scheduled Derating Extensions (DE) of any Planned Deratings (PD).

Planned Outage Hours (POH)

Sum of all hours experienced during Planned Outages (PO) and Scheduled Outage Extensions (SE) of any Planned Outages (PO).

Reserve Shutdown Hours (RSH)

Sum of all hours experienced during Reserve Shutdowns (RS). Some classes of units, such as gas turbines and jet engines, are not required to report Reserve Shutdown (RS) events. Reserve Shutdown Hours (RSH) for these units may be computed by subtracting the reported Service Hours (SH), Pumping Hours, Synchronous Condensing Hours, and all the outage hours from the Period Hours (PH).

Scheduled Derated Hours (SDH)

Sum of all hours experienced during Planned Deratings (PD), Maintenance Deratings (D4) and Scheduled Derating Extensions (DE) of any Maintenance Deratings (D4) and Planned Deratings (PD).

Scheduled Outage Extension Hours (SOEH)

Sum of all hours experienced during Scheduled Outage Extensions (SE) of any Maintenance Outages (MO) and Planned Outages (PO).

Scheduled Outage Hours (SOH)

Sum of all hours experienced during Planned Outages (PO), Maintenance Outages (MO), and Scheduled Outage Extensions (SE) of any Maintenance Outages (MO) and Planned Outages (PO).

Service Hours (SH)

Total number of hours a unit was electrically connected to the system.

Synchronous Condensing Hours

Total number of hours a unit was operated in the synchronous condensing mode.

Unavailable Hours (UH)

Sum of all Forced Outage Hours (FOH), Maintenance Outage Hours (MOH), and Planned Outage Hours (POH).

Unplanned Derated Hours (UDH)

Sum of all hours experienced during Forced Deratings (D1, D2, D3), Maintenance Deratings (D4), and Scheduled Derating Extensions (DE) of any Maintenance Deratings (D4).

Unplanned Outage Hours (UOH)

Sum of all hours experienced during Forced Outages (U1, U2, U3, SF), Maintenance Outages (MO), and Scheduled Outage Extensions (SE) of any Maintenance Outages (MO).

Capacity and Energy

Gross Maximum Capacity (GMC)

Maximum capacity a unit can sustain over a specified period of time when not restricted by seasonal, or other deratings.

Gross Dependable Capacity (GDC)

GMC modified for seasonal limitations over a specified period of time. The GDC and MDC (Maximum Dependable Capacity) used in previous GADS reports are the same in intent and purpose.

Gross Available Capacity (GAC)

Greatest capacity at which a unit can operate with a reduction imposed by a derating.

Gross Actual Generation (MWh) (GAG)

Actual number of electrical megawatthours generated by the unit during the period being considered.

Net Maximum Capacity (NMC)

GMC less the unit capacity utilized for that unit's station service or auxiliaries.

Net Dependable Capacity (NDC)

GDC less the unit capacity utilized for that unit's station service or auxiliaries.

Net Availability Capacity (NAC)

GAC less the unit capacity utilized for that unit's station service or auxiliaries.

Net Actual Generation (MWh) (NAG)

Actual number of electrical megawatthours generated by the unit during the period being considered less any generation (MWh) utilized for that unit's station service or auxiliaries.

*Notes:

-- Equivalent hours are computed for each derating and then summed.

-- Size of reduction is determined by subtracting the Net Available Capacity (NAC) from the Net Dependable Capacity (NDC). In cases of multiple deratings, the Size of Reduction of each derating is the difference in the Net Available Capacity of the unit prior to the initiation of the derating and the reported Net Available Capacity as a result of the derating.

Equations

Availability Factor (AF)

[AH/PH] x 100 (%)

Equivalent Availability (EA)

[(AH - (EUDH + EPDH + ESEDH))/PH] x 100 (%)

Equivalent Forced Outage Rate (EFOR)

[(FOH + EFDH)/(FOH + SH + EFDHRS)] x 100 (%)

Forced Outage Factor (FOF)

[FOH/PH] x 100 (%)

Forced Outage Rate (FOR)

[FOH/(FOH + SH)] x 100 (%)

Gross Capacity Factor (GCF)

[Gross Actual Generation/(PH x GMC)] x 100 (%)

Gross Output Factor (GOF)

[Gross Actual Generation/(SH x GMC)] x 100 (%)

Net Capacity Factor (NCF)

[Net Actual Generation/(PH x NMC)] x 100 (%)

Net Output Factor (NOF)

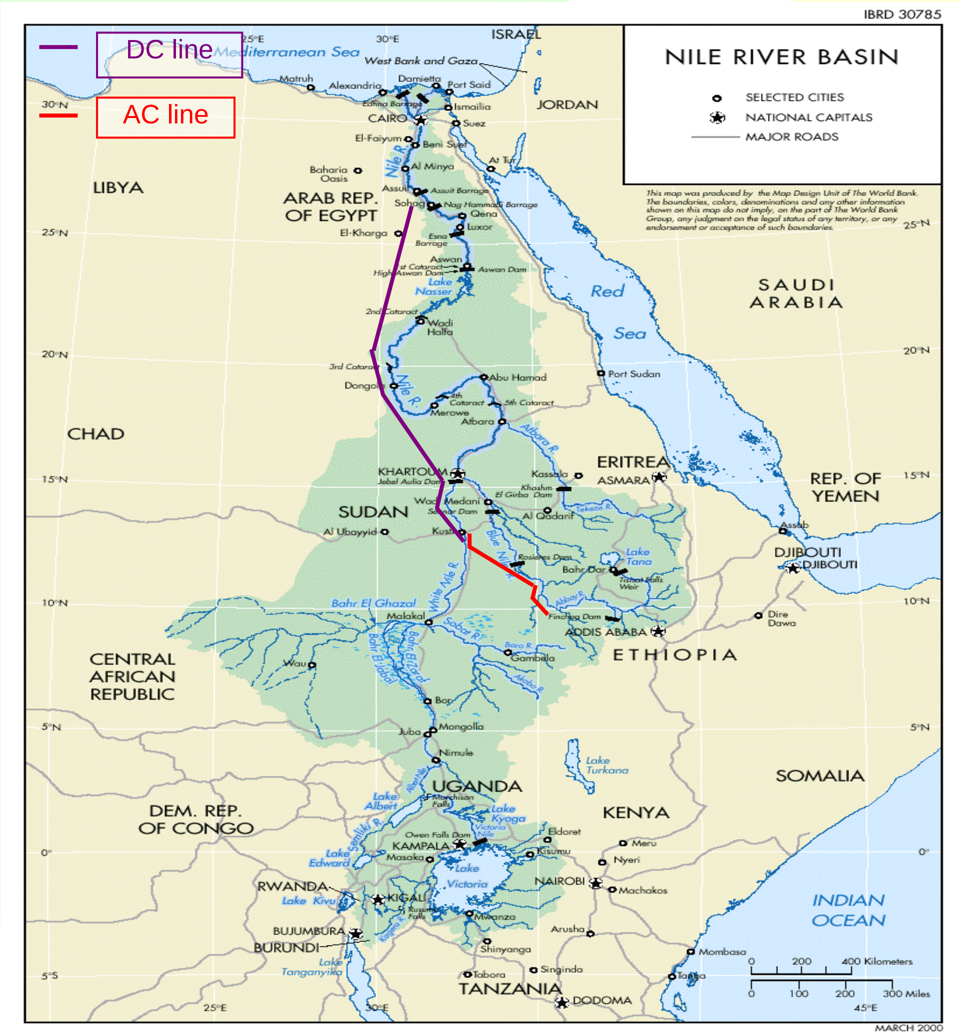
[Net Actual Generation/(SH x NMC)] x 100 (%)

Scheduled Outage Factor (SOF)

[SOH/PH] x 100 (%)

Nile Basin Initiative
Eastern Nile Subsidiary Action Program
Eastern Nile Technical Regional Office

EASTERN NILE POWER TRADE PROGRAM STUDY



M5 - OPERATION & MAINTENANCE

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
ACL	Access Control List
ASCR	Aluminium Conductor Steel Reinforced
BCM	Bipole Control Mode
CBDS	Control Break Disconnector
CGC	Converter Group Control
CRM	Customer Relationship Management
CT	Current Transformer
CVT	Capacitive Voltage Transformer
DC	Direct Current
ES	Earthing Switch
EHV	Extra High Voltage
EHVAC	Extra High Voltage Alternating Current
ENTRO	Eastern Nile Technical Regional Office
HMI	Human Machine Interface
HPP	Hydro Power Plant
HR	Human Resources
HV	High Voltage
HVDC	High Voltage Direct Current
I/O	Input/Output
IP	Internet Protocol
IR	Infra Red
ISDN	Integrated Services Digital network
IT	Information Technology
KN	Kilo Newton
KV	KiloVolt
LAN	Local area Network
LCP	Local Control Point
LV	Low Voltage

MCM	Manual Control Mode
NBI	Nile Basin Initiative
NR	Neutral Reactor
O/C	Open Circuit
OHL	Overhead Lines
OHTL	Over head Transmission Line
O&M	Operations and Maintenance
OPGW	Optic Fiber Ground Wire
PC	Pole Control
PDS	Pantograph Disconnector
PFC	Power Frequency Control
PMC	Power Modulation Control
PT	Power Transformer
RCP	Remote Control Point
RFE	Ready for Energization
RFS	Ready For Service
QoS	Quality of Service
SCL	Short Circuit Levels
SC	Station Control
SCADA	Supervisory Control And Data Acquisition
SDH	Synchronous Digital Hierarchy
SR	Shunt Reactor
SVC	Static Voltage Compensator
TSO	Transmission System Operator
UV	Ultra Violet
VPN	Virtual Private Network

EXECUTIVE SUMMARY

The purpose of this document entitled "M5 – Operation and Maintenance – Final Report" is to introduce O&M strategy for all interconnection infrastructures located on the three countries Egypt, Ethiopia and Sudan.

Training requirements inherent to the O&M of interconnection assets is developed separately in the Module 9: entitled "M9 – TRAINING – FINAL REPORT".

This report is divided into four (4) sub-modules relating to the different equipment types involved by this regional interconnection project :

- O&M for 400 & 500kV substations (including SVC)
- O&M for HVDC converter stations
- O&M for Overhead Lines
- O&M for Control systems, SCADA and metering

The first sub-module provides with general description on O&M for the three AC substations of Mandaya, Kosti, Nag-Hammadi and for SVC. The projected maintenance policy is based on a programme of preventive maintenance and corrective maintenance. These two types of maintenance are described in terms of activities and scheduling.

Regarding HVDC converter stations, an operational overview is given describing the structure of the control system, operational states and start up or shut down scenarios; the HMI is described with the main mimics. Then, routine and corrective maintenance activities are detailed. They range from monthly and yearly surveillance in-operation to actions out of operation.

For OHL, the mechanicals of 500 kV AC and 600 kV DC hotline maintenance are identical, but there are differences in the phenomena associated with the two systems that in some instances require significant differences in procedure. The line survey implies ground inspection, helicopter inspection, ground resistance measurements, according to international standards and climbed visits all 3, 6, 9 or 12 years. The periodicity and the aim of inspections are detailed in this sub-module. The supervision /inspection include:

- General checking of the facilities
- Blocking the facilities under maintenance.
- Supervising the commissioning test and energizing

The last sub-module is dedicated to Control Systems and the main items covered in this document are describing operation and maintenance activities, through material organization and coordination for the related equipments. This part contents also an important section relating to staff composition (proficiencies, team sizes) as well as staff training (at system provider premises and on control center site) of the Operator of this interconnection.

PART I

O&M AC substations

1 O&M GENERAL DESCRIPTION

This section provides with general description on Operation and Maintenance of the AC substations involved by the regional interconnection project between Ethiopia, Sudan and Egypt. These three substations are:

- AC 400kV- 500kV MANDAYA substation located in Ethiopia
- AC/DC 500kV KOSTI substation in Sudan connected to MANDAYA substation through two double 500kV AC circuits (544 km)
- DC/AC 500kV NAG HAMMADI substation connected to KOSTI substation through one bipolar DC line (1665 km)

The AC substations will be operated and maintained under the control of the Operator of the Egypt-Sudan-Ethiopian interconnection, called the Operator in this document, and could be supported through the provision of outsourced contracts with local or international companies skilled in O&M.

1.1 *MISSION ASSIGNED TO THE OPERATOR*

The Operator of this interconnection will be in charge of operating AC substations, in compliance with the requirements set in the Operating Agreements (OA) with the others TSOs from Egypt, Sudan and Ethiopia.

The main missions assigned to this Operator, are as follows:

a) To review the O&M manuals and to develop and update the Standing Instructions and Procedures related to the operation and the maintenance of the whole facility.

b) To operate and maintain the whole project facility including 500 kV substations and transmission lines, in order to procure the highest availability and performance of equipment in compliance with the O&M Manuals and Standing Instructions and Procedures.

c) To prepare and manage the maintenance outages for which external resources could be contracted from time to time.

d) To ensure the safety of people, works and equipment.

e) To establish and manage a procurement process of consumable, spares, support and services contracts.

f) To recruit, train and keep well-trained personnel with competencies necessary to carry out the current permanent activities.

g) To transfer O&M knowledge to the staff.

1.2 Pre-Operation Period

Before the commissioning period of the substation, the Operator shall address issues of the utmost importance to ensure a successful operation.

Before the taking over of the facilities, the Operator will:

a) get prepare to achieve the mission described above by setting-up an operational staff and organization;

b) prepare the staff recruited by providing suitable training;

c) establish O&M Manuals and Design Manuals from an operability and maintainability point of view, as well as the safety procedures and instructions;

d) prepare and issue the Standing Instructions and Procedures for the operation and maintenance of the Facility relating to: operation, maintenance, safety and first aid, performance monitoring, security, incident reporting, fire fighting and prevention, emergency plans, administration, environmental compliance;

e) prepare and enter into contracts for the various maintenance services;

f) specify, procure, implement and test the billing system associated to the multinational transmission lines (500kV AC OHTL between Mandaya and Kosti substations),

g) report on O&M implementation.

1.3 Operating Period

1.3.1 Core Activities

Core activities are activities directly related to the Operation and Maintenance of the whole facility, in compliance with the Operating Agreements contracted with the others utilities.

Core activities include the following clauses.

1.3.2 Operation

a) Operate, monitor and inspect the Facility;

b) Maintain records and reports of the operation of the Facility;

c) Prepare, co-ordinate and negotiate planned outage programs with others utilities involve by Project; and

d) Comply with all Standing Instructions and Procedures related to the operation of the whole facility.

1.3.3 MAINTENANCE

a) Plan and perform routine, periodic and occasional visual inspection of the Facility including tests of the equipment;

b) Plan and perform routine, scheduled and corrective maintenance of the Facility;

c) Maintain records and reports of all maintenance works;

d) Maintain and keep the Computerized Maintenance Management System updated;

e) Plan, organize and manage any subcontracted maintenance work;

f) Prepare the Operator's proposed Annual Maintenance Plan, with services to be subcontracted included; and

g) Comply with all Standing Instructions and Procedures related to the maintenance of the whole facility.

1.3.4 PROCUREMENT

a) Manage contracts for services

b) Procure consumables, equipment and spare parts; and

c) Maintain procedures for store-keeping, stock taking and the store module in the Computerized Maintenance Management System.

1.3.5 DOCUMENTATION

a) Maintain and manage the Computerized Management Information System, archive and filing systems;

b) Review and modify the O&M Manuals, the Standing Instructions and Procedures; and

c) Maintain and keep updated the as built drawings supplied by the Construction Contractor.

1.3.6 STAFFING AND TRAINING

a) Maintain the staffing of Facility as needed with suitably qualified personnel on a twenty-four (24) hours, seven (7) days per week basis;

b) Operate a staffing policy intended to provide well trained, re-trained and well motivated staff;

c) Keep the staff trained and aware of all Standing Instructions and Procedures.

1.3.7 NON CORE ACTIVITIES

Activities defined as non core activities include:

a) Site Security

b) Road and ground maintenance;

Above activities could fall under the operator or could be sub-contracted.

1.4 KEY FEATURES OF THE FACILITIES FROM AN O&M PERSPECTIVE

From an O&M perspective, the key features of the project are summarised below.

1.4.1 MANDAYA SUBSTATION

The Mandaya substation is in fact composed of 2 main substations, one 420kV substation connected to the Ethiopian transmission network, the other one 500kV substation dedicated to the international connection with Sudan.

The operators need to be familiar with O&M procedures of both type of equipment, specially the safety procedures conditioned by the insulation distance in 420kV or 500kV.

1.4.2 KOSTI SUBSTATION

The Kosti substation is in fact composed of 3 main substations, one AC-500kV substation connected to the Ethiopian transmission network, one for the 500kV SVC substation and one for the AC/DC converter substation dedicated to the international connection with Egypt.

The Operator need to be familiar with the three types of technologies or at least to foresee dedicated training for suitably personnel on O&M for SVC and AC/DC converter.

1.5 O&M ORGANISATION

1.5.1 GENERAL PRINCIPLES FOR SIZING AND STAFFING

a) The permanent personnel is sized with consideration of the goals for mastering the permanent activities and the definition and supervision of the activity relating to the major maintenance, taking account of the location (isolated) of the substation.

b) Activities that require specialized staff or equipment only from time to time, notably for controlling, expertise and periodical major maintenance activities are contracted in the frame of call for tenders to specialized local or international companies.

c) Activities that do not relate to the core business will as far as possible be contracted to local companies (e.g. security of the substation)

2 GENERAL DESCRIPTION OF THE MAINTENANCE ACTIVITIES

2.1 GENERAL

The projected maintenance policy is based on a prudent programme of preventive maintenance and scheduled maintenance. During the scheduled outages, a set of activities are carried out, including inspections and tests of equipment, in order to achieve the best availability factor during the following operating period.

2.2 DEFINITION

In this document, unless the context requires otherwise, the following words and phrases shall have the meaning:

- Preventive maintenance (IEC 60300-3-14): maintenance carried out at predetermined intervals intended to reduce the probability of failure or the degradation of the functioning of an item. E.g. : periodic visual checking of the insulator, oil level in cable sealing ends, counter, earth wire etc …
- Corrective (curative) (IEC 60300-3-14): maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function. E.g. : change of active part of the circuit breaker after an internal fault.

