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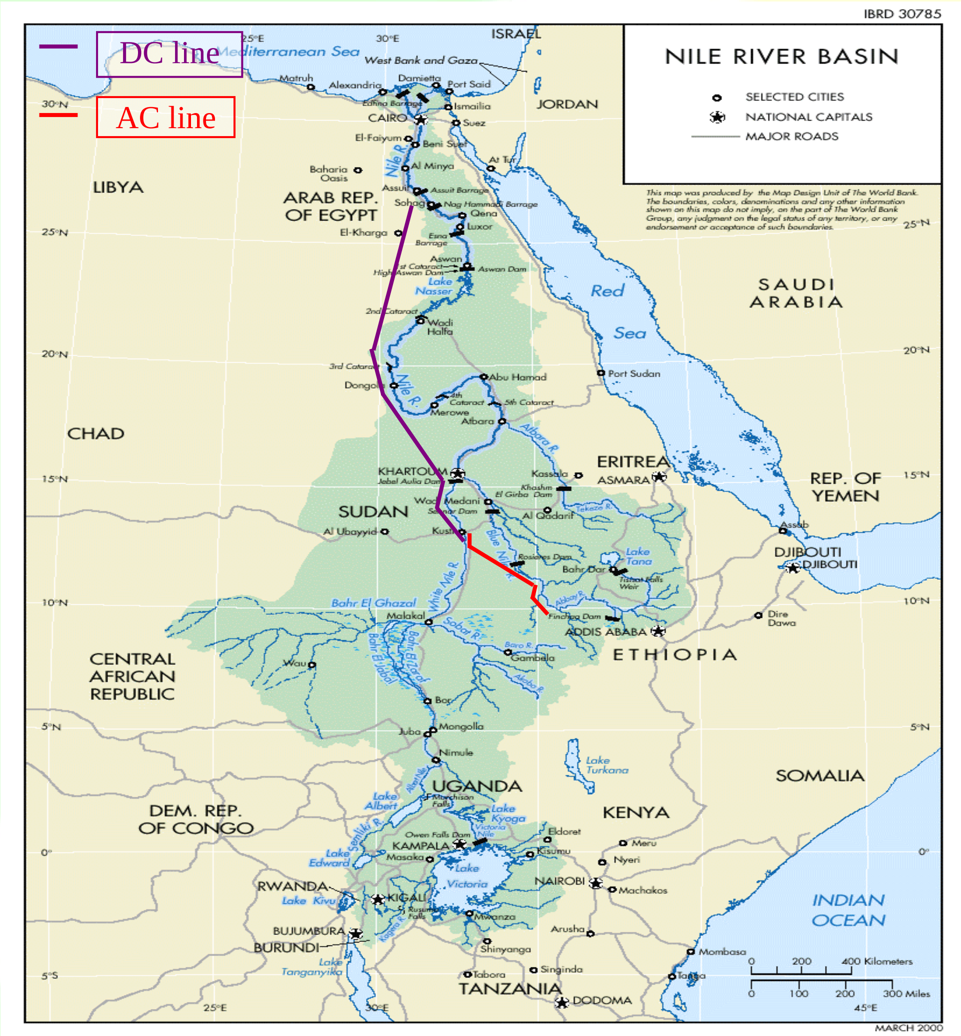
Nile Basin Initiative

Eastern Nile Subsidiary Action Program
Eastern Nile Technical Regional Office

FINAL REPORT

EASTERN NILE POWER TRADE PROJECT

VOLUME 1: POWER STUDIES



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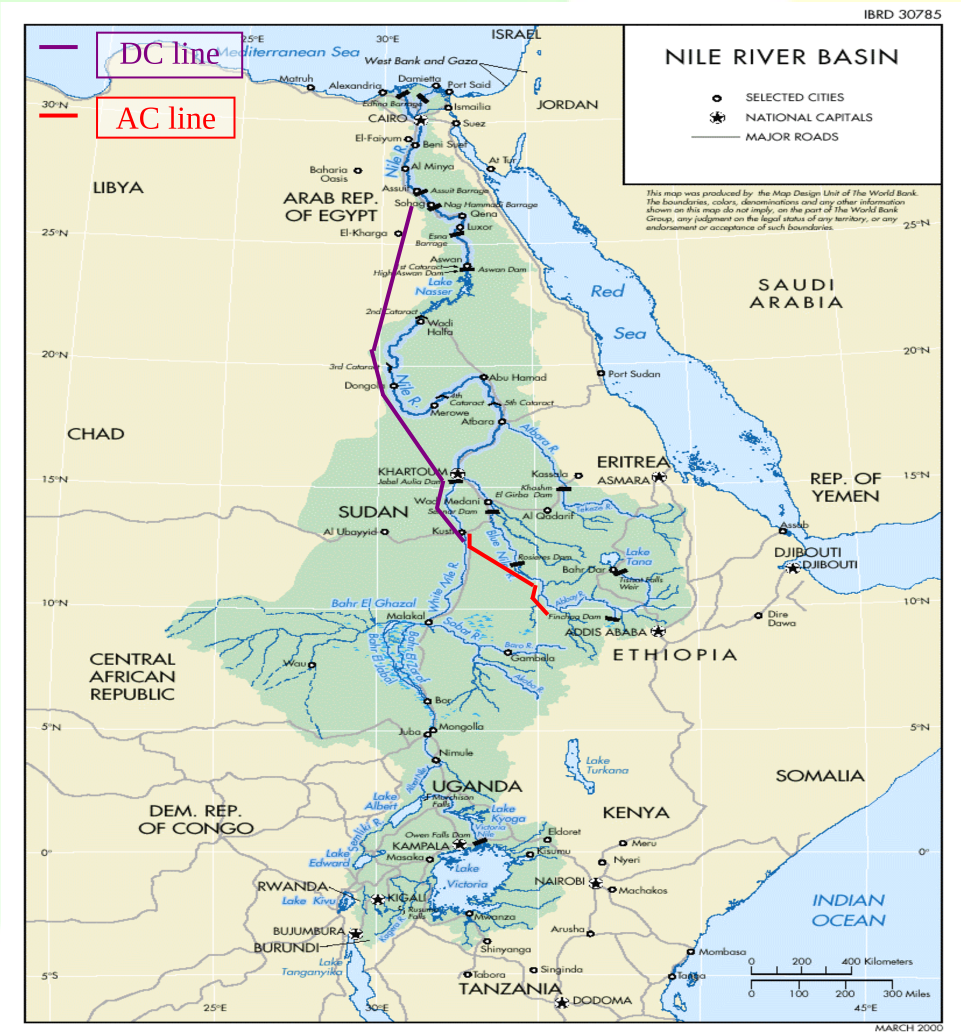
EASTERN NILE POWER TRADE PROGRAM STUDY



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.

Key Contributors

Power Studies : E. Varret, R. Leport, L. Magliano, O. Hurtiger

Line Routing : X. Daudey, X. Campagne

Technical Specifications :
- OHL : X. Daudey
- HVDC : L. Tullus
- AC Stations : L. Popiel
- Control Systems : Ph. Espinasse
- Training : Ph. Espinasse

Institutional Analysis : J. Roux

Financial Analysis :
- M. Muller, NODALIS

Environmental and Social Impact Analysis :
- SCOTT WILSON Ltd, England
- E. Mwelwa, ZESCO

Local Subconsultants for Line Routing and ESIA :
- Egypt : EPS, SPEEDOTRANS
- Ethiopia : TROPICS
- Sudan : YAM CdC

Philippe Lebreton, EDF-CIST

Project Manager

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.

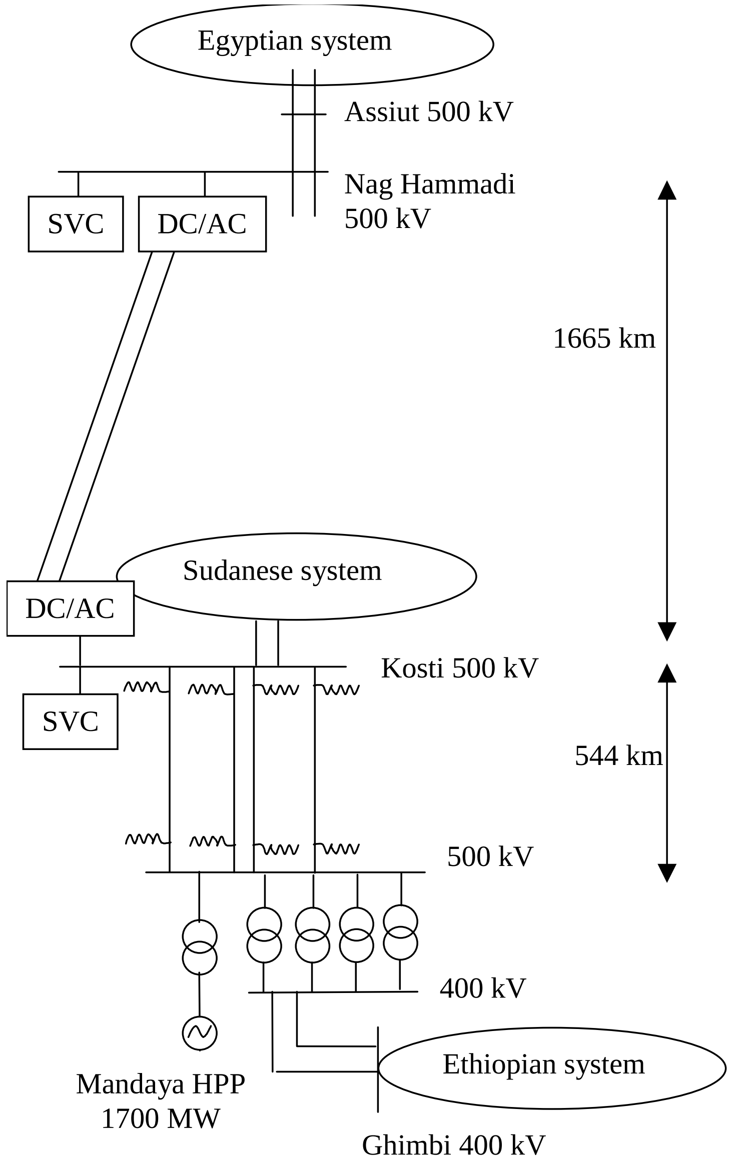
Despite this small ratio, this **Resettlement Action Plan is a key point for the implementation** of the interconnection. The project company shall take a special care and monitor closely that Contractor to fulfill ESIA recommendations and assignments.

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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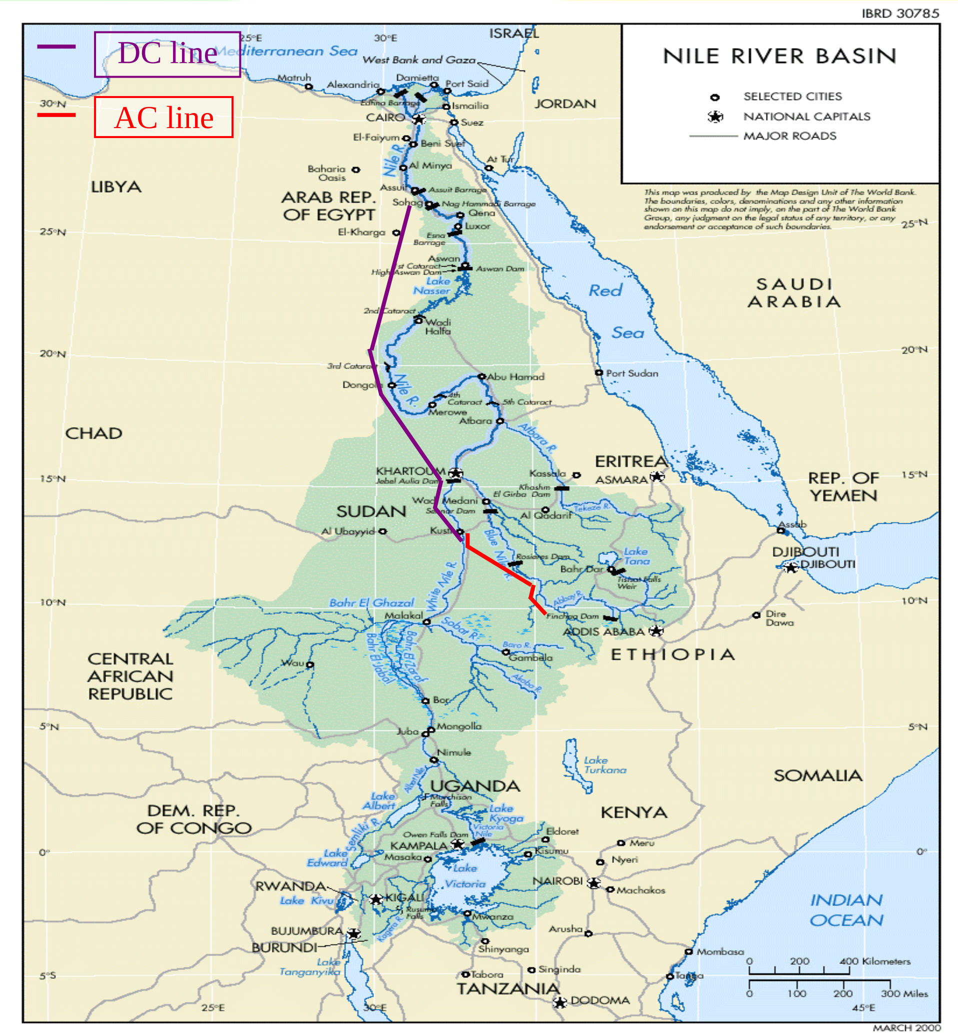

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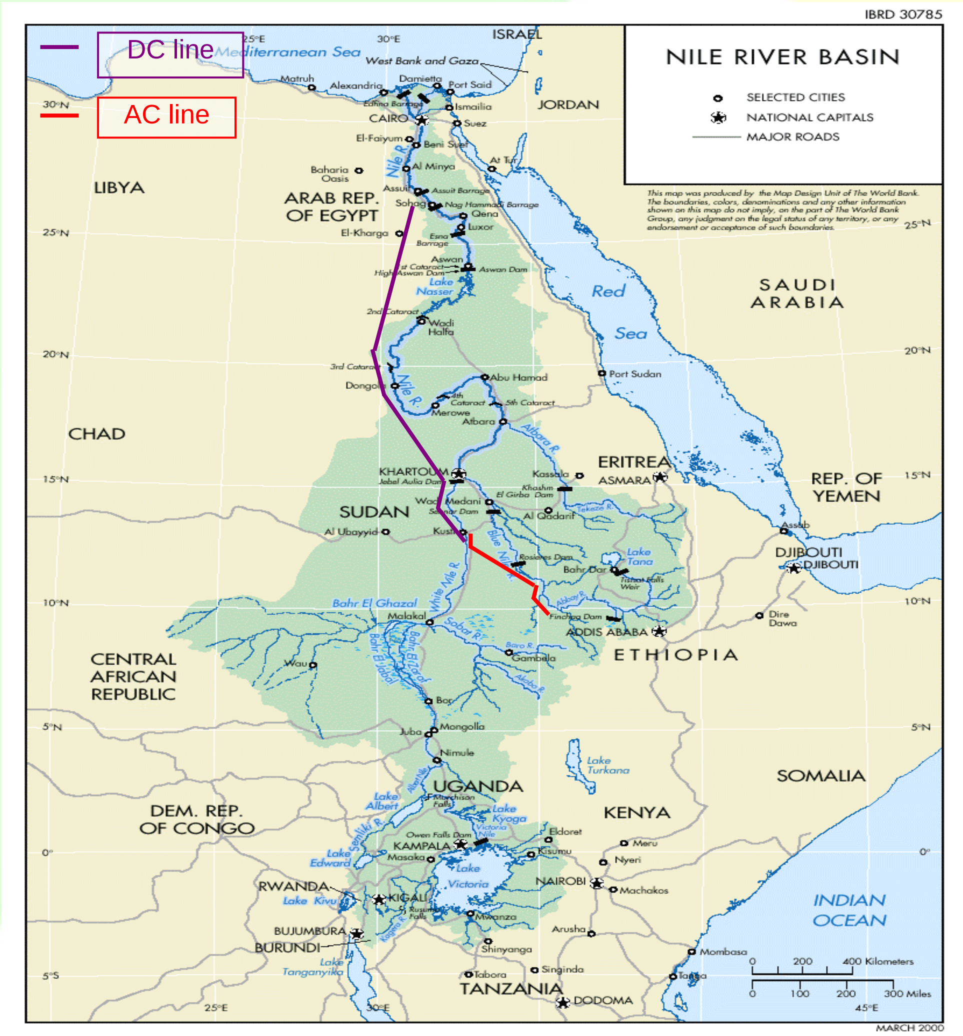

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
CCG	Combined Cycle Gas turbine
DC	Direct Current
EAPTPR	Eastern Nile Power Trade Program Study
EDF	Electricité de France
EEHC	Egyptian Electricity Holding Company
EEPCO	Ethiopian Electric Power Corporation
EHV	Extra High Voltage
EHVAC	Extra High Voltage Alternating Current
ESIA	Environmental and Social Impact Assessment
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
ENTRO PCU	Eastern Nile Technical Regional Office Power Coordination Unit
GEP	Generation Expansion Plan
HPP	Hydro Power Plant
HD	High Dam
HV	High Voltage
HVDC	High Voltage Direct Current
ICS	Interconnected System
NBI	Nile Basin Initiative
NEC	National Electricity Corporation (Sudan)
NH	Nag Hammadi
O&M	Operations and Maintenance
OHL	Over Head Line
pu	per unit
SC	Steering Committee
ST	Steam Turbine
SVC	Static Voltage Compensator
SW	Scott Wilson
TPP	Thermal Power Plant

EXECUTIVE SUMMARY

The anticipation of the AC interconnection between Mandaya and Kosti enabled 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.

This report presents the studies of the anticipation of the interconnection between Ethiopia and Sudan in 2015 for the peak load scenario in :

- Permanent state (normal and N-1 situation)
- Short circuit power
- Dynamic study

The operation in parallel of the 500 and 220 kV AC interconnections has been studied and a phase shift transformer is proposed for the 220 kV interconnection.

The behaviour of the interconnection and the interconnected system is satisfying.

The main results are :

AC 500 KV INTERCONNECTION :

Once energised, the operation in parallel of the 220 kV interconnection is necessary to enable the tripping of one of the two 500 kV circuits Mandaya - Kosti, to export 700 MW, without exceeding the maximum transfer power.

The reactive compensation required on the 500 kV circuit is : 300 MVAr (2 x (50 + 100) MVAr) at Mandaya side and 175 MVAr (100 + 75 MVAr) at Kosti side. A 250 MVA SVC is required at Kosti.

The energising of the interconnection is an issue because harmonic transient over-voltage risks, generated by 400 kV/500 kV Mandaya transformers. This potential issue need to be studied in a detailed way with the final known characteristics of the network of both countries. Several alternatives are analysed in this report, and the black-start from a gas turbine plant at Kosti appeared to be the best solution. Moreover, palliative devices might ease operation.

ETHIOPIA :

The N-1 situation on the 400 kV backbone Mandaya - Ghimbi - Ghedo - Sebeta - Kaliti and Gigel Gibe II is acceptable : no overload occurred, and the voltage remained within the +5/-5% values. The dynamic behaviour of the Ethiopian system is satisfying.

SUDAN :

The behaviour of the Sudanese system is satisfactory, in case of tripping or short-circuit around Kosti.

1 PRESENTATION OF THE INTERCONNECTED SYSTEM IN 2015

1.1 PRESENTATION

The commissioning of the full AC + DC interconnection scheme operated at the full power exchanges, depends on the commissioning of Mandaya HPP.
However, during Phase 1, the economic study pointed out the cost effectiveness of the anticipation in 2015 of the AC 500 kV interconnection between Ethiopia and Sudan, which would enable an increase of the power export from 200 to 700 MW, using the hydro surplus in Ethiopia.

This report investigated the technical possibility of such anticipation.

To investigate the behaviour of the interconnection between Ethiopia and Sudan for the year 2015, the network of the 2 systems was modelled for the year 2015. Regarding the network, the study was based on the data collected in Phase I, and no modification was noticed with the updated data provided during the April 08 meeting of Phase II in Cairo.

Input demand and generation expansion plan data come from the economic study performed in Phase I.

1.2 DESCRIPTION OF THE TRANSMISSION SYSTEM

1.2.1 DESCRIPTION OF THE INTERCONNECTION

Initially located in Rabak (East side of the Nile River), the line routing study located the interconnection substation in Sudan on the west side of the Nile river at Kosti

The anticipated interconnection scheme between the 2 countries is made up of a double 500 kV circuits (544 km) between Mandaya (Ethiopia) and Kosti (Sudan), each circuit compensated with two 150 MVAr reactors on Mandaya side, and two 100 MVAr + 75 MVAr reactors on Kosti side.

A 500/400 kV substation located on Mandaya HPP site is equipped with two 500/400 kV 510 MVA transformers. The compensation will be detailed in §2.2.1.

Shunt compensation :

- Mandaya 150 MVAr reactor is made up of a 50 MVAr reactor and a 100 MVAr one, which will be reallocated in 2030 for Border commissioning
- Kosti 100 MVAr reactor is made up of two 50 MVAr reactors, which will be reallocated in 2030 for Border commissioning

A 250 MVA SVC is needed in Kosti substation.

The interconnection also included the existing 220 kV double circuit interconnection between Gonder (Ethiopia) and Gedaref (Sudan).

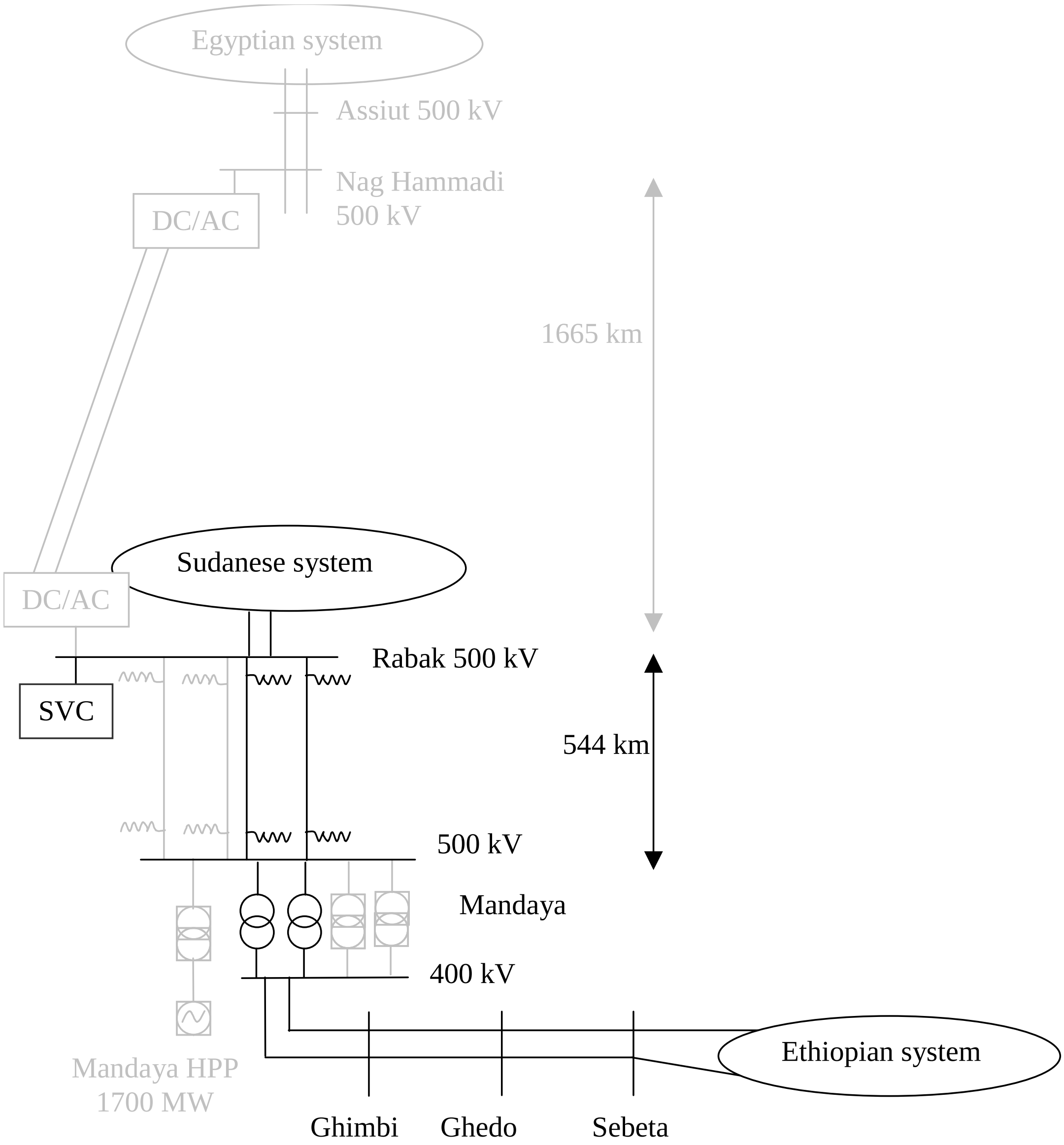


Figure 1: Interconnection Scheme in 2015

1.2.2 *Description of the system close to the interconnection points*

1.2.2.1 Description of the Ethiopian system close to Mandaya

Mandaya substation is connected to the 400 kV circuit in Addis Ababa with the following circuits :

- a double circuit Mandaya - Ghimbi (a third circuit is requested for 2020)
- a double circuit Ghimbi - Ghedo
- a double circuit Ghedo - Sebeta

1.2.2.2 Description of the Sudanese system close to Kosti

Kosti 500 kV is connected to the following substations :

- Fula with a double circuit
- Jebel Aulia with one single circuit (anticipation in 2015)
- Meringan with one single circuit (anticipation in 2015)

Kosti substation included 500/220 kV transformation.

1.3 *Demand and generation balance*

1.3.1 *Load Demand*

The demand values of both countries are displayed hereafter.

	Peak demand* (MW)
Ethiopia	2 100
Sudan	6 222

* These figures do not include the transmission losses, nor the exportations to Djibouti (50 MW) and Kenya for Ethiopia (400 MW)

Table 1: Ethiopian and Sudanese 2015 Load forecast

1.3.2 GENERATION

The generation expansion plans were reviewed in Phase 1 (Module 3), and were presented in the Economic study. For Ethiopia, it was adapted in Module 6 of Phase 1, to take into account the anticipation of Mandaya HPP from 2024 to 2020 to meet the power exchange selected.

Ethiopia Generation Plan

Commissioning Date	Hydro Project	Capacity MW	Average Generation GWh
2008	Gibe II	420	1 600
	Tekeze	300	1 200
2009	Beles	420	2 000
2010	Neshe	97	225
2011	Gibe III (I)		
2012	Gibe III (II)	1 870	6 240
2013			
2014			
2015			

Table 2: Ethiopian Generation Expansion Plan

Sudan Generation Plan

Year	Thermal Plant			Hydro Electric Plant	
	Plant Name	Installed Capacity (MW)	Net Capacity (MW)	Plant Name	Installed Capacity (MW)
	Existing Plant	639	491		341
2006	Garri 2 - GT4	40	39		
2007	Garri 4 Steam U1 & 2	100	95		
	Kassala Diesel U1 - 5	50	48		
	Kilo X GT - 2 x GT	59	58		
	El Fau Diesel (U2)	7	5		
	Port Sudan Existing Plant	31	27		
	Northern Diesels	26	25		
	Kuku GT's Retired	-23	-19		
	Garri 2 - 2xST	80	78		
2008	Khartoum North Steam U5 & 6	200	190		
				Merowe Hydroelectric (U1&U2)	250
2009	Port Sudan Steam U1-3	405	386		
	Kosti Steam U1 & 2	250	238		
	El Bagair Steam U1 & 2	270	257		
	Al Fula Steam U1 & 2	270	257		
	Kordofan Diesels	28	26		
	1 x OCGT (6FA)	61	60		
	1 x LSD Plant	280	272		
				Merowe Hydroelectric (U3-U10)	1,000
2010	Kosti Steam U3 & 4	250	238		
	Garri 3 Steam U1 -3	405	385		
	El Bagair Steam U3 & 4	270	257		
	Al Fula Steam U3 & 4	270	257		
	S. Darfur Diesels	50	49		
	Khartoum North GT (U1) Retired	-23	-17		
	El Fau Diesel (U1) Retired	-7	-5		
	El Fau Diesel (U2) Retired	-7	-5		
	Girba Diesel's Retired	-6	-4		
2011	Garri 3 Steam U4	135	129		
	Kassala Diesel's Retired	-13	-8		
	2 x Coal Fired Steam	300	285		
				Sennar Extension	50
				Rumela	30
2012	N. Darfur Diesels	28	25		
	1 x Coal Fired Steam	400	380		
				Rosieres Heightening with Dinder	136
2013				Shereiq	315
2014	W. Darfur diesels	31	30		
	1 x CCGT (6FA based)	214	208		
2015	Khartoum North ST's (U1&U2) Retired	-60	-55		
	Khartoum North GT's (U3&U4) Retired	-47	-34		
	1 x Coal Fired Steam	400	380		
				Low Dal	340

Table 3: Sudanese Generation Expansion Plan

2 STUDY OF THE INTERCONNECTION FOR PEAK LOAD SITUATION 2015

2.1 *ANALYSIS OF THE OPERATION OF THE 500 AND 220 KV INTERCONNECTION BETWEEN ETHIOPIA AND SUDAN*

Maximum transmitted power of the 400/500 kV interconnection

The maximum transmitted power in N-1 situation (one 500 kV circuit Mandaya - Kosti) reached 698 MW.

The calculation is detailed in Appendix A.1.1.

It is therefore not possible to operated the Ethiopia - Sudan interconnection at 700 MW without the 220 kV double circuit.
Note : a margin between the maximum transmitted power and the transmitted power is necessary to avoid a loss of synchronism in case of power swing on the interconnection following a short circuit on the system, especially close to the interconnection.

As an indication, the losses of the 400/500 kV interconnection operated alone in N situation amounted to 56.5 MW (2 x 28.3 MW), and are higher than with the 220 kV interconnection operated in parallel.

The 220 and 500 kV interconnections operated in parallel.

Sudan imported 700 MW from Ethiopia :

- 2 x 140 MW over the 220 kV interconnection (Gonder - Shehedi - Gedaref). Losses : 2 x 11 MW
- 2 x 210 MW over the 500 kV interconnection (Mandaya - Kosti). 500 kV Losses : 2 x 2.6 MW - Total losses Sebeta - Kosti : 2 x 11 MW

Ethiopia exported 744 MW (2 x 151 MW on the 220 kV interconnection, and 2 x 221 MW on the 400/500 kV interconnection) to Sudan.

The total losses on the 220 and 500 kV interconnection reached 44 MW.

The flow over the 220 kV interconnection is higher that the initial value (2 x 100 MW) proposed in the Ethiopia - Sudan interconnection study carried out in 2006. In case of N-1, the remaining Bahir Dahr - Gonder circuit is slightly overloaded by 1 % (274 MW at Gonder side).

Operation with the 250 MVA phase shift transformer on the 220 kV interconnection

To limit the flow over the 220 kV interconnection at its initial expected value (2 x 100 MW), it is proposed to insert a phase-shift transformer at Gedaref. The simulation indicated that an angle of bout 23 ° enabled to bring back the flow to 2 x 100 MW.

Sudan imported 700 MW from Ethiopia :

- 2 x 100 MW over the 220 kV interconnection (Gonder - Shehedi - Gedaref). Losses : 2 x 5 MW
- 2 x 250 MW over the 500 kV interconnection (Mandaya - Kosti). 500 kV Losses : 2 x 3.9 MW – Total losses Sebeta - Kosti : 2 x 14.4 MW

Ethiopia exported 739 MW (2 x 105 MW on the 220 kV interconnection, and 2 x 264 MW on the 400/500 kV interconnection) to Sudan.

With the phase-shift transformer in operation, the amount of losses on the 220 and the 400/500 kV interconnections amounted to 39 MW. The flow on the 230 kV double circuit Bahir Dahr - Gonder reached 2 x 120 MW.

Economic comparison between the two options of operation

Operation in parallel with a 250 MVA phase shift transformer

	Quantity	Capital cost (k$)	Investment (i=10%) (k$)	Annuity cost (k$)
Cost	250 MVA	4 000	4 600	464
Transformer bay (2)	2	1 031	2 371	239
O&M of the transformer	-	-	-	121
Total	-	-	-	824

Table 4: Investment and annuity costs for the 220 kV phase shift transformer

The total annuity cost have been calculated for both solution, taking into account the cost of losses and the investment cost of the phase-shift transformer.

The results are displayed in the following table :

	Annuity cost (k$)
With a phase shift transformer	13 460
Without phase shift transformer	14 256

Table 5: Annuity costs comparison with and without the 220 kV phase shift transformer

Conclusion:

The operation in parallel of the 220 and 500 kV interconnections with a 250 MVA phase shift transformer on the 220 kV interconnection is the most cost effective solution.

This solution is retained for the study of the interconnection.

2.2 Study in permanent state of the Interconnection for 2015 Peak Period

2.2.1 Normal situation

The interconnection

Ethiopia exported a total flow of 739 MW over the 220 and the 500 kV interconnection :

- 2 x 105 MW flowed from Gonder on the 220 kV interconnection
- 2 x 264 MW flowed from Sebeta on the 400/500 kV interconnection

Sudan received 700 MW :

- 2 x 100 MW arrived at Gedaref from the 220 kV interconnection (phase-shift angle of the transformer : 23°)
- 2 x 250 MW arrived at Kosti from the 500 kV interconnection

The losses on the interconnection amounted to 39 MW on the interconnection (Ethiopia - Sudan) : 2 x 14.4 MW on the 400/500 kV interconnection, 2 x 5 MW on the 220 kV interconnection

The flow and the voltage on the 400 and 500 kV network are displayed in appendix A.2.1.

The voltage profile is satisfactory, and displayed in the following table :

Substations	Voltage (kV)
Kosti	520
Mandaya 500 kV	515
Mandaya 400 kV	412
Ghimbi	412
Ghedo	414
Sebeta	409
Gonder	238
Gedaref	227

The SVC in Kosti absorbed 110 MVAr, Kosti units absorbed 4 x 8 MVAr, the interconnection contribution in reactive power reaching 2 x 70 MVAr. Fula double circuit injected 2x70 MVAr at Kosti side, Jebel Aulia circuit absorbed 40 MVAr and Meringan one 45 MVAr.

At Mandaya side, the interconnection reactive contribution is limited at 2 x 10 MVAr at Mandaya.

Shunt compensation :

On Kosti - Mandaya, a high reactive compensation of the line is needed, since the line remained very lightly loaded.

On Mandaya side, the 150 MVAr reactors needed for the second double circuit are necessary to compensate the first double circuit. Each line is therefore compensated at 300 MVAr on Mandaya side.

On Kosti side, the 100 MVAr busbar reactors needed for the energisation of each line remained permanently connected, one of them for each circuit. Each line is therefore compensated at 175 MVAr on Kosti side.

On the Ethiopian 400 kV backbone :

- a 50 MVAr reactor at Mandaya 400 kV busbar
- 3 x 50 MVAr reactors are requested on Ghimbi busbar, Ghimbi - Ghedo circuit being permanently compensated with a 25 MVAr reactor at both side of the line. (the reactors are requested in 2020 for the connection of Metu circuits, for Baro&Genji HPP connection)
- a 40 MVAr reactor at Ghedo 400 kV busbar

Interconnection Neighbouring circuits

Ethiopia

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Mandaya 510 MVA transformer	2	255	50
Ghimbi to Mandaya	2	257	37
Ghedo to Ghimbi	2	261	38
Sebeta to Ghedo	2	264	37
Kaliti to Sebeta	1	155	22
GGII to Sebeta	1	513	70

Table 6: Loading of the Ethiopian 400kV backbone Mandaya - Addis Ababa

The 400 kV transmission lines Gigel Gibe II to Sebeta is heavily loaded.

Shunt compensation:

At 700 MW power exchange, the 40 MVAr busbar reactor at Ghedo substation is disconnected, and one of the three 50 MVAr busbar reactors at Ghimbi is disconnected (2 remaining connected).

Sudan

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Kosti to Meringan	1	313	16
Kosti to Jabel Aulia	1	61	14
Kosti to Fula	2	48	17
Kosti 500/220 kV transformation	2	14	7

Table 7: Loading of the Sudanese 500kV circuits connected to Kosti

The 500 kV transmission network is lightly loaded.

The SVC absorbed 110 MVAr in Kosti.

2.2.2 N-1 SITUATION ON THE INTERCONNECTION

2.2.2.1 Tripping of one of the two 220 kV circuits Gonder - Shehedi

The initial flow on each circuit Gonder - Shehedi reached 105 MW (loading of 39 %).
After the tripping, the flow on the remaining circuit increased to 193 MW (loading of 70 %). The importation in Gedaref from the 220 kV interconnection decreased from 200 to 180 MW. The flow on each 500 kV circuit increased from 254 to 265 MW.

The voltage profile is not significantly affected.

2.2.2.2 Tripping of one of the two 220 kV circuits Shehedi - Gedaref

The initial flow on each circuit Shehedi - Gedaref reached 102 MW (loading of 26 %).
After the tripping, the flow on the remaining circuit increased to 174 MW (182 MW on Shehedi side - loading of 48 %). The flow on each 500 kV circuit increased from 250 to 264 MW at Kosti side.

The voltage profile is not significantly affected.

2.2.2.3 Tripping of the 220 kV phase-shift transformer in Gedaref

The initial flow on the 220 kV transformer in Gedaref reached 200 MW.
After the tripping, the flow on each 500 kV circuit increased from 250 to 364 MW at Kosti side.

The SVC generated 150 MVAr (initial output : -110 MVAr), so Kosti voltage is not affected, but the voltage on the 400/500 kV interconnection decreased by 20 kV, but remained within the -5/+5. % limits. But the voltage on the 220 kV interconnection (Sudan side) exceed the +5 % authorised (Ferranti effect), the overvoltage reaching 12 %. It needed to be tripped, either manually, or automatically with an automation.

Substations	Voltage (kV)	
	With 220 kV interconnection	220 kV interco. opened
Kosti	520	520
Mandaya 500 kV	515	496
Mandaya 400 kV	412	394
Ghimbi	412	394
Ghedo	414	397
Sebeta	409	399
Gonder	238	242
Gedaref interco. side	227	246 (1.12 pu)
Gedaref substation	227	202

2.2.2.4 Tripping of one of the two 500 kV circuits Mandaya - Kosti

The initial flow on each of the 2 circuits Mandaya - Kosti reached 254 MW (Kosti side - loading of 22 %).
After the tripping, the flow on the remaining circuit increased to 466 MW (480 MW at Mandaya side, loading of 30 %). The importation in Gedaref from the 220 kV interconnection increased from 200 to 231 MW.

The SVC reactive power generation increased from -110 to 50 MVAr, Kosti voltage remaining at 520 kV. With a 110 MVAr increase of the reactive generation of Kosti units (-30 to 80 MVAr), the SVC absorbed 50 MVAr, Kosti voltage remaining at its initial value.

The voltage profile is not significantly affected.

2.2.2.5 Tripping of one of the two 400/500 kV transformers at Mandaya substation

The initial flow on each of the 2 transformer reached 255 MW (loading of 50 %).
After the tripping, the flow on the remaining transformer increased to 502 MW (loading of 98 %). The flow on each 500 kV circuit slightly decreased from 254 to 250 MW.

The flow on the interconnection Gonder - Shehedi increased from 210 to 219 MW (loading of 40 %).

The voltage profile is not affected.

2.2.3 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT : MANDAYA

The purpose of this study is to assess the impact of the interconnection at Mandaya. The following cases have been simulated :

- Tripping of one of the two 400 kV circuits Mandaya - Ghimbi
- Tripping of one of the two 400 kV circuits Ghimbi - Ghedo
- Tripping of one of the two 400 kV circuits Ghedo - Sebeta
- Tripping of the 400 kV circuit Sebeta - Kaliti
- Tripping of the 400 kV circuit Sebeta - Gigel Gibe II
- Tripping of the 400 kV circuit Debre Markos - Sululta

The tripping of one 400 kV circuit on the link Gigel Gibe II / Kaliti - Sebeta - Ghedo - Ghimbi - Mandaya is acceptable for the system, no overload occurred and the voltage variation remained within +/- 5% of its nominal value.

The detailed results are displayed in Appendix A.2.2.1.

2.2.4 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The purpose of this study is to assess the impact of the interconnection in Kosti. The following cases have been simulated :

- Tripping of the 500 kV circuit Kosti - Jebel Aulia
- Tripping of the 500 kV circuit Kosti - Meringan
- Tripping of one of the two 500 kV circuits Kosti - Fula
- Tripping of the SVC in Kosti

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), the flow on the remaining circuits remained within the rating.

The tripping of one of the DC poles was studied in dynamic.

The detailed results are displayed in Appendix A.2.2.2.

2.2.5 NORMAL SITUATION WITH 0 MW EXCHANGE

The interconnection

With the same angle (23°) of the phase-shift transformer, the flow on the AC interconnection are the following one on Ethiopia side:

- 2 x 31.5 MW departed from Gonder on the 220 kV interconnection
- 2 x 27 MW arrived at Sebeta from the 400/500 kV interconnection

On Sudan side :

- 2 x 30.8 MW arrived at Gedaref from the 220 kV interconnection (phase-shift angle of the transformer : 23°)
- 2 x 30.4 MW departed from Kosti on the 500 kV interconnection

The losses on the interconnection amounted to 8 MW on the interconnection (Ethiopia - Sudan) : 2 x 3.3 MW on the 400/500 kV interconnection, 2 x 0.7 MW on the 220 kV interconnection

With 38° of angle on the phase-shift transformer, the flow on the AC interconnection are close to 0 MW. The losses on the interconnection amounted to 1 MW.

Shunt compensation

With the double circuit of the 400/500 kV interconnection in service, the full reactive compensation is requested in Ethiopia to keep the voltage under 1.05 pu : connection of the third 50 MVAr busbar reactor at Ghimbi and the 40 MVAR busbar reactor in Ghedo 400 kV, the 50 MVAR reactor in Mandaya 400 kV being already connected. These additional compensations are not connected when the circuits are loaded (when the exportations towards Egypt and Sudan are high), but are requested when the flow on these circuit is light, for low export, or permanently after 2030, due to the connection of Border HPP.

The voltage profile is satisfactory, and displayed in the following table :

Substations	Voltage (kV)
Kosti	520
Mandaya 500 kV	523
Mandaya 400 kV	419
Ghimbi	420
Ghedo	414
Sebeta	409
Gonder	235
Gedaref	227

The SVC in Kosti absorbed 138 MVAr (110 MVAr with 700 MW exchange), Kosti units absorbed 4 x 8 MVAr.

2.2.6 INTERCONNECTION ENERGISING

2.2.6.1 Presentation

The main issue of the anticipation of the interconnection is its energitization, especially with Mandaya 510 MVA (Sn) transformer, located at the middle of the Sebeta-Kosti interconnection circuit.

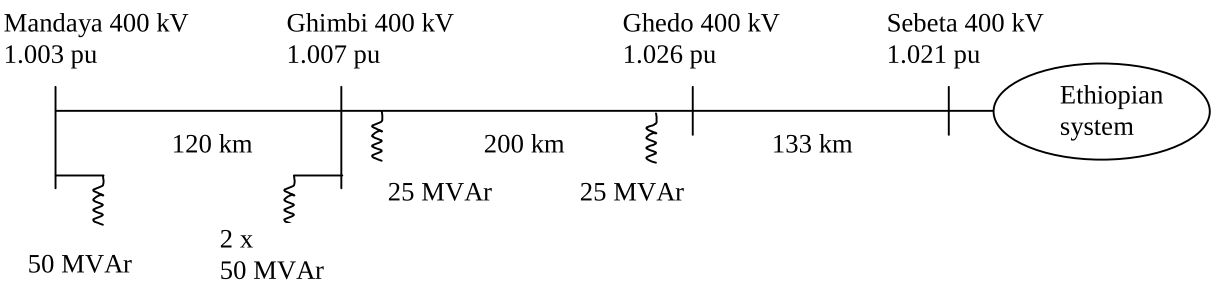
Such energitization is delicate due to the low short-circuit power on the interconnection substations, and due to the length of the circuits between the transformer and the bulk of each country (interconnection substations : Kosti and Sebeta).

The energising of a transformer can give rise to large peak currents characterised by a large aperiodic component with a slow decreasing and by a high level harmonic components which vary with time. The specific and typical shape of these current are due to saturation of the magnetic circuit of the transformer. The transformer behaves like a harmonic current generator : these currents can give rise to harmonic over-voltage, if the impedance of the concerned network is in parallel resonance at a natural frequency, which value is close to a low harmonic number frequency.

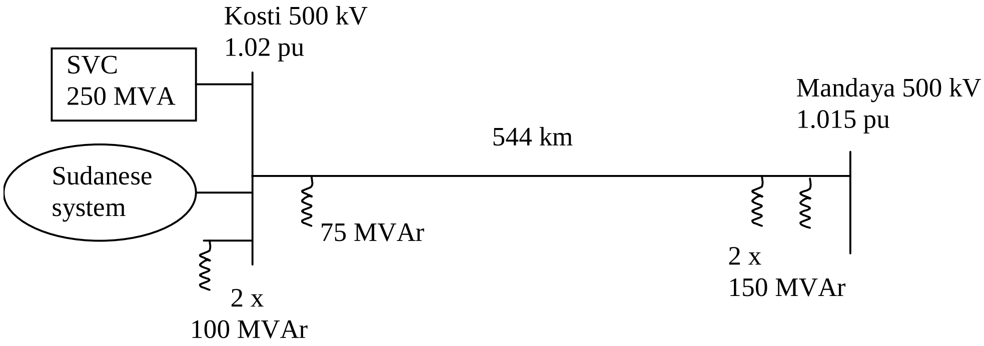
2.2.6.2 Configuration

<u>Energising the 400 kV and the 500 kV files</u> :

Voltage profile of the 400 kV antenna between Addis Ababa and Mandaya, energised from Sebeta.



Voltage profile of the 500 kV interconnection antenna between Kosti and Mandaya, energised from Kosti.



Short-circuit power at Mandaya :

Whatever the energising side of Mandaya busbar, the short-circuit power is very low in Mandaya for energising of the 510 MVA transformer :

- 875 MVA with one single circuit energised from Sebeta (Ethiopian side), the ratio Scc / Sn = 1.7 (voltage at Mandaya 400 kV with one 400 kV circuit file : 1.003 pu)
- 1 429 MVA with the double circuit energised from Sebeta (Ethiopian side), the ratio Scc / Sn = 2.8 (voltage at Mandaya 400 kV with the double 400 kV circuit file : 1.043 pu)
- 1 249 MVA with one single circuit energised from Kosti (Sudanese side), the ratio Scc / Sn = 2.4 (voltage at Mandaya 500 kV with one 500 kV circuit: 1.015 pu)
- 2 070 MVA with the double circuit energised from Kosti (Sudanese side), the ratio Scc / Sn = 4.06 (voltage at Mandaya 500 kV with the double 500 kV circuit : 1.015 pu)

Risk of appearance of unacceptable over-voltage :

As most part of the 2015 Ethiopian and Sudanese network does not exist, the uncertainties on network equipment characteristics does not allow to state in this report about the transient harmonic over-voltage risk. Additional studies need to be carried out with final design data.

2.2.6.3 Palliative solutions

Different palliative solutions exist :

- Operational solutions, such as :
    - o energising the transformer at reduced voltage decreases the harmonic over-voltage level. It is therefore proposed to reduce the operated voltage to energise the transformer with black-start unit, in islanded network
    - o modification of the network topology to change the natural frequency of the network

- Design technical solutions, with specific equipments

The final solution will be probably a mix.

Operational solution : Energising from black start with a gas turbine or an hydro unit

Prerequisite :

- The reactive power absorption capacity of the generator unit shall comply with the global reactive balance of the circuit to energise (shunt reactors and capacitive characteristic of the line). Taking into account a margin (5-10 %) about the reactive power generated by the circuit to energise is necessary to face characteristics uncertainties.
- The unit must have black-start and islanding capability

When energising a long line with a major transformer at the other end (and no load) with a low short-circuit power, it is recommended to energised the line from a black-start generator unit, started at its minimum voltage set-up to reduce the risk of harmonic over-voltage. The longer the raising voltage slope to reach the nominal voltage, the less risk.

GT and hydro units may have the black-start capability, if they have been specified and equipped for this ability : the voltage regulator and the generator protection module must be equipped with this function, and be modified accordingly, such as for instance:

- Voltage regulation :
  - inhibition of the Power System Stabilizer if any
  - inhibition of the minimum excitation current protection
  - adaptation of the ramp for the voltage setup increase (not standard)
- Protection module :
  - modification of the threshold of the reactive absorption protection (minimum impedance protection)

Operational procedure :

- start the unit without excitation at the nominal speed
- close the breaker of the whole file to energise (line + transformer) - breaker automation specification : to close without voltage
- set the voltage set point of the alternator at its minimal value (0.2 - 0.25 pu)
- close the breaker of the alternator and excite the unit

The ramp to increase the voltage up to 0.9 pu must be as long as possible (30 s).

Attention must be paid to the cooling motors on transformers, which have to be switch off, until the voltage reached its minimal acceptable voltage threshold (usual value : 0.8 pu)

Black-start energising reduced the risk, but does prevent it totally

Ethiopia :

The closest Ethiopia main unit is Gigel Gibe II (125 MVA) located 210 km far from Sebeta, so 663 km far from Mandaya. Its reactive absorption capacity (40 MVAr) is limited, and additional compensation on the Sebeta - Gigel Gibe II circuit is requested (two 20 MVAr reactors at each side on the line, 2x40 MVAr on Sebeta 400 kV busbar).

The reactive balance of the energised line at Gigel Gibe II is 22 MVAr to be absorbed by the generator, a 5 %/10 % margin on the line reactive generation and of the reactors reached about 20 / 40 MVAr, the security margin is not sufficient.

Gibe III (266 MVA) has a better reactive absorption capacity, but is 150 km far from Gigel Gibe II (so 813 km from Mandaya).
Additional reactive compensation would be required, supposing these units have the black start capability.

Sudan :

Four Kosti steam turbines (125 MVA) are planned to be commissioned in 2009 and 2010.
The reactive balance on the single circuit to energise (with both 100 MVAr reactors at Kosti busbar) reaches 10 MVAr to be absorbed by the ST unit. A 5/10 % margin on the line reactive generation and of the reactors reached about 30/60 MVAr, the security margin is not sufficient.

The generators of the planned 452 MW CCG have more reactive capability, and face the reactive uncertainties with sufficient margin.

The anticipation of this CCG (with black start capability) commissioning is the best operational solution.

<u>Design technical solutions :</u>

- Specific breakers are equipped with resistance insertion when closing, to damp oscillations.
- Specific protections are monitoring transient harmonic over-voltage values, and trip elements (the transformer or the generating unit) to protect in case of harmonic resonance.
- New devices are recently under testing, regarding transformer flux remanence measurement on the transformer. They perform calculation for the optimisation of the closing instant of the transformer on the 50 Hz voltage wave. In addition to the quality of the remanence measurement, the reliability of the breaker is crucial for the accuracy of the operation, and frequent testing of the breaker is therefore requested.
- If the natural resonance frequency of the network is close to an harmonic frequency, it is possible to shift this frequency by network topology modification, or by the connection of shunt reactors.

- The connection of load on the transformer ease oscillation damping, but is not possible in this case (no load at Mandaya).

2.3 STUDY OF THE SHORT-CIRCUIT POWER

Three-phase to ground and one-phase to ground short-circuit calculations were performed taking into account the following assumptions:

- V = 1.1 Vn
- Impedance of generator = X"d (sub transient reactance)

The highest short-circuit power on the Ethiopian 400 kV system is located in Gibe 3 substation, with 21 kA, and in Kaliti on the 220 kV system, with 16 kA.
The short-circuit power of the Sudanese system is compliant with the 40 kA limitation on the 220 and 500 kV system (12 kA in Merowe on the 500kV system, and 23 kA in Bager on the 220 kV system).

The results are displayed in Appendix 4.

2.4 DYNAMIC STUDY OF THE INTERCONNECTION FOR 2015 PEAK PERIOD

2.4.1 N-1 SITUATION ON THE INTERCONNECTION

The behaviour of the interconnected system was satisfactory in case of short-circuit on one of the two 500 kV interconnection circuits Mandaya - Kosti, one of the two 500/400 kV transformers in Mandaya and in case of tripping of the 220 kV interconnection (tripping of the phase-shift transformer).

The results are displayed in Appendix A.3.1.

2.4.2 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT : MANDAYA

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Ethiopian 400 kV backbone between Mandaya to Addis Ababa (Kaliti) and Gigel Gibe II. The voltage and the frequency recovered correctly. The behaviour of the system following the tripping of Ethiopia main unit (Gibe III 266 MVA, initial output 220MW) was acceptable.

The results are displayed in Appendix A.3.2.

2.4.3 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Sudanese network close to Kosti. The voltage and the frequency recovered correctly. The behaviour of the system following the tripping of Sudan main unit (Port Sudan 450 MVA, initial output 370 MW) was acceptable.

The results are displayed in Appendix A.3.3.

APPENDIX

Appendix 1. OPERATION IN PARALLEL OF THE 220 AND 500 KV INTERCONNECTIONS

A.1.1 MAXIMUM TRANSMITTED POWER

Ethiopian 400 kV circuit impedance

The length of Sebeta - Ghedo - Ghimbi - Mandaya reached 453 km (133 + 200 + 120).

The impedance of this double circuit reached 70.2 Ω (Length = 453 km, X = 0.31 Ω/km)

500/400 kV transformer impedance

$X = U^2/Sn \times ucc$

With Sn = 510 MVA and ucc = 8%

On the 400 kV side : X = 25.1 Ω

Operated in parallel, the 2 transformer impedance reached 12.5 Ω

Mandaya - Kosti 500 kV interconnection circuit impedance

The impedance of one 500 kV circuit Kosti - Mandaya reached 150.1 Ω (Length = 544 km, X = 0.276 Ω/km).

The maximum transmittable power of one 500kV circuit reached 1 665 MW (U^2/X, assuming the voltage maintained on both side), the equivalent impedance in 400 kV reaching 96.1 Ω

Equivalent impedance in Kosti and Sebeta

The equivalent impedance is elaborated with the short circuit power ($Ssc = U^2/Zsc$).

Equivalent impedance at Sebeta : Ssc in Sebeta reached 5 700 MVA, Zsc = 28 Ω (in 400 kV)

Equivalent impedance at Kosti : Ssc in Kosti reached 7 100 MVA, Zsc = 22.5 Ω (in 400 kV)

Maximum transmitted power :

$Pmax = U^2/X$

With X = 70.2 + 12.5 + 96.1 + 28 + 22.5 = 229.3 Ω

Pmax = 698 MW with U nominal

A.1.2 PHASE SHIFT TRANSFORMER

Between 2015 and 2020, the duration of the 700 MW export is about 8 100 h, for an average value of 5 700 GWh for the Tight Pool model (Phase I results : Module 6_Vol.2_Final, §13.7).
For the Loose Pool model, the duration of the 700 MW export is 6 400 h, for an average value of 4 500 GWh (Phase I results : Module 6_Vol.2_Final, §12.5), and the commissioning of the phase shift transformer is still cost-effective. The duration limit for the cost-effectiveness is 4 100 h.

220 kV interconnection without a phase shift transformer

	Losses MW	Duration (h)	Cost of losses ($/MWh)	Annual operation cost (k$)
Without phase-shift transformer	44	8 100	40	14 256

Table A1-1 – Annuity cost without the 220 kV phase shift transformer

Operation in parallel with a 250 MVA phase shift transformer

	Quantity	Capital cost (k$)	Investment (i=10%) (k$)	Annuity cost (k$)
Cost	250 MVA	4 000	4 600	464
Transformer bay (2)	2	1 031	2 371	239
O&M of the transformer	-	-	-	121
Total	-	-	-	824

Table A1-2 – Annuity cost of the 220 kV phase shift transformer

	Losses MW	Duration (h)	Cost of losses ($/MWh)	Annual operation and investment cost (k$)
With a phase-shift transformer	39	8 100	40	12 636
Phase shift tfo annuity cost	-	-	-	824
Total	-	-	-	13 460

Table A1-3 – Annuity cost with the 220 kV phase shift transformer

Appendix 2. LOAD FLOW RESULTS - PEAK LOAD SITUATION 2015

A.2.1 NORMAL SITUATION

A.2.1.1 Ethiopian Network

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
1MANDAS81	2KOSTI81	253.6	-5.9	414.4	462	3.8	-593.1	2128	21.7
1MANDAS81	2KOSTI81	253.6	-5.9	414.4	462	3.8	-593.1	2128	21.7

Table A2.1-1 - Power flow on the Ethiopian 500 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1B.DAR3S71	1D.MARS71	208.9	14.7	209.4	290.9	2.4	-101.0	1010	28.8
1BELESS71	1B.DAR3S71	219.3	-20.7	220.3	305.2	0.7	-34.5	1010	30.1
1BELESS71	1B.DAR3S71	219.3	-20.7	220.3	305.2	0.7	-34.5	1010	30.1
1D.MARS71	1SULULS71	215.1	17.3	215.8	310.6	3.1	-102.4	1010	30.8
1GG2S71	1GGOS71	119.8	13.4	120.6	166.1	0.1	-24.5	1010	17.2
1GG2S71	1SEBETS71	521.8	-31.2	522.7	719.9	13.4	-27.6	1010	70.7
1GHEDOS71	1GHIMBIS71	261.1	-75.3	271.8	377.5	3.3	-98.1	1010	37.4
1GHEDOS71	1GHIMBIS71	261.1	-75.3	271.8	377.5	3.3	-98.1	1010	37.4
1GHIMBIS71	1MANDAS71	256.9	-57.8	263.3	366.9	1.9	-58.9	1010	36.3
1GHIMBIS71	1MANDAS71	256.9	-57.8	263.3	366.9	1.9	-58.9	1010	36.3
1GIBE3S71	1GG2S71	340.6	-72.7	348.3	479.2	4.1	-63.1	1010	45.9
1GIBE3S71	1W.SODS71	506.7	-37.8	508.1	699.2	4.8	-13.7	1010	69.2
1GIBE3S71	1W.SODS71	506.7	-37.8	508.1	699.2	4.8	-13.7	1010	69.2
1KALITS71	1SEBETS71	147.5	-51.0	156.1	219.6	0.2	-22.3	1010	21.7
1SEBETS71	1GHEDOS71	264.3	-111.0	286.7	402.7	2.4	-62.6	1010	36.6
1SEBETS71	1GHEDOS71	264.3	-111.0	286.7	402.7	2.4	-62.6	1010	36.6
1W.SODS71	1KALITS71	418.7	-61.3	423.1	585.1	11.2	-80.3	1010	57.9
1W.SODS71	1KALITS71	418.7	-61.3	423.1	585.1	11.2	-80.3	1010	57.9

Table A2.1-2 - Power flow on the Ethiopian 400 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1GONDES61	1SHEHES61	105.0	-32.8	110.0	267.7	2.6	-18.4	690	38.8
1GONDES61	1SHEHES61	105.0	-32.8	110.0	267.7	2.6	-18.4	690	38.8

Table A2.1-3 - Power flow on the Ethiopian-Sudan 220 kV lines

Power exported from Ethiopia
Power flow leaving Ethiopia to Sudan :
- 400/500 kV interconnection : 2 x 264.3 MW = 529 MW (at Sebeta side)
- 220 kV interconnection : 2 x 105 MW = 210 MW

Total : 739 MW

From bus	To bus	Sn nominal [MVA]	P [MW]	Q [MVAR]	S [MVA]	I [A]	Loading [%]
1MANDAS71	1MANDAS81	510	255.0	-1.1	255.0	355.8	50.0
1MANDAS71	1MANDAS81	510	255.0	-1.1	255.0	355.8	50.0

Table A2.1-4 - Power flow on the Ethiopian 400/500 kV transformers

Substation.	V sol [pu]	V sol [kV]
1MANDAS81	1.036	518.0
1B.DAR3S71	1.046	418.4
1BELESS71	1.047	418.8
1D.MARS71	1.019	407.6
1GG2S71	1.048	419.2
1GGOS71	1.046	418.4
1GHEDOS71	1.042	416.8
1GHIMBIS71	1.038	415.2
1GIBE3S71	1.049	419.6
1KALITS71	1.028	411.2
1MANDAS71	1.037	414.8
1SEBETS71	1.031	412.4
1SULULS71	0.978	391.2
1W.SODS71	1.044	417.6

Table A2.1-5 - Voltage of the 400 and 500 kV Ethiopian substations

A.2.1.2 Sudanese Network

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
2ATBARS81	2KABASS81	351.2	-151.2	382.4	430.1	3.8	-276.2	2128	20.2
2ATBARS81	2KABASS81	351.2	-151.2	382.4	430.1	3.8	-276.2	2128	19.7
2BAGERS81	2H.HEI81	253.2	-56.3	259.4	294.2	0.7	-99.5	2128	13.8
2BAGERS81	2H.HEI81	253.2	-56.3	259.4	294.2	0.7	-99.5	2128	13.8
2FULA81	2KOSTI81	-48.3	-326.4	329.9	369.7	0.2	-637.1	2128	17.4
2FULA81	2KOSTI81	-48.3	-326.4	329.9	369.7	0.2	-637.1	2128	17.4
2FULA81	2NYALA81	226.3	-156.8	275.3	308.6	2.3	-400.2	2128	14.5
2FULA81	2NYALA81	226.3	-156.8	275.3	308.6	2.3	-400.2	2128	14.5
2H.HEI81	2MERIN81	23.1	-38.9	45.3	51.4	0.0	-60.5	2128	2.4
2KABASS81	2BAGERS81	290.1	-55.8	295.5	334.7	0.7	-78.1	2128	15.5

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
2KABASS81	2BAGERS81	290.1	-55.8	295.5	334.7	0.7	-78.1	2128	15.5
2KABASS81	2MARKHS81	65.7	99.3	119.1	134.9	0.1	-39.6	2128	8.2
2MARKHS81	2J.AULIAS81	249.3	21.2	250.2	284.9	0.5	-72.4	2128	14.3
2MEROWS81	2ATBARS81	201.2	-82.7	217.6	240.7	1.1	-253.8	2128	11.3
2MEROWS81	2MARKHS81	424.6	-135.7	445.8	493.2	6.9	-326.9	2128	23.2
2MEROWS81	2MARKHS81	424.6	-135.7	445.8	493.2	6.9	-326.9	2128	23.2
2P.SUD81	2ATBARS81	353.9	-213.2	413.2	454.4	5.8	-441.3	2128	21.4
2P.SUD81	2ATBARS81	353.9	-213.2	413.2	454.4	5.8	-441.3	2128	21.4
2KOSTI81	2FULA81	48.4	-310.8	314.5	349.2	0.2	-637.1	2128	17.4
2KOSTI81	2FULA81	48.4	-310.8	314.5	349.2	0.2	-637.1	2128	17.4
2KOSTI81	2J.AULIAS81	60.8	-100.8	117.7	130.7	0.4	-358.1	2128	14.2
2KOSTI81	2MERIN81	311.5	25.8	312.6	347.1	1.8	-155.8	2128	16.3
2KOSTI81	1MANDAS81	-249.9	-258.2	359.3	398.9	3.9	-590.0	2128	22
2KOSTI81	1MANDAS81	-249.9	-258.2	359.3	398.9	3.9	-590.0	2128	22

Table A2.1-6 - Power flows on the Sudanese 500 kV lines

From bus	To bus	P [MW]	Q [MVAr]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAr]	Ampacity (Norm.) [A]	Loading [%]
2GEDARS61	1SHEHE61	-99.8	3.2	99.9	254.2	2.5	-27.2	972	26.2
2GEDARS61	1SHEHE61	-99.8	3.2	99.9	254.2	2.5	-27.2	972	26.2

Table A2.1-7 - Power flows on the 220 kV interconnection Ethiopia - Sudan

Power imported from Ethiopia
Power flow arriving in Sudan from Ethiopia :
- 500 kV interconnection : 2 x 250 MW = 500 MW
- 220 kV interconnection : 2 x 100 MW = 200 MW

Total : 700 MW

To limit the flow and avoid an overload on the 220 kV interconnection, a phase-shift transformer has been installed at Gedaref substation.

Substation	V sol [pu]	V sol [kV]
2ATBARS81	1.027	513.5
2BAGERS81	1.018	509.0
2FULA81	1.03	515.0
2H.HEI81	1.016	508.0
2J.AULIAS81	1.007	503.5
2KABASS81	1.019	509.5
2MARKHS81	1.014	507.0
2MERIN81	1.016	508.0
2MEROWS81	1.044	522.0
2NYALA81	0.999	499.5

Substation	V sol [pu]	V sol [kV]
2P.SUD81	1.05	525.0
2KOSTI81	1.04	520.0

Table A2.1-8 - Voltage of the 500 kV Sudanese substations

A.2.2 N-1 SITUATION

A.2.2.1 Ethiopian Network

Recall of the flow on the Ethiopian 400 kV system between Addis Ababa and Mandaya

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Ghimbi to Mandaya	2	257	37
Ghedo to Ghimbi	2	261	38
Sebeta to Ghedo	2	264	37
Kaliti to Sebeta	1	155	22
GGII to Sebeta	1	513	70

A.2.2.1.1 Tripping of the 400 kV circuit Debre Markos - Sululta

The initial flow on Debre Markos - Sululta reached 210 MW (loading of 27°%)

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system. The flow on the two 230 kV circuits Ghedo to Gefersa increased from 2x95 to 2x139 MW (from 36 to 52 % of loading).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 240 MW (242 MVA - 96 % of loading of the phase shift transformer).
Voltage variation on the following substations

Substation	Initial voltage (pu)	Final Voltage (pu)
1B.DAR3S71	1.04	1.046
1D.MARS71	1.01	1.046
1SULULS61	1.02	0.998
1SEBETS71	1.027	1.01
1GHEDOS71	1.039	1.026

A.2.2.1.2 Tripping of the 400 kV circuit Kaliti - Sebeta

The initial flow on Kaliti - Sebeta reached 152 MW (loading of 22°%)

Following the tripping of the line, the flow on Gigel Gibe II - Sebeta increased from 515 MW to 559 MW (loading increasing from 70 % to 76 % - load report of 29 %).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 206 MW, the flow on the 500 kV interconnection is reduced from 500 to 493 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHEDOS71	1.039	1.039
1SEBETS71	1.027	1.027
1KALITIS71	1.026	1.025

A.2.2.1.3 Tripping of the 400 kV circuit Gigel Gibe II - Sebeta

The initial flow on Kaliti - Sebeta reached 515 MW (loading of 70°%).