A schematic of the maintenance and the activities (following the international standard IEC 60300-3-10 & 14) is shown as figure below

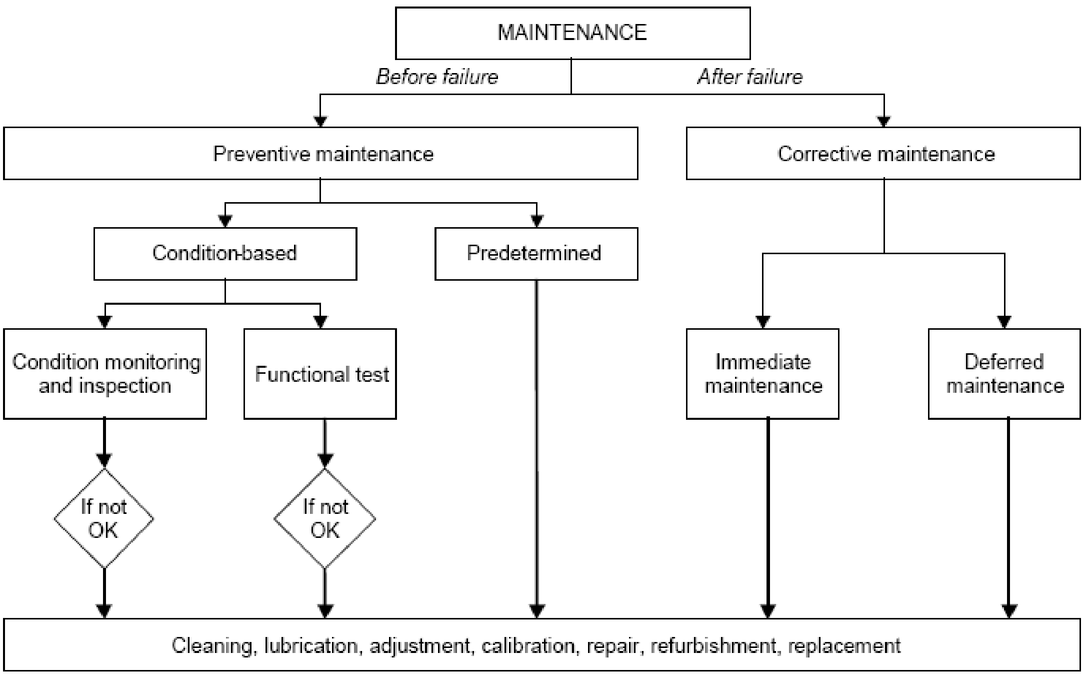


Figure 1 : Types of maintenance tasks

2.3 PREVENTIVE MAINTENANCE

The maintenance plan shall take into account the liability period and therefore the two following steps shall be considered:

a) Before end of defect liability period, the maintenance shall be performed in accordance with the manufacturer' O&M manual.

b) After the defect liability period, maintenance shall be performed in accordance with the Operator's O&M manual.

The maintenance tasks performed after the defect liability period are listed hereafter:

- Routine maintenance : the routine maintenance is the first level of assessment of the assets condition. Work request shall be recorded and planed at any abnormal points detected.
- Periodical Switchgear operation: closing and opening CBs and isolators,
- Maintenance during the defect liability period: the maintenance shall be performed according to the O&M Manual issued manufacturer.
- Current Maintenance: this plan includes Control on CB and IR thermovision on terminal connection and Periodical calibration of meters and their associated transducers.
- Minor overhaul : same as current maintenance plus Control of the SF6 density meter, charging of the spring duration, poles discrepancy, etc …
- Major overhaul: same as minor maintenance plus replacement of the main active parts of circuit breaker, disconnectors, …

Details of these maintenance activities after the defect liability period are given hereafter.

2.3.1 ROUTINE MAINTENANCE

Circuit Beaker, disconnectors

Main maintenance task	Details
General checking	Verify and record number of operation
	General condition of the apparatus
	HV terminals
	Earthing connection on the support
General check on the operating mechanism	General condition of the terminal
	Heater, thermostat, light, wires
Insulators	Condition and the insulators (cleanliness, impacts)

Table 1 : Routine Maintenance on Circuit Breaker and Disconnectors

Instrument transformers:

Main maintenance task	Details
General checking	General condition of the apparatus
	HV terminals
	Earthing connection on the support
	Oil level
Insulators	Condition and the insulators (cleanliness, impacts)

Table 2: Routine Maintenance on Instrument Transformers

Surge arrester

Main maintenance task	Details
General checking	General condition of the apparatus
	HV terminals
	Earthing connection on the support
	Surge counter
Insulators	Condition and the insulators (cleanliness, impacts)

Table 3: Routine Maintenance on Surge Arresters

Auxiliaries

Main maintenance task	Details
Batteries	Water level checking
	Note the general condition (dusted)
	control of the Electrolyse level
	Record the floating voltage on the terminal of complete battery set
	Check the Vaseline on the terminal
Rectifier	Note the general condition (dusted)
	Record the output current
Auxiliary transformer	Note the general condition
	Oil level checking
	Oil leakages
	Condition of the terminal

Table 4: Routine Maintenance on Auxiliaries

Static Voltage Converter (Kosti Substation)

The routine maintenance can be carried out by the Operator in charge of maintenance in Kosti AC substation or outsourced.

2.3.2 *PERIODICAL OPERATION*

Opening and closing operations

At least two O/C operations. The purpose is to clean up the tripping coils and interlocking devices

2.3.3 *CURRENT MAINTENANCE*

The current maintenance includes in one hand general checking and periodical calibration in outage condition and in other hand IR controls in loaded condition.

2.3.3.1 General checking on Circuit Breaker

General Maintenance task	Details
Preparation	Safety matters
	Verify and record number of operation
Visual Checking	Condition of the mechanical coupling rod between each pole and the operating mechanism
General check on the operating mechanism	Check if the operation recorder works properly
	General check of the operating mechanism cubicle
Functional Checks	Check of the two trip circuits
	Lock out: reclosing lock out, SF6 low pressure lock-out
	Anti-pumping features
	Out phase checks

Table 5: General Checking on Circuit Breaker

2.3.3.2 DC Auxiliaries

Battery

General Maintenance task	Details
Floating mode	Measurement of the floating voltage on the complete battery set. Use voltmeter with 0.5 accuracy. If necessary, adjust the level of the floating voltage on the rectifier.
	Measurement of the voltage on each cell.
	If some unit are damage, perform density measurement of the electrolyte et record the temperature. If the default is confirmed, replace the cell. If more than 35% of the cells are damaged, replace the all cells.
Rectifier switch off	Measurement of the voltage on the complete battery set when low voltage alarm is ON. Record the duration from the start of the discharge test to the alarm.
	Wait till the steady state of the voltage and record it.
	In case of doubt on the charge of battery (as result of voltage below the nominal voltage or abnormal changing compare to previous tests), perform float charge test after one or two Equalising charging voltage.
Rectifier switch on	Check the start of the equalizing charging and control the equalizing voltage (Use voltmeter with 0.5 accuracy). Is necessary, adjust the equalizing voltage from the rectifier.

Table 6: General Maintenance for Battery

Rectifier

General maintenance task	Details
General checking	Cleaning
Control and settings	Control of the floating and equalizing voltage. Adjust if necessary. Use voltmeter with 0.5 accuracy.
	Control of the alarm thresholds of the low and high voltage. Adjust if necessary. Use voltmeter with 0.5 accuracy.
	Control of the isolation device (if applicable).
Functional checks	Control of the signal and alarm in local an d remote condition

Table 7: General Maintenance for Rectifier

2.3.3.3 Reactor

Main Maintenance Task	Details
Preparation	Safety matters
General checking and cleaning	
	Check for any Oil Leakage (Main tank, flange, Draining, filling and test valves)
	Oil level in conservator(s)
	Terminal condition
	Clean the reactor thoroughly by using steam jet after necessary precautions to prevent water spraying on protective instruments and wiring terminals.
	After thorough cleaning, report if any major repair is required to stop the oil leaks
	Check the paint finish
Marshalling cubicle	Heater
	Visual checking of the cables connection
	Check the locking arrangement
Surge arresters (on cable sheath)	Check the condition of the terminal and wires
	Check the condition of the cubicle (rusting, locking arrangement)
Desiccant Breather(s)	Check if the breather operate properly
	Check and replace is necessary Silica gel
	Check oil level top if necessary
Oil analysis [1]	Oil sampling for Dissolved Gas Analysis, water content, acidy, particles contain, breakdown voltage.

Table 8: General Maintenance for Reactor

2.3.3.4 Power transformer

Reactor maintenance tasks plus the followings

General task	Details
Fans	General condition, abnormal sound, pollution, corrosion
indicators flow	Position
Pump	Oil leaks detection
Motor (fans and pumps)	Checking the insulation

Table 9: Supplementary Maintenance Power Transformer compared to Reactor

[1] Oil sampling shall be performed in accordance with IEC 60475 and 60567. Oil test shall be in accordance with IEC 60156 and IEC 60599.

Note : No current maintenance on auxiliary power transformer.

2.3.3.5 Static Voltage Converter (Kosti substation)

This maintenance is carried out with the SVC online.

The current maintenance is carried out while the SVC is in full operation. This maintenance involves trained personnel visiting the converter station sites once a year to carry out an inspection and to gather data. This maintenance usually outsourced.

Items such as the lubricating of pumps and the changing, if required, of water cooling system de-ionisers could be achieved during the current maintenance visit.

2.3.4 *PERIODICAL CALIBRATION*

According the Operating Agreements, meters and associated transducers shall be checked yearly.

2.3.5 *INFRARED THERMOVISION CONTROLS*

The purpose of this control is for detection of the hot spots on the HV contacts. The relevant HV apparatus are Circuit breakers, disconnectors (including main switching contacts), CT, CVT, surge arrester and line trap. Terminals on cable sealing ends, bushing and all the terminals of the bus bar and HV connection are also involved by infrared control.

Note 1: If hot spot has been detected by IR thermovision on HV connection, the operator will plan a work request to suppress the hot spot (retighten the bolts). This maintenance task refers to scheduled corrective maintenance.

Note 2: If hot spot has been detected by IR thermovision on the main contacts of the disconnectors, the operator will plan a work request to carry out measurement of the terminals contact resistance. If the resistance measurement confirms the default on the main contacts, then the contacts shall be cleaned or replaced, depending on the damages noticed. This maintenance task refers to scheduled corrective maintenance.

2.3.6 *MINOR OVERHAUL MAINTENANCE*

The minor overhaul maintenance tasks are carried out in outage condition on circuit breakers, disconnectors, relay protections, reactors, power transformers, and auxiliary equipments.

2.3.6.1 Circuit Breaker

In addition of the current maintenance tasks, the followings controls shall be carried out :

General Maintenance Task	Details
General check of the control cubicle	General cleaning
	Tighten the LV terminals
Resistance Measurement of the main contacts	The measurement must be carried out with a DC supply (ampacity ≥ 200A)
Circuit breaker operation	Check the closing and opening time of each pole and Check the recharging duration
Testing the density monitor	Check function of SF6 density monitor
	Check operating values of SF6 density monitor (see note1)

Table 10: General Maintenance for Circuit Breaker

Note : If drift is observed over the time, the operator will plan a work request for SF6 pressure sensors calibration or replacement. This maintenance task refers to scheduled corrective maintenance.

2.3.6.2 Disconnectors

The table details the maintenance tasks for Central Break Disconector (CBDS), Earthing switch (ES) and Pantograph Disconnector (PDS)

General Maintenance Task	Details	DS	ES	PDS
Preparation	Safety matters	X	X	X
	Verify and record number of operation	X	X	X
General visual checking	Control if the arms of the active part are in line.	X		
	Control the verticality of the insulators	X		
	Control if the protection surfaces are not damaged (including lattice support)	X		X
	Cubicle control : cleaning, re-tighten of the LV terminals, condition of sheaths of the low voltage, heater.	X	X	X
	Insulators : pollution ,	X		X

General Maintenance Task	Details	DS	ES	PDS
	impacts, verticality			
	Drive (operating mechanism) : working order, check the insulation of the motor, motor protection automatic switch	X	X	X
	Check the condition of the corona shield	X		X
Opening and Closing operations	The purpose is to clean up the tripping coils and interlocking devices Two O/C operations in remote control : control operating time on the remote disturbance recorder. Highlight the first operation. Check the proper operation of the interlocking devices and positions indicators with an ohmmeter.	X		X[2]
	Three O/C operations in local control : visual and sound control during each operation. Check for abnormal sound from shafts and main contacts.	X	X[3]	X[2]
Live part checking	After the Five mechanical operations, proceed to the measurement of the contact resistance on the live parts	X		X
	Check the condition of the contact surface (check the silver coating)	X		X
	Clean the contact of the live part and apply the recommended grease.	X		X
	Check the correct coupling of main contacts	X		X

[2] Special attention shall be made on disconnector with non bus transfer switching characteristic during making and breaking to reduce the arc phenomenon.

[3] Only local/manual control is available for ES.

General Maintenance Task	Details	DS	ES	PDS
	Check the contacts roller and the condition of terminal connections.	X		X
	Check if the mechanical parts are adequately lubricated	X	X	X

Table 11: General Maintenance for Disconnectors

2.3.6.3 Power transformer and Reactors (shunt and neutral)

In addition of the current maintenance tasks, the followings tasks shall be carried out :

General Maintenance Task	Details	PT	SR NR
General checking	Check the paint and carry out repainting if required	X	X
Checking of instruments	Oil temperature (dial indicator and gauge) : Alarm / Trip signals	X	X
	Winding temp. (dial indicator and gauge): Alarm / Trip signals	X	X
	Main tank oil level : low / Alarm	X	X
	Main tank Buchholz : Alarm & trip signal, operation	X	X
	Main Pressure Relief Device : trip signal, operation	X	X
Checking of the marshalling cubicle	Checking the terminal and wires (tighten if necessary)	X	X
Checking of the Cooling system (pumps, fans, radiator)	Oil flow indicators : mechanic and electric checking	X	
	Pumps : start/stop and check the oil flow indictor in relation with and abnormal sound	X	
	Fans : start/Stop, Abnormal sound	X	
	Control of the setting of the thermostat for fans tripping	X	
Checking on the bushing	Oil analysis on Bushing	X	
	Tang Delta on bushing	X	
Checking on Main tank	Insulation resistance measurement & Tang Delta	X	

Table 12: Recommended Complementary Maintenance for Power Transformer and Reactor

2.3.6.4 LV equipment

Relay protection

All measuring and signal processing circuits of the relays protection are provided with electronic components which do not require any maintenance. As the relays protection are almost completely self-monitored, from the measuring inputs up to the coils of the trip relays, device faults are automatically annunciated. This provides for a high degree of availability of the protection system. Thus the maintenance tests at short intervals become superfluous.

The scope of work of this tender refers only to the tests with long interval. The relays characteristics shall be checked by secondary injection and by recording the results.

The relay protections to be checked are listed in Part II of this Tender.

2.3.6.5 DC auxiliaries

Batteries

General maintenance task	Details
Discharge of the battery	Switch off the rectifier Record the discharge voltage over one hour.

Table 13: General Maintenance for DC auxiliaries

Note 1 : The battery shall be replaced if the voltage drops down too quickly.

Note 2 : No minor maintenance on rectifier neither auxiliary power transformer.

2.3.6.6 Static Voltage Converter :

Maintenance carried out in off line condition

Minor maintenance needs specialist intervention from the manufacturer team, in order to achieve operations such as the recalibration of instruments and control checks.

Minor Maintenance is usually achieved once every two years to maintain components which cannot be maintained on line.

Minor Maintenance would include any routine checks; tests and adjustments as per scheduled list and instruction manuals, the major inspection and maintenance tasks being as shown in the table below. These tasks cover only the power electronics related equipment.

Equipment	Details
Thyristor Valves	Visual inspection of all valve room equipment including Valve Base Electronics and other control items. Check all pipeworks. Clean surfaces of valves as necessary, including water manifold pipes and inter-tier insulators if required. Perform diagnostic electrical tests on any faulty thyristor levels.

Equipment	Details
Cooling system	Visual/audible inspection of motors, pumps and fans with CM instruments. Record data. Check lamps. Check/clean water filters Inspect/remove external debris from heat exchangers. Replace de-ioniser cylinder as required (replacements need to be purchased) Replace motors or pump seals (if necessary) Test motor overloads Check coolant SG and correct if necessary. Add coolant if necessary Vent coolant pipework Check Instrumentation and re-calibrate as necessary.
Control and Protection	Visual inspection Rotating test sequence to ensure all conventional protection circuits are checked once per 6 years Software operated tests on controls (I/O). Recalibrate electronic protection.
Auxiliary Supplies	Visual Inspection Visually check battery sets every 3 months. Check battery voltages and condition on a three yearly basis and perform discharge tests.
Air Conditioning and Ventilation	Check filters and change as required. Check that ventilation system is functioning correctly.
Other Components	Visual Inspection Lubricate contacts and mechanisms Check functions.

Table 14: General Maintenance for SVC

The maintenance related to all of the other equipment (switchgear, reactors, capacitors, etc) is the same as would be required for a standard AC substation.

2.3.7 *MAJOR OVERHAUL MAINTENANCE*

General Maintenance task	Condition To Perform The Task
Circuit Breaker	
Replacement of three poles (overhauling)	After 10000 operation in unloaded condition or Refer to the manufacturer instruction for maximum number of operation at rated current and fault current
Disconnector	
Inspection and Contacts Replacement	2000 operations or fault during making or breaking
Earthing Switch	
Inspection or replacement of the Contacts.	1000 operations, or fault during making or breaking
Power transformer, Reactor, SVC	
The above equipment are designed for a life cycle of 30-40 years. No major maintenance (overhauling) is requested during the normal period of life.	

Table 15: Major Overhaul Maintenance

Note on SVC :

Today, typically, an SVC is designed for a life of at least 40 years. The above does assume that adequate spares and support are arranged, either at the original contract stage or within 5 to 10 years of the scheme start-up. Main Vendors have agreement with all of the component suppliers such that they provide advice to vendor of the pending obsolescence of any components that they supply to us.

This advice is normally given more than one year before obsolescence occurs. This allows vendor to approach clients to propose a last time buy to suit their needs and also allows vendors time to prepare a alternative solution to the component which is pending obsolescence.