Following the tripping of the line, the flow on Kaliti - Sebeta increased from 152 MW to 506 MW (loading increasing from 22 % to 74 % - load report of 69 %).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 217 MW, the flow on the 500 kV interconnection is reduced from 500 to 481 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHEDOS71	1.039	0.986
1SEBETS71	1.027	0.968
1KALITIS71	1.026	0.974

A.2.2.1.4 Tripping of one of the 400 kV circuit Sebeta - Ghedo

The initial flow on each circuit Sebeta - Ghedo reached 264 MW (loading of 37°%)

Following the tripping of the line, the flow on the remaining circuit reached 515 MW (loading of 72 % - load report of 95 %).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 216 MW (216 MVA - 86 % of loading of the phase shift transformer).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.036	1.026
1GHEDOS71	1.039	1.025
1SEBETS71	1.027	1.011

A.2.2.1.5 Tripping of one of the two 400 kV circuit Ghedo - Ghimbi

The initial flow on each circuit Ghedo - Ghimbi reached 261 MW (loading of 38°%)

Following the tripping of the line, the flow on the remaining circuit reached 502 MW (loading of 71 %).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 223 MW (224 MVA).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final Voltage (pu)
1MANDAS81	1.034	1.019
1MANDAS71	1.035	1.016
1GHIMBIS71	1.036	1.012
1GHEDOS71	1.039	1.02
1SEBETS71	1.027	1.017

A.2.2.1.6 Tripping of one of the two 400 kV circuit Ghimbi - Mandaya

The initial flow on each circuit Ghimbi - Mandaya reached 257 MW (loading of 37°%)

Following the tripping of the line, the flow on the remaining circuit reached 501 MW (loading of 71 %).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 215 MW (215 MVA).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final Voltage (pu)
1MANDAS81	1.034	1.017
1MANDAS71	1.035	1.013
1GHIMBIS71	1.036	1.014
1GHEDOS71	1.039	1.025
1SEBETS71	1.027	1.02

A.2.2.1.7 Tripping of one of the two 230 kV circuits Bahir Dar - Gonder

The initial flow on each circuit Bahir Dahr - Gonder reached 121 MW (loading of 42°%)

Following the tripping of the line, the flow on the remaining circuit reached 214 MW (loading of 75 %).

The flow over the 220 kV Ethiopia - Sudan interconnection decreased from 200 to 179 MW.
Voltage variation on the following substations

Substation	Initial voltage (pu)	Final Voltage (pu)
1B.DARS61	1.05	1.032
1GONDERS61	1.041	1.011

A.2.2.1.8 Conclusion

The tripping of one 400 kV circuit on the link Gigel Gibe II / Kaliti - Sebeta - Ghedo - Ghimbi - Mandaya is acceptable for the system, no overload occurred and the voltage variation remained within +/- 5% of its nominal value.

A.2.2.2 Sudanese Network

Recall of the flow on the Sudanese 500 kV system around Kosti

From bus	To bus	N° of circuit	P [MW]	Loading %
2KOSTI81	1MANDAY81	2	-250	22
2KOSTI81	2FULA81	2	48	17
2KOSTI81	2J.AULIAS81	1	61	16
2KOSTI81	2MERIN81	1	313	16
2KOSTI81	2KOSTI71	2	14	7

A.2.2.2.1 Tripping of the 500 kV circuit Kosti - Jebel Aulia

The initial flow on Kosti - J.Aulia reached 61 MW (loading of 16°%)

The flow on Kosti - Meringan increased from 313 to 357 MW (from 16 to 19 % of loading), the flow on Kosti to Fula is not significantly affected (+1 MW).

The flow on the 500/220 kV transformation increased by 14 MW.

The voltage at Kosti substation is not affected, the SVC increasing its reactive absorption from -110 to -130 MVAr.

Voltage variation on the following substation

Substation	Initial voltage (pu)	Final voltage (pu)
Kosti	1.040	1.040
Meringan	1.016	1.010
J. Aulia	1.007	0.981

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.2.2.2.2 Tripping of the 500 kV circuit Kosti - Meringan

The initial flow on Kosti - Meringan reached 313 MW (loading of 16°%)

The flow on Kosti - J.Aulia increased from 61 to 244 MW (from 16 to 20 % of loading).

The flow on Kosti - Fula increased from 96 to 108 MW (17 % of loading).

The flow on the 500/220 kV transformation increased by 112 MW.

The voltage at Kosti substation is not affected, the SVC increasing its reactive output from -110 to -173 MVAr.

Voltage variation on the following substation

Substation	Initial voltage (pu)	Final Voltage (pu)
Kosti	1.040	1.046
Meringan	1.016	0.962
J. Aulia	1.007	0.987

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.2.2.2.3 Tripping of one of the two 500 kV circuits Kosti - Fula

The initial flow on Kosti - Fula reached 96 MW (loading of 17°%)

The flow on the remaining circuit Kosti - Fula increased from 48 to 86 MW (from 17 to 18 % of loading).

The flow on the 500/220 kV transformation decreased by 8 MW.

The voltage at Kosti (SVC) and Fula (generation plants) substation is not affected, the SVC decreasing its reactive absorption from -110 to -51 MVAr.

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.2.2.2.4 Tripping of the SVC at Kosti

In normal situation, the SVC reactive power generation is close to -110. Without any variation of Kosti reactive absorption, the voltage reached 1.06 pu in Kosti. An increase from -30 to -120 MVAr on Kosti units brought back Kosti voltage to 1.044 pu.

A.2.2.2.5 Conclusion

The behaviour of the Sudanese system is satisfactory, in case of tripping of one of the 500 kV circuit connected to Kosti. The flow remained far below the thermal limit, and the voltage remained within the limits (+5/-10 %).

Appendix 3. DYNAMIC RESULTS - PEAK LOAD SITUATION 2015

A.3.1 INTERCONNECTION

A.3.1.1 Short-circuit on one of the 2 Mandaya - Kosti circuits, on Kosti side

In case of short-circuit at Kosti on the interconnection, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on one of the 2 circuits Mandaya - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The flow on the remaining circuit Mandaya - Kosti transiently reached 512 MW, before stabilizing at 470 MW. The flow on the 220 kV interconnection transiently increased to 250 MW, before stabilizing at 228 MW.

Following the clearing of the fault, a 10% transient overvoltage occurred, the voltage recovering under 1.05 pu 1 second after the fault.

The SVC in Kosti decreased its reactive absorption from 127 to 44 MVAr.

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	548 kV	516 kV
Mandaya	517 kV	553 kV	512 kV
Mandaya	414 kV	442 kV	410 kV
Sebeta	410 kV	437 kV	410 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.1.2 Short-circuit on one of the 2 Mandaya - Kosti circuits, on Mandaya side

In case of short-circuit at Madaya on the interconnection, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Mandaya end, on one of the 2 circuits Mandaya - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The flow on the remaining circuit Mandaya - Kosti transiently reached 554 MW, before stabilizing at 471 MW. The flow on the 220 kV interconnection transiently increased to 267 MW, before stabilizing at 228 MW.

The SVC in Kosti decreased its reactive absorption from 127 to 44 MVAr.

Voltage variation :

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	538 kV	516 kV
Mandaya	517 kV	527 kV	512 kV
Mandaya	414 kV	421 kV	410 kV
Sebeta	410 kV	419 kV	410 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.1.3 Fault on one of the 2 Mandaya 500/400 kV transformers

In case of short-circuit at Mandaya 500 kV on one of the two 500/400 kV transformers at Mandaya, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at the 500 kV side of one of the two 500/400 kV transformers at Mandaya substation, cleared in 120 ms by the opening of the circuit breakers.

The flow on the remaining transformer transiently reached 620 MW, before stabilizing at 497 MW (initial flow on the transformer : 2 x 253 MW).
The flow on the 220 kV interconnection transiently increased to 250 MW, before stabilizing at 205 MW.

Voltage variation :

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	546 kV	516 kV
Mandaya	517 kV	528 kV	515 kV
Mandaya	414 kV	421 kV	413 kV
Sebeta	410 kV	420 kV	411 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.1.4 Fault on the 220 kV interconnection

In case of short-circuit at Gedaref 220 kV on the 220 kV phase-shift transformer, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Gedaref 220 kV side on the 220 kV phase shift transformer, cleared in 120 ms by the opening of the circuit breakers.

The flow on the each of the 500 kV circuit, reached 374 MW, before stabilizing at 352 MW (initial value : 254 MW).

Generator	Maximal frequency	Minimal frequency
Gedaref HPP	50.6 Hz	49.17 Hz

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	533 kV	516 kV
Mandaya	517 kV	525 kV	497 kV
Mandaya	414 kV	421 kV	397 kV
Sebeta	410 kV	421 kV	401 kV
Gedaref	227 kV	227 kV	221 kV
Gonder	237 kV	255 kV	250 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.2 ETHIOPIAN NETWORK

Recall of the flow on the Ethiopian 400 kV system between Addis Ababa and Mandaya

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Ghimbi to Mandaya	2	257	37
Ghedo to Ghimbi	2	261	38
Sebeta to Ghedo	2	264	37
Kaliti to Sebeta	1	155	22
GGII to Sebeta	1	513	70

A.3.2.1 Short-circuit at Ghimbi, on one of the two 400 kV circuits Ghimbi - Mandaya

In case of short-circuit at Ghimbi side on one of the 2 Ghimbi - Mandaya, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Ghimbi end, on one of the 2 circuits Mandaya - Ghimbi, cleared in 100 ms by the opening of the circuit breakers.

The flow on the remaining circuit transiently reached 602 MW, before stabilizing at 498 MW (initial flow on each circuit : 2 x 256 MW).
The flow on the 220 kV interconnection transiently increased to 253 MW, before stabilizing at 212 MW.

Voltage variation :

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	544 kV	519 kV
Mandaya	517 kV	516 kV	508 kV
Mandaya	414 kV	413 kV	405 kV
Ghimbi	414 kV	415 kV	405 kV
Sebeta	410 kV	419 kV	408 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.2.2 Short-circuit at Ghedo, on one of the two 400 kV circuits Ghedo - Ghimbi

In case of short-circuit at Ghedo side on one of the 2 Ghedo - Ghimbi, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Ghedo end, on one of the 2 circuits Ghedo - Ghimbi, cleared in 100 ms by the opening of the circuit breakers.

The flow on the remaining circuit transiently reached 697 MW, before stabilizing at 500 MW (initial flow on each circuit : 2 x 261 MW).
The flow on the 220 kV interconnection transiently increased to 303 MW, before stabilizing at 220 MW.

Voltage variation :

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	540 kV	519 kV
Mandaya	517 kV	528 kV	509 kV
Mandaya	414 kV	424 kV	406 kV
Ghimbi	414 kV	425 kV	405 kV
Ghedo	414 kV	432 kV	408 kV
Sebeta	410 kV	430 kV	407 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.2.3 Short-circuit at Sebeta, on one of the two 400 kV circuits Sebeta - Ghedo

In case of short-circuit at Sebeta side on one of the 2 Sebeta - Ghedo circuits, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Sebeta end, on one of the 2 circuits Sebeta - Ghedo, cleared in 100 ms by the opening of the circuit breakers.

The flow on the remaining circuit transiently reached 816 MW, before stabilizing at 507 MW (initial flow on each circuit : 2 x 264 MW).
The flow on the 220 kV interconnection transiently increased to 339 MW, before stabilizing at 213 MW.

Generator	Maximal frequency	Minimal frequency
Gigel Gibe II HPP	50.6 Hz	49.67Hz
Finchaa HPP	50.43 Hz	49.67Hz

Voltage variation :

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	535 kV	519 kV
Mandaya	517 kV	542 kV	514 kV
Mandaya	414 kV	437 kV	411 kV
Ghedo	414 kV	443 kV	410 kV
Sebeta	410 kV	436 kV	405 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.2.4 Short-circuit at Sebeta, on the 400 kV Sebeta - Kaliti circuit

In case of short-circuit at Sebeta side on the Sebeta - Kaliti circuit, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Sebeta end, on the Sebeta - Kaliti circuit, cleared in 100 ms by the opening of the circuit breakers.

The initial flow on Kaliti - Sebeta circuit reached 155 MW.

The flow on Gigel Gibe II - Sebeta circuit transiently reached 692 MW, before stabilizing at 551 MW (initial flow on each circuit : 508 MW).

The flow on eac hof the 2 Sebeta 400/230 kV transformers is reduced by 49 MW
The flow on the 220 kV interconnection transiently increased to 327 MW, before stabilizing at 204 MW. The flow on the 400/500 kV interconnection is reduced by 4 MW.

Generator	Maximal frequency	Minimal frequency
Gigel Gibe II HPP	50.6 Hz	49.67 Hz
Finchaa HPP	50.43 Hz	49.7 Hz

Voltage variation :

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	534 kV	519 kV
Mandaya	517 kV	544 kV	517 kV
Mandaya	414 kV	440 kV	414 kV
Sebeta	410 kV	442 kV	411 kV
Kaliti	410 kV	437 kV	408 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.2.5 Short-circuit at Gigel Gibe II, on the 400 kV circuits Gigel Gibe II - Sebeta

In case of short-circuit at Gigel Gibe II side on the Gigel Gibe II - Sebeta circuit, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Gigel Gibe II side on the Gigel Gibe II - Sebeta circuit, cleared in 100 ms by the opening of the circuit breakers.

The initial flow on Gigel Gibe II - Sebeta circuit reached 508 MW.

The flow on Kaliti - Sebeta circuit transiently reached 737 MW, before stabilizing at 505 MW (initial flow on each circuit : 155 MW).

The flow on each of the 2 Sebeta 400/230 kV transformers is reduced by 70 MW
The flow on the 220 kV interconnection transiently increased to 340 MW, before stabilizing at 213 MW. The flow on the 400/500 kV interconnection is reduced by 10 MW.

Generator	Maximal frequency	Minimal frequency
Gigel Gibe II HPP	50.77 Hz	49.6 Hz
Gibe III / Melka Wakana	50.36 Hz	49.6 Hz

Voltage variation :

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	535 kV	519 kV
Mandaya	517 kV	542 kV	507 kV
Mandaya	414 kV	438 kV	405 kV
Sebeta	410 kV	437 kV	396 kV
Gigel Gibe II	419 kV	456 kV	416 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.2.6 Tripping of Ethiopia main unit : Gibe III HPP unit

In case of tripping of 1 unit of Gibe III HPP, the behaviour of the system is satisfactory.

Event : 1 unit of Gibe III (the main unit in Ethiopia) is tripped (initial output : 220 MW).

The Ethiopia-Sudan frequency dropped to 49.8 Hz, before recovering to 49.94 Hz.

The flow on the 400/500 kV interconnection decreased from 2 x 250 MW to 2 x 194 MW.
The flow on the 220 kV interconnection decreased from 200 MW to 170 MW.

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.3 SUDANESE NETWORK

Recall of the flow on the Sudanese 500 kV system around Kosti

From bus	To bus	N° of circuit	P [MW]	Loading %
2KOSTI81	1MANDAY81	2	-250	22
2KOSTI81	2FULA81	2	48	17
2KOSTI81	2J.AULIAS81	1	61	16
2KOSTI81	2MERIN81	1	313	16
2KOSTI81	2KOSTI71	2	14	7

A.3.3.1 Short-circuit on one of the two 500 kV circuits Kosti - Fula, at Kosti side

In case of short-circuit on one of the 2 Kosti - Fula circuit, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on one of the 2 circuits Kosti - Fula, cleared in 100 ms by the opening of the circuit breakers.

The flow on the remaining circuit Kosti - Fula reached a maximum of -170 MW, before stabilizing at -79 MW (initial value of -47 MW).

The SVC in Kosti decreased its reactive absorption from 127 to 77 MVAr.

Generator	Maximal frequency	Minimal frequency
Fula ST	50.4 Hz	49.9 Hz
Kost	50.35 Hz	49.95 Hz

Node	Initial voltage	Maximal voltage	Final voltage
Fula	520 kV	548 kV	507 kV
Kosti	520 kV	548 kV	518 kV
Mandaya	517 kV	546 kV	516 kV
Mandaya	414 kV	437 kV	412 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.3.2 Short-circuit on the 500 kV circuit Kosti - Jebel Aulia, at Kosti side

In case of short-circuit on Kosti - Jebel Aulia, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on the circuits Kosti - Jebel Aulia, cleared in 100 ms by the opening of the circuit breakers.

The initial flow on Kosti - J.Aulia reached 60 MW.

The flow on Kosti - Meringan increased transitory to 473 MW, before stabilizing at 347 MW (initial value : 310 MW).

The SVC in Kosti increased its reactive absorption from 127 to 141 MVAr.

Generator	Maximal frequency	Minimal frequency
Fula ST	50.4 Hz	49.9 Hz
Kost	50.35 Hz	49.95 Hz

Node	Initial voltage	Maximal voltage	Final voltage
J.Aulia	503 kV	505 kV	496 kV
Kosti	520 kV	565 kV	521kV
Mandaya	517 kV	559 kV	518 kV
Mandaya	414 kV	447 kV	414 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.3.3 Short-circuit on the 500 kV circuit Kosti - Meringan, at Kosti side

In case of short-circuit on Kosti - Meringan, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on the circuits Kosti - Meringan, cleared in 100 ms by the opening of the circuit breakers.

The initial flow on Kosti - Meringan reached 310 MW.

The flow on Kosti - Jebel Aulia increased transitory to 295 MW, before stabilizing at 227 MW (initial value : 60 MW).

The flow on the 400/500 kV interconnection decreased from 2 x 250 MW to 2 x 239 MW, and the flow on the 220 kV interconnection increased from 200 to 210 MW.

The SVC in Kosti increased its reactive absorption from 127 to 189 MVAr.

Generator	Maximal frequency	Minimal frequency
Fula ST	50.4 Hz	49.93 Hz
Kost	50.35 Hz	49.94 Hz

Node	Initial voltage	Maximal voltage	Final voltage
Meringan	508 kV	506 kV	496 kV
Kosti	520 kV	578 kV	522 kV
Mandaya	517 kV	568 kV	520 kV
Mandaya	414 kV	453 kV	416 kV

The figures are displayed in M1 - 2015 Appendix Stability Study

A.3.3.4 Tripping of Sudan main unit : Port Sudan 450 MVA Steam Turbine

In case of tripping of Sudan main unit, the behaviour of the system is satisfactory.

Event : the 450 MVA steam unit of Port-Sudan (the main unit in Sudan) is tripped (initial output : 370 MW).

The Ethiopia-Sudan frequency dropped to 49.6 Hz, before recovering to 49.84 Hz.

The flow on the 400/500 kV interconnection increased from 2 x 250 MW to 2 x 304 MW, with a maximum swing at 2 x 344 MW.
The flow on the 220 kV interconnection increased from 200 MW to 232 MW, with a maximum swing at 264 MW.

The figures are displayed in M1 - 2015 Appendix Stability Study

Appendix 4. SHORT-CIRCUIT POWER - 2015

Three-phase to ground and one-phase to ground short-circuit calculations were performed taking into account the following assumptions:

- V = 1.1 Vn
- Impedance of generator = X"d (sub transient reactance)

The short-circuit power of the Egyptian system is compliant with the 40 kA limitation on the 220 and 500 kV system.

A.4.1 SHORT-CIRCUIT POWER IN ETHIOPIA, ALONG THE 400 KV BACKBONE ADDIS ABABA - MANDAYA

Busbar	kV. (Mult. = 1.10)	LLL		LG	
		I [A]	S [MVA]	I [A]	S [MVA]
1MANDAS81	550	4 393	3 804	2 812	2 435
1MANDAS71	440	5 283	3 660	3 449	2 390
1GHIMBIS71	440	5 320	3 686	3 539	2 452
1GHEDOS71	440	6 498	4 502	4 612	3 195
1SEBETS71	440	9 160	6 346	7 355	5 096
1GG2S71	440	9 518	6 594	9 438	6 539
1GIBE3S71	440	18 074	12 522	20 976	14 533
1KALITS71	440	9 620	6 665	8 156	5 651
1GONDES61	253	5 071	2 020	2 911	1 160
1SHEHE61	253	4 225	1 610	1 859	708
1KALITIS61	253	15 758	6 278	13 883	5 531
1SEBET1S61	253	13 890	5 533	11 328	4 513
1SEBET2S61	253	12 381	4 932	10 230	4 075
1KALITIS51	145.2	16 353	3 739	16 519	3 777
1SEBETS51	145.2	10 891	2 490	9 889	2 261

Table A4-1 - Short Circuit Power in the Ethiopian substations

A.4.2 SHORT-CIRCUIT POWER IN SUDAN IN THE SOUTH PART, AROUND KOSTI SUBSTATION

Busbar	KV (Mult. = 1.10)	LLL		LG	
		I [A]	S [MVA]	I [A]	S [MVA]
2FULA81	550	5 608	4 857	5 974	5 174
2J.AULIAS81	550	8 539	7 395	6 450	5 586
2MERIN81	550	8 455	7 322	6 113	5 294
2KOSTI81	550	9 076	7 860	7 653	6 628
2KABASS81	550	11 541	9 995	9 899	8 573
2MEROWS81	550	10 401	9 008	11 624	10 067
2MARKHS81	550	10 958	9 490	8 706	7 540
2BAGER61	242	22 259	8 482	22 747	8 668
2GARRIS61	242	19 099	7 278	21 502	8 193
2GEDARS61	242	4 643	1 769	5 582	2 127
2GEDARS62	242	4 320	1 646	1 263	481
2J.AULS61	242	18 671	7 115	14 631	5 575
2KABASS61	242	19 819	7 552	18 474	7 040
2KILOXS61	242	21 079	8 032	19 897	7 582
2MARKHS61	242	14 041	5 350	11 714	4 464
2MERINS61	242	14 817	5 646	10 957	4 175
2MEROWS61	242	8 805	3 355	8 855	3 374
2P.SOUDS61	242	10 368	3 951	10 624	4 048
2P.SUT61	242	10 812	4 120	11 773	4 486
2KOSTIS61	242	16 699	6 363	17 595	6 705
2ROSEI61	242	8 596	3 276	9 826	3 744

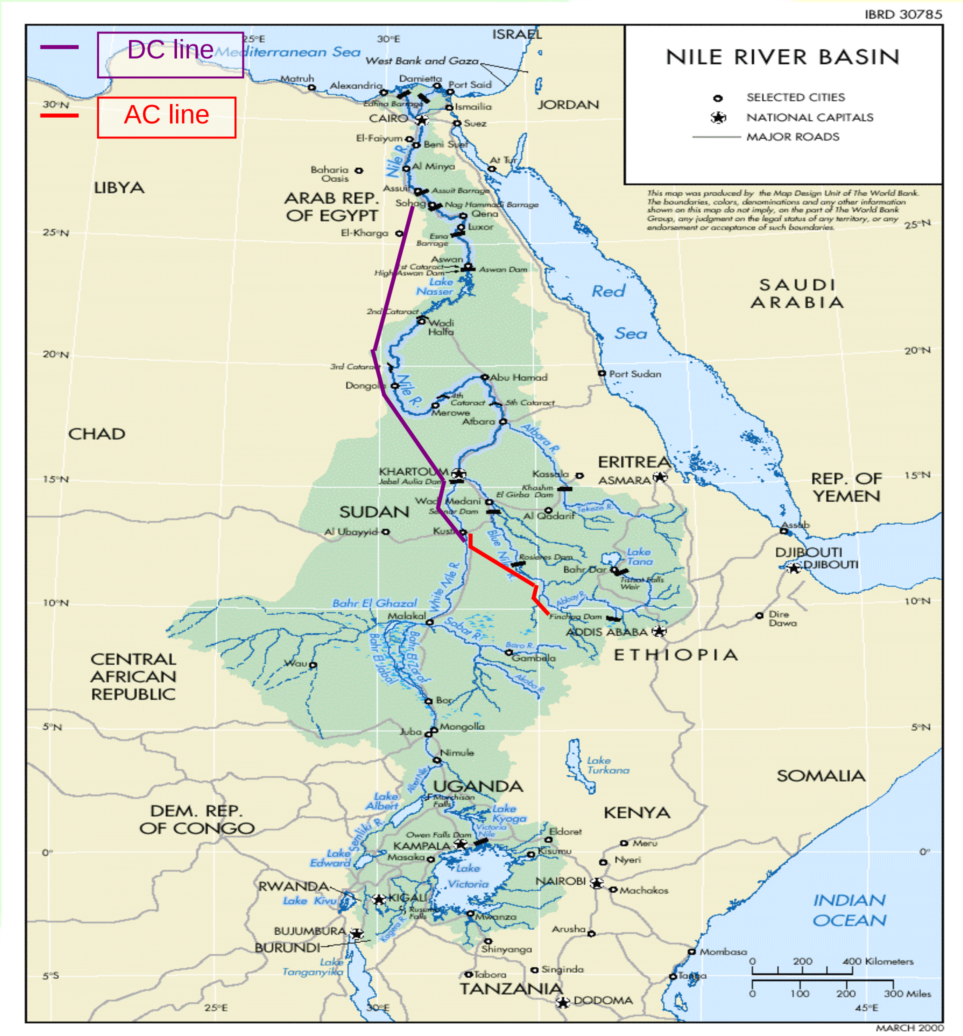
Table A4-2 - Short Circuit Power in the Sudanese substations

Nile Basin Initiative

Eastern Nile Subsidiary Action Program

Eastern Nile Technical Regional Office

EASTERN NILE POWER TRADE PROGRAM STUDY



M1 - 2020 - POWER STUDY

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
CCG	Combined Cycle Gas turbine
DC	Direct Current
ENPTPS	Eastern Nile Power Trade Program Study
EDF	Electricité de France
EEHC	Egyptian Electricity Holding Company
EEPCO	Ethiopian Electric Power Corporation
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
GEP	Generation Expansion Plan
HPP	Hydro Power Plant
HD	High Dam
HV	High Voltage
HVDC	High Voltage Direct Current
NBI	Nile Basin Initiative
NEC	National Electricity Corporation (Sudan)
NH	Nag Hammadi
O&M	Operation and Maintenance
OHL	Over Head Line
OHTL	Over Head Transmission Line
pu	per unit
ST	Steam Turbine
SVC	Static Voltage Compensator
SW	Scott Wilson
TPP	Thermal Power Plant

EXECUTIVE SUMMARY

For the peak and intermediate load situation in 2020/2021, this report presents the studies for the interconnected system in :

- Permanent state (normal and N-1 situation)
- Short circuit power
- Dynamic study

The operation in parallel of the 500 and 220kV AC interconnections has been studied and a phase shift transformer was proposed for the 220 kV interconnection.

The behaviour of the AC and DC interconnection is satisfying, providing that one pole of the DC interconnection is tripped in case of short-circuit on the 500 kV AC interconnection Mandaya – Kosti (initially located at Rabak (east side of the Nile), the line routing study located the interconnection substation in Sudan on the west side of the Nile river at Kosti).

The main results are :

- EGYPT

In peak load situation, the behaviour of the Egyptian system is satisfactory. In intermediate load situation, voltage oscillations lead to several consecutive commutation failures of the DC converter station. It is therefore proposed to reinforce the Nag Hammadi area with a 300 MVA SVC in Nag Hammadi.

- ETHIOPIA

The N-1 situation on the 400 kV backbone Mandaya - Ghimbi - Ghedo - Sebeta is acceptable. The tripping of one of these circuits leads to an acceptable overload. Attention should be paid to the unit commitment (to keep enough generation output in Mandaya and Baro & Genji), to limit the flow on the remaining circuit of the 400 kV backbone Sebeta - Ghedo - Ghimbi - Mandaya in case of N-1 situation to an acceptable overload (the limit is close to 2 x 420 MW for the flow on the 400 kV backbone, limit to be updated with the network evolution and generation update). The commissioning of Geba HPP in 2021 (370 MW), bringing additional power in Ghimbi, would greatly release this constraint. The dynamic behaviour of the Ethiopian system is satisfying.

- SUDAN

The behaviour of the Sudanese system is satisfactory, in case of tripping or short-circuit around Kosti.

1 PRESENTATION OF THE INTERCONNECTED SYSTEM IN 2020

1.1 PRESENTATION

To investigate the behaviour of the interconnection between Egypt, Ethiopia and Sudan for the year 2020/2021, it is necessary to determine the development of the transmission system of the 3 countries close to the connection points of the interconnection:

- Mandaya in Ethiopia
- Kosti in Sudan (initially located at Rabak (east side of the Nile), the line routing study located the interconnection substation in Sudan on the west side of the Nile river at Kosti),
- Nag Hammadi

The network of the 3 systems was modelled for the year 2020. Concerning the network, the study was based on the data collected in Phase I, and updated during the April 08 meeting of Phase II in Cairo.

Concerning the demand and the generation expansion plan, the data resulted of the economic study performed in Phase I.

1.2 DESCRIPTION OF THE TRANSMISSION SYSTEM

1.2.1 DESCRIPTION OF THE INTERCONNECTION

The interconnection scheme between the 3 countries selected at the beginning of Phase II, is made up of 2 different parts :

- An AC interconnection of 2 double 500 kV circuits (544 km) between Mandaya (Ethiopia) and Kosti (Sudan), each circuit compensated with a 150 MVAr reactor on Mandaya side, and a 75 MVAr reactor on Kosti side.
  A 500/400 kV substation located on Mandaya HPP site, equipped with four 500/400 kV 510 MVA transformers.
  The interconnection also included the existing 220 kV double circuit interconnection between Gonder (Ethiopia) and Gedaref (Sudan).
- A 600 kV DC interconnection between Kosti (Sudan) and Nag Hammadi (Egypt), made up of
  - AC/DC 2 x 1 075 MW converter station located at Kosti substation in Sudan, and a 500 MVAr SVC
  - A 600 kV DC bipolar line between Kosti and Nag Hammadi. The total length of the line is about 1665 km
  - A DC/AC 2 x 1 075 MW converter station located in Nag Hammadi in Egypt

In Egypt, the need of a third 500 kV circuit between Nag Hammadi and Assiut (internal reinforcement) will be examined.

Shunt compensation:

The 150 MVAr reactor at Mandaya side is made up of a 100 MVAr + a 50 MVAr reactors. After the commissioning of Border in 2030, the 100 MVAr reactor will be shifted at the new substation T.Border, created for the connection of Border HPP with a 500 kV double circuit (length : 70 km), on the circuit T.Border -Kosti. The 50 MVAr reactor will remain at the same place, on the line Mandaya - T.Border.

Two switchable 100 MVAr reactors are requested on Kosti busbar for the energisation of one Mandaya - Kosti circuit. Each of them is made up of two 50 MVAR reactors. All 50 MVAR reactors will be shifted at T.Border on every 4 Mandaya - T.Border circuits.

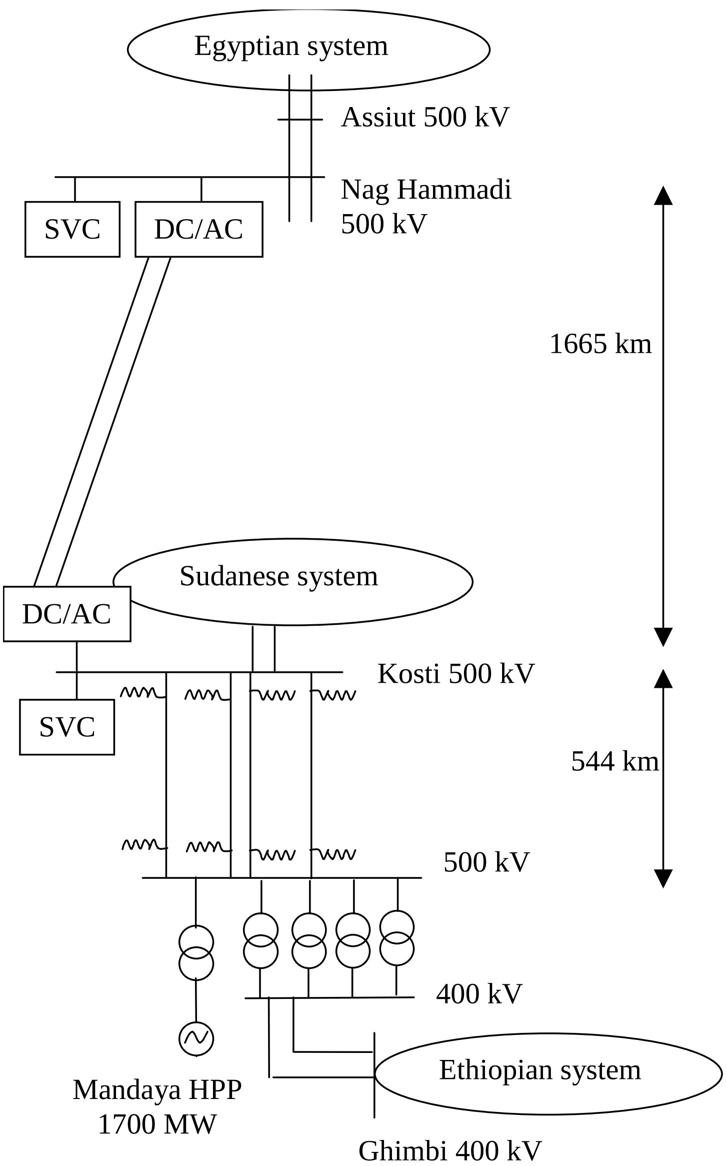


Figure 1: Interconnection Scheme

1.2.2 DESCRIPTION OF THE SYSTEM CLOSE TO THE INTERCONNECTION POINTS

1.2.2.1 Description of the Egyptian system close to Nag Hammadi

Nag Hammadi is located along the 500 kV double circuit backbone in the Nile valley, connecting High Dam HPP in the south to Kurimat and Cairo in the North, via Nag Hammadi, Assiut and Samalut substation.

In Nag Hammadi substation, 2 circuits are connected to High Dam HPP in the south, and 2 are connected to Assiut substation in the North, one of them tapping in Sohag substation. Nag Hammadi substation included 500/220 kV and 500/132 kV transformation.

1.2.2.2 Description of the Ethiopian system close to Mandaya

Mandaya substation is connected to the 400 kV circuit in Addis Ababa with the following circuits :

- 3 circuits Mandaya - Ghimbi
- a double circuit Ghimbi - Ghedo
- a double circuit Ghedo - Sebeta

Baro - Genji HPP, commissioned in 2020, are connected in 400 kV to Ghimbi, via Metu.

1.2.2.3 Description of the Sudanese system close to Kosti

Kosti 500 kV is connected to the following substations :

- Fula with a double circuit
- Jebel Aulia with one single circuit
- Meringan with one single circuit

Kosti substation included 500/220 kV transformation.

1.3 DEMAND AND GENERATION BALANCE

1.3.1 LOAD DEMAND

Two situations were examined to assess the impact of the interconnection and the power exchanges on the transmission systems :

- the annual peak, for which the total demand is the sum of the annual peak of each of the 3 countries
- the intermediate load period, corresponding to high load period for Sudan and Egypt and a maximum economic flow on the interconnections

For the peak period, there is a risk of shortage of generation in the importing countries, so the transmission system must be able to operate with the maximum import (2000 MW for Egypt, and 1200 MW for Sudan).

Out of the peak period, the transmission system must be able to import the maximum flow determined by the economic study, making the interconnection profitable :

- in Egypt, such situation appears in October with a demand reaching 70 % of the annual peak, and an import on the interconnection reaching 1850 MW
- in Sudan, such situation appears in July with a demand reaching 62 % of the annual peak, and an import on the interconnection reaching 1200 MW

The intermediate load demand situation is analysed to assess the behaviour of the networks close to the connection points of the importing systems : the importation is closed to the maximum value, and the local load is the lowest supplied by the network with this level of power import. In such situation, the power flow over the network close to the interconnection point are maximised.

The two demand values for each country are displayed hereafter.

Egypt	2020 / 2021
Peak demand* (MW)	40 350
Intermediate peak demand* (MW)	28 245

* These figures do not include the transmission losses

Table 1: Egyptian 2020/2021 Load forecast

Ethiopia	2020 / 2021
Peak demand* (MW)	2 372
Intermediate peak demand* (MW)	2 165

* These figures do not include the transmission losses, nor the exportation to Djibouti and Kenya

Table 2: Ethiopian 2020/2021 Load Forecast

Sudan	2020 / 2021
Peak demand* (MW)	9 040
Intermediate peak demand* (MW)	5 605

* These figures do not include the transmission losses

Table 3: Sudanese 2020/2021 Load Forecast

1.3.2 GENERATION

The generation expansion plans were reviewed in Phase 1 Module 3, and were presented in the Economic Study. For Ethiopia, it was adapted in Module 6 of Phase 1, to take into account the anticipation of Mandaya HPP from 2024 to 2020 to meet the power exchange selected.

Name of the plant	Plant site location	Type of generation unit	Fuel(s) types	Heating value (GJ/ 1000Nm3)	Installed capacity (MW)	Capacity derating	Auxiliary consump.	Net available capacity (MW)	15/16	16/17	17/18	18/19	19/20	20/21
Sidi Krir	East Delta	CCGT	NG/HFO	36.3	750	37.5	21.4	691.1						
Kurimat (3)	Upper Egypt	CCGT	NG/HFO	36.3	750	37.5	21.4	691.1						
Nobaria (3)	West Delta	CCGT	NG/HFO	36.3	750	37.5	21.4	691.1						
Atfe	West Delta	CCGT	NG/HFO	36.3	750	37.5	21.4	691.1						
Sharm El-Sheik	West Delta	CCGT	NG/HFO	36.3	750	37.5	21.4	691.1						
Alexandria East	West Delta	CCGT	NG/HFO	36.3	750	37.5	21.4	691.1	500					
Combined Cycle 750MW		CCGT	NG/HFO	36.3	750	37.5	21.4	691.1		500	500	500	1000	500
Open Cycle GT 250 MW		OCGT	NG/HFO	36.3	250	12.5	4.8	232.8						
Abu Qir	West Delta	ST	NG/HFO	36.3	650		26.0	624.0						
Suez	East Delta	ST	NG/HFO	36.3	450		18.0	432.0						
Steam Units 450MW		ST	NG/HFO	36.3	450		18.0	432.0	450		450	450		
Cairo West Ext.	Cairo	ST	NG/HFO	36.3	350		14.0	336.0						
Tebbin	Cairo	ST	NG/HFO	36.3	350		14.0	336.0						
Ayoun Musa Ext.	Upper Egypt	ST	NG/HFO	36.3	350		14.0	336.0						
Steam Units 650MW		ST	NG/HFO	36.3	350		14.0	336.0		1300	1300	1300	1300	650
Borg El-Arab		Solar/Thermal			300					300		300		
Kurimat	Upper Egypt	Solar/Thermal	NG/HFO		150									
Dabaa Nuclear		Nuclear			1000				1000					1000
New Naga Hammadi		Hydro			64									
Assiut		Hydro			40									
Damietta		Hydro			13									
Zefta		Hydro			5.5									
Zafarana	East Delta	Wind			125									
Zafarana / Gabal El-Zait	East Delta	Wind							200	200	200	200	200	200

Table 4: Egyptian Generation Expansion Plan

Commissioning Date	Hydro Project	Capacity MW	Average Generation GWh
2016	Halele Worabesa	420	2 245
2017			
2018			
2019			
2020	Madaya + Baro I + II + Genji	2700	16 509

Table 5: Ethiopian Generation Expansion Plan

Year	Thermal Plant			Hydro Electric Plant	
	Plant Name	Installed Capacity (MW)	Net Capacity (MW)	Plant Name	Installed Capacity (MW)
2015	Khartoum North ST's (U1&U2) Retired Khartoum North GT's (U3&U4) Retired 1 x Coal Fired Steam	-60 -47 400	-55 -34 380	Low Dal	340
2016				Kajbar	300
2017	1 x Crude Oil Fired Steam 1 x CCGT (6FA based)	250 214	238 208		
2018	1 x Coal Fired Steam	400	380		
2019	1 x CCGT (6FA based) 1 x Crude Oil Fired Steam	214 250	208 238	Dagesh	285
2020	2 x Crude Oil Fired Steam Southern Diesels	1,000 109	950 101	Fula 1	720

Table 6: Sudanese Generation Expansion Plan

2 STUDY OF THE INTERCONNECTION OF THE INTERCONNECTION FOR PEAK LOAD 2020/2021

2.1 ANALYSIS OF THE OPERATION OF THE 500 KV AND 220 KV INTERCONNECTION BETWEEN ETHIOPIA AND SUDAN

The 220 kV and 500 kV interconnections operated in parallel.

Ethiopia exported 3 350 MW to Sudan (including the 2 000 MW to Egypt) :

- 2 x 215 MW over the 220 kV interconnection (Gonder - Shehedi - Gedaref). Losses : 2 x 31.4 MW
- 4 x 730 MW over the 500 kV interconnection (Mandaya - Kosti). Losses : 4 x 34.4 MW

The total losses on the 220 and 500 kV interconnection reached 200 MW.

The flow over the 220 kV interconnection is much higher that the initial value (2 x 100 MW) proposed in the Ethiopia - Sudan interconnection study carried out in 2006. Moreover, the 230 kV network in Ethiopia between Bahir Dahr and Gonder was heavily loaded : 250 MW flowed over each circuit. The N-1 criteria is not satisfied on the 220 kV interconnection and on Bahir Dahr - Gonder circuits.

Moreover, the losses on this interconnection reached about 15 % of the flow.

Operation with a phase shift transformer on the 220 kV interconnection

To limit the flow over the 220 kV interconnection at its initial expected value (2 x 100 MW), it is proposed to insert a phase-shift transformer at Gedaref. The simulation indicated that an angle of bout 45 ° enabled to bring back the flow to 2 x 100 MW.

With the phase-shift transformer in operation, the amount of losses on the 220 and the 500 kV interconnections amounted to 174 MW (4 x 40.6 MW + 2 x 4.9 MW + 1 MW losses on the transformer). The flow on the 230 kV double circuit Bahir Dahr - Gonder reached 2 x 122 MW.

The 220 kV interconnection is permanently opened

All the power exchange flowed over the 500 kV Mandaya - Kosti circuits : 4 x 837.5 MW. The losses amounted to 188 MW (4 x 47 MW).

Economic comparison between the two options of operation

Operation in parallel with a 250 MVA phase shift transformer

	Quantity	Capital cost (k$)	Investment (i=10%) (k$)	Annuity cost (k$)
Cost	250 MVA	4 000	4 600	464
Transformer bay (2)	2	1 031	2 371	239
O&M of the transformer	-	-	-	121
Total	-	-	-	824

Table 7: Investment and annuity costs for the 220 kV phase shift transformer

The total annuity cost have been calculated for both solution, taking into account the cost of losses and the investment cost of the phase-shift transformer.

The results are displayed in the following table :

	Annuity cost (k$)
With a phase shift transformer	47 662
220 kV interconnection opened	50 317

Table 8: Annuity costs comparison with and without the 220 kV phase shift transformer

Conclusion:

The operation in parallel of the 220 and 500 kV interconnections with a 250 MVA phase shift transformer on the 220 kV interconnection is the most cost effective solution.

This solution is retained for the study of the interconnection.

2.2 STUDY IN PERMANENT STATE OF THE INTERCONNECTION FOR 2020 / 2021 PEAK PERIOD

2.2.1 NORMAL SITUATION

The interconnection

Ethiopia exported a total flow of 3 526 MW over the 220 and the 500 kV interconnection :

- 2 x 107 MW flowed from Gonder on the 220 kV interconnection
- 4 x 828 MW flow from Mandaya on the 500 kV interconnection

Sudan received 3353 MW :

- 2 x 101 MW arrived at Gedaref from the 220 kV interconnection (phase-shift angle of the transformer : 53°)
- 4 x 787 MW arrived at Kosti from the 500 kV interconnection

and exported 2150 MW to Egypt at the AC/DC converter station in Kosti

The losses on the interconnection amounted to 173 MW on the AC interconnection (Ethiopia - Sudan) : 4 x 40.6 MW on the 500 kV interconnection, 2 x (2.8+2.6) MW on the 220 kV interconnection

The flow on the interconnection neighbouring circuits are displayed in appendix.

The voltage profile is satisfactory, and displayed in the following table

Substations	Voltage (kV)
Mandaya 400 kV	418
Mandaya 500 kV	525
Kosti	523
Nag Hammadi	518
Gonder	234
Gedaref	224

Table 9: Voltage Profile

About 130 MVAr are sent to the interconnection at Mandaya.

About 144 MVAr are supplied by the 500 kV Sudanese network at Kosti to feed partially the reactors of the interconnection, and 10 Mvar are supplied by the 500/220 kV transformation (Steam Turbine connected in 220 kV).

Mandaya HPP generated 1700 MW and 266 MVAr.

Interconnection Neighbouring circuits

Egypt

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Nag Hammadi from High Dam	2	265	19
Nag Hammadi to Assiut	1	364	21
Nag Hammadi to Sohag	1	446	26
Samalut from Assiut	2	46	4
Samalut from Kurimat	1	662	37
Samalut from S.Giza	1	88	8

Table 10: Loading of the Egyptian 500kV backbone H.D. – Cairo

The transmission lines closed to the interconnection point (Nag Hammadi) are lightly loaded.

The balance point between the flow from the south (HD & Interconnection) and from the north (Kurimat & Cairo) is located in Samalut.

Ethiopia

The three circuits Ghimbi - Mandaya provided 1648 MW to Mandaya

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Ghimbi to Mandaya	3	550	76
Metu to Ghimbi	3	277	38
Ghedo to Ghimbi	2	418	60
Sebeta to Ghedo	2	425	59

Table 11: Loading of the Ethiopian 400kV Backbone Mandaya - Addis Ababa

The 400 kV transmission lines located between Mandaya and Addis Ababa is heavily loaded.

Sudan

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Kosti to Meringan	1	697	36
Kosti to Jabel Aulia	1	304	19
Fula to Kosti	2	100	17
Kosti transformation 500 to 220 kV	2	98.5	37

Table 12: Loading of the Sudanese 500kV Circuits Connected to Kosti

The 500 kV transmission network is lightly loaded.

The SVC absorbed -9 MVAr in Kosti

2.2.2 N-1 SITUATION ON THE INTERCONNECTION

2.2.2.1 Tripping of one of the two 220 kV circuits Gonder - Shehedi

The initial flow on each circuit Gonder - Shehedi reached 106 MW (loading of 40 %).
After the tripping, the flow on the remaining circuit increased to 191 MW (loading of 70 %). The importation in Gedaref from the 220 kV interconnection decreased from 201 to 178 MW. The flow on each 500 kV circuit increased from 788 to 794 MW.

The activation of the phase-shift transformer, would bring back the flow to 200 MW in Gedaref. The flow on the single Gonder - Shehedi would therefore reached 218 MW (loading of 80 %).

The voltage profile is not significantly affected

2.2.2.2 Tripping of one of the two 220 kV circuits Shehedi - Gedaref

The initial flow on each circuit Shehedi - Gedaref reached 101 MW (loading of 27 %).
After the tripping, the flow on the remaining circuit increased to 172 MW (loading of 47 %). The flow on each 500 kV circuit increased from 788 to 795 MW.

The activation of the phase-shift transformer, would bring back the flow to 200 MW in Gedaref. The flow on the single Shehedi - Gedaref would therefore reached 228 MW (loading of 53 %).

The voltage profile is not significantly affected

2.2.2.3 Tripping of one of the four 500 kV circuits Mandaya - Kosti

The initial flow on each of the 4 circuits Mandaya - Kosti reached 828 MW (loading of 44 %).
After the tripping, the flow on the remaining 3 circuits increased to 1030 MW (1105 MW at Mandaya side, loading of 57 %). The importation in Gedaref from the 220 kV interconnection increased from 201 to 260 MW.

Even with activation of the phase-shift transformer, it is not possible to decrease the flow to 200 MW in Gedaref.

The SVC reactive power generation increased from -3 to 400 MVAr, Kosti voltage droped by less than 1%, from 522 to at 518 kV. With a 100 MVAr increase of the reactive generation of Kosti units, Kosti voltage recovered its initial value. Mandaya increased its reactive output from 266 to 760 MVAr, to keep Mandaya voltage at 525 kV.

Due to Mandaya HPP and the SVC in Kosti, the voltage profile is not significantly affected

2.2.2.4 Tripping of one of the four 400/500 kV transformers at Mandaya substation

The initial flow on each of the 4 transformer reached 406 MW (loading of 80 %).
After the tripping, the flow on the remaining 3 transformers increased to 539 MW (overload of 8 %). The flow on each 500 kV circuit decreased from 788 to 786 MW.

The flow on the Gonder - Shehedi interconnection increased from 202 to 210 MW (loading of 42 %).

The voltage profile is not affected

2.2.2.5 Tripping of one of the 2 DC poles

The tripping of one of the 2 DC circuits (pole or converter station) will be studied in dynamic part of the report.

2.2.3 N-1 SITUATION IN EGYPT CLOSE TO THE INTERCONNECTION POINT : NAG HAMMADI

The purpose of this study is to assess the impact of the injection of 2000 MW at Nag Hammadi. The following cases have been simulated :

- Tripping of one of the two 500 kV circuits High Dam - Nag Hammadi
- Tripping of the 500 kV circuit Nag Hammadi - Sohag
- Tripping of the 500 kV circuit Nag Hammadi - Assiut
- Tripping of the 500 kV circuit Kurimat - Samalut

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), the flow on the remaining circuits was below their rating.

The tripping of one of the DC poles was studied in dynamic.

As the circuits Assiut - Samalut and Samalut- South Giza were very lightly loaded (respectively 8% and 4 %), the tripping of one of these circuits were not critical.

The detailed results are displayed Appendix.

2.2.4 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT : MANDAYA

The purpose of this study is to assess the impact of the interconnection at Mandaya. The following cases have been simulated :

- Tripping of one of the three 400 kV circuits Mandaya - Ghimbi
- Tripping of one of the two 400 kV circuits Ghimbi - Ghedo
- Tripping of the 400 kV circuit Ghedo - Sebeta
- Tripping of the 400 kV circuit Debre Markos - Sululta

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), and the tripping of one 400 kV circuit on the link Sebeta - Ghedo - Ghimbi - Mandaya leads the remaining circuit on acceptable overload (< 20 %), which can be released by increasing the generation output of Mandaya HPP, and the flow on the 220 kV interconnection.

The detailed results are displayed Appendix.

2.2.5 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The purpose of this study is to assess the impact of the interconnection at Kosti. The following cases have been simulated :

- Tripping of the 500 kV circuit Kosti - Jebel Aulia
- Tripping of the 500 kV circuit Kosti - Meringan
- Tripping of one of the two 500 kV circuits Kosti - Fula
- Tripping of the SVC in Kosti

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), the flow on the remaining circuits remained within the rating.

The tripping of one of the DC poles was studied in dynamic.

The detailed results are displayed Appendix.

2.3 STUDY OF THE SHORT-CIRCUIT POWER

Three-phase to ground and one-phase to ground short-circuit calculations were performed taking into account the following assumptions:

- V = 1.1 Vn
- Impedance of generator = X"d (sub transient reactance)

The short-circuit power of the Egyptian system is compliant with the 40 kA limitation on the 220 and 500 kV system.
The short-circuit power of the Sudanese system is compliant with the 40 kA limitation on the 220 and 500 kV system.

The results are displayed Appendix.

2.4 DYNAMIC STUDY OF THE INTERCONNECTION FOR 2020 / 2021 PEAK PERIOD

2.4.1 N-1 SITUATION ON THE INTERCONNECTION

The behaviour of the system in case of tripping of one of the 2 poles is also acceptable for the 3 systems.

In case of short-circuit on one of the 500 kV interconnection Mandaya - Kosti on Kosti side, Ethiopia and Sudan lost synchronism if the DC converter station recover to its initial value. The system recover satisfactorily if the DC flow is reduced at half of its power : 1000 MW. The reduction of power flow on the DC interconnection is acceptable on both side, leading to a transient over-frequency of 50.5 Hz on the Ethiopian - Sudan side stabilizing at 50.22 Hz, and to a frequency drop at 49.7 Hz on the Egyptian side.

2.4.2 N-1 SITUATION IN EGYPT CLOSE TO THE INTERCONNECTION POINT : NAG HAMMADI

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Egyptian network close to Nag Hammadi and High Dam. The voltage and the frequency recovered correctly. The disturbances causes on the Ethiopia-Sudan system were also acceptable.

The tripping of the main steam unit (765 MVA) was acceptable for the system.

2.4.3 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT : MANDAYA

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Ethiopian network close to Mandaya. The voltage and the frequency recovered correctly. The disturbances causes on the Egyptian system were also acceptable. The behaviour of the system following the tripping of 2 Ethiopia main units (Mandaya 266 MVA, initial output 2 x 212.5 MW) was acceptable.

2.4.4 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Sudanese network close to Kosti. The voltage and the frequency recovered correctly. The disturbances causes on the Egyptian system were also acceptable. The behaviour of the system following the tripping of Sudan main unit (Port Sudan 670 MVA, initial output 530 MW) was acceptable.

3 STUDY OF THE INTERCONNECTION FOR THE INTERMEDIATE LOAD PERIOD 2020 / 2021

The demand for each country are displayed hereafter.

Intermediate peak demand* (MW)	2020 / 2021
Egypt	28 245
Ethiopia	2 165
Sudan	5 605

* These figures do not include the transmission losses

Table 13: Interconnected System 2020/2021 load Forecast for Intermediate Load Period

3.1 STUDY IN PERMANENT STATE OF THE INTERCONNECTION FOR 2020 / 2021 INTERMEDIATE LOAD PERIOD

3.1.1 NORMAL SITUATION

The interconnection

Ethiopia exported a total flow of 3 321 MW over the 220 and the 500 kV interconnection :

- 2 x 105 MW flowed from Gonder on the 220 kV interconnection (loading of 40 %)
- 4 x 778 MW flow from Mandaya on the 500 kV interconnection (loading of 42 %)
- The angle of the phase-shift transformer is reduced from 55 to 45°

Sudan received 3 168 MW :

- 2 x 99 MW arrived at Gedaref from the 220 kV interconnection (loading of 26 %)
- 4 x 742 MW arrived at Kosti from the 500 kV interconnection

and exported 1 970 MW to Egypt at the AC/DC converter station in Kosti.

Egypt received 1 850 MW, according to the hypothesis.

The losses on the interconnection amounted to 153 MW on the AC interconnection (Ethiopia - Sudan)

The flow on the interconnection neighbouring circuits are displayed Appendix.

The voltage profile is satisfactory, and displayed in the following table :

Substations	Voltage (kV)
Mandaya 400 kV	418
Mandaya 500 kV	525
Kosti	522
Nag Hammadi	520
Gonder	238
Gedaref	228

Table 14: Voltage Profile

About 228 MVAr are sent to the interconnection at Mandaya.

The reactive balance on the interconnection in Kosti is close to 0 : 4 x 3 MVAr are send to the interconnection by the Sudanese system. A 100 MVAr reactor has been connected to Kosti bus-bar, the SVC generated 10 MVAr. The reactive flow on the 500/220 kV transformation (Steam Turbine connected in 220 kV) is close to 0.

Mandaya HPP generated 1700 MW and 104 MVAr.

Interconnection Neighbouring circuits

Egypt :

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Nag Hammadi from High Dam	2	475	26
Nag Hammadi to Assiut	1	753	42
Nag Hammadi to Sohag	1	752	43
Sohag to Assiut	1	629	36
Samalut from Assiut	2	535	30
Samalut to Kurimat	1	46	9
Samalut to S.Giza	1	428	29
S.Giza from Cairo	1	236	16

Table 15: Loading of the Egyptian 500kV Backbone H.D. – Cairo

The balance point between the flow from the south (HD & Interconnection) and from the north (Kurimat & Cairo) is located in Cairo (Krima and South Giza).

Ethiopia

The three circuits Ghimbi - Mandaya provided 1422 MW to Mandaya

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Ghimbi to Mandaya	3	474	67
Metu to Ghimbi	2	325	44
Ghedo to Ghimbi	2	407	57
Sebeta to Ghedo	2	414	57

Table 16: Loading of the Ethiopian 400kV Backbone Mandaya - Addis Ababa

The 400 kV transmission lines located between Mandaya and Addis Ababa are heavily loaded.

Sudan

Circuit	Nb of circuits	Flow (MW)	Loading (%)
Kosti to Meringan	1	774	37
Kosti to Jabel Aulia	1	446	24
Kosti from Fula	2	169	20
Kosti transformation 500 to 220 kV	2	58.3	20

Table 17: Loading of the Sudanese 500kV circuits Connected to Kosti

The 500 kV transmission network is lightly loaded.

The SVC absorbed 90 MVAr in Kosti.

3.1.2 N-1 SITUATION ON THE INTERCONNECTION

3.1.2.1 Tripping of one of the two 220 kV circuits Gonder - Shehedi

The initial flow on each circuit Gonder - Shehedi reached 105 MW (loading of 40 %).
After the tripping, the flow on the remaining circuit increased to 191 MW (loading of 71 %). The importation in Gedaref from the 220 kV interconnection decreased from 199 to 178 MW. The flow on each 500 kV circuit increased from 778 to 784 MW.

The activation of the phase-shift transformer, could bring back the flow to 200 MW in Gedaref. The flow on the single Gonder - Shehedi would therefore reached 218 MW (loading of 80 %).

The voltage profile is not significantly affected.

3.1.2.2 Tripping of one of the two 220 kV circuits Shehedi - Gedaref

The initial flow on each circuit Shehedi - Gedaref reached 102 MW (loading of 26 %).
After the tripping, the flow on the remaining circuit increased to 181 MW (loading of 45 %). The flow on each 500 kV circuit increased from 778 to 785 MW.

The activation of the phase-shift transformer, would bring back the flow from 173 to 200 MW in Gedaref. The flow on the single Shehedi - Gedaref would therefore reached 208 MW (loading of 53 %).

The voltage profile is not significantly affected.

3.1.2.3 Tripping of one of the four 500 kV circuits Mandaya - Kosti

The initial flow on each of the 4 circuits Mandaya - Kosti reached 778 MW (loading of 42 %).
After the tripping, the flow on the remaining 3 circuits increased to 1039 MW (loading of 54 %). The importation in Gedaref from the 220 kV interconnection increased from 199 to 250 MW.

Even with activation of the phase-shift transformer, it is not possible to decrease the flow to 200 MW in Gedaref.

The SVC reactive power generation increased from 10 to 400 MVAr to keep Kosti voltage at 522 kV, with the tripping of the 100 MVAr reactor, and a 60 MVAr output increase at Kosti units (initial generation : 0 MVAr). Mandaya increased its reactive output from 104 to 576 MVAr, to keep Mandaya voltage at 525 kV.

Due to Mandaya HPP and the SVC in Kosti, the voltage profile is not significantly affected.

3.1.2.4 Tripping of one of the four 400/500 kV transformers at Mandaya substation

The initial flow on each of the 4 transformer reached 356 MW (loading of 71 %).
After the tripping, the flow on the remaining 3 transformers increased to 472 MW (loading of 95 %). The flow on each 500 kV circuit decreased from 778 to 777 MW.

The flow on the 220 kV interconnection Gonder - Shehedi increased from 210 to 214 MW (loading of 41 %).

The voltage profile is not affected

3.1.2.5 Tripping of one of the 2 DC poles

The tripping of one of the 2 DC circuits (pole or converter station) will be studied in dynamic part of the report.

3.1.3 N-1 SITUATION IN EGYPT CLOSE TO THE INTERCONNECTION POINT : NAG HAMMADI

The purpose of this study is to assess the impact of the injection of 2000 MW at Nag Hammadi. The following cases have been simulated :

- Tripping of one of the two 500 kV circuits High Dam - Nag Hammadi
- Tripping of the 500 kV circuit Nag Hammadi - Sohag
- Tripping of the 500 kV circuit Nag Hammadi - Assiut
- Tripping of the 500 kV circuit Kurimat - Samalut

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), the flow on the remaining circuits was below their rating.

The tripping of one of the DC poles was studied in dynamic.

The detailed results are displayed Appendix.

3.1.4 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT : MANDAYA

The purpose of this study is to assess the impact of the interconnection at Mandaya. The following cases have been simulated :

- Tripping of one of the three 400 kV circuits Mandaya - Ghimbi
- Tripping of one of the two 400 kV circuits Ghimbi - Ghedo
- Tripping of the 400 kV circuit Ghedo - Sebeta
- Tripping of the 400 kV circuit Debre Markos - Sululta

The N-1 situation on the 400 kV backbone Mandaya - Ghimbi - Ghedo - Sebeta is acceptable. The tripping of one of these circuitsleadsto an acceptable overload. Attention should be paid to the unit commitment (to keep enough generation output in Mandaya and Baro & Genji), to limit the flow on the remaining circuit of the 400 kV backbone Sebeta - Ghedo - Ghimbi - Mandaya in case of N-1 situation to an acceptable overload (the limit is close to 2 x 420 MW for the flow on the 400 kV backbone, limit to be updated with the network evolution and generation update). The commissioning of Geba HPP in 2021 (370 MW), bringing additional power in Ghimbi, would greatly release this constraint.

The detailed results are displayed Appendix.

3.1.5 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The purpose of this study is to assess the impact of the interconnection at Kosti. The following cases have been simulated :

- Tripping of the 500 kV circuit Kosti - Jebel Aulia
- Tripping of the 500 kV circuit Kosti - Meringan
- Tripping of one of the two 500 kV circuits Kosti - Fula
- Tripping of the SVC in Kosti

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), the flow on the remaining circuits remained within the rating.

The tripping of one of the DC poles was studied in dynamic.

The detailed results are displayed Appendix.

3.2 DYNAMIC STUDY OF THE INTERCONNECTION FOR 2020 / 2021 INTERMEDIATE LOAD PERIOD

3.2.1 N-1 SITUATION ON THE INTERCONNECTION

The behaviour of the system in case of tripping of one of the 2 poles is also acceptable for the 3 systems.

In case of short-circuit on one of the 500 kV interconnection Mandaya - Kosti on Kosti side, Ethiopia and Sudan lost synchronism if the DC converter station recover to its initial value. The system recover satisfactorily if the DC flow is reduced at half of its power : 985 MW. The reduction of power flow on the DC interconnection is acceptable on both side, leading to a transient over-frequency of 50.95 Hz on the Ethiopian - Sudan side stabilizing at 50.3 Hz, and to a frequency drop at 49.6 Hz on the Egyptian side.

3.2.2 N-1 SITUATION IN EGYPT CLOSE TO THE INTERCONNECTION POINT : NAG HAMMADI

In case of short-circuit on the Egyptian network close to Nag Hammadi and High Dam, the recovery of the full power of the DC interconnection entailed a new voltage drop in Nag Hammadi, leading to a new commutation failure, and so on. Two solutions could lift this constraint : a additional 500 kV circuit between Nag Hammadi and Assiut, or a 300 MVA SVC in Kosti. The SVC is slightly less expensive, and less difficult to build. Wit hone of these devices, the behaviour of the Egyptian system in case of disturbance at Nag Hammadi is satisfying. The voltage and the frequency recovered correctly. The disturbances causes on the Ethiopia-Sudan system were also acceptable.

The tripping of the main steam unit (765 MVA) was acceptable for the system, the frequency dropping to 49.7 Hz.

3.2.3 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT : MANDAYA

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Ethiopian network close to Mandaya. The voltage and the frequency recovered correctly. The disturbances causes on the Egyptian system were also acceptable.

The behaviour of the system following the tripping of 2 Ethiopia main units (Mandaya 266 MVA, initial output 2 x 212.5 MW) was acceptable, the frequency dropping to 49.6 Hz before recovering to 49.87 Hz.

3.2.4 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Sudanese network close to Kosti. The voltage and the frequency recovered correctly. The disturbances causes on the Egyptian system were also acceptable. The voltage oscillation following the recovery of the DC converter station were more important than in the peak load situation, and might leadsto transient reduction of the flow on the DC interconnection, but not to additional commutation failure, which is acceptable.

The behaviour of the system following the tripping of Sudan main unit (Port Sudan 670 MVA, initial output 530 MW) was acceptable, the frequency dropping to 49.35 Hz before recovering to 49.85 Hz.