For financial studies required in module 8 of the project, a total renewing of control and protection system was integrated after 25 years of operation. The cost of this renewal is about 5 MUSD

2.3.8 *TIME SCHEDULED AND PERIODICITIES*

2.3.8.1 Time scheduled for maintenance activities

In order to minimize impact of outages on the facility availability, the projected maintenance and control works are split in such manner to allow their implementation over the year during the uncritical Energy periods, as frequent as possible. For outages that need longer, the works must be performed also during critical Energy period. The impact shall be minimised by working in 2 shifts per day.

In addition, to optimise the facility maintenance and availability:

- Planned outages carried out are planned at the beginning of the year; and
- Outdoors works are carried out as far as possible from November till May apart the hot season.
- The periodicity and work programme during outages shall take account of the operating constraints; therefore the anticipated typical programme is open to justified adjustments over the operating period.

2.3.8.2 Periodicities for Switchgear + auxiliary equipment

Maintenance Tasks	Periodicity/equipment				
	Circuit breaker	Disconnecting switch	Rectifier	Batteries	Auxiliary Transformer
Routine Maintenance	monthly				
Switchgear operation	3 monthly		None		
Maintenance during the defect liability	To be completed later as per O&M manual				
General checking	1 year	None	1years	1 year	None
Infra Red control	1 year	1 year	None	None	None
Minor Overhaul	6 years	6 years	None	6 years	None
Major overhaul	Conditional		None		

Table 16: Periodicities for Switchgear and Auxiliary Equipments Maintenance

2.3.8.3 Periodicities for step up Power transformer + Reactor

Maintenance Tasks	Periodicity
Routine maintenance	Monthly
Maintenance during the defect liability	To be completed later as per O&M manual
General checking	Yearly
Infra Red control	1 year
Minor overhaul	6 years
Major overhaul	None

Table 17: Periodicities for Step-up Transformers and Reactor Maintenance

2.3.8.4 Periodicities for Relay Protection + Meter

Maintenance Tasks	Periodicity/ Equipment	
	Relay protection + LV protection devices	Meter + Transducer
Routine maintenance	None	None
Maintenance during the defect liability period	None	None
Current Maintenance -	None	1 year
Minor overhaul	6 years	None
Major Overhaul	None	

Table 18: Periodicities for Relay Protection and Meter Maintenance

2.3.8.5 Periodicities for SVC

Maintenance Tasks	Periodicity
Routine maintenance	Monthly
Maintenance during the defect liability	To be completed later as per O&M manual
Current Maintenance	Yearly
Minor overhaul	2 years
Major overhaul	None

Table 19: Periodicities for SVC Maintenance

2.4 CORRECTIVE MAINTENANCE

2.4.1 GENERAL

Immediate actions can be undertaken for trouble shouting HV and LV equipments after unplanned unavailability's. This "emergency maintenance" involves all the equipment of the substation useful for the availability of the power plant as per the OA requirements. This type of maintenance can be outsourced to local or international company skilled in maintenance.

Moreover, corrective actions can be performed on defaults noted during preventive maintenance. This corrective maintenance task is performed over the planed outage period.

Trouble shouting at the first level: this activity is limited to the first level of diagnostic of the HV&LV equipment in order to manage the necessary actions (corrective maintenance) to recover the availability and initial performances of the facilities in the shorter time.

2.4.2 *TYPICAL FAULTS AND THEIR ASSOCIATED CORRECTIVE ACTIONS*

This table is given as Informative statement.

Typical faults	Maintenance task requested
All the HV equipment	
Internal short circuit and explosion	Replacement of one (or several) pole
Broken insulators	Depending on the damage, the equipment can be replace or kept with survey during routine maintenance
Hot spot detection	Retighten the HV terminal
Power transformer & Reactor	
Dissolved Gas Analysis	Action according to the diagnostic of the specialist
Water content, acidy	Oil treatment
Temperature alarm	Investigation on cooling system, on temperature sensors and Oil treatment
Buchholz alarm	Investigation by specialist.
Circuit breaker	
SF6 leakage up to first alarm	Refilling
SF6 leakage up to second alarm	Refilling and plane replacement of one pole.
Trouble on Operating drive mechanism	Repair at site or Replacement of one pole.
Drift observed on SF6 Density meter	SF6 pressure sensors calibration or replacement
Disconnector	
Trouble on Operating drive mechanism	Repair at site or Replacement of the drive..
Hot spot detection on main contacts	Cleaning of the main contact of disconnectors or replacement of the main contacts
CT and CVT	
Oil leakage	Replacement of one pole

Table 20: Typical Faults and Corrective Actions

3 SPARE PARTS AND SPECIAL TOOLS

All spare parts and special tools requested for corrective and preventive maintenance are listed in a sub-module of M4 entitled " M4- 500 & 400 kV AC Substations – Preparation of Technical Specifications".

SF6 / Nitrogen gas, transformer oil / switchgear oil either new oil or reconditioned and tested oil, for use on the jobs involved shall be procured in advance. The Operator will also provide distilled water for/batteries and silica gel crystals for dehydrating breathers.

PART II

O&M
HVDC converter stations

4 OPERATION OF AN HVDC INTERCONNECTOR

4.1 GENERAL DESCRIPTION OF OPERATIONS

4.1.1 GENERAL

The HVDC control system is responsible for the operation of the main scheme equipment (thyristor valves, breakers for ac filters and shunt reactors etc.). It ensures that the equipment is operated within its limits to achieve the desired power transfer within the specified control parameters. It is also responsible for the start up and shutdown sequences of the scheme.

4.1.2 OPERATOR FACILITIES

Control of the station can be exerted locally or via a Remote Control Point (RCP). The RCP may be located some distance apart from the installation and usually does not have access to the full range of control features. For a transmission scheme, there will be one Local Control Point (LCP) and one RCP on each end as shown in figure below.

Although four control points are shown, only one may be in control at any time.

An operator may take control by pressing a take control button on the respective control desk. The control point in control is therefore determined by the most recent location to perform this operation. Once a control point is in control, power orders and ramp rate can only be executed from that particular location. Other functions such as power limits can still however be set at any of the three control points.

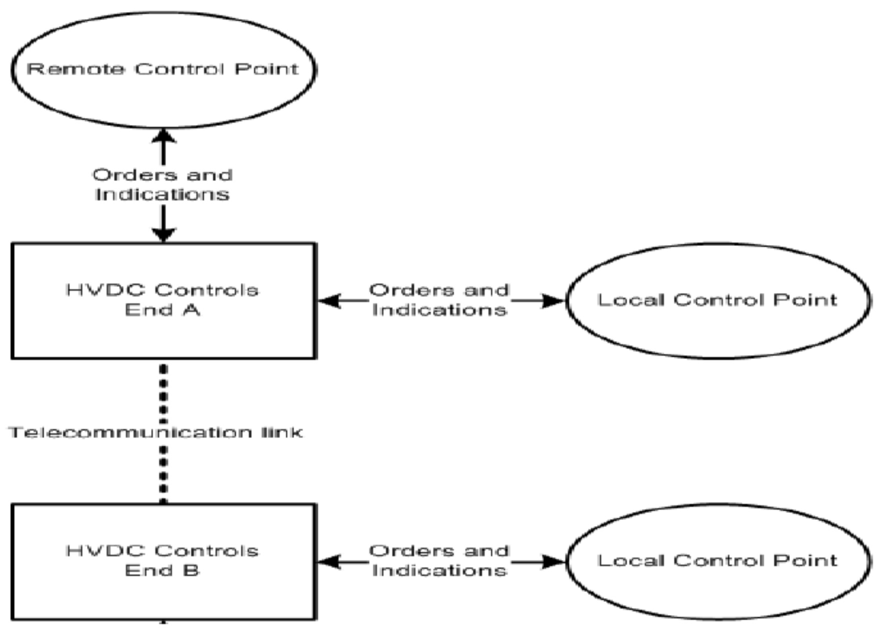


Figure 2 : Operator Control Points

The HVDC control Human Machine Interface (HMI) shall, as a minimum, provides the following:

- Provide relevant scheme level information to the operator in an intuitive and unambiguous manner, allowing informed decisions to be made.
- Provide a safe and secure mechanism for control actions which includes selector switches, execute buttons and data input mimics to order power and direction, and rate of change to achieve that power. Similar facilities shall be provided for setting import and export power limits, taking control button discussed earlier on in this section and End Ready confirmation discussed in Section.
- Maintain a historical log of plant activity for immediate reference and historical analysis.

The HMI is an unintelligent item entirely dependent on the control, from which it receives signals, and to which it sends signals. No control functionality shall be implemented in an HVDC HMI. The effect of switches on the HMI and the indications on the display, are entirely determined by the control. The control is able to address any display and update the data for it, which is registered (time-stamped) locally. Events and alarms shall be time-stamped with a time accuracy of no greater than 5ms. A complete update should made within 50ms.

In addition, an Engineer's Interface is installed which provides a direct interface with the HVDC control system. This is used during commissioning to monitor the activity of software systems or to diagnose faults. It provides a more detailed view and data logging of the control system variables and parameters. An engineer is able to use this system to adjust control parameters (subject to security rights).

4.1.3 STRUCTURE OF THE CONTROL SYSTEM

A hierarchical design approach is adopted in which the combined actions of control functions at a given level are coordinated at the next higher level. The control system is hierarchically structured as illustrated in figure 2 below.

The HVDC control system is divided into four main areas listed below in hierarchical order:

- Station Control (SC)
- Bipole Control (BC)
- Pole Control (PC)
- Converter Group Control (CGC)

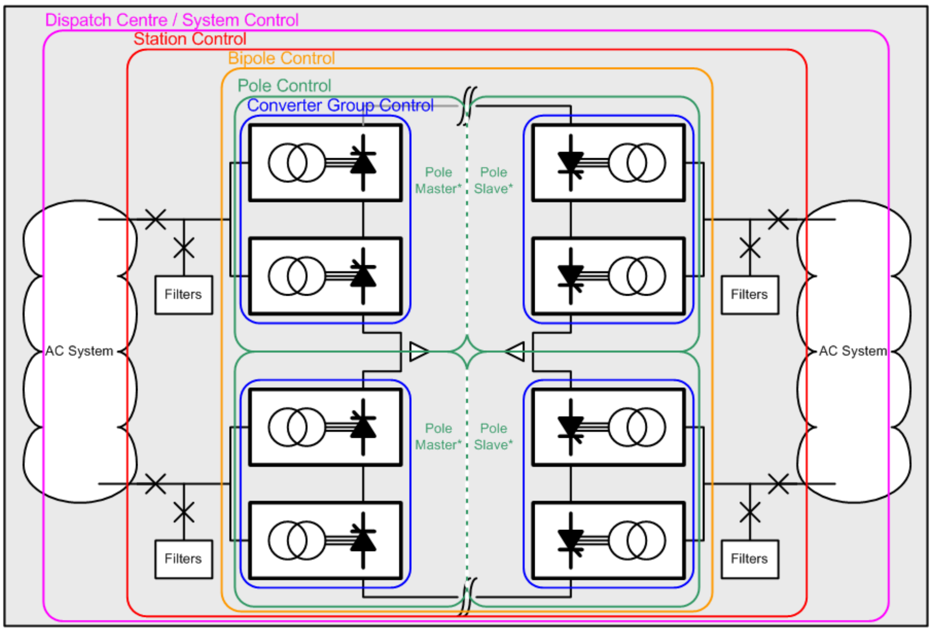


Figure 3: End to End communication

The station controls are concerned with scheme level interaction between the AC and DC system. The controls use AC bus information, inputs provided by the operators and power level information from the bipole controls to optimize the reactive exchange at different power transmission levels by switching reactive elements.

4.1.4 *OPERATIONAL STATES*

The HVDC scheme has principally two operation modes namely, the Bipole Control Mode (BCM) and the Manual Control Mode (MCM).

Bipole Control Mode is intended for normal operation, using a telecommunication system to transmit the current order digitally between ends. The bipole controls at both ends are identical and normally operate with one in Master control mode and the other in Slave control mode; their respective positions will normally be either a joint operator decision using manual switches (with discrepancy indication via the telecommunication) or a scheme specific control point arbitration mechanism.

The bipole control functioning as master may be either the rectifier or inverter station. The active control position (e.g. Remote Dispatch Center) may be at either end, independent of the position of the master control or direction of power flow.

The Manual controls are principally intended for use when telecommunication is not available; they normally use floating current-order at the inverter. Again one end functions as master and the other as slave; however, for this case it is essential for the master to be at the rectifier end. The Manual controls can also be put into a Manual Separate mode, with substantially simpler function, current order then being set directly by operator at each station.

4.1.5 END TO END TELECOMMUNICATION

End to end telecommunication is deployed to co-ordinate operation between the two terminals and to enhance the operation of a HVDC scheme. Communications can simply be in the form of an operator to operator phone line, or on the other hand a high speed digital communications channel using optic fiber, microwave, telephone line or power line carrier. When suitably deployed, it can automate certain co-ordination operations and enhance the reliability and security of the overall HVDC scheme. End to end co-ordination can broadly be categorized into scheme level functions and automatic control functions.

4.1.5.1 Scheme Level Functions

These co-ordination functions allow the HVDC system to be operated at either end of the link on a scheme level or from a remote dispatch center. The functions that require co-ordination between ends are:

- System configuration changes including converters, groups or poles insertion or removal, open line test mode and offline mode.
- Scheme startup and shutdown by co-coordinating the sequencing of the ends.
- Control of scheme power/current level and ramp rate.
- The display of operating and equipment status of the entire scheme.
- Alarm annunciation on a scheme basis to aid analysis of faults.

4.1.5.2 Automatic Control Functions

These co-ordination functions are provided to improve the security and speed of response of the overall scheme.

- The end to end co-ordination of current orders.
- The co-ordination of current limits between ends.
- The co-ordination of voltage order between ends for reduced voltage operation.
- The co-ordination of protection functions which include retarding the rectifier for inverter faults or inverter detected line fault, and line protection disabling for inverter ac faults or commutation failure.

4.1.5.3 Telecommunication Failure

The control system shall be tolerant to telecommunication failure. One approach is to have a redundant telecommunication link and the control system switches to the standby link on detection of a telecommunication fault.

The control system shall be able to continue operation for a short interruption of communications. One critical consideration is that adequate current margin is maintained between ends. Therefore power ramp shall be suspended during loss of communications.

For prolonged telecommunication failure, the control system shall revert to floating current control where remote end current order is estimated from local measurements. In order to avoid margin crossing, the current ramp rate shall be limited. This allows for the determination of operator involved changes compared to faults. The rectifier shall be designated as the control point master in terms of power/current level or ramp rate adjustments. Normally, when under bipole control, checks are made to ensure that both ends are Ready For Operation before the operator is permitted to enter the power order and ramp rate to deblock the scheme.

In order to cater for operation without telecommunications, provisions shall also be made for a Manual control mode where the operator is allowed to deblock and block one end of the scheme and to perform separate current control. The sequence of operation is expected to be coordinated over a telephone line between operators of the two ends. In general on changing from bipole to Manual control, the changeover switch at the inverter is operated first, and on switching from Manual to Bipole Control, the changeover switch at the rectifier is operated first. The following signals at a minimum must normally be exchanged between the two sides in addition to current and voltage order:

- Power/Frequency Control (PFC)
  - Is sent from the slave end to the Master end and represents the offset derived on the slave end added to the summing junction in Power Control.
- Power Modulation Control (PMC)
  - Is sent from the slave end to the Master end and represents the offset added to the summing junction in Power Control.
- Block command
  - Is sent from the Master end to the slave end to initiate a blocking sequence on the slave side.
- Blocked/Deblocked status
  - Is sent between both ends to coordinate the block and deblock sequences.

Figure below illustrates the salient signals exchanged between both sides.

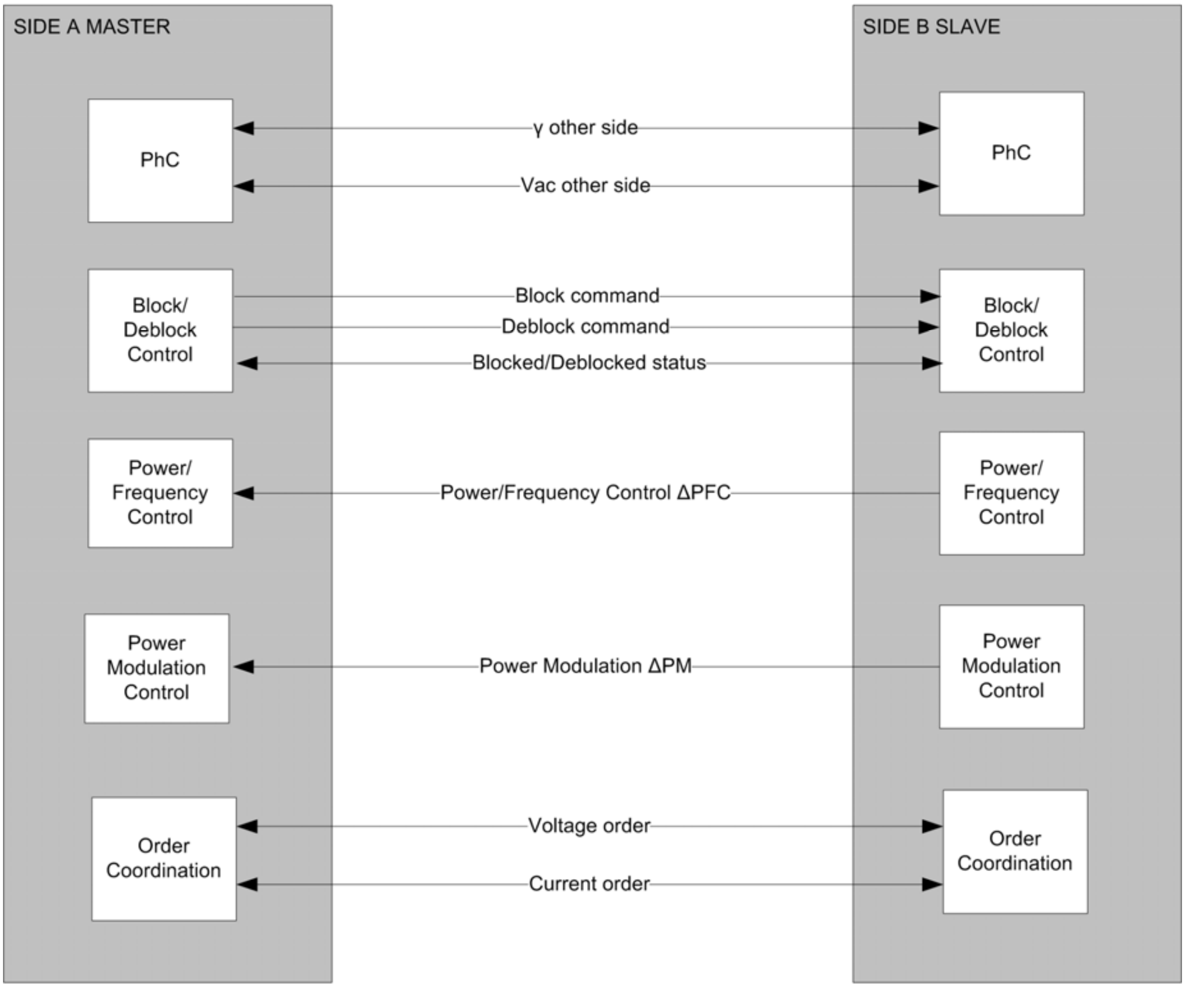


Figure 4 : End to End Communication

4.1.6 *START UP AND SHUT DOWN SCENARIOS*

Described below are simplified normal start up and shutdown scenarios.

4.1.6.1 Normal Start-up Scenario

In order to start up the scheme the bipole is started up in the following manner under the assumption that the bipole is in shutdown at the beginning of the scenario.

STEP 1

Assuming the poles are in the shutdown mode and Independent Control is selected, the Operator Selects “Go to Standby” which sets the status of each pole to “Going to Standby” and sends a “Go to In Service” command to the Converter Cooling Control. At the same time a “Start Transformer

Cooling" command shall be sent to the transformer cooling control. The interlocks are then checked to see if each pole is Ready For Energization (RFE).

STEP 2

As soon as all interlocks are healthy the operator receives the indication "**RFE"** which means the bipole can be energized to bring the pole into standby mode.

STEP 3

The operator is then expected to reconfigure any required switchgear to energize the bipole.

STEP 4

When the bipole is energized the bipole status is set to "**Standby**" (a combination of all pole status'). The "**RFS" (Ready for Service)** indication is given to the operator as soon as the interlocks are healthy for both sides.

STEP 5

The pole is now available for Bipole Control and Ready For Service and can be deblocked in response to orders received from Bipole Control.

STEP 6

Assuming that either the Operator has set a Master Power Demand or a PDO has been initiated a signed Power/Current Order and power ramp rate is received by the Power Order Interface. The signed Power/Current Order is used to decide the direction of power flow, i.e which end operates as rectifier/inverter. When the Power/Current Order exceeds a pre-set value a deblock request is sent to the Block/Deblock controller.

STEP 7

The Block/Deblock controller receives a deblock request from the Power/Current Order Interface and in response it will output a deblocking sequence that deblocks the inverter and then the rectifier.

STEP 8

The bipole is now both energized and deblocked, meaning that power is being transferred and that the bipole is in service.

4.1.6.2 Normal Shutdown Scenarios

In order to shut down a pole the following procedure shall be followed assuming that the pole(s) is in service in Bipole Control Mode at the beginning of the scenario:

STEP 1

The operator blocks the bipole by ramping the power order to zero. The bipole status will then change from "**In Service"** to "**Going to Standby**".

STEP 2

When the power has ramped down to a pre-set limit, a block request is sent to the Block/Deblock controller.

STEP 3

The rectifier is placed into 'force retard' until the measured dc current is below a defined threshold where it is blocked. The inverter voltage order is ramped to zero and below a measured dc voltage and current threshold the inverter is blocked. The Block/Deblock controller receives the block request and blocks the rectifier and then the inverter. When the bipole is blocked the pole status is set to "**Standby**".

STEP 4

The poles are now in standby mode and not transferring power. To take the poles to shutdown, the operator then initiates a Go to Shutdown sequence which sets the bipole status to "**Going to Shutdown**".

STEP 5

When all the de-energization interlocks are healthy the operator receives the indication **"RFDE" (Ready For De-Energization).**

STEP 6

The operator is then expected to reconfigure the switchgear to de-energize the bipole.

STEP 7

When the bipole is de-energized the pole status is set to "**Shutdown**" and a "Stop Transformer Cooling" is sent to the Transformer Cooling Control and a "Go to Shutdown" command is sent to the Converter Cooling Control.

4.2 HMI DESCRIPTION

4.2.1 PRINCIPLES

In summary, the principle requirements of an HVDC HMI are threefold:

- Provide relevant information to the operator in an intuitive and unambiguous manner allowing informed decisions to be made.
- Provide a safe and secure mechanism for operator control actions.
- Maintain a historical log of plant activity for immediate reference and historical analysis.

To meet these three requirements one or more PCs running a Windows operating system executing specialist HMI software shall be used.

No automatic control functionality shall be implemented in an HVDC HMI.

The HMI PC(s), plant control equipment and other electronic devices are connected together by a local area network (LAN). The arrangement shall ensure the system shall be tolerant to a single point of failure.

The HMI software and PC(s) provide the operator with a windows style display and a mouse and keyboard. This forms an operator work station (OWS).

Status information is sent from the plant equipment to the HMI and operator commands are issued from the HMI to the plant equipment.

The primary role for an HVDC HMI is to provide an interface for the plant operator, additional functionality required for an interface for an engineer shall be provided by a separate system.

4.2.2 DISPLAYS

In order to meet the first principle requirement, to provide information to the operator in an intuitive and unambiguous manner, information is displayed in a series of views.

4.2.2.1 Mimics

Views shall often contain mimics. The information on each mimic is logically grouped together. Mimics contain a graphical schematic representation of a system, which shall update to represent the live status of the system by animating figures and changing display colors. Mimics may also contain representations of analogue values, control system statuses and equipment conditions represented by lamps and digital meters.

4.2.2.2 Data Quality

If the quality of the data being displayed is compromised, e.g. due to communications failure, the condition of the affected data shall be displayed to the operator.

4.2.2.3 Alarms

Alarms are a mechanism used to enunciate abnormal conditions requiring action.

4.2.3 OPERATOR COMMANDS

In order to meet the second principle requirement, of providing a safe and secure mechanism for control actions, a series of pop-up command dialogue boxes are provided. The dialogues are produced by clicking the appropriate command buttons when the command is deemed available.

Not all commands will be available all the time. For commands to be available to be issued from the HMI the user is first required to be logged in and control taken to the HMI from any remote control center or other local control point. Further, a particular command may not be available due to the physical condition of the plant and/or state of the control system. Command availability shall be indicated to the operator.

4.2.4 *HISTORICAL ANALYSIS*

Historical analysis requirements shall be met by means of an event list and graphical analogue trending.

4.2.4.1 Events

The event list shall display a series of millisecond time stamped text entries representing plant activity in a searchable scrollable list. All events shall also be logged in ASCII format to non-volatile storage. As a minimum, storage provision shall be made for 3 months of events.

4.2.4.2 Analogue Trending

The history of principal analogue signals shall be displayed graphically by a series of trend graphs.

4.2.5 *STANDARD CONTROLS AND DISPLAYS*

4.2.5.1 Main displays

The main displays are shown in figures below.