APPENDIX 1. OPERATION IN PARALLEL OF THE 220 AND 500 KV INTERCONNECTIONS

220 kV interconnection permanently opened

	Losses MW	Duration (h)	Cost of losses ($/MWh)	Annual operation cost (k$)
500 kV interconnection	188	6 300	40	47 376
	49.0	1500	40	2 941
Total				50 317

Table appendix 1-1 – Annuity cost Without the 220 kV Phase Shift Transformer

Operation in parallel with a 250 MVA phase shift transformer

	Quantity	Capital cost (k$)	Investment (i=10%) (k$)	Annuity cost (k$)
Cost	250 MVA	4 000	4 600	464
Transformer bay (2)	2	1 031	2 371	239
O&M of the transformer	-	-	-	121
Total	-	-	-	824

Table appendix 1-2 – Annuity Cost of the 220 kV Phase Shift Transformer

	Losses MW	Duration (h)	Cost of losses ($/MWh)	Annual operation and investment cost (k$)
500 and 220kV interconnection	175	6 300	40	44 100
	45.6	1 500	40	2 738
Phase shift tfo annuity cost	-	-	-	824
Total	-	-	-	47 662

Table appendix 1-3 – Annuity Cost with the 220 kV Phase Shift Transformer

APPENDIX 2. LOAD FLOW RESULTS – PEAK SITUATION 2020

A.2.1 INITIAL SYSTEM – NORMAL SITUATION

A.2.1.1 EGYPTIAN NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
A.Z.500	BASII500	-442.3	-387.9	588.3	660.1	0.8	-19.6	2020.7	31.6
A.Z.500	HELIO500	1275.1	-139.8	1282.7	1439.3	7.0	41.0	2000	72
A.Z.500	N.DELTA500*	-958.1	-111.5	964.6	1082.3	7.1	10.0	2000	54.1
A.Z.500	SUEZ500	-1219.8	-5.2	1219.9	1368.8	13.7	78.1	2049.6	66.8
A.Z.500	SUEZ500	-1219.8	-5.2	1219.9	1368.8	13.7	78.1	2049.6	66.8
A.Z.500	TEB.500	521.2	-198.0	557.5	625.5	2.2	-66.3	2049.6	30.5
ABKIR500	KAFR.Z500	499.8	-57.7	503.2	554.2	1.8	-72.7	2020	27.4
ABKIR500	KAFR.Z500	499.8	-57.7	503.2	554.2	1.8	-72.7	2020	27.4
ABKIR500	N.DELTA500*	-37.9	-115.6	121.6	134.0	0.0	-216.6	2020	6.6
AMOUS500	SUEZ500	839.3	32.9	839.9	924.4	1.2	-4.5	2049.6	45.1
AMOUS500	SUEZ500	839.3	32.9	839.9	924.4	1.2	-4.5	2049.6	45.1
AMOUS500	TABA500	11.9	-45.8	47.4	52.1	0.1	-247.3	2049.6	2.5
AUST500	N.H.500	-361.8	-10.7	362.0	405.3	2.3	-175.7	1963	20.6
AUST500	SAML500	46.6	-92.6	103.7	116.1	0.0	-146.2	1963	4
AUST500	SAML500	46.6	-92.6	103.7	116.1	0.0	-146.2	1963	4
AUST500	SOHAG500	-215.8	73.9	228.1	255.4	0.6	-104.6	1960	13
BASII500	C.W.500	253.9	81.6	266.6	295.1	0.1	-8.7	2020.7	14.6
BASII500	KAFR.Z500	-338.7	-49.3	342.2	378.8	0.9	-85.3	2020	18.8
BASII500	KAFR.Z500	-338.7	-49.3	342.2	378.8	0.9	-85.3	2020	18.8
CAIRO500	C.W.500	-1315.6	-426.8	1383.1	1546.8	2.3	17.8	2020.7	76.5
CAIRO500	KRIMA500	-12.5	-188.8	189.2	211.6	0.2	-136.4	1963	10.8
CAIRO500	NOBAR500	-891.5	-30.5	892.0	997.6	6.1	-5.1	2020.7	49.4
CAIRO500	NOBAR500	-891.5	-30.5	892.0	997.6	6.1	-5.1	2020.7	49.4
CAIRO500	S.GIZA500	662.1	-75.9	666.4	745.3	4.7	-72.4	1700	43.8
H.D.500	N.H.500	267.0	-22.6	268.0	294.8	1.5	-225.5	2049.6	18.5
H.D.500	N.H.500	267.0	-22.6	268.0	294.8	1.5	-225.5	2049.6	18.5
DABAA500	SALOUM500	209.3	-110.2	236.5	261.7	1.1	-291.8	2000	13.1
DABAA500	SKRIR500	647.9	-47.0	649.6	718.6	3.8	-55.2	2000	35.9
DABAA500	SKRIR500	647.9	-47.0	649.6	718.6	3.8	-55.2	2000	35.9
HELIO500	A.Z.500	-1268.1	180.8	1281.0	1431.8	7.0	41.0	2000	72
HELIO500	TEB.500	-319.8	-174.9	364.5	407.4	0.5	-47.5	1750	23.3
KRIMA500	SAML500	667.2	-1.3	667.2	733.3	5.6	-91.0	1963	38
KRIMA500	TEB.500	675.3	39.2	676.4	743.4	2.1	-34.1	2020.7	37.1
N.H.500	NH500_ACDC**	-2000.0	40.6	2000.4	-	-	-	-	-
N.H.500	SOHAG500	446.0	-59.7	450.0	509.8	1.8	-86.3	1960	26
N.OCT500	S.GIZA500	-128.2	-76.4	149.2	167.6	0.2	-133.0	1700	9.9
NOBAR500	SKRIR500	-798.6	48.8	800.1	885.9	6.4	-41.9	2020.7	43.8
NOBAR500	SKRIR500	-798.6	48.8	800.1	885.9	6.4	-41.9	2020.7	43.8
S.GIZA500	SAML500	88.5	-107.5	139.2	155.9	0.1	-174.4	1700	9.2
SALOUM500	TOBROK500	102.6	-26.8	106.0	119.6	0.2	-158.5	2020	5.9

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
TABSW400	S_TAB400***	200.5	-50.0	206.6	299.5	0.1	-9.5	2562	11.7
S_TAB400	S_AQA400	200.4	-40.5	204.4	296.0	0.3	-79.6	2562	11.6
S_AQA400	AKABA400	100.0	19.5	101.9	147.8	0.0	-5.1	2562	5.8
S_AQA400	AKABA400	100.0	19.5	101.9	147.8	0.0	-5.1	2562	5.8

*N.Delta 500 has been replaced by W.Domatia 500 kV, in the latest 2015 Egyptian data
** N.H500_ACDC : DC/AC converter station in Nag Hammadi
*** Egypt exported 200 MW to Jordan

Table appendix 2.1-1 - Power flow on the Egyptian 400 and 500 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
SALOUM500	TOBROK500	106.2	-35.9	112.1	127.3	0.2	-156.7	2020	6.3
SALOUM220	TOBROK220	47.3	-16.2	50.0	129.6	0.3	-28.9	1207.2	10.7
SALOUM220	TOBROK220	47.3	-16.2	50.0	129.6	0.3	-28.9	1207.2	10.7

The power flow exported from Egypt to Libya reached 200 MW

Table appendix 2.1-2 - Power Flow Exported from Egypt to Libya

Substation	V sol [pu]	V sol [kV]
A.Z.500	1.029	514.5
ABKIR500	1.048	524
AMOUS500	1.049	524.5
AUST500	1.031	515.5
BASII500	1.043	521.5
C.W.500	1.042	521
CAIRO500	1.032	516
DABAA500	1.044	522
H.D.500	1.05	525
HELIO500	1.033	516.5
KAFR.Z500	1.047	523.5
KRIMA500	1.050	525
N.DELTA500	1.050	525
N.H.500	1.019	509.5
N.OCT500	1.028	514
NH500_ACDC	1.019	509.5
NOBAR500	1.043	521.5
S.GIZA500	1.031	515.5
SALOUM500	1.024	512
SAML500	1.034	517
SKRIR500	1.041	520.5
SOHAG500	1.017	508.5
SUEZ500	1.047	523.5
TABA500	1.024	512
TEB.500	1.043	521.5

Substation	V sol [pu]	V sol [kV]
TOBROK500	1.012	506
TABSW400	0.996	398.4

Table appendix 2.1-3 - Voltage of the Egyptian 500 kV Substations

A.2.1.2 ETHIOPIAN NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
1MANDAS81	2RABAK81	828.2	-32.9	851.6	936.9	40.65	-242.3	2128	44
1MANDAS81	2RABAK81	828.2	-32.9	851.6	936.9	40.65	-242.3	2128	44
1MANDAS81	2RABAK81	828.2	-32.9	851.6	936.9	40.65	-242.3	2128	44
1MANDAS81	2RABAK81*	828.2	-32.9	851.6	936.9	40.65	-242.3	2128	44

* Rabak substation has been replaced by Kosti

Table appendix 2.1-4 - Power Flow on the Ethiopian 500 kV Lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1B.DAR3S71	1BELESS71	-218.6	-26.8	220.2	304.3	0.7	-35.1	1010	30.1
1B.DAR3S71	1BELESS71	-218.6	-26.8	220.2	304.3	0.7	-35.1	1010	30.1
1B.DAR3S71	1D.MARS71	190.4	70.3	202.9	280.4	2.5	-98.7	1010	27.8
1BARO1S71	1BARO2S71	-231.2	9.1	231.4	319.3	0.6	-26.4	1010	31.6
1BARO1S71	1BARO2S71	-231.2	9.1	231.4	319.3	0.6	-26.4	1010	31.6
1BARO1S71	1GENJIS71	-199.2	33.8	202.1	278.8	0.2	-11.0	1010	27.6
1BARO1S71	1METUS71	420.4	-76.1	427.3	589.6	1.4	-19.4	1515	38.9
1BARO1S71	1METUS71	420.4	-76.1	427.3	589.6	1.4	-19.4	1515	38.9
1BELESS71	1B.DAR3S71	219.3	-8.3	219.5	302.0	0.7	-35.1	1010	30.1
1BELESS71	1B.DAR3S71	219.3	-8.3	219.5	302.0	0.7	-35.1	1010	30.1
1D.MARS71	1SULULS71	233.8	40.3	237.2	346.5	4.0	-91.0	1010	34.3
1GENJIS71	1BARO1S71	199.4	-44.8	204.4	282.2	0.2	-11.0	1010	27.6
1GG2S71	1GGOS71	-5.0	47.6	47.9	66.0	0.0	-25.3	1010	10
1GG2S71	1GIBE3S71	-192.6	-20.5	193.7	266.9	0.7	-180.8	2020	13.2
1GG2S71	1SEBETS71	596.5	-14.5	596.6	822.1	17.6	4.7	1010	80.9
1GGOS71	1GG2S71	5.1	-72.9	73.1	101.1	0.0	-25.3	1010	10
1GHEDOS71	1GHIMBIS71	418.1	-116.0	433.9	604.6	8.5	-59.4	1010	59.9
1GHEDOS71	1GHIMBIS71	418.1	-116.0	433.9	604.6	8.5	-59.4	1010	59.9
1GHEDOS71	1SEBETS71	-418.9	89.1	428.3	596.8	6.1	-34.1	1010	59.1
1GHEDOS71	1SEBETS71	-418.9	89.1	428.3	596.8	6.1	-34.1	1010	59.1
1GHIMBIS71	1MANDAS71	549.5	-99.4	558.4	769.3	8.6	-10.6	1010	76.2
1GHIMBIS71	1MANDAS71	549.5	-99.4	558.4	769.3	8.6	-10.6	1010	76.2
1GHIMBIS71	1MANDAS71	549.5	-99.4	558.4	769.3	8.6	-10.6	1010	76.2
1GHIMBIS71	1METUS71	-277.1	6.9	277.2	381.8	2.2	-58.4	1010	37.8
1GHIMBIS71	1METUS71	-277.1	6.9	277.2	381.8	2.2	-58.4	1010	37.8

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1GHIMBIS71	1METUS71	-277.1	6.9	277.2	381.8	2.2	-58.4	1010	37.8
1GIBE3S71	1W.SODS71	439.4	-36.9	440.9	611.2	3.7	-21.6	1010	60.5
1GIBE3S71	1W.SODS71	439.4	-36.9	440.9	611.2	3.7	-21.6	1010	60.5
1KALITS71	1SEBETS71	259.7	-128.8	289.8	411.5	0.8	-17.6	1010	40.7
1KALITS71	1W.SODS71	-334.0	-45.6	337.1	478.7	7.6	-105.0	1010	47.8
1KALITS71	1W.SODS71	-334.0	-45.6	337.1	478.7	7.6	-105.0	1010	47.8

Table appendix 2.1-5 - Power Flow on the Ethiopian 400 kV Lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1GONDES61	1SHEHES61	106.5	-32.8	111.5	274.4	2.7	-17.4	690	39.8
1GONDES61	1SHEHES61	106.5	-32.8	111.5	274.4	2.7	-17.4	690	39.8

Table appendix 2.1-6 - Power Flow on the Ethiopian-Sudan 220 kV Lines

From bus	To bus	Sn nominal [MVA]	P [MW]	Q [MVAR]	S [MVA]	I [A]	Loading [%]
1MANDAS71	1MANDAS81	510	405.7	-66.6	411.1	563.7	81.4
1MANDAS71	1MANDAS81	510	405.7	-66.6	411.1	563.7	81.4
1MANDAS71	1MANDAS81	510	405.7	-66.6	411.1	563.7	81.4
1MANDAS71	1MANDAS81	510	405.7	-66.6	411.1	563.7	81.4

Table appendix 2.1-7 - Power Flow on the Ethiopian 400/500 kV Transformers

Substation	V sol [pu]	V sol [kV]
1MANDAS81	1.05	525
1B.DAR3S71	1.045	418
1BARO1S71	1.046	418.4
1BARO2S71	1.047	418.8
1BELESS71	1.049	419.6
1D.MARS71	0.988	395.2
1GENJIS71	1.045	418
1GG2S71	1.048	419.2
1GGOS71	1.043	417.2
1GHEDOS71	1.032	412.8
1GHIMBIS71	1.042	416.8
1GIBE3S71	1.041	416.4
1KALITS71	1.016	406.4
1MANDAS71	1.043	417.2
1METUS71	1.048	419.2
1SEBETS71	1.022	408.8
1SULULS71	0.932	372.8
1W.SODS71	1.037	414.8

Table appendix 2.1-8 - Voltage of the 400 and 500 kV Ethiopian Substations

A.2.1.3 SUDANESE NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
2ATBARS81	2KABASS81	373.5	-146.0	401.0	447.4	4.3	-276.3	2128	21
2ATBARS81	2KABASS81	373.5	-146.0	401.0	447.4	4.3	-276.3	2128	20.7
2ATBARS81	2MEROWS81	-264.6	-157.1	307.7	343.3	1.8	-250.7	2128	14.6
2ATBARS81	2P.SUD81	-309.3	-224.8	382.4	426.6	4.5	-457.8	2128	20.2
2ATBARS81	2P.SUD81	-309.3	-224.8	382.4	426.6	4.5	-457.8	2128	20.2
2BAGERS81	2H.HEI81	214.0	-19.7	214.9	242.3	0.5	-102.2	2128	11.4
2BAGERS81	2H.HEI81	214.0	-19.7	214.9	242.3	0.5	-102.2	2128	11.4
2BAGERS81	2J.AULIAS81	-78.4	62.1	100.0	112.8	0.1	-42.4	2128	5.3
2BAGERS81	2KABASS81	-236.2	-28.8	237.9	268.2	0.5	-81.6	2128	12.6
2BAGERS81	2KABASS81	-236.2	-28.8	237.9	268.2	0.5	-81.6	2128	12.6
2BORS81	2JUBAS81	-342.2	-64.7	348.3	392.0	2.0	-154.0	2128	18.4
2BORS81	2MALAKAS81	266.4	-183.4	323.4	364.0	2.7	-358.8	2128	17.1
2FULA81	2NYALA81	325.4	-146.9	357.0	392.5	4.6	-392.2	2128	21.7
2FULA81	2NYALA81	325.4	-146.9	357.0	392.5	4.6	-392.2	2128	18.4
2FULA81	2RABAK81*	101.0	-328.9	344.0	378.2	0.6	-648.8	2128	17.8
2FULA81	2RABAK81*	101.0	-328.9	344.0	378.2	0.6	-648.8	2128	17.8
2GEDARE81	2MERIN81	114.1	-54.7	126.6	138.5	0.4	-247.5	2128	6.5
2GEDARE81	2P.SUD81	-346.8	-323.3	474.1	518.8	9.3	-728.2	2128	24.4
2H.HEI81	2MERIN81	-297.4	-277.8	407.0	461.5	0.9	-52.7	2128	21.7
2J.AULIAS81	2MARKHS81	-144.4	-14.2	145.0	164.1	0.2	-77.5	2128	7.7
2J.AULIAS81	2RABAK81*	-300.5	-203.1	362.6	410.2	3.3	-336.5	2128	19.3
2JUBAS81	2RUMBEKS81	257.7	-205.0	329.3	369.3	2.4	-347.6	2128	17.4
2KABASS81	2MARKHS81	130.8	90.9	159.3	179.4	0.1	-39.7	2128	9.8
2MARKHS81	2MEROWS81	-482.2	-178.2	514.1	581.9	9.1	-310.2	2128	26.3
2MARKHS81	2MEROWS81	-482.2	-178.2	514.1	581.9	9.1	-310.2	2128	26.3
2MERIN81	2RABAK81*	-689.3	-39.4	690.4	769.8	8.0	-99.5	2128	36.3
2RABAK81*	1MANDAS81	-787.6	-44.1	788.8	870.8	40.7	-242.4	2128	44
2RABAK81*	1MANDAS81	-787.6	-44.1	788.8	870.8	40.7	-242.4	2128	44
2RABAK81*	1MANDAS81	-787.6	-44.1	788.8	870.8	40.7	-242.4	2128	44
2RABAK81*	1MANDAS81	-787.6	-44.1	788.8	870.8	40.7	-242.4	2128	44
2RABAK81*	2RABAK_5ACDC**	2150.0	-25.4	2150.2	2373.6	-	-	-	-
2RUMBEKS81	2WAUS81	153.8	-205.9	257.0	287.6	0.9	-384.7	2128	13.5

* Rabak substation has been replaced by Kosti

** RABAK_5ACDC : AC/DC converter station in Kosti

Table appendix 2.1-9 - Power Flows on the Sudanese 500 kV Lines

From bus	To bus	P [MW]	Q [MVAr]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAr]	Ampacity (Norm.) [A]	Loading [%]
2GEDARS61	1SHEHE61	-101.2	5.7	101.3	260.8	2.6	-25.6	972	26.8
2GEDARS61	1SHEHE61	-101.2	5.7	101.3	260.8	2.6	-25.6	972	26.8

Table appendix 2.1-10 - Power Flows on the 220 kV Interconnection Ethiopia - Sudan

Power imported from Ethiopia

Power flow arriving from Ethiopia to Sudan :

- 500 kV interconnection : 4 x 788 MW = 3 150 MW

- 220 kV interconnection : 2 x 101 MW = 202 MW

Total : 3353 MW

Among these 3353 MW, 2150 MW are absorbed by the AC/DC converter station in Rabak (hypothesis : losses on the DC lines and converter stations = 150 MW). 1200 MW are for the Sudanese system.

To limit the flow and avoid an overload on the 220 kV interconnection, a phase-shift transformer has been installed at Gedaref substation.

Substation	V sol [pu]	V sol [kV]
2ATBARS81	1.035	517.5
2BAGERS81	1.024	512
2BORS81	1.026	513
2FULA81	1.05	525
2GEDARE81	1.05	525
2H.HEI81	1.018	509
2J.AULIAS81	1.021	510.5
2JUBAS81	1.03	515
2KABASS81	1.025	512.5
2MALAKAS81	1.016	508
2MARKHS81	1.02	510
2MERIN81	1.036	518
2MEROWS81	1.05	525
2NYALA81	1.012	506
2P.SUD81	1.05	525
2RABAK81*	1.046	523
2RUMBEKS81	1.032	516
2WAUS81	1.031	515.5

* Rabak substation has been replaced by Kosti

Table appendix 2.1-11 - Voltage of the 500 kV Sudanese Substations

A.2.2 INITIAL SYSTEM – N-1 SITUATION

A.2.2.1 EGYPTIAN NETWORK

Recall of the flows on the 500 kV backbone along the Nile Valley

From bus	To bus	N° of circuits	P [MW]	Loading %
H.D.500	N.H.500	2	267.0	18.5
N.H.500	AUST500	2	361.8	20.6
N.H.500	SOHAG500	1	446.0	26
SOHAG500	AUST500	1	215.8	13
AUST500	SAML500	2	46.6	4
SAML500	S.GIZA500	1	-88.5	9.2
SAML500	KRIMA500	1	-661.8	38

Table appendix 2.1-12 - Power Flows on the Egyptian 500 kV Lines

A.2.2.1.1 Tripping of One of the 2 Circuits High Dam - Nag Hammadi

The initial flow on each of the 2 circuits High Dam - Nag Hammadi reached 267 MW (18 % of loading). High Dam HPP generated initially 450 MVAr.

The situation after the tripping of the line is satisfactory. The flow on the remaining circuit reached 478 MW (37 % of loading - report of 90 % of the initial flow). High Dam HPP generated 808 MVAr, to keep the voltage at its set point (1.05 pu).

In High Dam substation, the flow on the 500/220 kV transformation increased by 36 MW, and the flow on the 500/132 kV transformation increased by 19 MW.

The voltage in Nag Hammadi dropped from 1.02 pu to 0.94 pu.

A.2.2.1.2 Tripping of the circuit Nag Hammadi - Sohag

The initial flow on the circuit Nag Hammadi - Sohag reached 446 MW (26 % of loading).

The flow on the circuit Nag Hammadi - Assiut increased from 364 MW to 626 MW (respectively 21 % and 36 %of loading - load report of 77 %).

The flow on the circuit Sohag - Assiut reversed from 216 MW (13 % of loading) to -226 MW.

In Nag Hammadi substation, the flow on the 500/220 kV transformation increased by 150 MW, and the flow on the 500/132 kV transformation increased by 22 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
Nag Hammadi	1.02	0.997
Sohag	1.017	0.98
Assiut	1.03	1.005

Table appendix 2.1-12 - Voltage on the Egyptian 500kV Substations

The situation after the tripping of the line is satisfactory.

A.2.2.1.3 Tripping of the circuit Nag Hammadi - Assiut

The initial flow on the circuit Nag Hammadi - Assiut reached 364 MW (21 % of loading).

The flow on the circuit Nag Hammadi - Sohag increased from 446 MW to 693 MW (26 % to 42 %of loading - load report of 85 %).

In Nag Hammadi substation, the flow on the 500/220 kV transformation increased by 82 MW, and the flow on the 500/132 kV transformation increased by 28 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
Nag Hammadi	1.02	0.983
Sohag	1.017	0.98
Assiut	1.03	1.003

Table appendix 2.1-13 – Voltage Variation on Substations

The situation after the tripping of the line is satisfactory.

A.2.2.1.4 Tripping of the circuit Kurimat - Samalut

The initial flow on the circuit Kurimat - Samalut reached 662 MW (38 % of loading).

The flow on the circuit South Giza - Samalut increased from 88 MW to 533 MW (9 % to 36 %of loading).

The flow on the circuit Cairo - South Giza increased from 662 MW to 867 MW (44 % to 58 %of loading).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
South Giza	1.031	0.998
Samalut	1.034	0.976
Assiut	1.031	0.98

Table appendix 2.1-14 - Voltage Variation on Substations

A.2.2.1.5 Conclusion

Whatever the tripped line in the 500 kV system in the Upper Nile Valley, the behaviour of the system is satisfactory. The flow remained far below the thermal limit, and the voltage remained within the limits (+5/-10 %).

A.2.2.2 *ETHIOPIAN NETWORK*

Recall of the flow on the Ethiopian 400 kV system between Addis Ababa and Mandaya

From bus	To bus	N° of circuit	P [MW]	Loading %
1MANDAS71	1GHIMBIS71	3	-549.5	76.2
1GHIMBIS71	1GHEDOS71	2	-418.1	59.9
1GHIMBIS71	1METUS71	3	-277.1	37.8
1GHEDOS71	1SEBETS71	2	-418.9	59.1

Table appendix 2.1-15- Power Flows on the 400kV Ethiopian Lines

A.2.2.2.1 Tripping of the 400 kV circuit Debre Markos - Sululta

The initial flow on Debre Markos - Sululta reached 233 MW (loading of 34°%)

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system. The flow on the two 230 kV circuits Ghedo to Gefersa increased from 2x133 to 2x222 MW (from 66 to 83 % of loading).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 202 to 253 MW (256 MVA - 2 % overload on the phase shift transformer - that is acceptable in N-1 situation).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1B.DAR3S71	1.045	1.05
1D.MARS71	0.988	1.039
1SULULS61	1.027	1.004
1SEBETS71	1.022	1.011
1GHEDOS71	1.032	1.029

Table appendix 2.1-16- Voltage Variation on Substations

A.2.2.2.2 Tripping of one of the 400 kV circuit Sebeta - Ghedo

The initial flow on each circuit Ghedo - Sebeta reached 425 MW (loading of 59°%)

Following the tripping of the line, the remaining circuit was overloaded by 17 % (which is acceptable in N-1 situation), its flow reaching 824 MW (loading of 117 % - load report of 97 %).

Note : the commissioning in 2021 of Geba1&2 (370 MW - connected to Metu, and then Ghimbi), would reduce or lift this constraint, by reducing the power flow coming from the generation located eastward.

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 202 to 233 MW (234 MVA).

To release the 17 % overload constraint before the commissioning of Geba, two solutions :

- a 150 MW increase of generation output of Manadaya and Baro & Genji is necessary. The flow on the remaining circuit is reduced to 680 MW (loading of 94 %).
- an increased of the flow on the 220 kV interconnection up to 330 MW, by installing a 350 MVA phase shift transformer instead of the 250 MVA one
- an transitory increase of the 220 kV flow to an acceptable overload, and a smaller increase of the output of Mandaya

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.042	1.040
1GHEDOS71	1.032	1.020
1SEBETS71	1.022	0.999

Table appendix 2.1-17- Voltage Variation on Substations

A.2.2.2.3 Tripping of one of the 400 kV circuit Ghedo - Ghimbi

The initial flow on each circuit Ghedo - Ghimbi reached 418 MW (loading of 60°%)

Following the tripping of the line, the remaining circuit was overloaded by 14 % (which is acceptable in N-1 situation), its flow reaching 801 MW (loading of 114 %).

Note : the commissioning in 2021 of Geba1&2 (370 MW - connected to Metu, and then Ghimbi), would lift this constraint, by reducing the power flow coming from the east and the south part of Ethiopia.

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 202 to 245 MW (248 MVA).

To release the 14 % overload constraint, two solutions before the commissioning of Geba:

- a 150 MW increase of generation output of Manadaya and Baro & Genji is necessary. The flow on the remaining circuit is reduced to 670 MW (loading of 94 %)
- an increased of the flow on the 220 kV interconnection up to 300 MW, by installing a 320 MVA phase shift transformer instead of a 250 MVA one. But in case of N-1 on Gonder - Shehedi, the remaining circuit would be on 20 % overload (acceptable)
- an transitory increase of the 220 kV flow to an acceptable overload, and a smaller increase of the output of Mandaya and Baro & Genji

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.042	1.037
1GHEDOS71	1.032	1.011
1SEBETS71	1.022	1.008

Table appendix 2.1-18- Voltage Variation on Substations

A.2.2.2.4 Tripping of one of the three 400 kV circuit Ghimbi - Mandaya

The initial flow on each circuit Ghimbi - Mandaya reached 550 MW (loading of 76°%)

Following the tripping of the line, the two remaining circuits were overloaded by 14 % (which is acceptable in N-1 situation), its flow reaching 820 MW (loading of 114 %).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 202 to 220 MW (221 MVA).

To release the 14 % overload constraint, the two following actions are to be taken :

- a 150 MW increase of generation output of Mandaya is necessary
- an increased of the flow on the 220 kV interconnection up to 330 MW, by installing a 350 MVA phase shift transformer instead of a 250 MVA one
- a mix solution of the previous ones

The flow on the 2 remaining circuits are reduced to 680 MW (loading of 93 %).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.042	1.037
1GHEDOS71	1.032	1.029
1SEBETS71	1.022	1.021

Table appendix 2.1-19- Voltage Variation on Substations

A.2.2.2.5 Tripping of one of the two 230 kV circuits Bahir Dar - Gonder

The initial flow on each circuit Bahir Dar - Gonder reached 128 MW (loading of 47°%)

Following the tripping of the line, the flow on the remaining circuit reached 225 MW (loading of 80 %).

The flow over the 220 kV Ethiopia - Sudan interconnection decreased from 202 to 178 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1B.DARS61	1.029	1.026
1GONDERS61	1.020	1.005

Table appendix 2.1-20- Voltage Variation on Substations

A.2.2.2.6 Conclusion

The tripping of one 400 kV circuit on the link Sebeta - Ghedo - Ghimbi – Mandaya leadsthe remaining circuit on acceptable overload (< 20 %), which can be released by increasing the generation output of Mandaya HPP and Baro & Genji, and the flow on the 220 kV interconnection

A.2.2.3 SUDANESE NETWORK

Recall of the flow on the Sudanese 500 kV system around Kosti

From bus	To bus	N° of circuit	P [MW]	Loading %
2RABAK81*	1MANDAY81	4	-787.4	44
2RABAK81*	2FULA81	2	-100.4	17.8
2RABAK81*	2J.AULIAS81	1	303.5	19.3
2RABAK81*	2MERIN81	1	696.8	36.3
2BAGERS81	2H.HEI81	2	214.0	11.4
2BAGERS81	2J.AULIAS81	1	-78.4	5.3
2GEDARE81	2MERIN81	1	114.1	6.5
2H.HEI81	2MERIN81	1	-297.4	21.7

* Rabak substation has been replaced by Kosti

Table appendix 2.1-21- Power Flows on the Sudanese 500kV Lines

A.2.2.3.1 Tripping of the 500 kV circuit Kosti - Jebel Aulia

The initial flow on Kosti - J.Aulia reached 304 MW (loading of 19°%)

The flow on Kosti - Meringan increased from 697 to 919 MW (from 36 to 48 % of loading).

The flow on the 500/220 kV transformation increased by 69 MW.

The voltage at Kosti substation is not affected, the SVC increasing its reactive output from -9 to 239 MVAr.

Voltage variation on the following substation

Substation	Initial voltage (pu)	Final voltage (pu)
Kosti	1.046	1.046
J. Aulia	1.021	0.987

Table appendix 2.1-22- Voltage Variation on substations

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.2.2.3.2 Tripping of the 500 kV circuit Kosti - Meringan

The initial flow on Kosti - Meringan reached 697 MW (loading of 36°%)

The flow on Kosti - J.Aulia increased from 304 to 720 MW (from 19 to 39 % of loading).

The flow on Fula - Kosti decreased from -201 to -166 MW (from 17.8 to 17.5 % of loading).

The flow on the 500/220 kV transformation increased by 229 MW.

The voltage at Kosti substation is not affected, the SVC increasing its reactive output from –9 to 173 MVAr.

Voltage variation on the following substation

Substation	Initial voltage (pu)	Final voltage (pu)
Kosti	1.046	1.046
Meringan	1.036	0.986
J. Aulia	1.021	0.99

Table appendix 2.1-23- Voltage Variation on substations

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.2.2.3.3 Tripping of one of the two 500 kV circuits Kosti - Fula

The initial flow on Kosti - Fula reached -100 MW (loading of 17.8°%)

The flow on the remaining circuit Kosti - Fula increased from -100 to -173 MW (from 17.8 to 19.3 % of loading).

The flow on the 500/220 kV transformation decreased by 18 MW.

The voltage at Kosti (SVC) and Fula (generation plants) substation is not affected, the SVC increasing its reactive output from -9 to 84 MVAr.

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.2.2.3.4 Tripping of the SVC at Kosti

In normal situation, the SVC reactive power generation is close to 0. The tripping of the SVC did not entail significant voltage variation.

A.2.2.3.5 Conclusion

The behaviour of the Sudanese system is satisfactory, in case of tripping of one of the 500 kV circuit connected to Kosti. The flow remained far below the thermal limit, and the voltage remained within the limits (+5/-10 %).

APPENDIX 3. DYNAMIC RESULTS - PEAK LOAD 2020

A.3.1 INTERCONNECTION

A.3.1.1 TRIPPING OF ONE OF THE 2 POLES OF THE DC INTERCONNECTION

In case of tripping of one of the 2 poles of the DC interconnection, the behaviour of the system is satisfactory.

Event : a tripping of one of the 2 poles of the DC interconnection, and disconnection of half of the capacitor banks in each f the HVDC converter station 300 ms after.

Following the reduction of the transmitted power by half of its initial value :

- for the Ethiopia - Sudan system, the frequency raised to 50.35 Hz, before stabilizing around 50.18 Hz, after activation of the primary regulation of the generation governors
- for the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 49.7 Hz, after activation of the primary regulation of the generation governors with spinning reserve, and the self regulation of the load (estimated to 360 MW).

Libya contributed with 50 MW of its primary reserve, and around 60 MW self regulation of the load
Jordan and Syria contributed with 100 MW of primary reserve, and about 130 MW of self regulation of the load

Node	Initial voltage	Maximal voltage	Final voltage
NH500	509 kV	530 kV	510 kV
Kosti	522 kV	575 kV	527 kV
Mandaya	525 kV	560 kV	528 kV

Table appendix 3.1-1- Voltage Variation on Interconnection System

The flow on the 4 circuits Mandaya - Kosti decreased from 828 to 746 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.1.2 SHORT-CIRCUIT ON ONE OF THE 4 MANDAYA - KOSTI CIRCUITS, ON KOSTI SIDE

In case of short-circuit at Kosti on the interconnection, the behaviour of the system is satisfactory in case of tripping of one of the 2 poles of the DC station, or a reduction at half power on the DC Interconnection.

Event : a 3 phase short-circuit at Kosti end, on one of the 4 circuits Mandaya - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) leadsto a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to half of its initial value. At the same time, half of the capacitor banks were tripped.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Without the reduction of the power transmitted on the interconnection, a fault on Kosti side on the AC interconnection leadsto a loss of synchronism between Ethiopia and Sudan. The maximum transmitted power on one 570 km circuit reached 1510 MW, assuming that the voltage is kept on both end.

One of the pole of the DC converter station is tripped 200 ms after the clearance of the fault, and half of the capacitors banks of each of the converter station is disconnected at the same time

Following the reduction of the transmitted power by half of its initial value :

- for the Ethiopia - Sudan system, the frequency raised to 50.5 Hz, before stabilizing around 50.22 Hz, after activation of the primary regulation of the generation governors
- for the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 49.7 Hz, after activation of the primary regulation of the generation governors with spinning reserve, and the self regulation of the load (estimated to 360 MW).

Libya contributed with 50 MW of its primary reserve, and around 60 MW self regulation of the load. Jordan and Syria contributed with 100 MW of primary reserve, and about 130 MW of self regulation of the load

Node	Initial voltage	Maximal voltage	Final voltage
NH500	509 kV	547 kV	507 kV
Kosti	522 kV	615 kV	512 kV
Mandaya	525 kV	563 kV	519 kV

Table appendix 3.1-2- Voltage Variation on Interconnection System

The flow on the 3 remaining circuits Mandaya - Kosti reached 1235 MW, before stabilizing at 1082 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.1.3 SHORT-CIRCUIT ON ONE OF THE 4 MANDAYA - KOSTI CIRCUITS, ON MANDAYA SIDE

A.3.1.3.1 With full recovery of the DC power flow

In case of short-circuit at Mandaya on the interconnection, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Mandaya end, on one of the 4 circuits Mandaya - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0.6 pu) leadsto a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0 before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Generator	Maximal frequency	Minimal frequency
Mandaya	50.65 Hz	49.85 Hz
Gibe 3	50.35 Hz	49.75 Hz
Kost	50.45 Hz	49.6 Hz
Fula ST	50.4 Hz	49.9 Hz
High Dam	50.45 Hz	49.55 Hz

Table appendix 3.1-3- Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	509 kV	547 kV	444 kV	507 kV
Kosti	522 kV	590 kV	-	505 kV
Mandaya	525 kV	555 kV	-	512 kV

Table appendix 3.1-4- Voltage Variation on Interconnection System

The flow on the 3 remaining circuits Mandaya - Kosti reached 1235 MW, before stabilizing at 1082 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.1.3.2 With half recovery of the DC power flow

In case of short-circuit at Mandaya on the interconnection, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Mandaya end, on one of the 4 circuits Mandaya - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0.6 pu) leadsto a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to half of its initial value 300 ms after the clearing of the fault. At the same time, half of the capacitors bank of each converter station is disconnected.

Following the reduction of the transmitted power by half of its initial value :

- for the Ethiopia - Sudan system, the frequency raised to 50.5 Hz, before stabilizing around 50.22 Hz, after activation of the primary regulation of the generation governors
- for the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 49.7 Hz, after activation of the primary regulation of the generation governors with spinning reserve, and the self regulation of the load (estimated to 360 MW).

Libya contributed with 50 MW of its primary reserve, and around 60 MW self regulation of the load.

Jordan and Syria contributed with 100 MW of primary reserve, and about 130 MW of self regulation of the load

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	509 kV	547 kV	492 kV	507 kV
Kosti	522 kV	584 kV	-	512 kV
Mandaya	525 kV	565 kV	-	518 kV

Table appendix 3.1-5- Voltage Variation on Interconnection System

The flow on the 3 remaining circuits Mandaya - Kosti reached 11705 MW, before stabilizing at 1022 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study.

A.3.1.4 FAULT ON ONE OF THE 4 MANDAYA 500/400 KV TRANSFORMERS

In case of short-circuit at Mandaya 500 kV on one of the four 500/400 kV transformers at Mandaya, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at the 500 kV side of one of the four 500/400 kV transformers at Mandaya substation, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0.5 pu) leadsto a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Generator	Maximal frequency	Minimal frequency
Mandaya	50.7 Hz	49.85 Hz
Baro/Genji	50.65 Hz	49.8 Hz
Kost	50.55 Hz	49.9 Hz
High Dam	50.45 Hz	49.55 Hz

Table appendix 3.1-6- Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	509 kV	547 kV	444 kV	507 kV
Kosti	522 kV	590 kV	-	505 kV
Mandaya	525 kV	555 kV	-	512 kV

Table appendix 3.1-7- Voltage Variation on Interconnection System

The flow on the 3 remaining transformers reached 625 MW, before stabilizing at 536 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.1.5 FAULT ON THE 220 KV INTERCONNECTION

In case of short-circuit at Gedaref 220 kV, on the 220 kV phase-shift transformer, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Gedaref 220 kV side on the 220 kV phase-shift transformer, cleared in 120 ms by the opening of the circuit breakers.

The DC interconnection is not affected.

Generator	Maximal frequency	Minimal frequency
Mandaya	50.07 Hz	49.95 Hz
Gedaref HPP	50.5 Hz	49.45 Hz

Table appendix 3.1-8- Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
Kosti	522 kV	565 kV	450 kV	517 kV
Mandaya	525 kV	550 kV	485 kV	520 kV

Table appendix 3.1-9- Voltage Variation on Interconnection Nodes

The flow on the remaining 500 kV interconnection, reached 915 MW, before stabilizing at 876 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.2 EGYPTIAN NETWORK

Recall of the flows on the 500 kV backbone along the Nile Valley

From bus	To bus	N° of circuits	P [MW]	Loading %
H.D.500	N.H.500	2	267.0	18.5
N.H.500	AUST500	2	361.8	20.6
N.H.500	SOHAG500	1	446.0	26
SOHAG500	AUST500	1	215.8	13
AUST500	SAML500	2	46.6	4
SAML500	S.GIZA500	1	-88.5	9.2
SAML500	KRIMA500	1	-661.8	38

Table appendix 3.2-1- Power Flows on 500kV Egyptian Backbone

A.3.2.1 SHORT-CIRCUIT OF ONE OF THE 2 CIRCUITS HIGH DAM - NAG HAMMADI, AT HIGH DAM SIDE

In case of short-circuit in High Dam, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at High Dam end, on one of the 2 circuits High Dam - Nag Hammadi, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0.4 pu) leadsto a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	533 kV	524 kV
NH500	509 kV	518 kV	507 kV
Kosti	522 kV	613 kV	522 kV
Mandaya	525 kV	586 kV	525 kV

Table appendix 3.2-2- Voltage Variation on Substations

The transitory over voltage in Kosti reached 23 %, the SVC absorbing at its maximum capacity : 500 MVAr.

The flow on the remaining circuit High Dam - Nag Hammadi reached transiently a maximum value 1523 MW, before recovering to 466 MW (initial value of 265 MW).

High dam reached transitory 50.4 Hz before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 2000 MW export toward Egypt leads to a transitory over-frequency of 250 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 2000 MW of import is smaller than 60 mHz.

The figures are displayed in M1 - 2020 Appendix Stability Study.

A.3.2.2 *SHORT-CIRCUIT ON ONE OF THE 2 CIRCUITS HIGH DAM - NAG HAMMADI, AT NAG HAMMADI SIDE*

In case of short-circuit in Nag Hammadi, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Nag Hammadi end, on one of the 2 circuits High Dam - Nag Hammadi, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0 pu) leads to a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	529 kV	524 kV
NH500	509 kV	530 kV	507 kV
Kosti	522 kV	613 kV	522 kV
Mandaya	525 kV	586 kV	525 kV

Table appendix 3.2-3- Voltage Variation on Substations

The transitory over voltage in Kosti reached 23 %, the SVC absorbing at its maximum capacity : 500 MVAr.

The flow on the remaining circuit High Dam - Nag Hammadi reached transiently a maximum value 1250 MW, before recovering to 473 MW (initial value of 265 MW).

High dam transitory frequency variations reached 250 mHz before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 2000 MW export toward Egypt leads to a transitory over-frequency of 250 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 2000 MW of import is smaller than 60 mHz.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.2.3 *SHORT-CIRCUIT ON THE CIRCUIT NAG HAMMADI - SOHAG, AT NAG HAMMADI SIDE*

In case of short-circuit in Nag Hammadi, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Nag Hammadi end, on Nag Hammadi - Sohag, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0 pu) leads to a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	540 kV	525 kV
NH500	509 kV	547 kV	504 kV
Kosti	522 kV	613 kV	522 kV
Mandaya	525 kV	586 kV	525 kV

Table appendix 3.2-4- Voltage Variation on Substations

The transitory over voltage in Kosti reached 23 %, the SVC absorbing at its maximum capacity : 500 MVAr.

The flow on the remaining circuit Nag Hammadi - Assiut reached transiently a maximum value 1175 MW, before recovering to 630 MW (initial value of 362 MW).

High dam transitory frequency variations reached 400 mHz before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 2000 MW export toward Egypt leads to a transitory over-frequency of 250 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 2000 MW of import is smaller than 60 mHz.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.2.4 TRIPPING OF EGYPT MAIN STEAM UNIT : 765 MVA

In case of tripping of Egypt main steam unit, the behaviour of the system is satisfactory.

Event : the 625 MW steam unit of Abu Kir is tripped (initial output : 614 MW).

The DC power flow is not affected. The Ethiopia-Sudan system remained unchanged.

The Egyptian frequency dropped to 49.85 Hz, before recovering to 49.9 Hz. The self regulation of the load is estimated to 120 MW in Egypt.

Libya contributed with 20 MW of its primary reserve, and around 20 MW self regulation of the load

Jordan and Syria contributed with 80 MW of its primary reserve, and about 40 MW of self regulation of the load

The voltage is not significantly affected.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.3 ETHIOPIAN NETWORK

Recall of the flow on the Ethiopian 400 kV system between Addis Ababa and Mandaya

From bus	To bus	N° of circuit	P [MW]	Loading %
1MANDAS71	1GHIMBIS71	3	-549.5	76.2
1GHIMBIS71	1GHEDOS71	2	-418.1	59.9
1GHIMBIS71	1METUS71	3	-277.1	37.8
1GHEDOS71	1SEBETS71	2	-418.9	59.1

Table appendix 3.2-5- Power Flows on the Ethiopian 400 kV between Addis Ababa and Mandaya

A.3.3.1 SHORT-CIRCUIT AT MANDAYA, ON ONE OF THE THREE 400 KV CIRCUITS GHIMBI - MANDAYA

In case of short-circuit at Mandaya side on one of the 3 Ghimbi - Mandaya, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Mandaya end, on one of the 3 circuits Mandaya - Ghimbi, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Kosti (to 0.6 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the return of the voltage.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

The behaviour of the interconnected system is satisfactory, following a short circuit at Mandaya side on one of the 3 circuits Mandaya - Ghimbi.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	529 kV	524 kV
NH500	509 kV	530 kV	507 kV
Kosti	522 kV	610 kV	522 kV
Mandaya 500	525 kV	555 kV	525 kV
Mandaya 400	417 kV	446 kV	417 kV

Table appendix 3.2-6- Voltage Variation on Substations

The transitory over voltage in Kosti reached 22 %, the SVC absorbing at its maximum capacity : 500 MVAr.

The flow on the remaining circuits Mandaya - Ghimbi reached transiently a maximum value 910 MW, before recovering to 813 MW (initial value of 549 MW).

Generator	Maximal frequency	Minimal frequency
Genji / Baro	50.7 Hz	49.8 Hz
Kost	50.45 Hz	49.9 Hz
Mandaya	50.4 Hz	49.8 Hz
Gibe 3	50.25 Hz	49.9 Hz

Table appendix 3.2-7- Frequency Variation of generators

On the Ethiopia - Sudan side, the transitory blocking of the 2000 MW export toward Egypt leads to a transitory over-frequency of 250 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 2000 MW of import is smaller than 60 mHz.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.3.2 TRIPPING OF ETHIOPIA MAIN 2 UNITS : MANDAYA HPP UNITS

In case of tripping of 2 units of Mandaya, the behaviour of the system is satisfactory.

Event : 2 units of Mandaya (the main unit in Ethiopia) is tripped (initial output : 2 x 212.5 MW = 425 MW).

The DC power flow is not affected. The Egyptian system remained unchanged.

The Ethiopia-Sudan frequency dropped to 49.85 Hz, before recovering to 49.92 Hz.

The flow on the 500 kV interconnection decreased from 828 MW to at 757 MW

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.4 SUDANESE NETWORK

Recall of the flow on the Sudanese 500 kV system around Kosti.

From bus	To bus	N° of circuit	P [MW]	Loading %
2RABAK81*	1MANDAY81	4	-787.4	44
2RABAK81*	2FULA81	2	-100.4	17.8
2RABAK81*	2J.AULIAS81	1	303.5	19.3
2RABAK81*	2MERIN81	1	696.8	36.3
2BAGERS81	2H.HEI81	2	214.0	11.4
2BAGERS81	2J.AULIAS81	1	-78.4	5.3
2GEDARE81	2MERIN81	1	114.1	6.5
2H.HEI81	2MERIN81	1	-297.4	21.7

* Rabak substation was replaced by Kosti

Table appendix 3.3-1- Power Flows on the Sudanese 500 kV System

A.3.4.1 SHORT-CIRCUIT ON ONE OF THE TWO 500 KV CIRCUITS KOSTI - FULA, AT KOSTI SIDE

In case of short-circuit on Kosti - Fula, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on one of the 2 circuits Kosti - Fula, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

In case of short-circuit on one of the 2 circuits Kosti - Fula, on Kosti side, the behaviour of the system is satisfactory.

Generator	Maximal frequency	Minimal frequency
Mandaya	50.85 Hz	49.85 Hz
Gibe 3	50.6 Hz	49.75 Hz
Kost	50.6 Hz	49.85 Hz
Fula ST	50.3 Hz	49.75 Hz

Table appendix 3.3-2- Frequency Variation of Generators

The flow on the remaining circuit Kosti - Fula reached a maximum of -422 MW, before stabilizing at -185 MW initial value of -100 MW).

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	509 kV	547 kV	444 kV	507 kV
Kosti	522 kV	586 kV	-	510 kV
Mandaya	525 kV	565 kV	-	523 kV

Table appendix 3.3-3- Voltage Variation on Nodes

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.4.2 SHORT-CIRCUIT ON THE 500 KV CIRCUIT KOSTI - JEBEL AULIA, AT KOSTI SIDE

In case of short-circuit on Kosti - Jebel Aulia, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on the circuits Kosti - Jebel Aulia, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

The initial flow on Kosti - J.Aulia reached 304 MW (loading of 19°%)

The flow on Kosti - Meringan increased transitory to 2390 MW, before stabilizing at 914 MW.

Generator	Maximal frequency	Minimal frequency
Mandaya	50.85 Hz	49.85 Hz
Gibe 3	50.6 Hz	49.75 Hz
Kost	50.6 Hz	49.6 Hz
Fula ST	50.3 Hz	49.7 Hz

Table appendix 3.3-4- Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	509 kV	547 kV	444 kV	507 kV
Kosti	522 kV	631 kV	-	521 kV
Mandaya	525 kV	590 kV	-	525 kV

Table appendix 3.3-5- Voltage Variation on Nodes

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.4.3 SHORT-CIRCUIT ON THE 500 KV CIRCUIT KOSTI - MERINGAN, AT KOSTI SIDE

In case of short-circuit on Kosti - Meringan, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on the circuits Kosti - Meringan, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

The initial flow on Kosti - Meringan reached 701 MW (loading of 36 %).

The flow on Kosti - Jebel Aulia increased transitory to 1654 MW, before stabilizing at 692 MW (initial value : 303 MW).

Generator	Maximal frequency	Minimal frequency
Mandaya	50.85 Hz	49.83 Hz

Gibe 3	50.5 Hz	49.77 Hz
Kost	50.66 Hz	49.7 Hz
Fula ST	50.65 Hz	49.65 Hz

Table appendix 3.3-6- Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	509 kV	547 kV	444 kV	507 kV
Kosti 500 kV	522 kV	657 kV	-	521 kV
Kosti 220 kV	227 kV	251 kV	-	226 kV
Mandaya	525 kV	605 kV	-	525 kV

Table appendix 3.3-7- Voltage Variation on Nodes

The transitory over voltage in Kosti reached 31 % in 500 kV, and 14 % in 220 kV, the SVC absorbing at its maximum capacity : 500 MVAr.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.3.4.4 TRIPPING OF SUDAN MAIN UNIT : PORT SUDAN 670 MVA STEAM TURBINE

In case of tripping of Sudan main unit, the behaviour of the system is satisfactory.

Event : the 670 MVA steam unit of Port-Sudan (the main unit in Sudan) is tripped (initial output : 530 MW).

The DC power flow is not affected. The Egyptian system remained unchanged.

The Ethiopia-Sudan frequency dropped to 49.7 Hz, before recovering to 49.9 Hz.

The flow on the 500 kV interconnection increased from 828 MW to 868 MW

The figures are displayed in M1 - 2020 Appendix Stability Study

APPENDIX 4. SHORT-CIRCUIT POWER – 2020

Three-phase to ground and one-phase to ground short-circuit calculations were performed taking into account the following assumptions:

V = 1.1 Vn

Impedance of generator = X"d (sub transient reactance)

The short-circuit power of the Egyptian system is compliant with the 40 kA limitation on the 220 and 500 kV system.

A.4.1 SHORT-CIRCUIT POWER IN THE 500 KV SUBSTATION OF THE NILE VALLEY IN EGYPT

Busbar	KV. (Mult. = 1.10)	LLL		LG	
		I [A]	S [MVA]	I [A]	S [MVA]
H.D.500	550	12 432	11 843	13 134	12 511
N.H.500	550	10 627	10 123	9 705	9 245
SOHAG500	550	8 544	8 139	6 570	6 258
AUST500	550	12 088	11 515	10 870	10 355
SAML500	550	14 796	14 094	12 739	12 135
KRIMA500	550	29 674	28 268	29 289	27 901
H.D.220	242	20 688	8 671	21 405	8 972
N.H.220	242	18 703	7 839	17 245	7 228
SOHAG220	242	10 623	4 452	8 941	3 747
AUST220	242	20 499	8 592	19 527	8 184
SAML220	242	17 428	7 305	15 836	6 637
KURIM220	242	31 931	13 384	31 757	13 311
H.D.132I	145.2	22 452	5 646	2 2543	5 669
H.D.132II	145.2	22 452	5 646	2 2543	5 669
N.H2_132	145.2	25 247	6 349	23 843	5 996
ASU132	145.2	18 275	4 596	17 646	4 437
SAML132	145.2	20 816	5 235	19 563	4 919

Table appendix 4-1 - Short Circuit Power in the Egyptian substations

The short-circuit power of the other 132 and 220 kV substations in the Nile Valley is smaller than the one in these 500/220/132 kV substations, since there is no generation connected to these substations.

A.4.2 Short-circuit power in Ethiopia along the network between Mandaya and Addis Ababa

Busbar	KV. (Mult. = 1.10)	LLL		LG	
		I [A]	S [MVA]	I [A]	S [MVA]
1MANDAS81	550	14 440	13 755	17 130	16 318
1MANDAS71	440	14 977	11 414	16 454	12 539
1GHIMBIS71	440	12 876	9 812	11 587	8 830
1METUS71	440	10 103	7699	9 770	7 445
1BARO1S71	440	9 445	7 197	10 340	7 879
1BARO2S71	440	8 194	6 244	9 194	7 006
1GENJIS71	440	7 982	6 082	8 334	6 351
1GHEDOS71	440	9 476	7 221	6 933	5 283
1SEBETS71	440	11 831	9 016	9 356	7 130
1GHEDOS61	253	10 194	4 467	8 835	3 871
1METUS61	253	793	347	915	400
1SEBET1S61	253	17 110	7 497	13 679	5 994
1SEBET2S61	253	14 865	6 514	12 171	5 333
1SULULS61	253	13 374	5 860	10 125	4 436
1GONDES61	253	5 326	2 333	2 966	1 299
1SHEHE61	253	4 933	2 067	1 941	813
1GHEDOS51	145.2	1 872	470	1 843	463
1SEBETS51	145.2	11 899	2 992	10 823	2 721

Table appendix 4-2 - Short Circuit Power in the Ethiopian substations

A.4.3 SHORT-CIRCUIT POWER IN SUDAN IN THE SOUTH PART, AROUND KOSTI SUBSTATION

Busbar	KV (Mult. = 1.10)	LLL		LG	
		I [A]	S [MVA]	I [A]	S [MVA]
2FULA81	550	8 416	8 016	9 843	9 376
2GEDARE81	550	5 505	5 244	4 422	4 212
2H.HEI81	550	11 110	10 583	8 178	7 790
2J.AULIAS81	550	11 610	11 059	9 146	8 712
2MERIN81	550	10 746	10 236	7 722	7 356
2RABAK81*	550	13 240	12 612	10 581	10 080
2FULAS61	242	14 941	6 262	17 880	7 494
2GEDARS61	242	6 956	2 915	1 364	571
2GEDARS62	242	8 297	3 477	9 145	3 833
2H.HEIS61	242	18 917	7 929	14 371	6 023
2J.AULS61	242	20 069	8 412	16 105	6 750
2MERINS61	242	17 398	7 292	13 130	5 503
2RABAKS61*	242	18 333	7 684	19 213	8 053
2RANKS61	242	9 437	3 955	6 256	2 622
2ROSEIS61	242	8 560	3 588	9 809	4 111
2SENNAS61	242	8 576	3 594	6 104	2 558

*Rabak substation was replaced by Kosti

Table appendix 4-3 - Short Circuit Power in the Sudanese substations

APPENDIX 5. LOAD FLOW RESULTS - INTERMEDIATE LOAD 2020

A.5.1 INITIAL SYSTEM - NORMAL SITUATION

A.5.1.1 EGYPTIAN NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
A.Z.500	BASII500	-77.3	-99.1	125.7	139.7	0.0	-30.7	2020.7	5.7
A.Z.500	N.DELTA500*	-462.6	-108.6	475.2	528.3	1.7	-73.6	2000	26.4
A.Z.500	TEB.500	194.4	-134.8	236.6	263	0.3	-94.4	2049.6	12.8
A.Z.500	SUEZ500	-720.8	-38.6	721.8	802.5	4.7	-55.2	2049.6	39.2
A.Z.500	SUEZ500	-720.8	-38.6	721.8	802.5	4.7	-55.2	2049.6	39.2
A.Z.500	HELIO500	641.7	-246.6	687.5	764.4	1.9	-29.1	2000	38.2
ABKIR500	N.DELTA500*	-38.6	-109.9	116.5	128.1	0.0	-216.9	2020	6.3
ABKIR500	KAFR.Z500	204.6	-71.6	216.8	238.4	0.3	-93.4	2020	11.8
ABKIR500	KAFR.Z500	204.6	-71.6	216.8	238.4	0.3	-93.4	2020	11.8
AMOUS500	SUEZ500	398.7	61.0	403.3	443.8	0.3	-18.2	2049.6	21.7
AMOUS500	TABA500	-36.5	-39.9	54.1	59.5	0.2	-246.6	2049.6	2.9
AMOUS500	SUEZ500	398.7	61.0	403.3	443.8	0.3	-18.2	2049.6	21.7
AUST500	N.H.500	-744.0	-7.8	744.0	829.4	9.2	-87.2	1963	42.3
AUST500	SAML500	538.6	-109.0	549.6	612.6	3.3	-102.8	1963	30.3
AUST500	SAML500	538.6	-109.0	549.6	612.6	3.3	-102.8	1963	30.3
AUST500	SOHAG500	-625.7	20.9	626.0	697.8	3.5	-66.8	1960	35.6
BASII500	KAFR.Z500	-192.3	-111.2	222.1	246.2	0.3	-93.9	2020	12.2
BASII500	KAFR.Z500	-192.3	-111.2	222.1	246.2	0.3	-93.9	2020	12.2
BASII500	C.W.500	-541.0	-6.9	541.1	599.8	0.2	-6.5	2020.7	29.7
C.W.500	CAIRO500	-290.0	273.9	398.9	442	0.2	-13.7	2020.7	22.5
CAIRO500	NOBAR500	-872.7	22.0	873.0	971.9	5.8	-9.4	2020.7	48.1
CAIRO500	NOBAR500	-872.7	22.0	873.0	971.9	5.8	-9.4	2020.7	48.1
CAIRO500	S.GIZA500	236.2	-25.6	237.6	264.5	0.6	-128.0	1700	15.6
CAIRO500	C.W.500	290.2	-287.6	408.6	454.8	0.2	-13.7	2020.7	22.5
CAIRO500	KRIMA500	-264.4	-127.2	293.4	326.6	0.8	-128.5	1963	16.6
DABAA500	SALOUM500	335.0	-112.0	353.2	390.4	2.7	-268.4	2000	19.5
DABAA500	SKRIR500	630.9	-39.3	632.1	698.6	3.6	-58.6	2000	34.9
DABAA500	SKRIR500	630.9	-39.3	632.1	698.6	3.6	-58.6	2000	34.9
H.D.500	N.H.500	479.3	83.8	486.6	535.4	0.0	0.0	2049.6	26.1
H.D.500	N.H.500	479.3	83.8	486.6	535.4	0.0	0.0	2049.6	26.1
HELIO500	TEB.500	-281.4	41.3	284.4	312.9	0.3	-51.0	1750	17.9
KRIMA500	SAML500	-46.2	-20.7	50.6	55.7	0.1	-166.9	1963	8.7
KRIMA500	TEB.500	1049.7	-27.5	1050.1	1155.3	5.1	9.1	2020.7	57.1
N.H.500	NH500_ACDC**	-1850.0	-83.1	1851.8	2055.3	-	-	-	-
N.H.500	SOHAG500	751.7	-34.5	752.5	835.1	5.0	-47.6	1960	42.6
From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
N.OCT500	S.GIZA500	-145.6	-2.5	145.6	162.2	0.3	-132.6	1700	9.5
NOBAR500	SKRIR500	-711.4	22.5	711.8	789.5	5.1	-61.0	2020.7	39.1

NOBAR500	SKRIR500	-711.4	22.5	711.8	789.5	5.1	-61.0	2020.7	39.1
S.GIZA500	SAML500	-426.0	-90.8	435.6	488.9	2.5	-142.2	1700	28.8
S.GIZA500	N.OCT500	145.9	-130.1	195.5	219.4	0.3	-132.6	1700	9.5
SALOUM500	TOBROK500	101.2	-28.2	105.0	117.0	0.2	-162.6	2020	5.8
TABSW400	S_TAB400***	200.6	-50.7	206.9	299.5	0.1	-9.5	2562	11.7
S_TAB400	S_AQA400	200.5	-41.2	204.7	296.0	0.3	-79.6	2562	11.4
S_AQA400	AKABA400	100.0	19.2	101.9	147.8	0.0	-5.1	2562	5.7
S_AQA400	AKABA400	100.0	19.2	101.9	147.8	0.0	-5.1	2562	5.7

*N.Delta 500 has been replaced by W.Domatia 500 kV, in the latest 2015 Egyptian data
** N.H500_ACDC : DC/AC converter station in Nag Hammadi
*** Egypt exported 200 MW to Jordan

Table appendix 5.1-1 - Power flow on the Egyptian 400 and 500 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
SALOUM500	TOBROK500	101.2	-28.2	105.0	117.0	0.2	-162.6	2020	5.8
SALOUM220	TOBROK220	50.0	-21.0	54.3	139.4	0.4	-29.3	1207.2	11.6
SALOUM220	TOBROK220	50.0	-21.0	54.3	139.4	0.4	-29.3	1207.2	11.6

The power flow exported from Egypt to Libya reached 200 MW

Table appendix 5.1-2 - Power flow exported from Egypt to Libya

Substation.	V sol [pu]	V sol [kV]
A.Z.500	1.039	519.5
ABKIR500	1.05	525
AMOUS500	1.049	524.5
AUST500	1.036	518
BASII500	1.042	521
C.W.500	1.042	521
CAIRO500	1.037	518.5
D1H.D.5	1.049	524.5
D2H.D.5	1.049	524.5
DABAA500	1.045	522.5
H.D.500	1.049	524.5
HELIO500	1.049	524.5
KAFR.Z500	1.05	525
KRIMA500	1.05	525
N.DELTA500*	1.05	525
N.H.500	1.04	520
N.OCT500	1.037	518.5
NOBAR500	1.041	520.5
Substation.	**V sol [pu]**	**V sol [kV]**
S.GIZA500	1.029	514.5
SALOUM500	1.027	513.5
SAML500	1.039	519.5

SKRIR500	1.04	520
SOHAG500	1.035	517.5
SUEZ500	1.047	523.5
TABA500	1.024	512
TEB.500	1.047	523.5
TOBROK500	1.02	510

*N.Delta 500 has been replaced by W.Domatia 500 kV, in the latest 2015 Egyptian data

Table appendix 5.1-3 - Voltage of the Egyptian 500 kV substation

A.5.1.2 ETHIOPIAN NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
1MANDAS81	2RABAK81*	777.9	-51.9	807.8	889.4	35.8	-292.1	2128	41.7
1MANDAS81	2RABAK81*	777.9	-51.9	807.8	889.4	35.8	-292.1	2128	41.7
1MANDAS81	2RABAK81*	777.9	-51.9	807.8	889.4	35.8	-292.1	2128	41.7
1MANDAS81	2RABAK81*	777.9	-51.9	807.8	889.4	35.8	-292.1	2128	41.7

* Rabak substation was replaced by Kosti

Table appendix 5.1-4 - Power flow on the Ethiopian 500 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1B.DAR3S71	1BELESS71	-218.6	-35.7	221.5	306	0.7	-35.1	1010	30.3
1B.DAR3S71	1BELESS71	-218.6	-35.7	221.5	306	0.7	-35.1	1010	30.3
1B.DAR3S71	1D.MARS71	202.0	59.8	210.6	291	2.6	-98.5	1010	28.8
1BARO1S71	1METUS71	325.8	-46.6	329.1	454.2	0.8	-25.0	1515	30
1BARO1S71	1METUS71	325.8	-46.6	329.1	454.2	0.8	-25.0	1515	30
1BARO1S71	1BARO2S71	-231.2	8.1	231.3	319.3	0.6	-26.4	1010	31.6
1BARO1S71	1BARO2S71	-231.2	8.1	231.3	319.3	0.6	-26.4	1010	31.6
1BARO1S71	1GENJIS71	-99.7	6.5	99.9	137.8	0.1	-12.1	1010	13.6
1D.MARS71	1SULULS71	252.0	39.9	255.2	371.3	4.5	-88.2	1010	36.8
1GGOS71	1GG2S71	98.6	-69.7	120.7	166.8	0.1	-24.6	1010	16.5
1GG2S71	1GIBE3S71	-18.8	-84.1	86.2	118.8	0.0	-187.4	2020	5.9
1GG2S71	1SEBETS71	506.2	-56.8	509.3	701.5	12.6	-35.1	1010	68.1
1GHEDOS71	1GHIMBIS71	407.2	-87.7	416.6	576	7.8	-65.0	1010	57
1GHEDOS71	1GHIMBIS71	407.2	-87.7	416.6	576	7.8	-65.0	1010	57
1GHEDOS71	1SEBETS71	-408.1	60.5	412.5	570.4	5.5	-40.2	1010	56.5
1GHEDOS71	1SEBETS71	-408.1	60.5	412.5	570.4	5.5	-40.2	1010	56.5
1GHIMBIS71	1METUS71	-321.9	10.5	322.0	445	3.0	-52.1	1010	44.1
From bus	**To bus**	**P [MW]**	**Q [MVAR]**	**S [MVA]**	**I [A]**	**Losses P [MW]**	**Losses Q [MVAR]**	**Ampacity (Norm.) [A]**	**Loading %**
1GHIMBIS71	1METUS71	-321.9	10.5	322.0	445	3.0	-52.1	1010	44.1
1GHIMBIS71	1MANDAS71	480.2	-76.7	486.3	672	6.5	-25.1	1010	66.5
1GHIMBIS71	1MANDAS71	480.2	-76.7	486.3	672	6.5	-25.1	1010	66.5
1GHIMBIS71	1MANDAS71	480.2	-76.7	486.3	672	6.5	-25.1	1010	66.5

1GIBE3S71	1W.SODS71	324.7	-70.9	332.4	458.2	2.0	-34.8	1010	45.4
1GIBE3S71	1W.SODS71	324.7	-70.9	332.4	458.2	2.0	-34.8	1010	45.4
1KALITS71	1W.SODS71	-257.3	-65.6	265.5	371.6	4.3	-133.6	1010	36.8
1KALITS71	1W.SODS71	-257.3	-65.6	265.5	371.6	4.3	-133.6	1010	36.8
1KALITS71	1SEBETS71	265.0	-124.3	292.7	409.7	0.8	-18.3	1010	40.6

Table appendix 5.1-5 - Power flow on the Ethiopian 400 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1GONDES61	1SHEHES61	104.6	-36.4	110.8	273	2.7	-17.7	690	39.5
1GONDES61	1SHEHES61	104.6	-36.4	110.8	273	2.7	-17.7	690	39.5

Table appendix 5.1-6 - Power flow on the Ethiopian - Sudan 220 kV interconnection

Mandaya generated 112 MVAr.