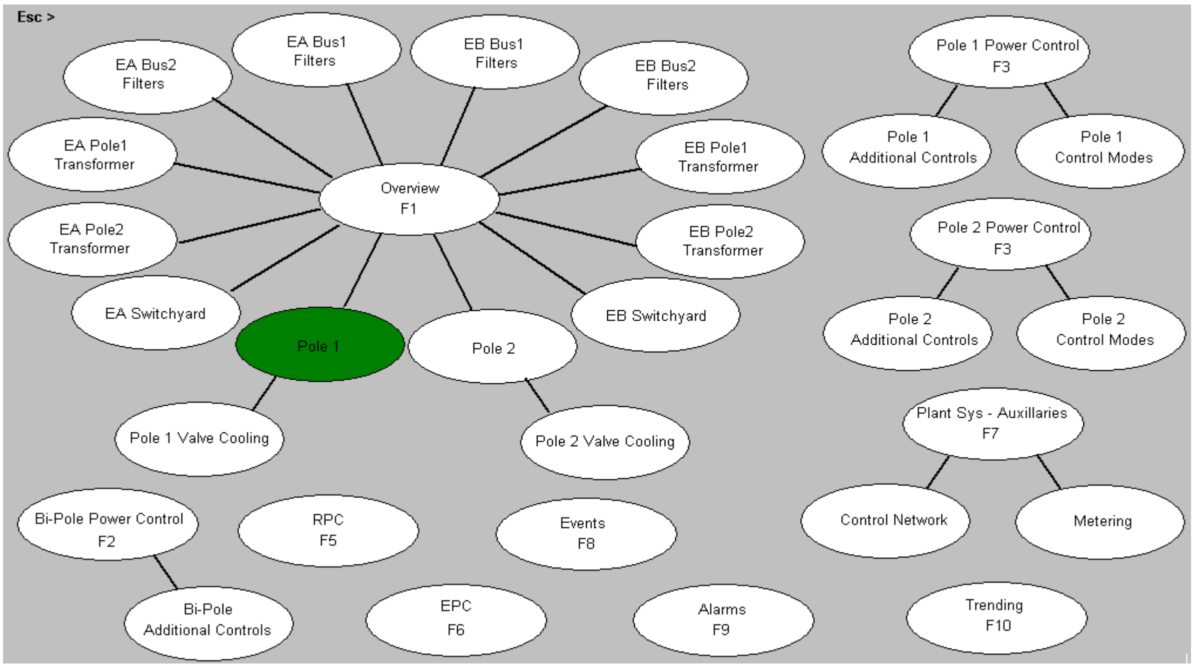


Figure 5: View Map

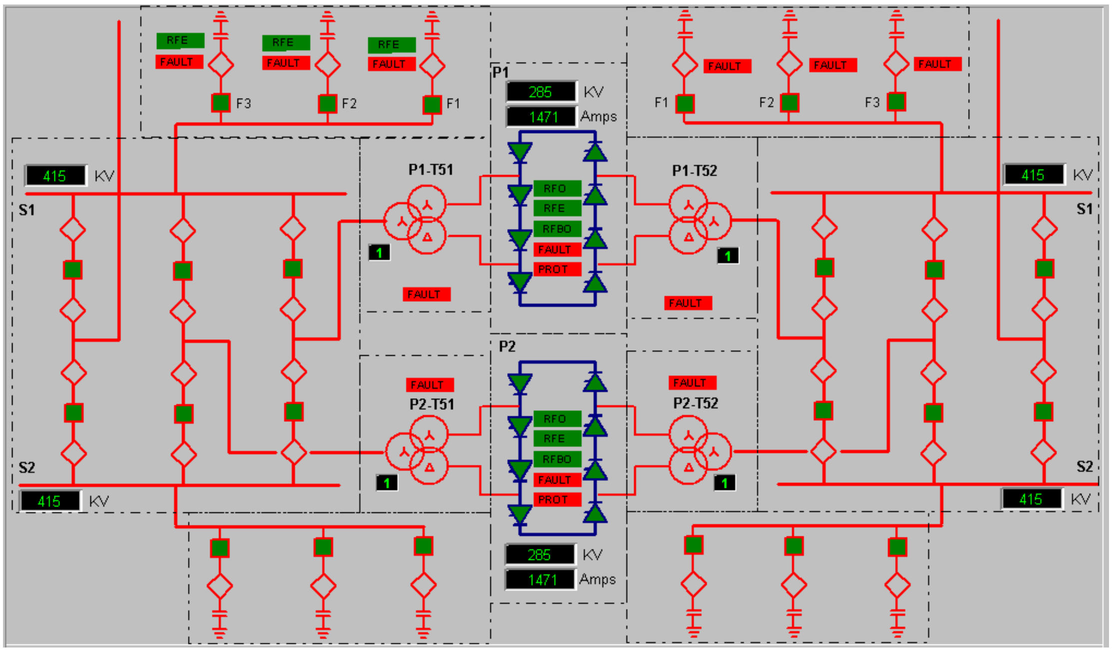


Figure 6: Overview Mimic

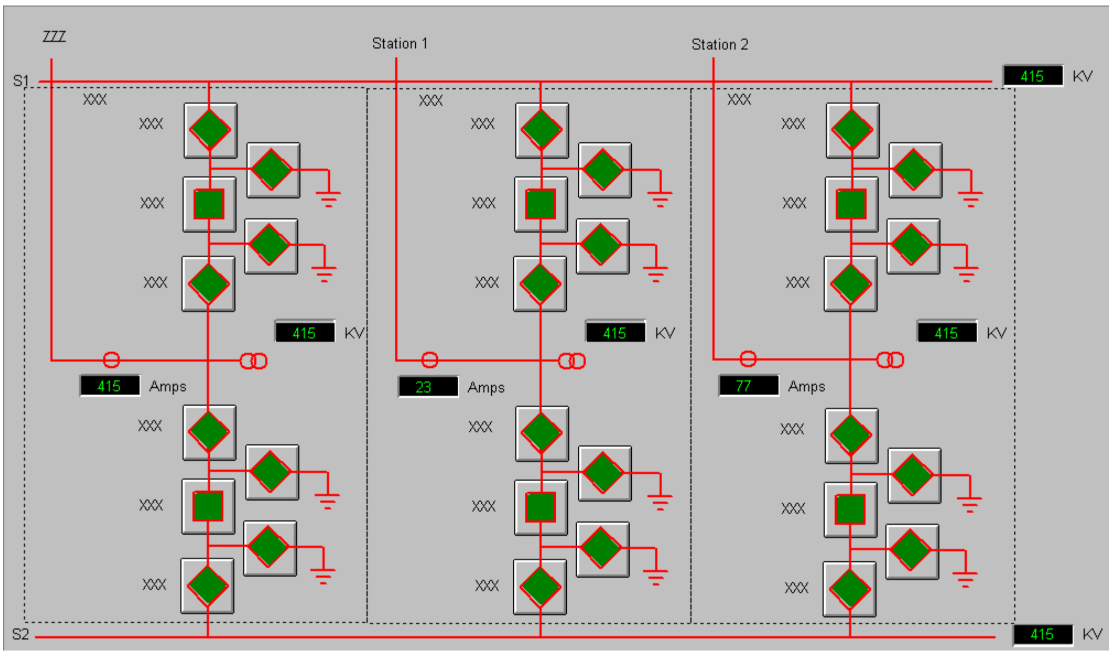


Figure 7: Switchgear Mimic

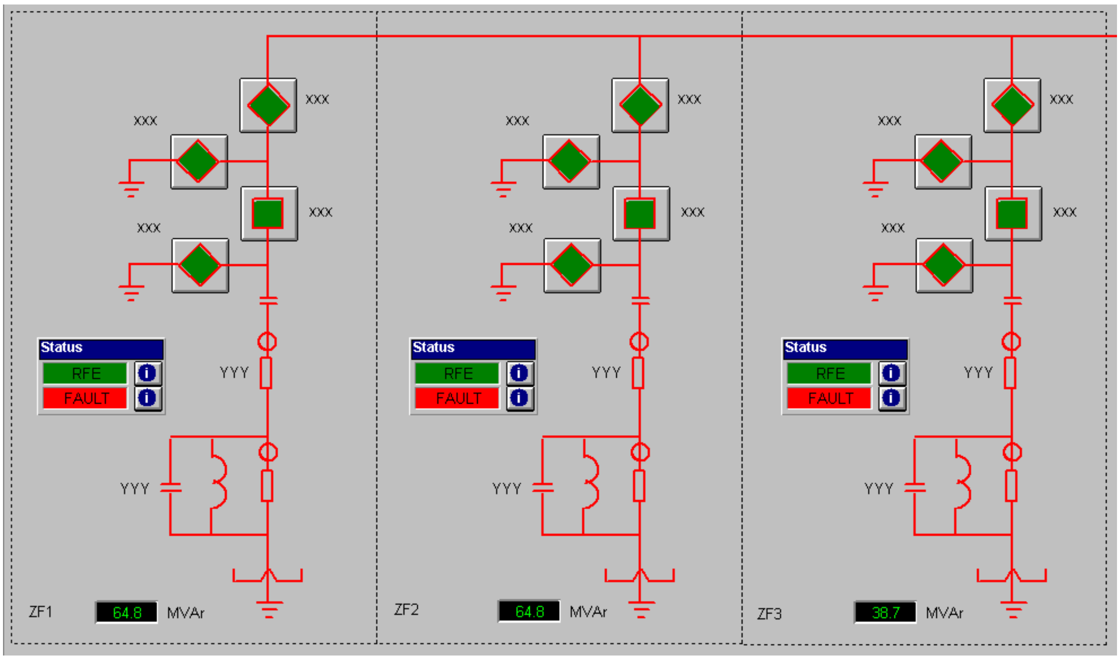


Figure 8: Filter Bank Mimic

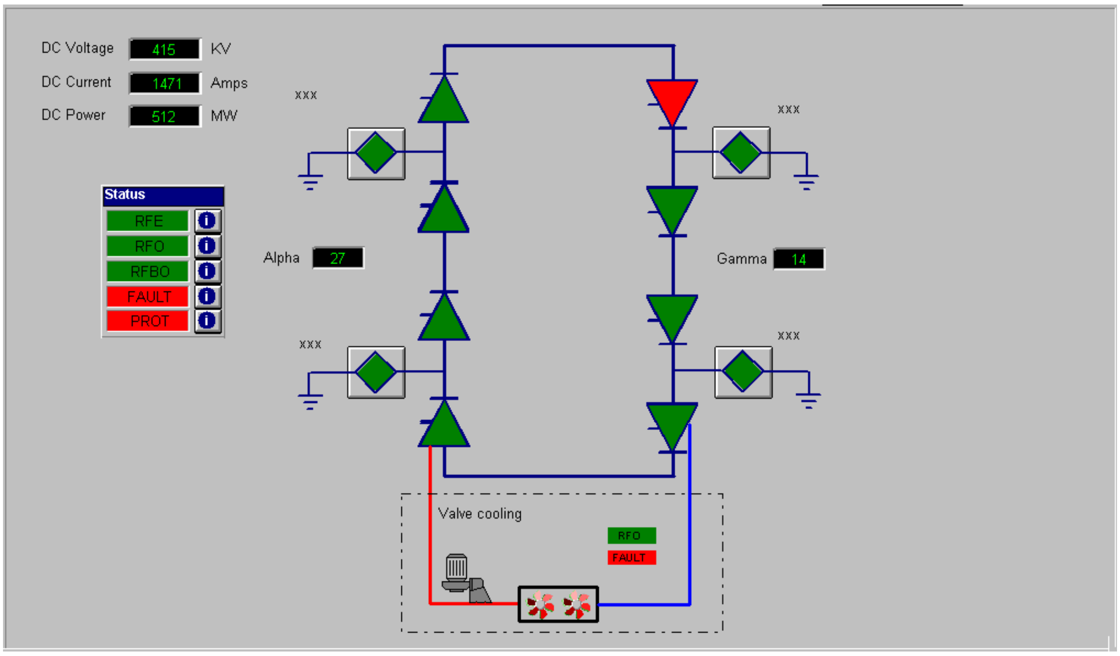


Figure 9: Pole Mimic

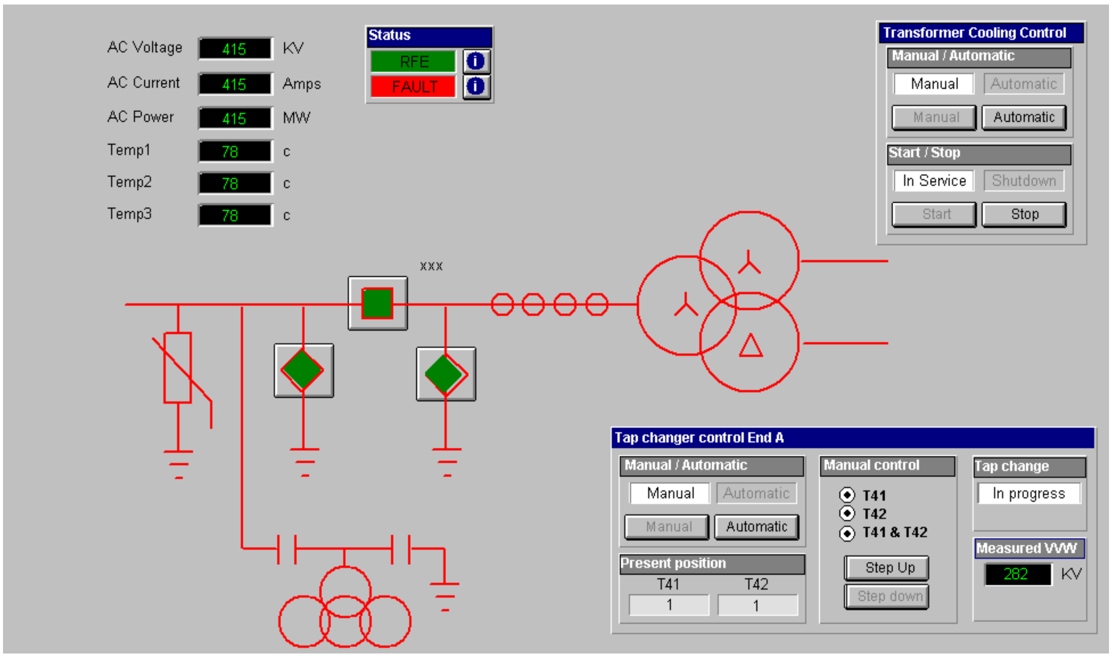


Figure 10: Transformer Mimic

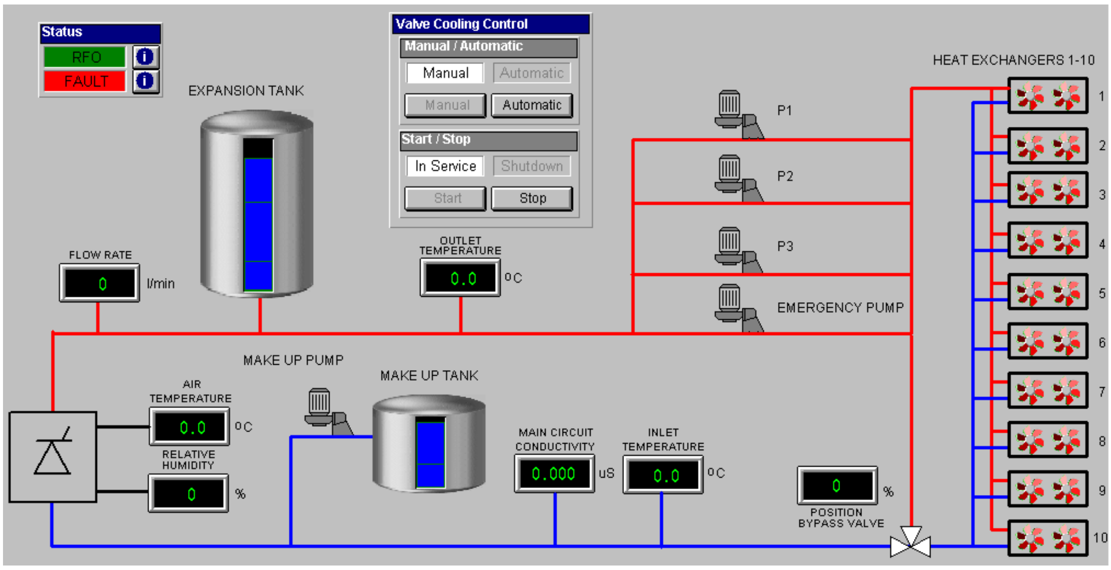


Figure 11: Valve Cooling Mimic

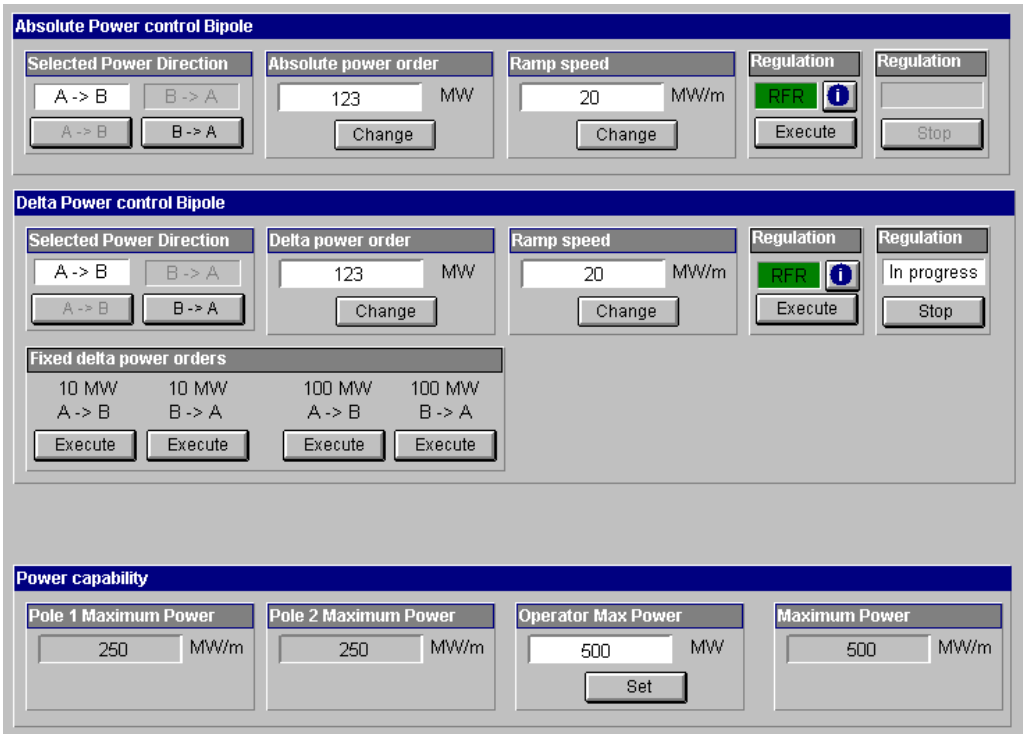


Figure 12: Power Control Mimic

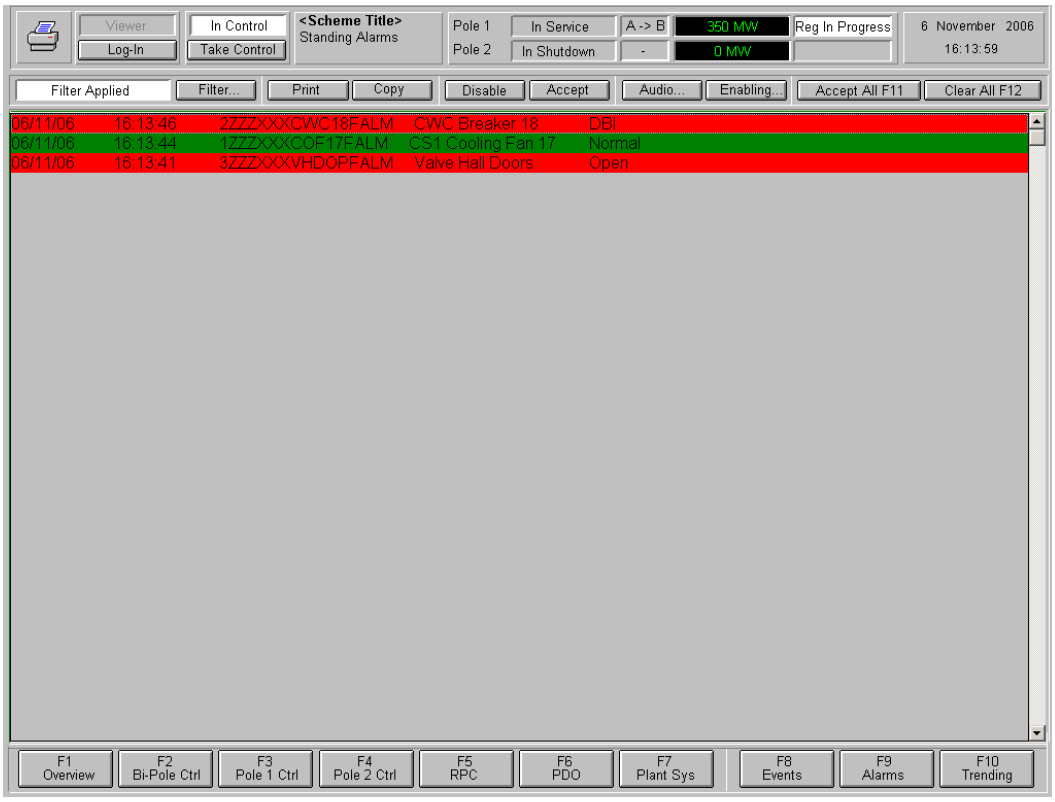


Figure 13: Standing Alarm View

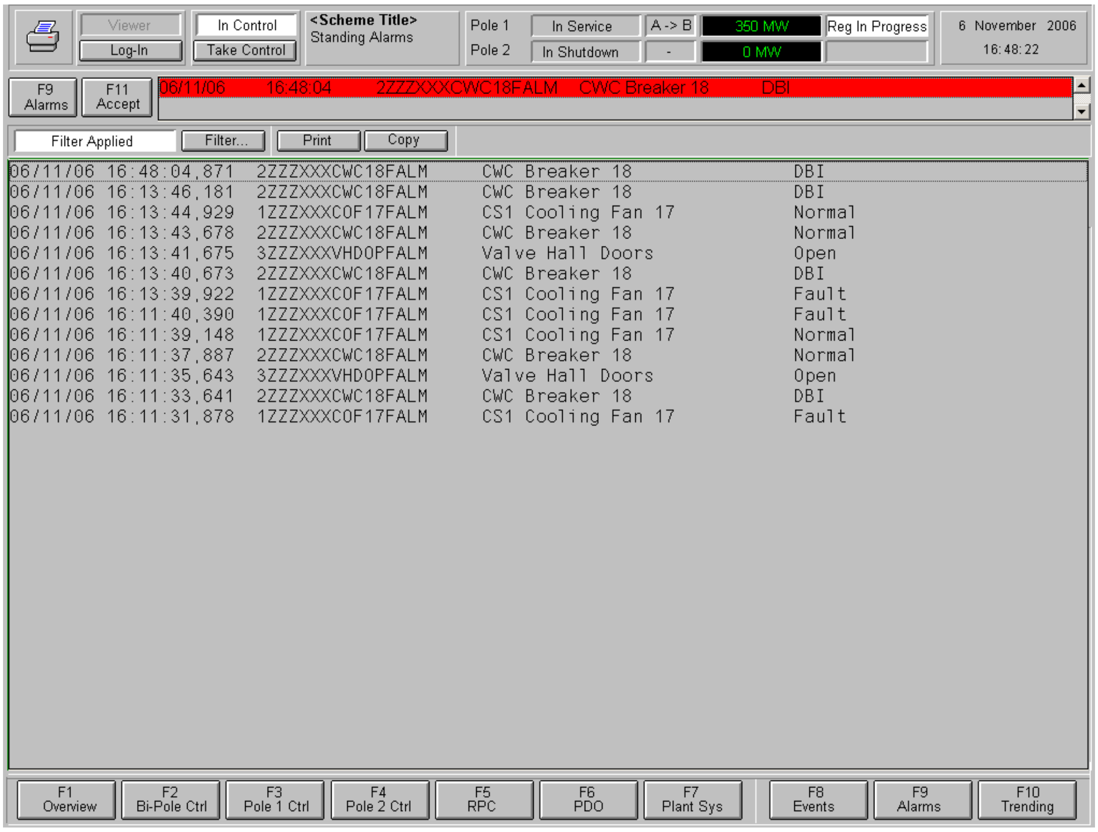


Figure 14: Historical Event List View

4.2.5.2 Schematic representation of HV equipment

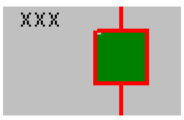


Figure 15: Closed breaker

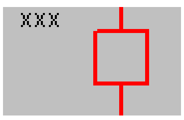


Figure 16: Open breaker

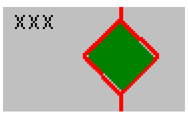


Figure 17: Closed disconnector

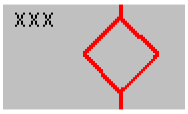


Figure 18: Open disconnector

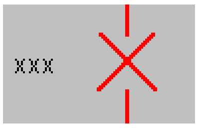


Figure 19: Switch DBI

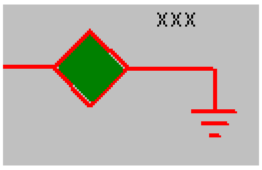


Figure 20: Earth switch

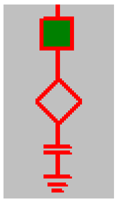


Figure 21: AC Shunt Filter Arrangement

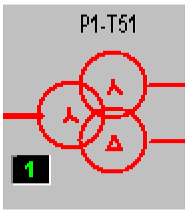


Figure 22: Transformer (star-star-delta)

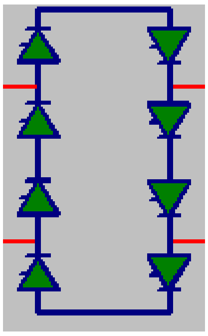


Figure 23: 12 pulse back-to-back bridge or Pole

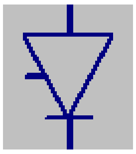


Figure 24: Blocked Valve

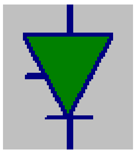


Figure 25: De-Blocked Valve

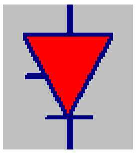


Figure 26: Valve with a standing fault

4.3 STAFFING

4.3.1 STAFFING

The number of staff required will depend on how the scheme is to be operated, options are:

- The converter stations are completely unmanned, with the scheme being controlled from a regional dispatch center (this regularly occurs for schemes in Europe and North America). This would require that a minimum of one of the persons on duty at all times in the regional dispatch center is a fully trained HVDC scheme operator. Assuming 2 x 12 hours shifts, plus cover for absences, etc, we would recommend that a minimum of 6 operators are fully trained.
- Just one converter station is manned, with the other controlled from the manned station. This would require that a minimum of two fully trained HVDC scheme operators are on duty at all times in the manned converter station. Assuming 3 x 12 hours shifts, plus cover for absences, etc, we would recommend that a minimum of 12 operators are fully trained.
- Both converter stations are manned. This would require that a minimum of two fully trained HVDC scheme operators are on duty at all times in both of the converter stations. Assuming 2 x 12 hours shifts, plus cover for absences, etc, we would recommend that a minimum of 16 operators are fully trained.

5 MAINTENANCE OF AN HVDC TRANSMISSION BIPOLE SCHEME

5.1 MAINTENANCE

The equipment is designed for minimum maintenance requirements which ensure both routine (planned) and corrective (unplanned) outages are kept to the shortest possible times.

The objective of the maintenance program is to ensure that the Converter stations are kept in good working order such that they are able to meet the performance requirements throughout their life.

5.1.1 ROUTINE MAINTENANCE

Routine maintenance consists in :

- A monthly surveillance (HVDC in operation)
- A yearly surveillance (HVDC in operation)
- A routine preventive maintenance every three years (HVDC out of operation).

5.1.1.1 Monthly surveillance

Monthly surveillance of the equipment is often carried out by the local maintenance teams of the Operator. It could be KOSTI and NAG HAMMADI teams.

But, if necessary, this maintenance could be provided by the Contractor of the stations.

The “housekeeping” maintenance duties throughout the operating period will be made during the Monthly surveillance.

5.1.1.2 Yearly surveillance

The yearly special surveillance is carried out while the HVDC scheme is in full operation.

The yearly surveillance is required to carry out certain operations such as the recalibration of instruments and control checks.

Yearly Surveillance involves trained personnel visiting the converter station sites to carry out an inspection and to gather data. Yearly surveillance is provided by the Manufacturer.

Items such as the lubricating of pumps and the changing, if required, of water cooling system de-ionisers could be achieved during the Yearly Surveillance visit.

5.1.1.3 Routine preventive maintenance

It is necessary that each pole of the bipole is shut down for Routine Preventative Maintenance once every **three years** to maintain components which cannot be maintained on line.

The second pole will be shut down at some other time as determined by the Operator’s outage requirements.

The poles are arranged such that the maximum number of components can be maintained off line without disturbance to the system.

As the outage will affect both ends of the link, it is important that maintenance be carried out simultaneously on each pole end. It is also possible to carry out some maintenance (but not all) when the equipment is online and this can be accomplished at convenient times as required.