From bus	To bus	Sn nominal [MVA]	P [MW]	Q [MVAR]	S [MVA]	I [A]	Loading [%]
1MANDAS71	1MANDAS81	510	357.3	-38.7	357.3	493.7	71
1MANDAS71	1MANDAS81	510	357.3	-38.7	357.3	493.7	71
1MANDAS71	1MANDAS81	510	357.3	-38.7	357.3	493.7	71
1MANDAS71	1MANDAS81	510	357.3	-38.7	357.3	493.7	71

Table appendix 5.1-7 - Power flow on the Ethiopian 400/500 kV transformers

Substation.	V sol [pu]	V sol [kV]
1MANDAS81	1.05	525
1B.DAR3S71	1.045	418
1BARO1S71	1.046	418.4
1BARO2S71	1.047	418.8
1BELESS71	**1.05**	420
1D.MARS71	0.992	396.8
1GENJIS71	1.046	418.4
1GG2S71	1.048	419.2
1GGOS71	1.045	418
1GHEDOS71	1.044	417.6
1GHIMBIS71	1.044	417.6
1GIBE3S71	1.047	418.8
1KALITS71	1.031	412.4
1MANDAS71	1.045	418
Substation.	**V sol [pu]**	**V sol [kV]**
1METUS71	1.046	418.4
1SEBETS71	1.037	414.8
1SULULS71	0.936	374.4
1W.SODS71	1.049	419.6

Table appendix 5.1-8 - Voltage of the 400 and 500 kV Ethiopian substations

A.5.1.3 SUDANESE NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
2ATBARS81	2MEROWS81	-248.7	-151.5	291.1	324.6	1.6	-252.6	2128	14
2ATBARS81	2KABASS81	171.4	-157.3	232.7	259.4	0.9	-311.5	2128	12.2
2ATBARS81	2KABASS81	171.4	-157.3	232.7	259.4	0.9	-311.5	2128	12.1
2ATBARS81	2P.SUD81	-131.1	-259.1	290.4	323.7	0.8	-494.6	2128	14
2ATBARS81	2P.SUD81	-131.1	-259.1	290.4	323.7	0.8	-494.6	2128	14
2BAGERS81	2KABASS81	-30.8	-28.2	41.8	46.8	0.0	-87.3	2128	2.2
2BAGERS81	2KABASS81	-30.8	-28.2	41.8	46.8	0.0	-87.3	2128	2.2
2BAGERS81	2H.HEI81	-35.6	-66.2	75.2	84.2	0.0	-109.4	2128	4
2BAGERS81	2J.AULIAS81	-154.5	6.2	154.6	173	0.1	-42.7	2128	8.1
2BAGERS81	2H.HEI81	-35.6	-66.2	75.2	84.2	0.0	-109.4	2128	4
2BORS81	2JUBAS81	-287.1	-36.1	289.4	323.3	1.4	-161.1	2128	15.2
2BORS81	2MALAKAS81	239.9	-200.8	312.8	349.5	2.2	-372.2	2128	16.4
2FULA81	2RABAK81*	170.4	-341.3	381.5	423.9	1.8	-630.4	2128	19.9
2FULA81	2RABAK81*	170.4	-341.3	381.5	423.9	1.8	-630.4	2128	19.9
2FULA81	2NYALA81	210.6	-174.6	273.6	304	1.9	-414.1	2128	17
2FULA81	2NYALA81	210.6	-174.6	273.6	304	1.9	-414.1	2128	14.3
2GEDARE81	2MERIN81	53.5	-30.4	61.6	66.7	0.3	-252.6	2128	3.1
2GEDARE81	2P.SUD81	-95.6	-385.1	396.8	430	0.7	-820.1	2128	20.2
2H.HEI81	2MERIN81	-520.0	-97.8	529.1	591.2	1.6	-46.8	2128	27.8
2J.AULIAS81	2MARKHS81	22.0	-27.1	34.9	39	0.0	-80.7	2128	1.8
2J.AULIAS81	2RABAK81*	-439.1	-146.2	462.8	518.2	6.9	-304.7	2128	24.4
2JUBAS81	2RUMBEKS81	172.9	-229.4	287.3	321.8	1.1	-364.2	2128	15.1
2KABASS81	2MARKHS81	-54.8	1.7	54.8	61.4	0.0	-41.3	2128	3.7
2MARKHS81	2MEROWS81	-295.2	-200.8	357.0	400.3	3.3	-370.2	2128	17.8
2MARKHS81	2MEROWS81	-295.2	-200.8	357.0	400.3	3.3	-370.2	2128	17.8
2MERIN81	2RABAK81*	-763.9	8.1	763.9	847.3	9.8	-82.4	2128	40.4
2MEROWS81	2ATBARS81	250.2	-101.2	269.9	297.1	1.6	-252.6	2128	14
2MEROWS81	2MARKHS81	298.6	-169.4	343.3	377.8	3.3	-370.2	2128	17.8
2MEROWS81	2MARKHS81	298.6	-169.4	343.3	377.8	3.3	-370.2	2128	17.8
2RABAK81*	2RABAK_5ACDC**	1970.0	32.5	1970.3	2175.1	-	-	-	-
2RABAK81*	1MANDAS81	-743.1	-73.2	746.7	824.3	35.8	-290.4	2128	41.8
2RABAK81*	1MANDAS81	-743.1	-73.2	746.7	824.3	35.8	-290.4	2128	41.8
2RABAK81*	1MANDAS81	-743.1	-73.2	746.7	824.3	35.8	-290.4	2128	41.8
2RABAK81*	1MANDAS81	-743.1	-73.2	746.7	824.3	35.8	-290.4	2128	41.8
2RUMBEKS81	2WAUS81	108.4	-200.7	228.1	252.7	0.4	-396.3	2128	11.9

* Rabak substation was replaced by Kosti
* RABAK_5ACDC : AC/DC converter station in Kosti

Table appendix 5.1-9 - Power flows on the Sudanese 500 kV lines

From bus	To bus	P [MW]	Q [MVAr]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAr]	Ampacity (Norm.) [A]	Loading [%]
2GEDARS61	1SHEHE61	-97.9	2.6	98.0	248.8	2.4	-27.8	972	25.6
2GEDARS61	1SHEHE61	-97.9	2.6	98.0	248.8	2.4	-27.8	972	25.6

Table appendix 5.1-10 - Power flows on the 220 kV interconnection Ethiopia - Sudan

Power imported from Ethiopia

Power flow arriving from Ethiopia to Sudan :

- 500 kV interconnection : 4 x 743 MW = 2 972 MW

- 220 kV interconnection : 2 x 98 MW = 196 MW

Total : 3168 MW

Among these 3 168 MW, 1 970 MW are absorbed by the AC/DC converter station in Kosti (hypothesis : losses on the DC lines and converter stations = 120 MW). 1 200 MW are for the Sudanese system.

To limit the flow and avoid an overload on the 220 kV interconnection, a phase-shift transformer has been installed at Gedaref substation.

Substation	V sol [pu]	V sol [kV]
2ATBARS81	1.036	518
2BAGERS81	1.032	516
2BORS81	1.034	517
2FULA81	1.039	519.5
2GEDARE81	1.066	533
2H.HEI81	1.033	516.5
2J.AULIAS81	1.031	515.5
2JUBAS81	1.031	515.5
2KABASS81	1.031	515.5
2MALAKAS81	1.03	515
2MARKHS81	1.03	515
2MERIN81	1.041	520.5
2MEROWS81	1.049	524.5
2NYALA81	1.014	507
2P.SUD81	1.049	524.5
2RABAK81*	1.046	523
2RUMBEKS81	1.042	521
2WAUS81	1.039	519.5

* Rabak substation was replaced by Kosti

Table appendix 5.1-11 - Voltage of the 500 kV Sudanese substations

A.5.2 INITIAL SYSTEM – N-1 SITUATION

A.5.2.1 EGYPTIAN NETWORK

Recall of the flows on the 500 kV backbone along the Nile Valley

From bus	To bus	N° of circuits	P [MW]	Loading %
H.D.500	N.H.500	2	479.3	24.8
N.H.500	AUST500	1	753.2	42.3
N.H.500	SOHAG500	1	751.7	42.6
SOHAG500	AUST500	1	629.2	35.6
AUST500	SAML500	2	538.6	30.3
SAML500	S.GIZA500	1	428.5	28.8
SAML500	KRIMA500	1	46.2	8.7

Table appendix 5.2 -1 - Short Circuit Power in the Egyptian substations

To have the most constraining situation (maximum power flow from the south to Cairo), High Dam and Aswan dams were generating at their maximum output.

A.5.2.1.1 Tripping of one of the 2 circuits High Dam - Nag Hammadi

The initial flow on each of the 2 circuits High Dam - Nag Hammadi reached 479 MW (25 % of loading). High Dam HPP generated initially 302 MVAr.

The situation after the tripping of the line is satisfactory. The flow on the remaining circuit reached 862 MW (49 % of loading - report of 80 % of the initial flow). High Dam HPP generated 436 MVAr, to keep the voltage at its set point (1.05 pu).

In High Dam substation, the flow on the 500/220 kV transformation increased by 62 MW, and the flow on the 500/132 kV transformation increased by 34 MW.

The voltage in Nag Hammadi dropped from 1.04 pu to 1.0 pu.

A.5.2.1.2 Tripping of the circuit Nag Hammadi - Sohag

The initial flow on the circuit Nag Hammadi - Sohag reached 752 MW (43 % of loading).

The flow on the circuit Nag Hammadi - Assiut increased from 753 MW to 1182 MW (respectively 42 % and 68 %of loading - load report of 57 %).

The flow on the circuit Sohag - Assiut reversed from 629 MW (43 % of loading) to -105 MW.

In Nag Hammadi substation, the flow on the 500/220 kV transformation increased by 256 MW (from 49 to 67 % of loading), and the flow on the 500/132 kV transformation increased by 50 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)	Final voltage (pu) with disconnection of the 165 MVAr reactor in N.H
Nag Hammadi	1.04	1.012	1.04
Sohag	1.035	0.999	1.005
Assiut	1.036	1.008	1.019

Table appendix 5.2 -2 - Voltage Variation on Egyptian substations

The situation after the tripping of the line is satisfactory.

A.5.2.1.3 Tripping of the circuit Nag Hammadi - Assiut

The initial flow on the circuit Nag Hammadi - Assiut reached 753 MW (42 % of loading).

The flow on the circuit Nag Hammadi - Sohag increased from 752 MW to 1261 MW (43 % to 74 %of loading - load report of 61 %).

In Nag Hammadi substation, the flow on the 500/220 kV transformation increased by 168 MW (from 49 to 67 % of loading), and the flow on the 500/132 kV transformation increased by 56 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)	Final voltage (pu) with disconnection of the 165 MVAr reactor in N.H
Nag Hammadi	1.04	1.003	1.029
Sohag	1.035	0.989	1.01
Assiut	1.036	1.002	1.016

Table appendix 5.2 -3 - Voltage Variation on Substations

The situation after the tripping of the line is satisfactory.

A.5.2.1.4 Tripping of one the 2 circuits Assiut - Samalut

The initial flow on each of the circuit Assiut - Samalut 537 MW (30 % of loading).

The flow on the remaining circuit Assiut - Samalut increased from 537 MW to 939 MW (30 % to 54 %of loading - load report of 75 %).

In Assiut substation, the flow on the 500/220 kV transformation increased by 92 MW, and the flow on the 220/132 kV transformation increased by 17 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
Assiut	1.036	1.017
Samalut	1.039	1.026

Table appendix 5.2 -4 - Voltage Variation on Substations

The situation after the tripping of the line is satisfactory.

A.5.2.1.5 Tripping of the circuit Samalut - South Giza

The initial flow on the circuit Samalut - South Giza reached 429 MW (29 % of loading).

The flow on the circuit Samalut - Kureimat increased from 46 MW to 357 MW (9 % to 22 %of loading).

The flow on the circuit Cairo - South Giza increased from 241 MW to 428 MW (16 % to 28 %of loading).

The flow on the circuit Krima - Cairo increased from 255 MW to 415 MW (16 % to 25 %of loading).

In Samalut substation, the flow on the 500/220 kV transformation increased by 52 MW, and the flow on the 500/132 kV transformation increased by 24 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
South Giza	1.029	1.016
Samalut	1.039	1.037

Table appendix 5.2 -5 - Voltage Variation on Substations

The situation after the tripping of the line is satisfactory.

A.5.2.1.6 Conclusion

Whatever the tripped line in the 500 kV system in the Upper Nile Valley, the behaviour of the system is satisfactory. The flow remained far below the thermal limit, and the voltage remained within the limits (+5/-10 %).

A.5.2.2 ETHIOPIAN NETWORK

Recall of the flow on the Ethiopian 400 kV system between Addis Ababa and Mandaya.

From bus	To bus	N° of circuit	P [MW]	Loading %
1MANDAS71	1GHIMBIS71	3	-480.2	67
1GHIMBIS71	1GHEDOS71	2	-399.4	57
1GHIMBIS71	1METUS71	2	-322	44.1
1GHEDOS71	1SEBETS71	2	-408.1	57

Table appendix 5.2 -6 - Power Flows on the 400 kV system between Addis Ababa and Mandaya

A.5.2.2.1 Tripping of the 400 kV circuit Debre Markos - Sululta

The initial flow on Debre Markos - Sululta reached 252 MW (loading of 37°%)

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system. The two 230 kV circuits Ghedo to Gefersa reached 2 x 174 to 2 x 222 MW (66 % to 82 % of loading).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 210 to 274 MW (280 MVA - loading of 51 % of Gonder - Shehedi) on the Ethiopian side. The phase shift transformer (256 MW - 265 MVA) is overloaded by 6 %.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1B.DAR3S71	1.045	1.050
1D.MARS71	0.99	1.042
1SULULS61	1.031	1.011
1SEBETS71	1.037	1.018
1GHEDOS71	1.042	1.019

Table appendix 5.2 -7 - Voltage Variation on Substations

A.5.2.2.2 Tripping of one of the two 400 kV circuits Sebeta - Ghedo

The initial flow on each circuit Sebeta - Ghedo reached 414 MW (loading of 57°%)

Following the tripping of the line, the remaining circuit was overloaded by 13 % (which is acceptable in N-1 situation), its flow reaching 805 MW (loading of 113 % - load report of 94 %).

Note : (same comment for Ghedo - Sebeta circuit) to meet the intermediate load and export program, the Ethiopian unit commitment has been modified by switching off one of the 2 groups of Baro 1 (100 MW) and Genji (107 MW). A bigger reduction of generation in Mandaya and close to Mandaya interconnection would increased the power flow coming from generation located in the south of Ethiopia : the flow on the 400 kV backbone Ghimbi - Ghedo - Sebeta would be higher, and the tripping of one of these circuits would leave the remaining circuit on overload exceeding the acceptable limit : 120 %. Until the commissioning of Geba, attention should be paid in 2020 to the unit commitment to respect a maximum flow on this 400 kV backbone under 2 x 420 MW (limit to be updated with the evolution of the Ethiopian network and generation). In 2021, the commissioning of Geba (370 MW - connected to Metu, and then Ghimbi) would lift this constraint.

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 210 to 240 MW (252 MVA).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.039	1.0358
1GHEDOS71	1.027	1.023
1SEBETS71	1.02	1.014

Table appendix 5.2 -8 - Voltage Variation on Substations

A.5.2.2.3 Tripping of one of the two 400 kV circuits Ghedo - Ghimbi

The initial flow on each circuit Ghedo - Ghimbi reached 407 MW (loading of 57°%)

Following the tripping of the line, the remaining circuit was overloaded by 9 % (which is acceptable in N-1 situation), its flow reaching 780 MW (loading of 109 %).

Note : (same comment for Ghedo - Sebeta circuit) to meet the intermediate load and export program, the Ethiopian unit commitment has been modified by switching off one of the 2 groups of Baro 1 (100 MW) and Genji (107 MW). A bigger reduction of generation in Mandaya and close to Mandaya interconnection would increased the power flow coming from generation located in the south of Ethiopia : the flow on the 400 kV backbone Ghimbi - Ghedo - Sebeta would be higher, and the tripping of one of these circuits would leave the remaining circuit on overload exceeding the acceptable limit : 120 %. Until the commissioning of Geba, attention should be paid in 2020 to the unit commitment to respect a maximum flow on this 400 kV backbone under 2 x 420 MW (limit to be updated with the evolution of the Ethiopian network and generation). In 2021, the commissioning of Geba (370 MW - connected to Metu, and then Ghimbi) would lift this constraint.

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 196 to 239 MW (247 MVA).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.039	1.029
1GHEDOS71	1.027	0.994
1SEBETS71	1.02	0.999

Table appendix 5.2 -9 - Voltage Variation on Substations

A.5.2.2.4 Tripping of one of the three 400 kV circuit Ghimbi - Mandaya

The initial flow on each circuit Ghimbi - Manadaya reached 475 MW (loading of 67°%)

Following the tripping of the line, the two remaining circuits were slightly overloaded by 1 % (which is acceptable in N-1 situation), its flow reaching 718 MW (loading of 101 %).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 196 to 212 MW (213 MVA).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.039	1.031
1GHEDOS71	1.027	1.022
1SEBETS71	1.02	1.016

Table appendix 5.2 -10 - Voltage Variation on Substations

A.5.2.2.5 Tripping of one of the two 230 kV circuits Bahir Dar - Gonder

The initial flow on each circuit Bahir Dahr - Gonder reached 117 MW (loading of 44°%)

Following the tripping of the line, the flow on the remaining circuit reached 205 MW (loading of 74 %).

The flow over the 220 kV Ethiopia - Sudan interconnection decreased from 196 to 174 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1B.DARS61	1.034	1.035
1GONDERS61	1.034	1.029

Table appendix 5.2 -11 - Voltage Variation on Substations

A.5.2.2.6 Conclusion

The N-1 situation on the 400 kV backbone Mandaya - Ghimbi - Ghedo - Sebeta is acceptable. The tripping of one of these circuits leads to an acceptable overload. Attention should be paid to the unit commitment (to keep enough generation output in Mandaya and Baro&Genji), to limit the flow on the remaining circuit of the 400 kV backbone Sebeta - Ghedo - Ghimbi - Mandaya in case of N-1 situation to an acceptable overload (the limit is close to 2 x 420 MW for the flow on the 400 kV backbone, limit to be updated with the network evolution and generation update). The commissioning of Geba HPP in 2021 (370 MW), bringing additional power in Ghimbi, would greatly release this constraint.

A.5.2.3 SUDANESE NETWORK

Recall of the flow on the Sudanese 500 kV system around Kosti

From bus	To bus	N° of circuit	P [MW]	Loading %
2RABAK81*	1MANDAY81	4	-742.3	41.7
2RABAK81*	2FULA81	2	-169.2	19.5
2RABAK81*	2J.AULIAS81	1	444.9	24.3
2RABAK81*	2MERIN81	1	771	36.6
2BAGERS81	2H.HEI81	2	-35.6	3.5
2BAGERS81	2J.AULIAS81	1	-154.0	8.1
2GEDARE81	2MERIN81	1	55.4	3.4
2H.HEI81	2MERIN81	1	-519.6	22.7

* Rabak substation was replaced by Kosti

Table appendix 5.2 -12 - Power Flows on the 500 kV Sudanese System

Compared with the peak load situation :

- the flow on Kosti - Fula has increased from 2 x -100 to 2 x -169 MW
- the flow on Kosti - Jebel Aulia has increased from 303 to 445 MW
- the flow on Kosti - Meringan has increased from 691 to 771 MW

A.5.2.3.1 Tripping of the 500 kV circuit Kosti - Jebel Aulia

The initial flow on Kosti - J.Aulia reached 445 MW (loading of 24°%)

The flow on Kosti - Meringan increased from 771 to 1099 MW (from 37 to 57 % of loading).

The flow on the 500/220 kV transformation increased by 108 MW, from 2 x 59 MW to 2 x 113 MW.

The flow on Kosti - Fula is slightly affected : -6 MW.

The voltage at Kosti substation is not affected, the SVC increasing its reactive output from 10 to 193 MVAr.

Voltage variation on the following substation.

Substation	Initial voltage (pu)	Final voltage (pu)
KOSTI	1.046	1.046
J. AULIA	1.032	1.013

Table appendix 5.2 -13 - Voltage Variation on Substations

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.5.2.3.2 Tripping of the 500 kV circuit Kosti - Meringan

The initial flow on Kosti - Meringan reached 771 MW (loading of 37°%)

The flow on Kosti - J.Aulia increased from 445 to 912 MW (from 24 to 48 % of loading).

The flow on Fula - Kosti decreased from -338 to -312 MW (19 % of loading).

The flow on the 500/220 kV transformation increased by 266 MW (from 2 x 59 MW to 2 x 192 MW).

The voltage at Kosti substation is not affected, the SVC increasing its reactive output from 10 to 203 MVAr.

Voltage variation on the following substation

Substation	Initial voltage (pu)	Final voltage (pu)
KOSTI	1.046	1.046
MERINGAN	1.046	0.986
J. AULIA	1.032	0.99

Table appendix 5.2 -14 - Voltage Variation on Substations

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.5.2.3.3 Tripping of one of the two 500 kV circuits Kosti - Fula

The initial flow on Kosti - Fula reached -169 MW (loading of 19.5°%).

The flow on the remaining circuit Kosti - Fula increased from -169 to -310 MW (from 19.5 to 23.4 % of loading).

The flow on the 500/220 kV transformation decreased by 20 MW.

The voltage at Kosti (SVC) and Fula (generation plants) substation is not affected, the SVC increasing its reactive output from 10 to 180 MVAr.

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.5.2.3.4 Tripping of the SVC at Kosti

In normal situation, the SVC reactive power generation is close to 0. The tripping of the SVC did not entail significant voltage variation.

A.5.2.3.5 Tripping of the 100 MVAR reactor at Kosti

To face the tripping of the 100 MVAr reactor, the SVC reactive power generated decreased from +10 to -90 MVAr. The voltage is not affected

A.5.2.3.6 Conclusion

The behaviour of the Sudanese system is satisfactory, in case of tripping of one of the 500 kV circuit connected to Kosti. The flow remained far below the thermal limit, and the voltage remained within the limits (+5/-10 %).

APPENDIX 6. DYNAMIC RESULTS - INTERMEDIATE LOAD 2020

A.6.1 INTERCONNECTION

A.6.1.1 TRIPPING OF ONE OF THE 2 POLES OF THE DC INTERCONNECTION

In case of tripping of one of the 2 poles of the DC interconnection, the behaviour of the system is satisfactory.

Event : a tripping of one of the 2 poles of the DC interconnection, and disconnection of half of the capacitor banks in each f the HVDC converter station 300 ms after.

Following the reduction of the transmitted power by half of its initial value :

- for the Ethiopia - Sudan system, the frequency raised to 50.7 Hz, before stabilizing around 50.32 Hz, after activation of the primary regulation of the generation governors
- for the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 49.6 Hz, after activation of the primary regulation of the generation governors with spinning reserve, and the self regulation of the load estimated to 330 MW.

Libya contributed with 50 MW of its primary reserve, and about 50 MW self regulation of the load.

Jordan and Syria contributed with 100 MW of primary reserve, and about 120 MW of self regulation of the load

Node	Initial voltage	Maximal voltage	Final voltage
NH500	520 kV	554 kV	525 kV
Kosti	522 kV	584 kV	527 kV
Mandaya	525 kV	563 kV	530 kV

Table appendix 6.1 -1 - Voltage Variation on Nodes

The flow on the 4 circuits Mandaya - Kosti decreased from 778 to 720 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.1.2 SHORT-CIRCUIT ON ONE OF THE 4 MANDAYA - KOSTI CIRCUITS, ON KOSTI SIDE

In case of short-circuit at Kosti on the interconnection, the behaviour of the system is satisfactory in case of tripping of one of the 2 poles of the DC station, or a reduction at half power on the DC Interconnection.

Event : a 3 phase short-circuit at Kosti end, on one of the 4 circuits Mandaya - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) leads to a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to half of its initial value 300 ms after the voltage return. At the same time, half of the capacitor banks were tripped.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Without the reduction of the power transmitted on the interconnection, a fault on Kosti side on the AC interconnection leads to a loss of synchronism between Ethiopia and Sudan. The maximum transmitted power on one 570 km circuit reached 1510 MW, assuming that the voltage is kept on both end.

One of the pole of the DC converter station is tripped 200 ms after the clearance of the fault, and half of the capacitors banks of each of the converter station is disconnected at the same time

Following the reduction of the transmitted power by half of its initial value :

- for the Ethiopia - Sudan system, the frequency raised to 50.9 Hz (51.2 Hz for Kosti units), before stabilizing around 50.32 Hz, after activation of the primary regulation of the generation governors
- for the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 49.6 Hz, after activation of the primary regulation of the generation governors with spinning reserve, and the self regulation of the load estimated to 330 MW.

Libya contributed with 50 MW of its primary reserve, and about 50 MW self regulation of the load.

Jordan and Syria contributed with 100 MW of primary reserve, and about 120 MW of self regulation of the load

Node	Initial voltage	Maximal voltage	Final voltage
NH500	520 kV	572 kV	525 kV
Kosti	522 kV	630 kV	514 kV
Mandaya	525 kV	573 kV	521 kV

Table appendix 6.1 -2 - Voltage Variation on Nodes

The flow on the 3 remaining circuits Mandaya - Kosti reached 1164 MW, before stabilizing at 942 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.1.3 SHORT-CIRCUIT ON ONE OF THE 4 MANDAYA - KOSTI CIRCUITS, ON MANDAYA SIDE

A.6.1.3.1 With full recovery of the DC power flow

In case of short-circuit at Mandaya on the interconnection, the full recovery of the DC flow leads to other trippings of the DC substation due to voltage drop at Kosti,. This situation is not satisfying. Therefore, it is recommended to trip one of the pole (or half of the DC power flow), to reduce the flow on the AC interconnection.

A.6.1.3.2 With half recovery of the DC power flow

In case of short-circuit at Mandaya on the interconnection, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Mandaya end, on one of the 4 circuits Mandaya - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0.4 pu) leads to a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to half of its initial value 300 ms after the clearing of the fault. At the same time, half of the capacitors bank of each converter station is disconnected.

Following the reduction of the transmitted power by half of its initial value :

- for the Ethiopia - Sudan system, the frequency raised to 50.8 Hz (51 Hz for Mandaya), before stabilizing around 50.32 Hz, after activation of the primary regulation of the generation governors
- for the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 49.6 Hz, after activation of the primary regulation of the generation governors with spinning reserve, and the self regulation of the load estimated to 330 MW.

Libya contributed with 50 MW of its primary reserve, and about 50 MW self regulation of the load.

Jordan and Syria contributed with 100 MW of primary reserve, and about 120 MW of self regulation of the load

Node	Initial voltage	Maximal voltage	Final voltage
NH500	520 kV	572 kV	525 kV
Kosti	522 kV	576 kV	514 kV
Mandaya	525 kV	569 kV	521 kV

Table appendix 6.1 -3 - Voltage Variation on Nodes

The flow on the 3 remaining circuits Mandaya - Kosti reached 1114 MW, before stabilizing at 942 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.1.4 FAULT ON ONE OF THE 4 MANDAYA 500/400 KV TRANSFORMERS

In case of short-circuit at Mandaya 500 kV on one of the 4 500/400 kV transformers at Mandaya, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at the 500 kV side of one of the four 500/400 kV transformers at Mandaya substation, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0.3 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory commutation blocking of the DC stations, the capacitors bank remained connected.

The voltage drop in Nag Hammadi (V = 0.84 pu) following the recovery of the DC substation, leads to a new commutation failure (inverter side), and this sequence (tripping of the DC substation and recovery) will resume. It is therefore recommended to trip one of the pole (of half of the DC power exchange).

Following the reduction of the transmitted power by half of its initial value :

- for the Ethiopia - Sudan system, the frequency raised to 50.8 Hz (Mandaya reaching 51 Hz due to the short-circuit oscillation and the frequency surge), before stabilizing around 50.32 Hz, after activation of the primary regulation of the generation governors
- for the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 49.6 Hz (High Dam initial oscillation reaching 50.2 and 49.55 Hz), after activation of the primary regulation of the generation governors with spinning reserve, and the self regulation of the load estimated to 330 MW.

Libya contributed with 50 MW of its primary reserve, and about 50 MW self regulation of the load. Jordan and Syria contributed with 100 MW of primary reserve, and about 120 MW of self regulation of the load

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	520 kV	574 kV	482 kV	521 kV
Kosti	522 kV	600 kV	-	527 kV
Mandaya	525 kV	589 kV	-	530 kV

Table appendix 6.1 -4 - Voltage Variation on Nodes

The flow on the 3 remaining transformers reached 530 MW, before stabilizing at 425 MW (initial value : 355 MW).

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.1.5 FAULT ON THE 220 KV INTERCONNECTION

In case of short-circuit at Gedaref 220 kV, on the 220 kV phase-shift transformer, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Gedaref 220 kV side on the 220 kV phase-shift transformer, cleared in 120 ms by the opening of the circuit breakers.

The DC interconnection is affected.

Generator	Maximal frequency	Minimal frequency
Mandaya	50.17 Hz	49.99 Hz
Gedaref HPP	50.7 Hz	49.27 Hz

Table appendix 6.1 -5 -Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
Kosti	522 kV	565 kV	394 kV	517 kV
Mandaya	525 kV	550 kV	485 kV	520 kV

Table appendix 6.1 -6 - Voltage Variation on Substations

The flow on the remaining 500 kV interconnection, reached 888 MW, before stabilizing at 825 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.2 EGYPTIAN NETWORK

Recall of the flows on the 500 kV backbone along the Nile Valley

From bus	To bus	N° of circuits	P [MW]	Loading %
H.D.500	N.H.500	2	479.3	24.8
N.H.500	AUST500	1	753.2	42.3
N.H.500	SOHAG500	1	751.7	42.6
SOHAG500	AUST500	1	629.2	35.6
AUST500	SAML500	2	538.6	30.3
SAML500	S.GIZA500	1	428.5	28.8
SAML500	KRIMA500	1	46.2	8.7

Table appendix 6.2 -1 -Power Flows on the Egyptian 500kV Backbone

A.6.2.1 SHORT-CIRCUIT OF ONE OF THE 2 CIRCUITS HIGH DAM - NAG HAMMADI, AT HIGH DAM SIDE

In case of short-circuit in High Dam, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at High Dam end, on one of the 2 circuits High Dam - Nag Hammadi, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0.4 pu) leads to a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault. The voltage on Nag Hammadi bus bar dropping to 0.92 pu, a commutation fault might occur, leading to a second blocking of the converter station. A SVC would improve the voltage profile.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	548 kV	526 kV
NH500	520 kV	552 kV	521 kV
Kosti	522 kV	621 kV	522 kV
Mandaya	525 kV	592 kV	525 kV

Table appendix 6.2 -2 -Voltage Variation on Nodes

The transitory over voltage in Kosti reached 24 %, the SVC absorbing at its maximum capacity : 500 MVAr.

The flow on the remaining circuit High Dam - Nag Hammadi reached transiently a maximum value 1523 MW, before recovering to 852 MW (initial value of 475 MW).

High dam initial oscillation reached transitory 50.4 Hz and 49.6 Hz, before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 1970 MW export toward Egypt leads to a transitory over-frequency of 400 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 1850 MW of import is smaller than 100 mHz.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.2.2 SHORT-CIRCUIT OF ONE OF THE 2 CIRCUITS HIGH DAM - NAG HAMMADI, AT NAG HAMMADI SIDE

In case of short-circuit in Nag Hammadi, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Nag Hammadi end, on one of the 2 circuits High Dam - Nag Hammadi, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0 pu) leads to a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	550 kV	526 kV
NH500	520 kV	562 kV	521 kV
Kosti	522 kV	621 kV	522 kV
Mandaya	525 kV	592 kV	525 kV

Table appendix 6.2 -3 - Voltage Variation on Nodes

After the recovery of the DC converter station, the voltage dropped to 0.94 pu in Nag Hammadi.

The transitory over voltage in Kosti reached 24 %, the SVC absorbing at its maximum capacity : 500 MVAr.

The flow on the remaining circuit High Dam - Nag Hammadi reached transiently a maximum value 16863 MW, before recovering to 852 MW (initial value of 475 MW).

High dam initial oscillation reached transitory 50.25 Hz and 49.65 Hz, before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 1970 MW export toward Egypt leads to a transitory over-frequency of 400 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 1850 MW of import is smaller than 100 mHz.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.2.3 *SHORT-CIRCUIT ON THE CIRCUIT NAG HAMMADI - SOHAG, AT NAG HAMMADI SIDE*

In case of short-circuit in Nag Hammadi, the behaviour of the system is satisfactory, with the commissioning of a 300 MVAr SVC in Nag Hammadi.

Event : a 3 phase short-circuit at Nag Hammadi end, on Nag Hammadi - Sohag, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0 pu) leads to a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault. During the transitory blocking of the DC stations, the capacitors bank remained connected.

But the voltage dropped again under 0.9 pu after the recovery of the station, leading to a new commutation failure. This might occur several times, before the definitive tripping of the DC station. This is not satisfying. The tripping of one pole (or the reduction of the DC power flow by half of its value) would lift the constraint, but this configuration had not been faced in the peak situation. Two solution could be contemplated :

- Addition of a third circuit between Nag Hammadi and Assiut
- Addition of a SVC at Nag Hammadi

Both situation will be studied.