The timing of Routine Maintenance shall be planned by around the Operator's loading requirement. The frequency of outages may be varied following operational experience and assessment of plant condition.

The Routine Maintenance shall include any routine checks; tests and adjustments as per scheduled list and instruction manuals, the major inspection and maintenance tasks being as shown in the table below.

These tasks cover only the power electronics related equipment.

Equipment	Work
Thyristor Valves	• Visual inspection of all valve room equipment including Valve Base Electronics and other control items. Check all pipework. • Clean surfaces of valves as necessary, including water manifold pipes and inter-tier insulators if required. • Perform diagnostic electrical tests on any faulty thyristor levels.
Cooling system	• Visual/audible inspection of motors, pumps and fans with CM instruments. Record data. • Check lamps and annunciator. • Check/clean water filters • Inspect/remove external debris from heat exchangers. • Replace de-ioniser cylinder as required (replacements need to be purchased) • Replace motors or pump seals (if necessary) • Test motor overloads • Check coolant SG and correct if necessary. • Add coolant if necessary • Vent coolant pipework • Check Instrumentation and re-calibrate as necessary.
Control and Protection	• Visual inspection • Rotating test sequence to ensure all conventional protection circuits are checked once per 6 years • Software operated tests on controls (I/O). • Recalibrate electronic protection.
Auxiliary Supplies	• Visual Inspection • Visually check battery sets every 3 months. • Check battery voltages and condition on a three yearly basis and perform discharge tests.
Air Conditioning and Ventilation	• Check filters and change as required. • Check that ventilation system is functioning correctly
Other Components	• Visual Inspection • Lubricate contacts and mechanisms • Check functions.

Table 21: Routine Preventive Maintenance

The maintenance related to all of the other equipment (switchgear, reactors, capacitors, etc) is the same as would be required for a standard AC substation.

The maintenance of the DC and AC yard equipments shall be performed scheduled during the planed outage of the poles.

5.1.2 CORRECTIVE MAINTENANCE

Corrective Maintenance is that which is performed to repair or replace a failed item. If this action occurs outside the terms of the warranty then this will be a chargeable extra.

This item is not predictable so a Call Out Rate should be agreed, with an appropriate supplier, plus the cost of materials. This could be agreed with the Manufacturer.

5.1.3 GENERAL MAINTENANCE COMMENTS

To be able to track accurately previous work on a plant and establish the current status the maintenance team shall maintain and sign a Site log (record sheet) for each Converter Station containing a record of each attendance, routine or otherwise. A maintenance report will be issued outlining work completed, spares used and any recommendations for additional work.

The following service documents and systems would typically be set up:

- O&M manuals
- Site log - (copies to Manufacturer, The client and site)
- Site maintenance sheets for Routine Maintenance
- Maintenance reports
- Breakdown documentation reports
- Method statements
- Risk assessments

The site log records every visit and action by maintenance staff.

5.1.4 TIMINGS

5.1.4.1 Monthly surveillance

The typical duration for monthly surveillance is 10 man.hours, for each station.

5.1.4.2 Yearly surveillance

The typical duration for the Yearly Surveillance is about 100 man.hours for each station.

As this work does not involve a shut down of the link, it can be scheduled as and when it is convenient.

5.1.4.3 Preventive Routine Maintenance

The Preventive Routine Maintenance typically requires a shutdown of one pole for about 48 hours every 3 years.

It also requires about 150 man hour of maintenance without outage. The maintenance which does not need to shut down the pole can be scheduled as convenient, but in the same period of the 2 previous days , in order to use specialist who are on site (without any extra costs due to extra

All the maintenance of the DC and AC yard, that would require outage shall be scheduled during the 2 days. It means that an other team of maintenance staff can work in parallel at each end of the link if necessary.

5.2 EQUIPMENT REVAMPING/RENEWING

Today, typically, the manufacturers of HVDC scheme affirm that a station is designed for a life time of at least 40 years. With modern schemes, the main reasons to renew parts are modifications of capability/rating (increase), or obsolescence.

The above does assume that adequate spares and support are arranged, either at the original contract stage or within 5 to 10 years of the scheme start-up.

The manufacturers have agreements with all of the component suppliers such that they provide advice of the pending obsolescence of any components that they supply to us. This advice is normally given more than one year before obsolescence occurs. This allows manufacturers to approach clients to propose a last time buy to suit their needs and also allows manufacturers time to prepare a alternative solution to the component which is pending obsolescence.

Any way, some examples of HVDC stations show that it is some time necessary to renew the most sensitive components after 25 years (mainly control and protection system, which is numerical equipment, and thyristor valves).

Important note:

For ENPTPS project study, a total renewal of control and protection system has been included after 25 years of operation.

PART III
O&M
OHL

6 OHL GENERAL

Among the main missions assigned to the Operator of this interconnection, one is related to the O&M of the 500kV and ± 600kV Over Head Transmission Line in order to procure the highest availability and performance of equipment.

The maintenance during the defect liability period will be defined according to the O&M manual issued by the manufacturer.

The 500kV and ± 600kV Over Transmission lines Contract should be provided with spare parts and special tools. These materials and tools should be given to the Operator for maintenance works. To support the Operator in its duties and core activities, the maintenance works which request specific maintenance tasks, tools and skills that could be subcontracted.

The preventive maintenance works described in this document are applicable to the following main items :

- Maintenance of the main AC 500kV Over Head Transmission Line Transmission line between the 400/500kV Mandaya substation (Ethiopia) and 500kV/600 kV Kosti substation (Sudan);
- Maintenance of the main DC ± 600kV Over Head Transmission Line Transmission line between the 500/600kV Kosti substation (Sudan) and 500kV/600 kV Nag Hammadi substation (Egypt);

The corrective maintenance works, called “emergency and scheduled works”, are applicable to all equipments useful for the availability of the Transmission lines.

The maintenance plan detailed in the following clauses includes tow types of maintenance activities: preventive and corrective maintenance. These maintenance activities are implemented differently and separately over the year as the result of the tasks performed and their impacts on the power plant availability.

In this document, unless the context requires otherwise, the following words and phrases shall have the meaning:

- **Preventive maintenance (IEC 60300-3-14):** maintenance carried out at predetermined intervals intended to reduce the probability of failure or the degradation of the functioning of an item. E.g. : periodic visual checking of the insulator, conductor, etc …For this purpose, patrols are necessary to ensure that the safety requirements are not being infringed, thereby preventing accidents and reducing line faults.
- **Corrective (curative) (IEC 60300-3-14):** maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function. E.g. : insulator replacement.

6.1 General Description Of 500 kV AC Transmission Lines

The Mandaya HPP (Ethiopia) is connected to Sudan network (via Kosti Substation) through two AC 500kV Transmission line with double circuit. This main transmission line, starts from the gantry of the 500kV substation located in nearby the power plant (Mandaya Substation) to the Kosti Substation (Sudan).

DESCRIPTION	500 kV OHTL Mandaya - Kosti
Total Length	158 km (Ethiopia) + 336 km (Sudan)
Type	2 lines with Double circuit
Number of Towers	1050
Suspension towers	950
Anchor towers	100
Number of Gantries	one at the substation yard
Insulators	IEC Class (160 kN, 210 kN).
Type	Composite
Pollution class	31 mm/kV
Conductors	ACSR DOVE
Number / Phase	4 bundles / Phase
Earth Wires	ACSR and OPGW
Minimum Ground Clearance	11 m
Maximum tower footing resistance	10 Ohms

Table 22 : General Description of the AC 500 kV Transmission Lines

6.2 GENERAL DESCRIPTION OF THE 600KV DC TRANSMISSION LINES

The DC OHTL ± 600kV is made with one bipole configuration lattice towers and two overhead earth wires with one fiber optical equipped. The suspension set are single except on the most important crossing areas (road river, etc …). This Main transmission line, starts from the gantry of the ± 600kV Kosti substation (Sudan) to the Nag Hammadi Substation. (Egypt)

DESCRIPTION	± 600 kV OHTL Kosti - Nag Hammadi
Total Length	1130 km (Sudan) + 535 km (Egypt)
Type	One bipole with 6 sub-conductors per pole
Number of Towers	3330
Suspension towers	3030
Anchor towers	300
Number of Gantries	one at the substation yard
Insulators	IEC Class (160 kN,210 kN).
Type	Composite
Pollution class	40 mm/kV
Conductors	ACSR CURLEW
Number / Phase	6 bundles / Pole
Earth Wires	ACSR and OPGW
Minimum Ground Clearance	13 m
Maximum tower footing resistance	10 Ohms

Table 23 : General Description of the ± 600 kV DC Transmission Lines

6.3 SPECIAL SERVICE CONDITIONS

6.3.1 FLOODED AREAS

Some areas in Ethiopia and Sudan Border are not accessible during the rainy season and therefore the implementation of corrective maintenance activities could be difficult or even impossible.

6.3.2 WOODED AREA

The OHTL crosses a wooded area between Mandaya and Sudan-Ethiopian Border. The corridor below the OHTL in the wooded area is 130 m. Trimming visit are planed under the Operator responsibility to keep this corridor clear of vegetation as per the wooded area and the vegetation clear plan given in appendix 02.

6.3.3 AGRICULURE FIELD

In agriculture field, access to the OHTL through field for maintenance purpose is restricted.

7 OHL PREVENTIVE MAINTENANCE

The maintenance plan shall take into account the liability period and therefore the two following steps shall be considered:

- Before end of defect liability period, the maintenance shall be performed by the Contractor of OHTL according to the manufacturer recommendations specified in the Operation & Maintenance manual.
- After the defect liability period, maintenance shall be performed by the Operator. The maintenance tasks performed by the Operator are listed hereafter:
    - Ground visits
    - Trimming visits
    - Painting Visit
    - Maintenance on the insulator
    - Visit by Helicopter Patrol
    - Climbed visits
    - IR and UV controls : this maintenance task is carried out with special arrangement on the substation to load as much as possible the AC 500kV/ DC 600 kV circuit under IR control.

7.1 GROUNDED VISITS

This set of activities corresponds to periodic visits to assess the condition of the equipment and plan the necessary conditional or corrective maintenance. The periodicity is set to once a year.

7.2 TRIMMING VISITS AND WORKS

This set of activities corresponds to periodic visits to assess the margin of distance conductor-vegetation and the speed of the growth of the vegetation, especially in Ethiopia.

7.3 PAINTING VISITS

The visit are generally done by sampling the towers during the Grounded visits and Trimming visits.

7.4 MAINTENANCE OF THE INSULATOR

In zones where there is pollution, besides a good election of the insulator is advisable to have a maintenance plan: wash or clean the insulator. This is more important in areas with severe environments of pollution or low rain probability, being necessary the elimination of the pollutant layer placed on the insulator.

This maintenance can be carried out with the system energized, wash in hot, or de-energized. The later method is used when cannot be applied another method by technical reasons or when the adhesive characteristics of the pollutant, require the use of wash with chemical solutions to recover the insulation level. Many times, the wash is carried out by hand.

In general the most employed methods are: the wash by water to high, average or low pressure, with dry air compressed or with spurts of abrasive materials and more recently the use of ultrasonic. Any of the techniques used has to guarantee that the insulator will not suffer damage, neither that we are going to get worse the present situation.

The wash with spurts of water is the most effective and economic method, if the contaminant is dust, salt or land, If the contaminant element has a high adhesion, (for example the cement or pollutant originating from chemical businesses or by-products of the petroleum) we have to wash the insulator with abrasive elements. They can be smooth elements, as shattered shell of cobs of corn or shells of nut, fine dust of lime, or more abrasive elements as the fine sand. Always the opinion of the manufacturer will be kept in mind for not damaging the surface of the insulator.

7.5 VISITS BY HELICOPTER PATROL

The purpose of this visit is to carry out visual checking to assess the condition of the OHTL features. The main components checked are :

- Conductors, joints, spacer

- Insulators, fittings, jumper
- Top of the towers…

Helicopter transportation should get the duty authorization to cross the border with one helicopter between Ethiopia / Sudan and Egypt.

7.6 CLIMBED VISITS

The Contractor under planned circuit shutdown must carry out the following work.

- Examine conductors at the points of attachment to insulator sets and check the condition and tightness of nuts, bolts and split pins on all insulator and earth wire fittings, including vibration dampers.
- Check for excessive wear on the fittings for attaching the insulator sets and earth wire to the tower structure and replace as found necessary. Special attention shall be made on the wear of the interface between the towers and insulators (shackles) and on the interface between the insulators and the conductor (clamps).
- Check alignment and gap distance on insulator sets, arcing horns and adjust it according to the specifications.
- Check insulator units for cracks and chips and replace as necessary.
- Check and report in case an abnormal quantity of rust found on the stubs and braces of steel structure.
- Check for bends on main leg and lattice.
- Check with binocular the condition of Joint and for any broken strands
- Check the hazard beacon on Mekong crossing towers

For AC 500 kV, the climbed visit shall not interfere on the availability of the remaining on line circuit. The outage of one or two 500kV circuit is requested. It is important to manage the safety matters related to the specific risks involve by climbed visits with one dead and one energized circuit.

For DC 600 kV, the climbed visit shall be done while the line is energized for continuity of service. Thus the operator should be trained for "barehand" method. The special procedure and precautions required in barehand maintenance include:

- Isolation of the workman from earth
- Protection of the workman from discharge currents upon initial contact with the energized conductor
- Shielding of the workman from ion currents and other field effects
- Special tools for barehand method

7.7 CONTROLS PATROL

7.7.1 INFRARED CONTROLS

The purpose of this control is for detection of the hot spots along the Transmission Lines.

The control shall be carried out by aerial patrol (helicopter) on one circuit only. Scheduled operation on the substation switchgear is necessary to load one Circuit of the OHTL at its max ampacity.

7.7.2 ULTRA VIOLET CONTROLS

The purpose of this control is for detection insulators damaged. The control can be done on both circuits. This patrol should need helicopter and UV camera for this task.

7.8 PERIODICITIES

Designation	Periodicity	Associated Documents
Maintenance during the defect liability	To be completed later as per O&M manual	
Visits by Helicopter patrol	Yearly	Report
Climbed Visits	All the towers shall be visited every 20 years	Tower Record
UV control by helicopter patrol	Every 3 years	Report
IR control by helicopter patrol	Every 3 years	Report

Table 24 : Periodicities for preventive maintenance

8 OHL CORRECTIVE MAINTENANCE

8.1 EMERGENCY CORRECTIVE MAINTENANCE

Emergency corrective maintenance corresponds to actions that should be undertaken immediately to mitigate the effect of forced outage of the transmission line (tower collapsed, broken conductors or insulators, etc …) . Operator’s staff performs the first diagnostic of the faulty equipment.

This emergency maintenance involves all the spare parts and equipment of the OHTL including in the 500 and 600 kV Tender Specification.

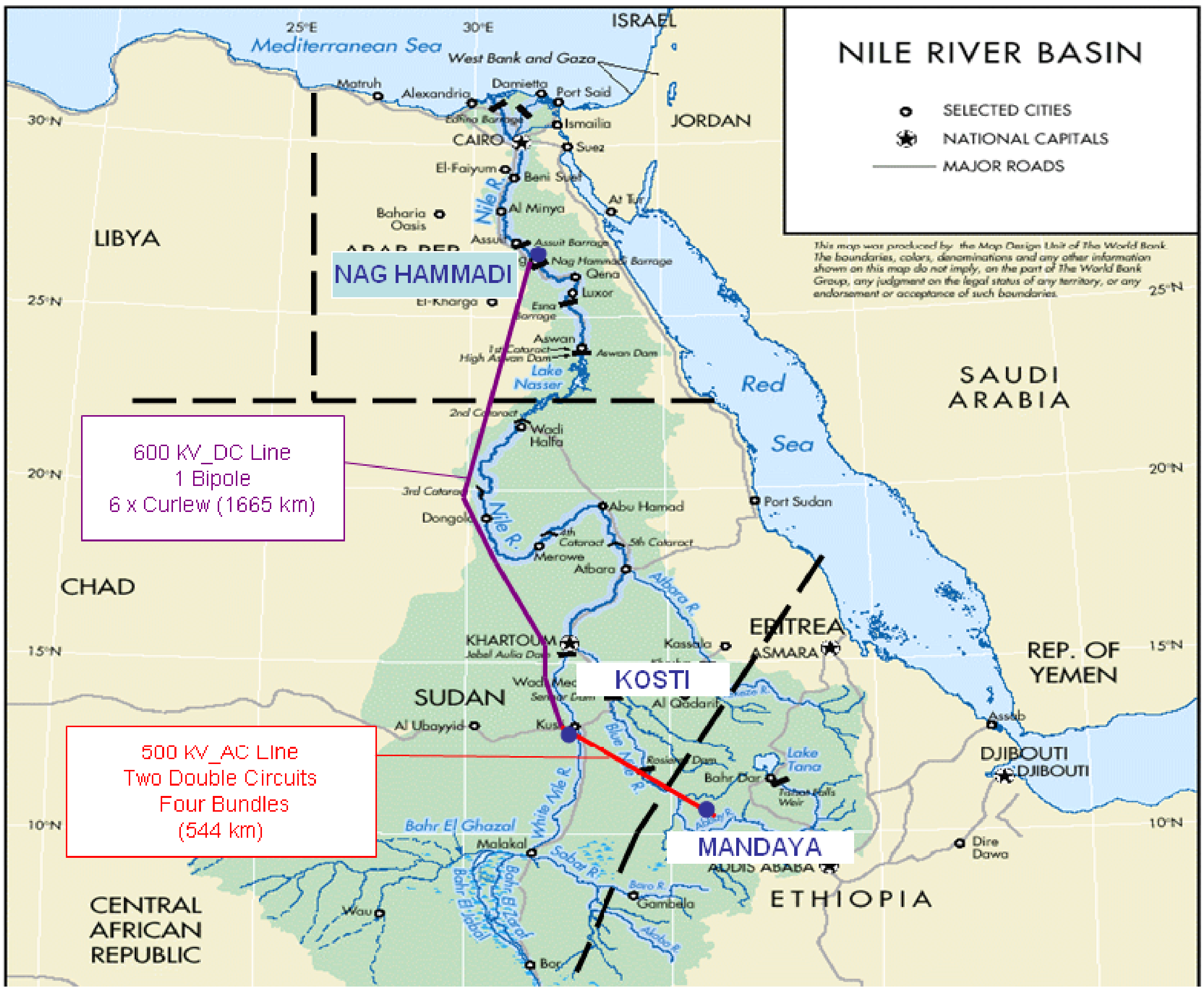
8.2 SCHEDULED CORRECTIVE MAINTENANCE

Postponed actions or "scheduled corrective maintenance". Time for responding is planed by the Operator during scheduled outage of the plant. Operator undertake actions to repair anomalies after detection during the patrol visits or by the Contractor during climbed visits. The maintenance works are scheduled by the Operator depending on the critical category of the fault.

Typical faults	Maintenance task requested
Towers collapsed with or without foundations not affected	Towers reconstruction or Temporary line implementation
Heavy failure on OHTL (insulators string damage, tower collapsed)	Emergency visit in case of exceptional failure (tower collapsed)
Cracks on Insulators	Insulators replacement
Hot spot on joint	Joint reparation or replacement
Strand broken	Jointing
Members missing	Replacement of the missing parts
Rusted part on towers detected during Operator Visit	Painting
Damages ground wires or terminals	Ground wires or terminal repair
Damages on optical features	Repair of the damages on optical features (OPGW + features)
Damages on Beacon and Neon	Replacement of the damages beacon and Neon

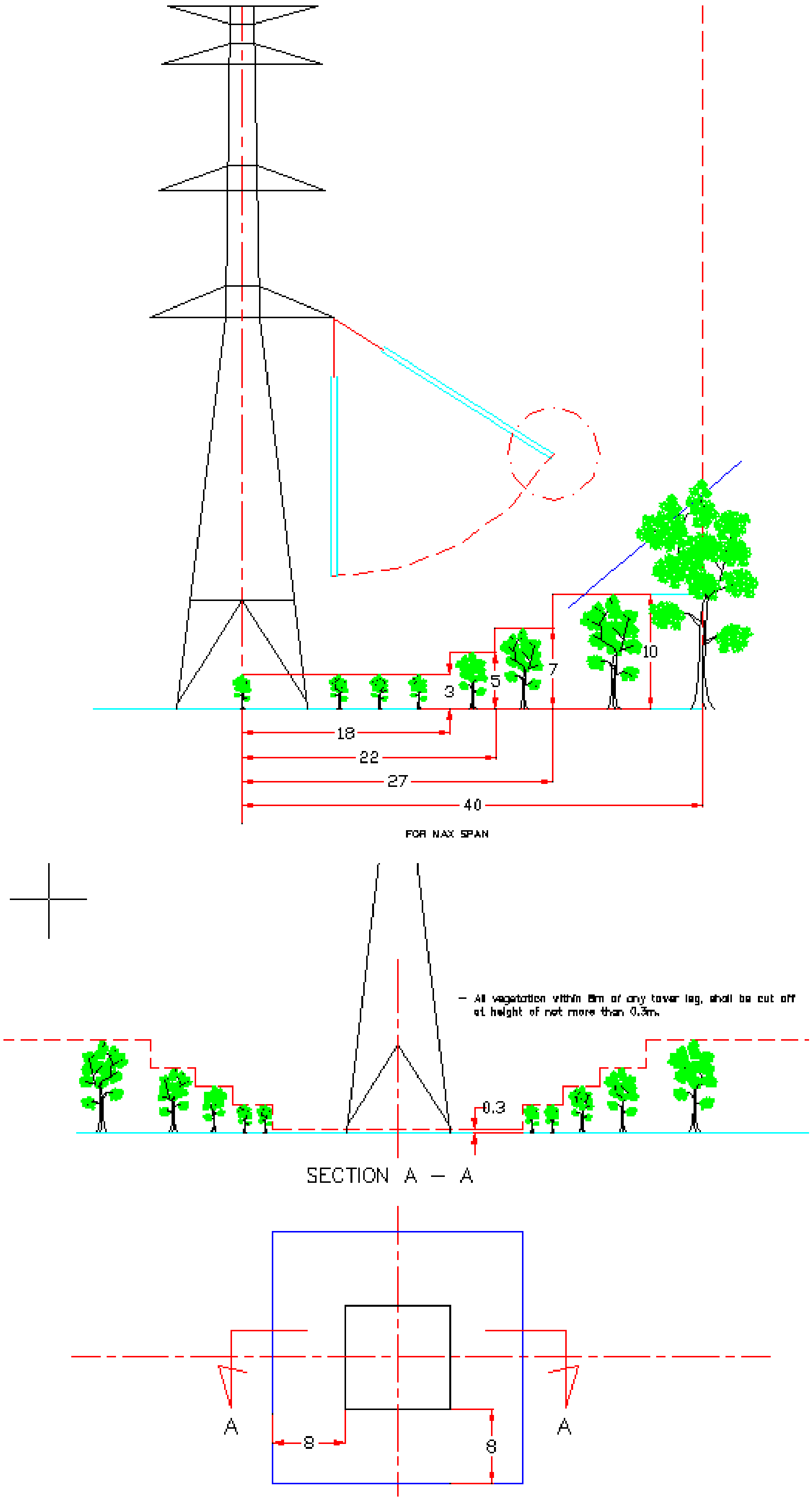
Table 25 : Corrective Maintenance

Appendix 1 : Overview of the AC 500kV and DC ± 600kV Transmission lines



Appendix 2 : Wooded area

The corridor under the OHTL in wooded are shall be maintained as follow.



PART IV
O&M
Control Systems

9 CONTROL SYSTEMS O&M STRUCTURE

This document details the proposed structures for :

- the Operation & Maintenance performed by the future Operator of the Egypt-Sudan-Ethiopian interconnection
- Operation & Maintenance of supervisory control, telecom and metering systems.

This document describes first the proposed main principles to be adopted concerning real-time operation of this interconnection. Then a proposal of maintenance activities related to medium term (around 5 years) is detailed.

According to principles retained in M4 chapter for Telecommunications, Metering, and Control systems only, the corresponding operation and maintenance principles are defined hereafter. Technical staff is supposed to have some relevant experience or some minimal educational background in electrical O&M for HV electrical systems.

It is recommended, at the creation technical team of the Operator of this interconnection to recruit a mix of :

- experienced dispatchers
- electrical engineers being involved in the interconnector design and in building phases
- fresh graduate electrical and control engineers.

9.1 ORGANIZATION FOR OPERATIONAL O&M

Human resources aspects are of prior importance for system operation.

- The management team leads operation, maintenance, planning and support activities. The General Manager reports to the management and to the Board.
- As it is a continuous duty system operation (24h a day and 7 days a week), rotating operation shifts must be constituted. The minimum composition of the team of operators serving at the same time should be at a minimum of 2 or 3 people.
- The planning team includes energy exchanges planning, deviation management, and national TSO relationship.
- The maintenance team is in charge of maintenance assessment and maintenance procurement and control: preparation (activities, periodicity, tools, spare parts, qualification), procurement services and contracts follow up.
- Regarding the importance for operation of control systems, simulation tools and communication systems, a control team is in charge of all IT systems (SCADA, network servers, telecommunication subsystems, productivity and simulation tools, ..)

- The support team is in charge of all activities supporting operational team : HR management, accounting & financial reporting and communication.

Below is proposed a chart with proposal of each employees estimation:

EMPLOYEE MAIN ACTIVITIES	ESTIMATED STAFF
Operator Management	**2** : 1 General Manager & 1Deputy
Management of operation team (maintenance team, IT systems team, support function team)	**4** Team Managers
Operation team	**10** Dispatchers
Maintenance team	**3** Engineers (OHL, Stations, protections)
Control systems team - SCADA - Networks and communication systems - Simulation tools - Productivity	**4** engineers and **1** IT guy
Support function Team - Accounting and financial - HR - Energy exchanges planning and network analysis	**6** professionals
TOTAL ESTIMATED MINIMUM IO CONTROL CENTER STAFF	**30**

Table 26 : Employees estimation

9.2 OPERATION AND MAINTENANCE COORDINATION

Operation staff will have to coordinate with maintenance teams. Maintenance teams will essentially be located on site, all along transmission line, either for preventive or curative maintenance.

In this chapter are first detailed maintenance teams details (number, initial location, access constraints, and repair time performances to be taken into account, repair time optimization…).

Apart of technical communications equipment especially dedicated to maintenance duties, this chapter should also contain basic rules of interactions between operation teams (at a centralized place) and maintenance teams, who will be usually quite mobile all along transmission equipments.

It is strongly advised to forecast system provider assistance, even inside the initial tender process. This should cover remote maintenance capabilities, maintenance process and spare parts management.

10 CONTROL SYSTEMS O&M

According to principles retained in M4 chapter, for Telecommunications, Metering, and Control systems only, the corresponding operation and maintenance principles are defined hereafter.

10.1 MATERIAL ORGANIZATION FOR MONITORING

Previously mentioned needs (in M4 module Telecommunications, Metering, and Control systems), should be translated also, apart of turnkey contact, into daily operation and maintenance.

As it is very likely that a centralized system will be retained for the operation of this interconnection (with potential data exchange with respective participating countries), the necessary technical provisions are provided through the SDH Telecom loop, proposed. This enables to easily adapt centre location, as this one is not defined today, and could also be modified after initial choices, before beginning of building.

Priority aspects, such as redundant access to telecommunications means, building physical accessibility, even under emergency conditions, political agreements (neutral locations…) should also be taken into account, for control centre location (main control centre and backup one).

10.1.1 SCOPE OF SYSTEM TO BE MAINTAINED

Please refer to M4 module to assess configuration to be dealt with current maintenance needs:

MAIN CONTROL CENTER CONFIGURATION	ORIGIN	UNIT	QUANTITY
Real time data servers (SCADA and advanced functions)	offshore	Unit	2
Inter-dispatching communication servers	offshore	Unit	1
Historical system servers	offshore	Unit	2
Simulator server	offshore	Unit	1
Data base management and development server	offshore	Unit	1
Hard disks array	offshore	Unit	1
Operator workstation with 5 screens TFT 21" minimum	offshore	Unit	1
Load frequency control workstation with 2 screen TFT 21" minimum	offshore	Unit	1
General purpose workstation with 2 screens TFT 21" minimum	offshore	Unit	1
Simulator (instructor) workstation with 2 screens TFT 21" minimum	offshore	Unit	1
Simulator (trainee) workstation with 2 screens TFT 21" minimum	offshore	Unit	1
System administration workstation with 2 screens TFT 21" minimum	offshore	Unit	1
Historical system workstation with 2 screens TFT 21" minimum	offshore	Unit	1
Video wall workstation with 1 screen TFT 21" minimum	offshore	Unit	1
Routers, hubs, etc …	offshore	Unit	2
GPS clock, antenna receiver and frequency measurement	offshore	Set	2
Hard-copy laser color printer (A4)	offshore	Unit	4
Hard-copy laser color printer (A4/A3)	offshore	Unit	4
Color A0 plotter	offshore	Unit	1
Wall-board 4*2 blocks (67’’ width for control room)	offshore	Unit	1
42 U cabinets	offshore	Unit	4
Meteorological station	offshore	Set	1

BACK UP CENTRE HARDWARE CONFIGURATION	ORIGIN	UNIT	QUANTITY
Real time data servers (SCADA and advanced functions)	offshore	Unit	2
Inter-dispatching communication servers	offshore	Unit	1
Historical system server	offshore	Unit	1
Routers, hubs, etc …	offshore	Unit	2
GPS clock, antenna receiver and frequency measurement	offshore	Set	1
Operator workstation with 5 screens TFT 21" minimum	offshore	Unit	1
Load Frequency Control workstation with 2 screens TFT 21" minimum	offshore	Unit	1
General purpose and administration workstation with 2 screens TFT 21" minimum	offshore	Unit	1
42 U cabinets	offshore	Unit	2
Video projector	offshore	Unit	1
Hard-copy laser color printer (A4)	offshore	Unit	2
Hard-copy laser color printer (A4/A3)	offshore	Unit	2

Table 27 : Systems to be maintained

10.1.2 MAINTENANCE SERVICES TO BE PROVIDED BY SYSTEM PROVIDER

It is requested that the following services are provided by original system provider :

Hardware Services

- Spare part management

Software Services

- Access to a Support/Call Centre for continuous support (24h / 7days)
- Access to User Groups
- Access to a Monthly Technical Newsletter
- Incident Reports

On-Site Services

- On-Site Services required for maintenance (not remotely possible).

10.1.3 SERVICE LEVEL AGREEMENT PROPOSAL

10.1.3.1 Key definitions

Response Time

- Time to acknowledge the incident in the CRM tool
- A ticket is given to the customer to follow up the incident management process

Resolution time

- Time to complete the action of restoring the critical function
- As soon as practically possible, a workaround is proposed to restore the critical function, while the engineer is gathering data to fix the problem
- Can include workaround and temporary fixing

Repair time

- Time to deliver a permanent fix of the problem
- Can be R&D patch, Spare parts replenishment

Loss of Critical function downtime

- Excludes non critical function & components (printers, monitor, workstation, redundant availability)
- Excludes scheduled / planned and mutually agreed shutdown

Error categories

- **CRITICAL** Software is inoperative or unusable. Critical or material impact on normal business operations.
- **HIGH** Software is partially inoperative, and there are no work-around available. Less critical but severely restrictive impact on normal business operations.
- **MEDIUM** Software is usable with limited functions. Work-around exists to prevent impact on business operations.
- **LOW** Software is usable, but problem has been identified and correction is required.
- **SIR** Software is usable and is functioning properly. A change or enhancement has been identified, and is required.

Critical Functions

The purpose of defining Critical Functions is to ensure that an organization is in place to allow minimum downtime on these functions.

All errors reported on these critical functions are automatically classified as Critical. The classification can be downgraded after analysis

10.1.3.2 Quality of Service (QoS)

Error Categories	Response Time	Resolution Time (target)
Critical	2 hours	2 days
High	6 hours	10 days
Medium	1 days	30 days
Low	2 days	60 days
SIR	On agreement	On agreement

Table 28 : Quality of Service

10.1.4 SUPPORT ORGANISATION

10.1.4.1 « Support » entity

The « Support » entity manages the maintenance of the systems delivered by our project teams. It is constituted with its own resources and processes and maintains a strong interface with the project team.

10.1.4.1.1 Maintenance Project Manager

The maintenance project manager shall guarantee to the Customer that the service commitments are fulfilled

His main actions are listed below:

- Guarantee the availability of the whole service commitments and the higher level of technical assistance.
- Manage the human resources availability and the appropriate technical skill's level during the whole contract service.
- Monitor major incidents, in case of critical situation, elaborate with the support engineer an action plan to recover a normal situation.
- Escalate problems that cannot be solved with the back office or on call team to a higher level of expertise, and maintains a close contact with the customer during this phase.
- Provide incident report to the Customer after problem has been solved.
- Manage the commercial and financial part of the project.

10.1.4.1.2 The Call System

A dedicated phone number will be available.

The maintenance project manager will respond to any customer calls.

In case of busy line, no answer the client's call will be automatically connected to an external call center. The external call center will be in charge of contacting the support engineer according to a procedure previously defined i.e.: customer's name, maintenance contract, the Service Level Agreements for this customer.

10.1.4.1.3 Back Office team

The Back Office team is in charge of corrective and preventive maintenance. Our support engineers:

- Provide assistance to the customers by phone, through on-line networks, and / or by e-mail

- Open an incident at each customer's call on the CRM tool
- Communicates with customers to help them understand how to use the product properly.
- Solve the problem by providing advanced code fixes for bugs, which do not require re-design of correction.
- Ask through an escalation process if higher level of technical support is needed, and define the appropriate specialist profile to the customer service manager,
- Describe on the CRM tool the already taken actions in case of escalation,
- Inform the Customer Service Manager in case of critical problem, problem with contractual response time and solution not found in the contractual time,
- Give a clear reporting for each intervention on the Incident Management tool,
- Give a weekly progress report to the Maintenance Project Manager.

The Back Office team performs adaptive and upgrading maintenance (upon agreement with the customer), especially:

- It performs the design work, development, the testing and deployment of the new versions of the system
- It writes the project technical documentation (user documentation, acceptance book, etc)
- It provides in-house training for the on-call team, and occasionally external training.

10.1.4.1.4 On-Call team

The on-call team is an emergency support team, which can be called outside of working hours to solve an anomaly as quickly as possible. The on-call team is contacted through a call centre.

The on-call team is also in charge of SMS messages analysis received from the customer team in order to ensure early interventions.

Each team member has followed in-house training on the customer applications specifically for on-call personnel.

When they are mobilised, the on-call engineers use the same processes and tools as the back office team. They access the maintenance system either through remote access or by accessing the site.

The on-call team has an updated documentation kit at its disposal (giving a detailed description of the software and hardware architecture, the specifications, the user manual, etc.).

10.1.5 *PROCESSES AND TOOLS*

10.1.5.1 Processes

Main Support Processes are :

- Customer call handle
- Incident tracking
- Incident fixing
- Problem fixing
- Escalation
- Knowledge transfer
- Reporting

Processes must be described in a Quality Management Procedures.

The customer issues the maintenance request relating to its system. It should have three different communication channels:

- A telephone number corresponding to a call centre to deal with blocking anomalies. This is the preferred channel.
- A single e-mail address for the Support team to address the technical fact sheets
- Access via Internet to the Incident Management System, i.e. technical fact sheets. This access allows processing of the technical fact sheets to be monitored..

The escalation process is key to guarantee that the provider management is involved to

- Understand with the customer the actual severity level of the incident and the implication on the customer business process
- Mobilise enough skilled resources within the minimum time to ensure that the system critical function is restored within the minimum amount of time
- Make sure that enough technical data is collected during the system restoration phase to fix the problem and ensure the incident will not reappear again
- Check with the customer that the critical function has been restored
- Check with the customer that the problem has been fixed

10.1.5.2 Tools

10.1.5.2.1 Incident Management Tool

A Customer Support incident management system software should be provided for example: ServiceWise by TechExcel. This tool must be used to track each customer incident from open to close with regular status and updates maintained in each incident record.

This tool main required features are described hereafter:

- Incident tracking and background of the actions implemented to manage an SMR, loading and downloading of documents.
- A secure gateway from Internet
- Monitoring of the various Incidents statuses
- Multi-criteria searches and ease of reporting.
- Use by all geographical units with a service activity.
- Management of different contributor profiles
- Exports to office tools (EXCEL, WORD)
- Integration with mail boxes (manual or automatic generation of messages)
- Management of a knowledge base (self fed by new calls)

The knowledge database is shared between our support centres and helps support engineers to strongly improve their capability to resolve customer problems by quick access to existing solutions.

10.1.5.2.2 Remote maintenance link

Internet Virtual Private Network (VPN strongly advised) link or ISDN connection to the customer system

The access to remote systems installed at customer site is achieved as an Ethernet LAN-to-LAN interconnection. The services used for remote support are transported above the IP protocol. These services are mainly telnet, ftp, terminal server client, http, Xwindows, etc.

The public networks are used whenever it is possible and especially the international ISDN data service and the Internet . The VPN link over the Internet requires that a fixed Internet access is available at the customer premises.

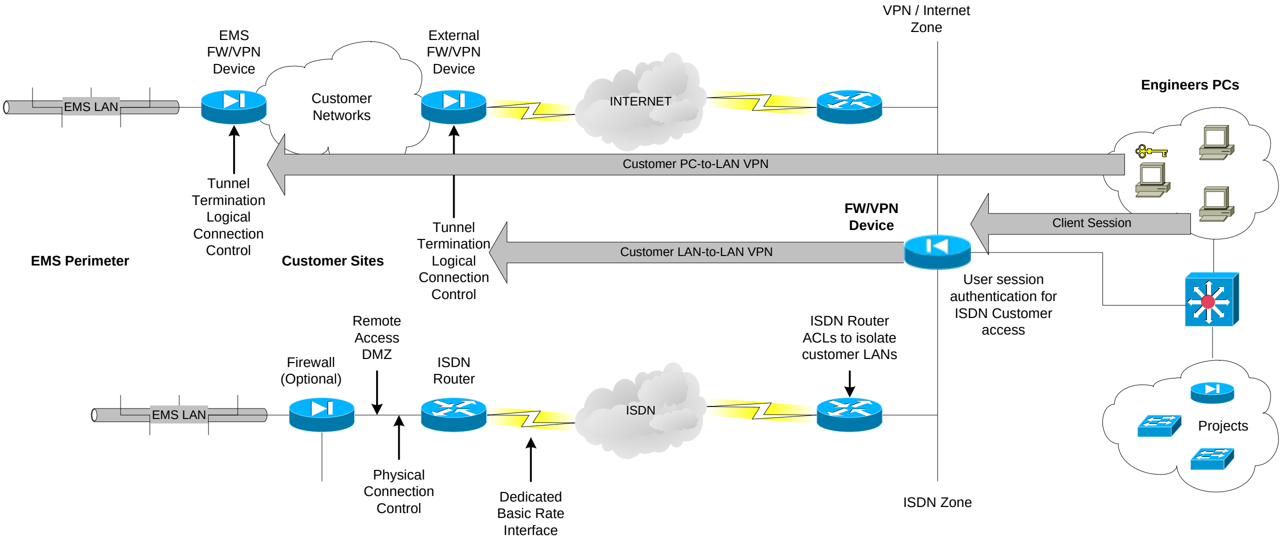


Table 29 : Sample VPN or ISDN link architecture

The Operator of this interconnection should provide to system provider a fixed IP address.

Network Security

Maintenance provider's network should be protected by specific devices strategically placed within the networking environment. Access to customer's networks should be granted only to authorized personnel. Users of remote maintenance links should be authenticated before any action can trigger the connection. The traffic should be monitored to prevent any unauthorized attempts to access customer's network.

Careful attention must be paid to protect end devices against configuration spoofing by securing all the device accesses, especially by using strong password encryption and disabling unused services. ACLs are configured to restrict traffic to the identified parties. The devices supplied by Maintenance provider are configured accordingly.

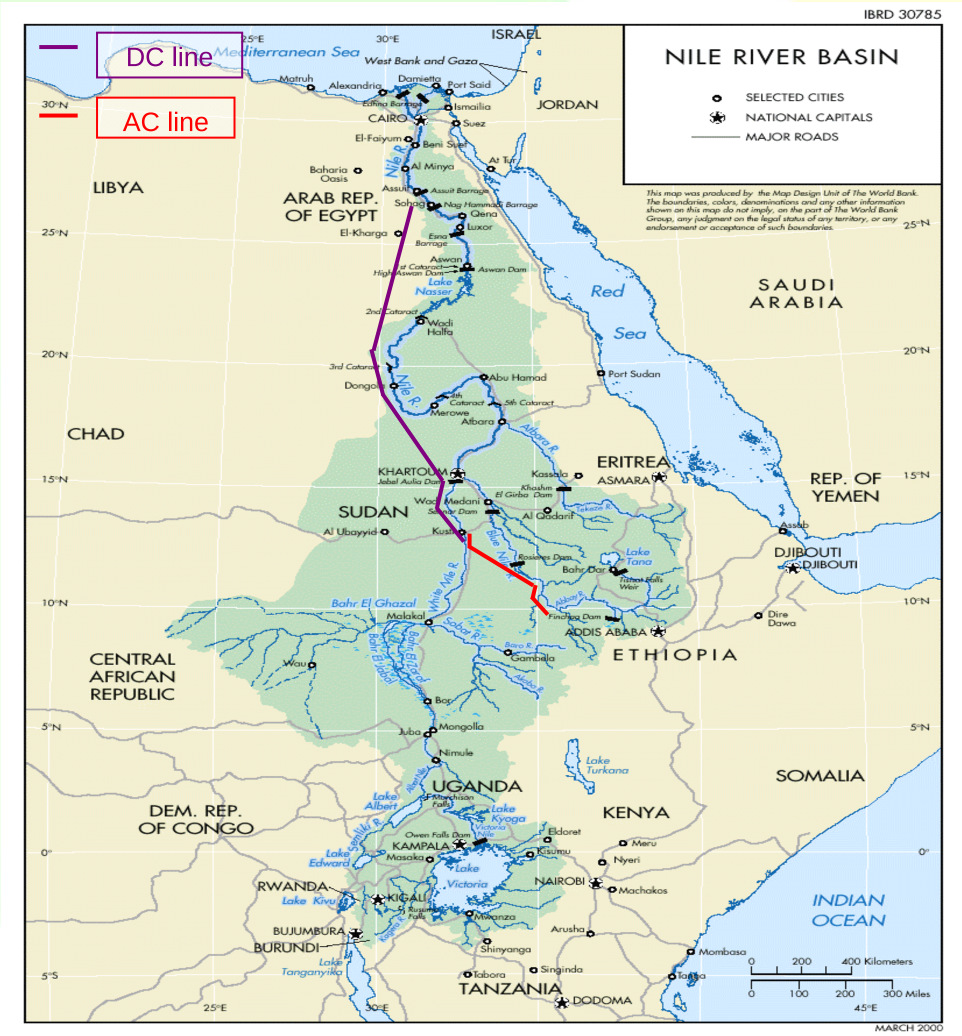
Nile Basin Initiative

Eastern Nile Subsidiary Action Program

Eastern Nile Technical Regional Office

NILE BASIN INITIATIVE
Initiative du Bassin du Nil

EASTERN NILE POWER TRADE PROGRAM STUDY



M9 – TRAINING FINAL REPORT

TABLE OF CONTENTS

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

Here follows main used acronyms definitions: referred with a (*) in the text below.

- **General ENTRO abbreviations and acronyms:**

AC	Alternative Current
DC	Direct Current
EEHC	Egyptian Electricity Holding Company
EEPCO	Ethiopian Electric Power Corporation
EHV	Extra High Voltage
ENTRO	Eastern Nile Technical Regional Office
ENTRO PCU	Eastern Nile Technical Regional Office Power Coordination Unit
HV	High Voltage
HVDC	High Voltage Direct Current
NBI	Nile Basin Initiative
NEC	National Electricity Corporation (Sudan)
SVC	Static Voltage Compensator

EXECUTIVE SUMMARY

This document proposes the training activities for Interconnection operation.

This is a complementary document, in addition to previous technical modules.

This module gathers training principles for the different infrastructure parts of interconnection.

Training paragraphs are put together, in accordance to Terms Of Reference documents.

These specifications cover :

- Alternative current substations,
- Staticvar compensator facility
- Direct current converting stations,
- Physical transmission lines
- Control centers (main and back up) equipment and system operation teams.

1 DOCUMENT OVERVIEW

This document details the proposed training for the different equipment of the interconnector.

The intent is to provide with operational and maintenance guidelines for future operator management and staff, in order to organize training activities before and during interconnector operation.
Several parameters may impact the below presented proposals:

- Initial skills level of hired staff ,
- Effective planning of project implementation,
- Assessment of training needs during operation (new hires, necessity of maintaining and updating knowledges).

The training program shall be defined more precisely during the project development phase.
It will be refined during hiring process and with contractor support.

To get a better picture, appendix 1 illustrates a sample of inspection training program development checklist for OHL.

2 AC, SVC AND HVDC STATIONS AND TRANSMISSION LINES

The objectives of the training shall be to ensure that:

a) An adequate number of trained staff are available to support the O&M of the transmission facilities. Large distances between AC stations have to be taken into consideration. This imply to have at least at all time two operational teams able to withstand contingencies at least at two different locations. Therefore the number and duration of training sessions should be compliant to that fact.

b) In due time, the necessary skills and knowledge will be gained by the personnel to allow sustained O&M without assistance, because of remote areas concerned by AC substations locations. This represent a particular constraint in case of need of contractor assistance: Operation teams should be autonomous enough between occurrence of incident and contractor support in order to make the right diagnosis.

Three categories of training are identified:

a) Specific training courses provided and coordinated by the Construction Contractors at their premises. Constructors shall define the minimum level of skills required to attend to their training sessions.

b) Additional on-the-job training could be obtained during equipment manufacturing and testing through O&M staff participation at the factory inspection and acceptance testing activities.

c) Site on-the-job training during erection, testing and commissioning by the Construction Contractors.

On site training sessions shall be accomplished using drafts or final operation procedures. A specific team, compounded of the most experienced individuals owning teaching skills, should be in charge of drafts operational procedure writings.

All training content shall be organized, in order to have a logical way of progress :

- from the easiest to the more complex
- from local to global
- from hardware to functional

This could be illustrated by the following charts:

Technologies	Description	Number of factory sessions	Number of site sessions
Alternative current stations	Providing comprehensive knowledge on all AC equipment	4	4
Static Voltage Compensator station	Providing specific theoretical knowledge about thyristor, conversion technologies	1	2
Direct current converting stations	Providing specific theoretical knowledge about thyristor, conversion technologies	2	2
Transmission lines	Providing necessary background either for AC transmission lines built in ENTRO specific climate conditions, and also DC transmission specific techniques	2	4

Table 1 Technologies Training

Operational skills	Description	Number of factory sessions	Number of site sessions
Alternative current stations	Comprehensive know how to appropriately handle off-normal or emergency situations related to AC equipment	2	2
Static Voltage Compensator station	Comprehensive know how to appropriately handle off-normal or emergency situations related to DC converting stations, especially to be able to operate even with restricted power factor	1	2
Direct current converting stations	Comprehensive know how to appropriately handle off-normal or emergency situations related to DC converting stations, especially to be able to operate even partially transmission capacities	2	2
Transmission lines	Providing with necessary background to appropriately and safely operate transmission lines (handle usual switching on and off, recover operation in best delays while enforcing security guidances …)	4	4

Table 2 Operational Skills Training

3 CONTROL CENTRES AND OPERATION RELATED EQUIPMENTS

3.1 STAFF TRAINING

As of today, a team under daily continuous duty (6am-10pm), should be constituted. The minimum composition of the staff serving at the same time should be at a minimum of 3 people.

Corresponding training needs (initial and also regular during operation) should are detailed in this paragraph.

As the interconnection operation will interact with the three other countries already existing dispatching systems and therefore their respective operating staff, a particular study should define what will be the training needs for Egypt, Ethiopia and Sudan system operators, in order to enable appropriate operation in coordination with the staff of the future Interconnection Operator.

Here follows tables to propose breakdown of operation staff training:

- General training
- Operator training
- Maintenance training

3.1.1 GENERAL TRAINING

Subsystem	Description	Number site sessions	Number Days/session
Interconnector	Interconnector : General	1	3
	Interconnector General O&M (control, communication, safety, auxiliaries, back-up switch-over)	1	4
	Energy exchanges planning & management	1	4

Table 3 General Training

It is likely to invite the interlocutors from TSO companies of EN countries Interconnector session "General".

3.1.2 OPERATOR TRAINING

Subsystem	Description	Number site sessions	Number Days/session
Grid Equipments	Subsystems descriptions and operation	2	4
SCADA and advanced functions	Operational procedures, outages management	1	4
Communication system	Remote terminal units, Telecommunication front ends	1	2

Table 4 Operator Training

3.1.3 MAINTENANCE TRAINING

It is assumed that trainees have a good power facilities maintenance background in terms of maintenance organization, scheduling, strategy definition and maintenance contract management.

Subsystem	Description	Number factory sessions	Number site sessions
AC systems	Subsystems & components description, maintenance activities, procedures, failures detection, repairing strategies,	1	1/station
HVDC stations & SVC		1	1
Control systems		0	1
AC & DC OHL		0	1
Communication system		0	1

Table 5 Maintenance Training

3.2 OPERATION TRAINING

Operation will of course require appropriate human resources.

As of today, a team under continuous duty (24 h/7 days), should be constituted. The minimum at the same time should be at a minimum of 1 individual.

Corresponding training needs (initial and also regular during operation) are detailed in this paragraph.

Here follows tables to propose breakdown of operation staff training:

- Control System training
- Simulation system

3.2.1 CONTROL SYSTEM TRAINING

Subsystem	Description	Number factory sessions	Number site sessions
Hardware	Hardware configuration maintenance		1
	Servers maintenance	1	
	Hubs, routers and firewalls	1	
	Wall board system		1
	Uninterruptible Power Supply		1
General software	Operating system training	1	
	Data base management	1	
	Oracle database (historical data)	1	
Display and data base modelling	Data modelling rules	1	
	Data modelling tool	1	
	Display modelling	1	
	Historical reports modelling	1	
SCADA and advanced functions	SCADA and associated services	1	
	Overview of power system applications	1	
	Network analysis functions	1	
	Generation management	1	
Communication system	Remote terminal units	1	
	Telecommunication front ends	1	
System integrity	Internal SCADA system integrity	1	
	External communications management	1	

Table 6 Control System Training

3.2.2 SIMULATION SYSTEM TRAINING

Subsystem	Description	Number site sessions by year
Instructor training	Simulator architecture	1
	Simulator exclusive functions	1
Trainee management	Training session set-up	1
	Training scenarios	1

Table 7 Simulation System Training

APPENDIX 1

Sample Inspection Training Program Development Checklist for OHL

1. Assign an instructional developer for the training development project. Publicize it and make sure there is strong management support before proceeding. If you do NOT have management support now, you may as well NOT proceed further.
2. What is the problem? (Develop a problem statement, even though you “know” there is a lack of training or standards for inspection.)
3. Is training part of the problem? (In this case there appears to be no formal or organized training, so lack of training and/or inspection standards is part of the problem.)
4. Develop lists of all possible tasks to properly inspect a tower, pole, ROW or other line component. (Respond with more than “fly slowly over the pole” or “drive slowly by the pole.” Be specific. How close do you get to the pole? Do you climb it? Do you test it before you climb it? How do you document what you find? etc.) Use the Inspection Handbook and the Pictorial Notebook as references to aid in the breaking down of each task into specific activities.
5. Subdivide the above task lists by structure type, component, or by patrol type, whichever best suits the inspector’s requirements. (Use a spreadsheet to keep it as clear as possible.)
6. Identify who performs the tasks. (Identify personnel by job or job description, not by name.)
7. Identify which tasks are difficult to learn. (Prioritize from most to least difficult to learn-keep it at three levels such as A, B, C, with A being the most difficult.)
8. Identify how often the tasks are performed, e.g. patrol frequency. (Prescribed frequency, as needed, etc.)
9. Validate the list. (Let veteran experts on the subject matter and apprentices critique the lists.)
10. Prioritize the tasks. (Criticality, frequency of performance, 1, 2, 3, with 1 being the most critical and most frequently performed.)
11. Select tasks for instruction. (Do you cover all tasks, most critical ones, most frequent, etc.?)
12. Develop a training plan. (What will be the methods of instruction --- classroom, on-job-training (OJT), or a combination? Consideration must be given to “how to get there from here,” OJT guide format, follow-on training [what/when/how/who], documentation requirements, system changes required, inspection standards to follow, responsibilities, etc.).
13. Assign personnel to training development and identify future instructors. (Use internal training staff or contracted professionals. Don’t just “assign” individuals, but get them to the training they need, i.e. train the trainers. Courseware developers and instructors need to be trained in these specialties. A good inspector will not necessarily be a good courseware writer or instructor.)
14. Publicize the training development project and its potential benefits to the staff. (Keep the staff informed as to what is happening, why training is being developed, who it’s for, etc. Public relations is part of the training developer’s tasks.)
15. Develop a timeline for training development, if not already covered in the plan. (When do you want the first class to be conducted when will the OJT guide be implemented, when must you have names of all personnel requiring training, when do you conduct data collection, when do you validate the courses and OJT guides, etc.?)
16. Develop the training. (Remember your target audience, their skills and knowledge. Write so they can understand. Consider the environment in which the trainee will be using the material. The information needs to stand alone. In the inspection business, you need clear directions and good

visual aids.)
17. Produce the training material. (You should still make quality improvements as you produce.)
18. Validate the training. (Try the course and the OJT guide on a small group of typical students. Now is the time to make any needed changes.)
19. Institute management changes to accommodate training. (Direct the responsibilities that were identified in the training plan.)
20. Implement the training. (Tasks identified, students identified, training developed now do it.)
21. Follow up. (How do you know if it's working? Get a team of experts to perform some quality checks of some line components inspected by "trained" students.)
22. Begin next phase of training. (How is the classroom and OJT guide approach working? Is it time to consider using additional resources such as video, computers, CD ROM, DVD, E-books, and other classroom and field instruction, etc.?)
23. Develop and implement a training program maintenance plan to include a schedule of periodic reviews. (If you don't schedule it and make it a mandatory item on your calendar or the company calendar, it will not get done.)
24. Consider periodic (annual, semi-annual, etc.) refresher or update training.
25. Develop a system to identify new problems being found in the field and implement a method of training people in the new problems' resolutions.
26. Develop a system to identify new tools or inspection practices that may enhance and implement appropriated training for these resources.