With a 300 MVAr SVC

Without any device, the voltage in Nag Hammadi dropped to 0.84 pu after the recovery of the DC power flow on the interconnection.

With a 200 MVAr SVC at Nag Hammadi, the voltage in Nag Hammadi dropped to 0.91 pu after the recovery of the DC power flow on the interconnection.

With a 300 MVAr SVC at Nag Hammadi, the voltage in Nag Hammadi dropped to 0.95 pu after the recovery of the DC power flow on the interconnection.

It is therefore recommended to install a 300 MVAr SVC in Nag Hammadi

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	545 kV	525 kV
NH500	520 kV	578 kV	515 kV
Kosti	522 kV	621 kV	522 kV
Mandaya	525 kV	592 kV	525 kV

Table appendix 6.2 -4 - Voltage Variation on Nodes

The transitory over voltage in Kosti reached 23 %, the SVC absorbing at its maximum capacity : 500 MVAr.

The flow on the remaining circuit Nag Hammadi - Assiut reached transiently a maximum value 1500 MW, before recovering to 1196 MW (initial value of 750 MW).

High dam initial oscillation reached transitory 50.25 Hz and 49.6 Hz, before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 1970 MW export toward Egypt leads to a transitory over-frequency of 400 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 1850 MW of import is smaller than 100 mHz.

<u>With an additional circuit Nag Hammadi - Assiut</u>

Without any device, the voltage in Nag Hammadi dropped to 0.84 pu after the recovery of the DC power flow on the interconnection.

With a additional circuit Nag Hammadi - Assiut, the voltage in Nag Hammadi dropped to 0.925 pu after the recovery of the DC power flow on the interconnection.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	545 kV	525 kV
NH500	520 kV	578 kV	515 kV
Kosti	522 kV	621 kV	522 kV
Mandaya	525 kV	592 kV	525 kV

Table appendix 6.2 -5 - Voltage Variation on Nodes

The transitory over voltage in Kosti reached 23 %, the SVC absorbing at its maximum capacity : 500 MVAr.

The flow on the remaining circuit Nag Hammadi - Assiut reached transiently a maximum value 906 MW, before recovering to 711 MW (initial value of 516 MW).

High dam initial oscillation reached transitory 50.25 Hz and 49.6 Hz, before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 1970 MW export toward Egypt leads to a transitory over-frequency of 400 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 1850 MW of import is smaller than 100 mHz.

Comparison of both solutions:

Both solution complied with the minimum voltage threshold in Nag Hammadi : the damping of oscillation is slightly better with an additional circuit between the Nag Hammadi and Assiut, and the voltage margin between the minimum voltage value after the recovery of the DC substation is better with the SVC (0.95 pu) than with the additional circuit (0.92 pu).

The cost of a 300 MVAr SVC is slightly less expensive than the cost of a new NH - Assiut circuit. Moreover, it is easier to build a SVC than a new line.

It is therefore recommended to reinforce the system with the commissioning of a 300 MVAr SVC in Nag Hammadi

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.2.4 TRIPPING OF EGYPT MAIN STEAM UNIT : 765 MVA

In case of tripping of Egypt main steam unit, the behaviour of the system is satisfactory.

Event : the 625 MW steam unit of Abu Kir is tripped (initial output : 614 MW).

The DC power flow is not affected. The Ethiopia-Sudan system remained unchanged.

The Egyptian frequency dropped to 49.72 Hz, before recovering to 49.77 Hz. The Egyptian self regulation of the load estimated to 200 MW.
Libya contributed with 50 MW of its primary reserve, and about 30 MW self regulation of the load.

Jordan and Syria contributed with 100 MW of primary reserve, and about 70 MW of self regulation of the load

The voltage is not significantly affected.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.3 ETHIOPIAN NETWORK

Recall of the flow on the Ethiopian 400 kV system between Addis Ababa and Mandaya

From bus	To bus	N° of circuit	P [MW]	Loading %
1MANDAS71	1GHIMBIS71	3	-480	67
1GHIMBIS71	1GHEDOS71	2	-399	57
1GHIMBIS71	1METUS71	2	-322	44.1
1GHEDOS71	1SEBETS71	2	-408	57

Table appendix 6.3 -1 - Power Flows on the Ethiopian 400kV system

A.6.3.1 SHORT-CIRCUIT AT MANDAYA, ON ONE OF THE THREE 400 KV CIRCUITS GHIMBI - MANDAYA

In case of short-circuit at Mandaya on Ghimbi - Mandaya, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Mandaya end, on one of the 3 circuits Mandaya - Ghimbi, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Kosti (to 0.5 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

The behaviour of the interconnected system is satisfactory, following a short circuit at Mandaya side on one of the 3 circuits Mandaya - Ghimbi.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	548 kV	525 kV
NH500	520 kV	557 kV	521 kV
Kosti	522 kV	633 kV	522 kV
Mandaya 500	525 kV	570 kV	522 kV
Mandaya 400	414 kV	451 kV	410 kV

Table appendix 6.3 -2 - Voltage Variation on Nodes

The transitory over voltage in Kosti reached 26 %, the SVC absorbing at its maximum capacity : 500 MVAr. The flow on the remaining circuits Mandaya - Ghimbi reached transiently a maximum value 824 MW, before recovering to 712 MW (initial value of 480 MW).

Generator	Maximal frequency	Minimal frequency
Mandaya	50.5 Hz	49.9 Hz
Genji / Baro	50.7 Hz	49.85 Hz
Kost	50.6 Hz	49.8 Hz
Port Sudan	50.55 Hz	49.9 Hz

Table appendix 6.3 -3 - Frequency Variation of Generators

On the Ethiopia - Sudan side, the transitory blocking of the 1970 MW export toward Egypt leads to a transitory over-frequency of 300 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 1850 MW of import is smaller than 100 mHz.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.3.2 *TRIPPING OF ETHIOPIA MAIN 2 UNITS : MANDAYA HPP UNITS*

In case of tripping of 2 units of Mandaya, the behaviour of the system is satisfactory.

Event : 2 units of Mandaya (the main unit in Ethiopia) is tripped (initial output : 2 x 212.5 MW = 425 MW).

The DC power flow is not affected. The Egyptian system remained unchanged.

The Ethiopia-Sudan frequency dropped to 49.6 Hz, before recovering to 49.87 Hz.

The flow on the 500 kV interconnection decreased from 778 MW to 708 MW, with a minimum at 695 MW.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.4 SUDANESE NETWORK

Recall of the flow on the Sudanese 500 kV system around Kosti

From bus	To bus	N° of circuit	P [MW]	Loading %
2RABAK81	1MANDAY81	4	-742.3	41.7
2RABAK81	2FULA81	2	-169.2	19.5
2RABAK81	2J.AULIAS81	1	444.9	24.3
2RABAK81	2MERIN81	1	771	36.6
2BAGERS81	2H.HEI81	2	-35.6	3.5
2BAGERS81	2J.AULIAS81	1	-154.0	8.1
2GEDARE81	2MERIN81	1	55.4	3.4
2H.HEI81	2MERIN81	1	-519.6	22.7

* Rabak substation was replaced by Kosti

Table appendix 6.4 -1 -Power Flows on the Sudanese 500kV System

A.6.4.1 *SHORT-CIRCUIT ON ONE OF THE TWO 500 KV CIRCUITS KOSTI - FULA, AT KOSTI SIDE*

In case of short-circuit on Kosti - Fula, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on one of the 2 circuits Kosti - Fula, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

In case of short-circuit on one of the 2 circuits Kosti - Fula, on Kosti side, the behaviour of the system is satisfactory.

Generator	Maximal frequency	Minimal frequency
Mandaya	50.82 Hz	49.78 Hz
Gibe 3	50.64 Hz	49.73 Hz
Kost	50.78 Hz	49.75 Hz
Fula ST / Merowe / P. Sudan	50.75 Hz	49.75 Hz
High Dam	50.33 Hz	49.6 Hz

Table appendix 6.4 -2 - Frequency Variation of Generators

The flow on the remaining circuit Fula - Kosti ached a maximum of 500 MW, before stabilizing at 314 MW initial value of 171 MW).

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	520 kV	557 kV	463 kV	520 kV
Kosti	522 kV	652 kV	375 kV	518 kV
Mandaya	525 kV	594 kV	409 kV	524 kV

Table appendix 6.4 -3 - Voltage Variation on Nodes

Nag Hammadi is supposed to be equipped with a 300 MVAr SVC.

The transient over voltage in Kosti reached 30 %. A Kosti substation, the most sensitive equipment to over-voltage are Kost alternators, and their maximum over-voltage reached 1.09 pu (the minimum value reaching 0.82 pu). There is therefore no risk on the alternators.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.4.2 SHORT-CIRCUIT ON THE 500 KV CIRCUIT KOSTI - JEBEL AULIA, AT KOSTI SIDE

In case of short-circuit on Kosti - Jebel Aulia, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on the circuits Kosti - Jebel Aulia, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

The initial flow on Kosti - J.Aulia reached 445 MW (loading of 24°%)

The flow on Kosti - Meringan increased transitory to 2251 MW, before stabilizing at 1081 MW (initial value of 771 MW).

Generator	Maximal frequency	Minimal frequency
Merowe / P. Sudan	50.95 Hz	49.7 Hz
Fula ST	50.9 Hz	49.65 Hz
Mandaya	50.82 Hz	49.78 Hz
Gibe 3	50.65 Hz	49.65 Hz
Kost	50.78 Hz	49.75 Hz
High Dam	50.33 Hz	49.6 Hz

Table appendix 6.4 -4 - Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	520 kV	557 kV	463 kV	520 kV
Kosti 500	522 kV	653 kV	366 kV	519 kV
Kosti 220	228 kV	266 kV	176 kV	227 kV
Kost Alterators	10.6 kV	11.9 kV	8.9 kV	10.6 kV
Mandaya	525 kV	599 kV	415 kV	524 kV

Table appendix 6.4 -5 - Voltage Variation on Nodes

Nag Hammadi is supposed to be equipped with a 300 MVAr SVC.

The transient over voltage in Kosti reached 36 %. A Kosti substation, the most sensitive equipment to over-voltage are Kost alternators, and their maximum over-voltage reached 1.09 pu (the minimum value reaching 0.78 pu). There is therefore no risk on the alternators.

The voltage drop at Kosti following the recovery of the DC substation, will not entail a commutation failure, but a transitory reduction of power flow on the DC interconnection.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.4.3 SHORT-CIRCUIT ON THE 500 KV CIRCUIT KOSTI - MERINGAN, AT KOSTI SIDE

In case of short-circuit on Kosti - Meringan, the behaviour of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on the circuits Kosti - Meringan, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) leads to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

The initial flow on Kosti - Meringan reached 771 MW (loading of 37 %).

The flow on Kosti - Jebel Aulia increased transitory to 1672 MW, before stabilizing at 862 MW (initial value : 438 MW).

Generator	Maximal frequency	Minimal frequency
Merowe / P. Sudan	50.95 Hz	49.7 Hz
Fula ST	50.9 Hz	49.65 Hz
Mandaya	50.82 Hz	49.78 Hz
Gibe 3	50.65 Hz	49.65 Hz
Kost	50.78 Hz	49.75 Hz
High Dam	50.33 Hz	49.6 Hz

Table appendix 6.4 -6 - Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	520 kV	557 kV	463 kV	520 kV
Kosti 500	522 kV	673 kV	353 kV	519 kV
Kosti 220	228 kV	267 kV	173 kV	227 kV
Kosti alterators	10.6 kV	11.9 kV	8.5 kV	10.6 kV
Mandaya	525 kV	594 kV	409 kV	524 kV

Nag Hammadi is supposed to be equipped with a 300 MVAr SVC.

Table appendix 6.4 -7 - Voltage Variation on Nodes

The transient over voltage in Kosti reached 36 %. At Kosti substation, the most sensitive equipment to over-voltage are Kost alternators, and their maximum over-voltage reached 1.09 pu (the minimum value reaching 0.78 pu). There is therefore no risk on the alternators.

The voltage drop at Kosti following the recovery of the DC substation, will not entail a commutation failure, but a transitory reduction of power flow on the DC interconnection.

The figures are displayed in M1 - 2020 Appendix Stability Study

A.6.4.4 TRIPPING OF SUDAN MAIN UNIT : PORT SUDAN 670 MVA STEAM TURBINE

In case of tripping of Sudan main unit, the behaviour of the system is satisfactory.

Event : the 670 MVA steam unit of Port-Sudan (the main unit in Sudan) is tripped (initial output : 530 MW).

The DC power flow is not affected. The Egyptian system remained unchanged.

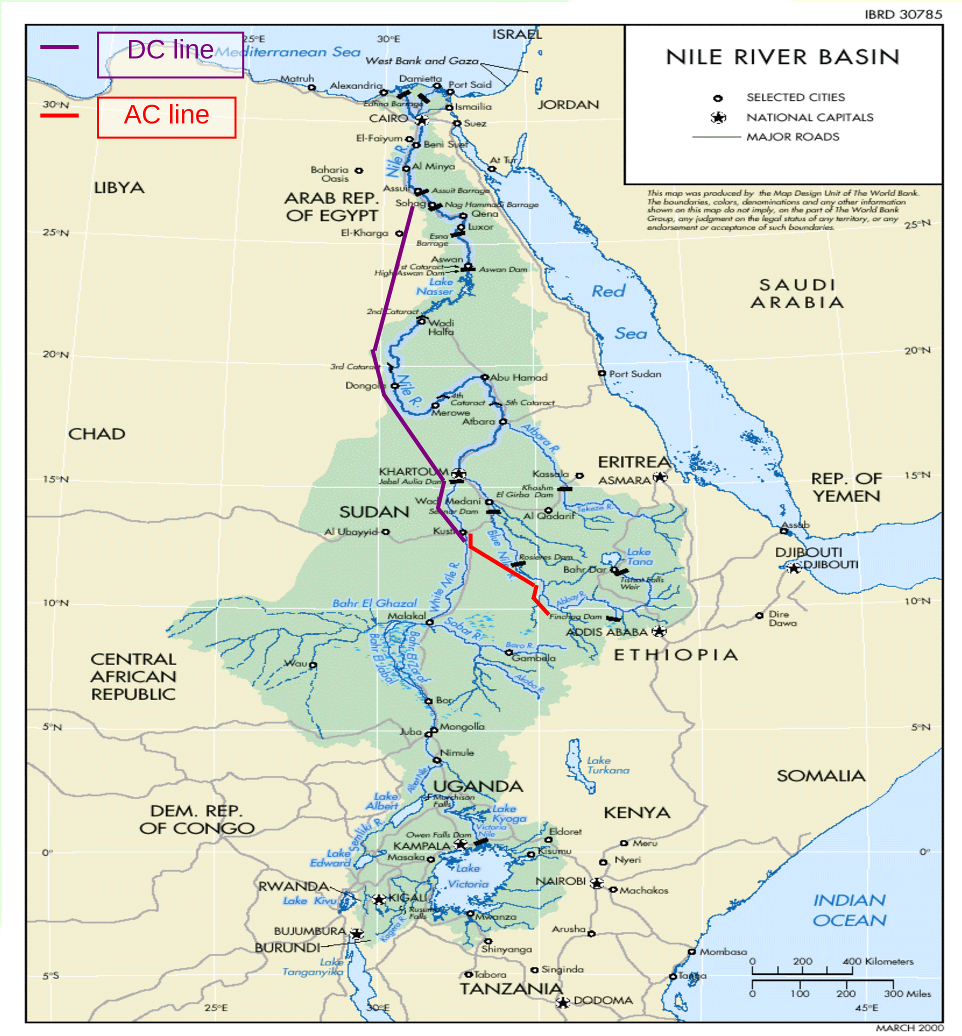
The Ethiopia-Sudan frequency dropped to 49.35 Hz, before recovering to 49.85 Hz.

The flow on the 500 kV interconnection increased from 778 MW to 832 MW

The figures are displayed in M1 - 2020 Appendix Stability Study

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

EASTERN NILE POWER TRADE PROGRAM STUDY



M1 - 2025 - POWER STUDY

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
CCG	Combined Cycle Gas turbine
DC	Direct Current
ENPTPS	Eastern Nile Power Trade Program Study
EDF	Electricité de France
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
GEP	Generation Expansion Plan
HPP	Hydro Power Plant
HD	High Dam
HV	High Voltage
HVDC	High Voltage Direct Current
NBI	Nile Basin Initiative
NH	Nag Hammadi
p.u	Per Unit
ST	Steam Turbine
SVC	Static Voltage Compensator
SW	Scott Wilson
TPP	Thermal Power Plant

EXECUTIVE SUMMARY

Introducing Regional Interconnector

An economic study performed during the Phase I of ENPTPS demonstrated that it was profitable to export hydro power generated in Ethiopia to Sudan and Egypt. Mandaya Hydro Power Station, located on the Blue Nile River which the installed capacity amounts to 2000 MW, was selected to be commissioned in year 2020 to participate to power exchanges.

This study has estimated that Ethiopia could export 2000 MW to Egypt and 1200 MW to Sudan.

To provide such exchanges and supply the load demand in Ethiopia at least up to the year 2030, Karadobi HPP and Border HPP, located also on the Blue Nile River, would be successively put in operation in 2025 and 2030. Their installed capacity amounts respectively to 1600 MW and 1200 MW.

In parallel with the economic study, a technical study was carried on:

- to propose several interconnection alternatives,
- to perform the necessary studies proving that it was technically possible to export such power from Ethiopia to Sudan and Egypt;
- to design the equipment and estimate their cost.

Resulting of this study and the discussions about the several alternatives, EN Countries has selected the following scheme option for the Egypt-Ethiopia-Sudan interconnector:

- One 500 kV AC link between Ethiopia and Sudan,
- One +/- 600 kV DC link between Sudan and Egypt.

The 500 kV AC link included two 544 km double circuit lines between Mandaya in Ethiopia and Kosti in Sudan, initially in phase I Rabak (East side of the Nile). A 500/400 kV substation at Mandaya equipped with four 510 MVA transformers connects Madaya power station to Ethiopian grid. The line routing study has located the interconnection substation in Sudan on the West side of the Nile river at Kosti.

The +/- 600 kV link included one 1665 km bipolar DC line between Kosti and Nag Hammadi in Egypt, one 2150 MW AC/DC converter station located at each end of the link. One 500 MVAr and one 300 MVAr static var compensators were installed at Kosti and Nag Hammadi.

This new interconnector be operated in parallel with the 220 kV interconnection between Gonder in Ethiopia and Gedaref in Sudan, commissioned in 2009.

The present report is devoted to the analysis of the behaviour of the Interconnected System including Egypt, Ethiopia and Sudan in year 2025.

Results of the power study for the year 2025

General

To demonstrate that it was possible to export 3200 MW from Ethiopia to Sudan and Egypt, the operation of the interconnected system was simulated in year 2025 for the period of the annual peak load demand.

Simulations were carried out in permanent state to calculate power flows over the transmission system, the voltage profile and the active and reactive generation of the generators. Contingency situations, consisting in the tripping of one element belonging to the interconnection and to the feeding network, e.g. Mandaya, Kosti and Nag Hammadi substations, were examined. Whatever the situation, the Interconnected System must be able to satisfy power exchanges and must be operated within the acceptable limits.

Simulations were also performed in transient state to verify system ability to recover an acceptable situation without loss of synchronism of any generator or sustained oscillations.

Results

Whatever the situation, Ethiopia can export 2000 MW to Egypt and 1200 MW to Sudan. The 220 kV interconnection equipped with one 250 MVA phase shift transformer at Gedaref can operate in parallel with the 500 kV link and transmit about 200 MW in normal situation.

Concerning the interconnection itself, the main points can be underlined.

Following the tripping of one of the four 500 kV circuits between Mandaya and Kosti or one of the four 500/400 kV transformers at Mandaya, the behaviour of the system is satisfactory, no overload occurred on the system, Ethiopian and Sudanese systems operated in synchronism, no major disturbance appeared in Egypt. The interconnected system is able to exchange 3200 MW, even with one 500 kV circuit out of operation.

The tripping of one of the two DC poles do not induce any loss of synchronism in Ethiopia and Sudan. The frequency surge, due to the reduction of half of the power exported to Egypt (1000 MW out of 2000 MW), induces a frequency surge in Ethiopia and Sudan below 1%. The system frequency recovers a value close to 50.15 Hz 15 seconds after the fault.

In Egypt the frequency decreases down to 49.84 Hz and recovers a value close 49.88 Hz 15 seconds after the fault.

The temporary blocking of the AC/DC converter stations, due to a commutation fault of the converters or a short circuit in the vicinity of Kosti and Nag Hammadi, do not induce major disturbances in the three systems. Voltage surge and frequency surge in Sudan and Ethiopia remain below acceptable limits in transient state. In Egypt, frequency decline reaches 0.2%.

Concerning the Egyptian system, the following points can be underlined.

The power imported from Ethiopia supplied the local demand in Nag Hammadi area. Therefore, the power flows over the 500 kV circuits of the Upper Nile network are far below their rating. Whatever the location of the fault and the tripped circuit, the behaviour of the system is satisfactory, no overload occurred, the generators operated in synchronism, all the oscillations are totally damped in 15 seconds.

Concerning the Ethiopian system the following points can be underlined.

Ethiopia can export 3200 MW to Sudan in Egypt in normal situation and following the tripping of any 400 kV and 230 kV circuit in the vicinity of Mandaya and Gonder. Whatever the fault, the Ethiopian system is operated within acceptable limits in N-1 condition.

To discharge the generation of Karadobi HPP, that amounts to 1600 MW, it is proposed to equip the 400 kV double circuit line between Karadobi and Ghedo with three 450 mm² bundle conductors. With such equipment, no overload occurred on the remaining circuit when one circuit Karadobi-Ghedo was tripped.

Following a short circuit, the behaviour of the system is satisfactory, the generators operated in synchronism with the Sudanese generators, voltage oscillations are well damped.

Concerning the Sudanese system the following points can be underlined.

The Sudanese system can import 3200 MW from Ethiopia over both the 500 kV and 220 kV interconnections and can feed 2000 MW to the AC/DC converter station at Kosti.

System behaviour is satisfactory in normal and in N-1 situation.

To discharge the power generated by Fula TPP that added to the 1000 MW arriving at Kosti from Ethiopia, one second 500 kV circuit must be in operation between Kosti and Meringan. This second circuit avoid unacceptable overloads of the under laying 220 kV network in case of tripping of the first 500 kV circuit. This second circuit will have to be commissioned in phase with the increase of installed power in Fula TPP.

With such equipment, whatever the location of the fault and the tripped circuit, the behaviour of the system is satisfactory, no overload occurred, the generators operated in synchronism, all the oscillations are totally damped in less than 15 seconds.

1 INTRODUCING THE INTERCONNECTED SYSTEM IN 2025

1.1 INTRODUCING NETWORK STUDY

An economic study performed during the Phase I of the ENTRO Project proved that it was highly profitable to export hydro power generated in Ethiopia to Sudan and Egypt. Mandaya Hydro Power Station, located on the Blue Nile River which the installed capacity amounts to 2000 MW, was selected to be commissioned in year 2020 to participate to power exchanges.

This study estimated that Ethiopia could export 2000 MW to Egypt and 1200 MW to Sudan.

To provide such exchanges and supply the load demand in Ethiopia at least up to the year 2030, Karadobi HPP and Border HPP, located also on the Blue Nile River, would be successively put in operation in 2025 and 2030. Their installed capacity amounts respectively to 1600 MW and 1200 MW.

In parallel with the Economic Study, a Technical Study was carried on:

- to propose several interconnection alternatives,
- to perform the necessary studies proving that it was technically possible to export such power from Ethiopia to Sudan and Egypt;
- to design the equipment and estimate their cost.

Resulting of this study and the discussions about the proposed alternatives, ENTRO selected the following alternative.

The interconnection consisted in:

- One 500 kV AC link between Ethiopia and Sudan,
- One +/- 600 kV DC link between Sudan and Egypt.

The 500 kV AC link included two 544 km double circuit lines between Mandaya in Ethiopia and Kosti in Sudan, a 500/400 kV substation at Mandaya equipped with four 510 MVA transformers.

The +/- 600 kV link included one 1665 km bipolar DC line between Kosti and Nag Hammadi in Egypt, one 2150 MW AC/DC converter station located at each end of the link. One 500 MVAr and one 300 MVAr static var compensators were installed at Kosti and Nag Hammadi.

This new interconnection would have to operate in parallel with the 220 kV interconnection between Gonder in Ethiopia and Gedaref in Sudan commissioned in the coming year.

The present document is devoted to the analysis of the behaviour of the Interconnected System including Egypt, Ethiopia and Sudan in year 2025.

1.2 DESCRIPTION OF THE TRANSMISSION SYSTEM

1.2.1 DESCRIPTION OF THE INTERCONNECTION

The interconnection between the 3 countries selected at the beginning of Phase II, is made up of 2 different parts :

- One AC interconnection including two 500kV double circuit lines, 544 km length, between Mandaya (Ethiopia) and Kosti (Sudan). Each of the four circuits is compensated with one 150 MVAr reactor on Mandaya side, and one 75 MVAr reactor on Kosti side.
  A 500/400 kV substation located on Mandaya HPP site, equipped with four 500/400 kV 510 MVA transformers.
  The interconnection also included the existing 220 kV double circuit line between Gonder (Ethiopia) and Gedaref (Sudan). To limit the power flow over the 220kV interconnection one 350MVA phase-shift transformer was installed at Gedaref 220kV substation.
- A 600 kV DC interconnection between Kosti (Sudan) to Nag Hammadi (Egypt), made up of :
  - One AC/DC 2 x 1 075 MW converter station located at Kosti substation in Sudan, and one +/- 500 MVAr SVC
  - One 600 kV DC bipolar line between Kosti and Nag Hammadi. The total length of the line is about 1665 km
  - One DC/AC 2 x 1 075 MW converter station located in Nag Hammadi in Egypt

One +/- 300 MVAr SVC is installed at Nag Hammadi to control the voltage in transient state.

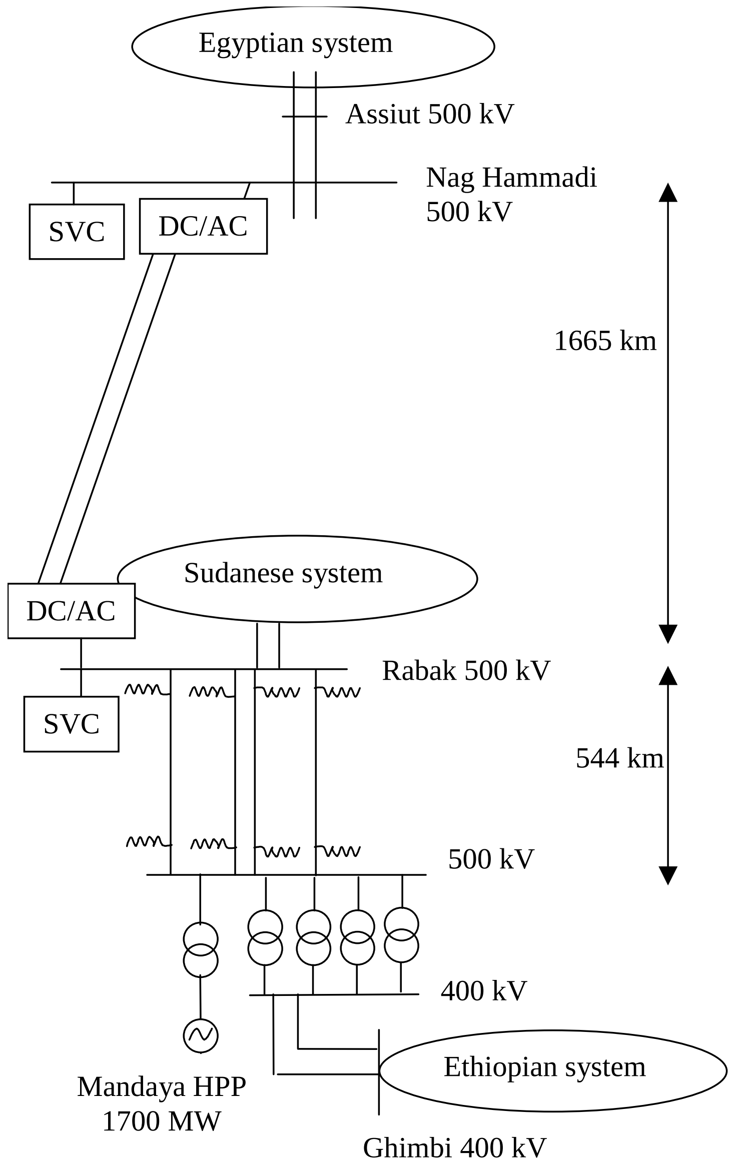


Figure 1: Interconnection Scheme

1.2.2 DESCRIPTION OF THE SYSTEM CLOSE TO THE INTERCONNECTION POINTS

1.2.2.1 Description of the Egyptian transmission system close to Nag Hammadi

Nag Hammadi is located along the 500 kV double circuit backbone in the Nile valley, connecting High Dam HPP in the south to Kurimat and Cairo in the North, passing into Nag Hammadi, Assiut and Samalut substations.

In Nag Hammadi substation, two 500kV circuits are connected to High Dam HPP in the south, and two others are connected to Assiut substation in the North. Sohag 500kV substation is connected by derivation of one 500 kV circuit Nag Hammadi - Assiut. Nag Hammadi substation includes 500/220 kV and 500/132 kV transformations.

1.2.2.2 Description of the Ethiopian system close to Mandaya

Mandaya 400kV substation is connected to the 400 kV system at Sebeta in Addis Ababa area with the following circuits :

- Three circuits Mandaya - Ghimbi
- One double circuit line Ghimbi - Ghedo
- One double circuit line Ghedo - Sebeta

Baro 1&2, Genji HPP, both commissioned in 2020, and Geba 1&2 commissioned in 2021 are connected to Metu 400 kV substation with one double circuit line; Metu is connected to Ghimbi with three 400 kV circuits.

Ghedo is connected to Debre Markos with one 400 kV double circuit line passing into Karadobi HPP.

1.2.2.3 Description of the Sudanese transmission system close to Kosti

Kosti 500 kV is connected to the following substations :

- Fula, in the west part of the system, with one 500kV double circuit line
- Jebel Aulia with one 500kV single circuit line
- Meringan with one 500kV single circuit line

Kosti substation is equipped with two 300MVA 500/220 kV transformers.

Meringan 500kV substation is connected to Hassa Heisa with one single circuit line and two Port Sudan TPP with one single circuit line passing into Gedaref 500/220kV substation.

1.3 DEMAND AND GENERATION BALANCE

1.3.1 LOAD DEMAND

The behaviour of the interconnected system was examined for the peak period. The demand corresponding to the annual peak is the sum of the annual peak of each of the three countries. The values are displayed in the following table:

Peak demand* (MW)	2025 / 2026
Egypt	51 850
Ethiopia	3 973
Sudan	11 412
Total	67 235

* These figures include the transmission losses

Table 1: 2025/2026 Peak Load Demand

1.3.2 GENERATION

The generation expansion plans were reviewed in Phase 1 (Module 3), and were presented in the Economic study. For Ethiopia, it was adapted in Module 6 of Phase 1, to take into account the anticipation of Mandaya HPP from 2024 to 2020 to meet the power exchange selected.

Egyptian Generation Expansion Plan

Name of the plant	Unit number	Plant site location	Type of generation unit	Installed capacity (MW)	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27
Sidi Krir	1	East Delta	CCGT	750	500	250																	
Kurimat (3)	1	Upper Egypt	CCGT	750	500	250																	
Nobaria (3)	1	West Delta	CCGT	750	500	250																	
Atfe	1	West Delta	CCGT	750	500	250																	
Sharm El-Sheik	1	West Delta	CCGT	750				750															
Alexandria Eas	1..2	West Delta	CCGT	750						500	500	500											
Combined Cycl	1..8		CCGT	750						500	500		500	500	500	1000	500	500	500	500	500		
Open Cycle GT 250 MW			OCGT	250																			
Abu Qir	1..2	West Delta	ST	650			650	650															
Suez	1	East Delta	ST	450					450														
Steam Units 45	1..16		ST	450						1350	450	450		450	450				450	900	900	1350	450
Cairo West Ext	1..2	Cairo	ST	350			700																
Tebbin	1..2	Cairo	ST	350		700																	
Ayoun Musa E	1	Upper Egypt	ST	350				350															
Steam Units 65	1..22		ST	350					1300		650		1300	1300	1300	1300	650	1950	650	1300		1300	1300
Borg El-Arab			Solar/Therma	300									300		300								
Kurimat	1	Upper Egypt	Solar/Therma	150	150																		
Dabaa Nuclear	1..5		Nuclear	1000								1000					1000		1000		1000		1000
New Naga Han	4		Hydro	64	64																		
Assiut			Hydro	40					40														
Damietta			Hydro	13			13																
Zefta			Hydro	5.5				5.5															
Zafarana		East Delta	Wind	125	125																		

Table 1: Egyptian Generation Expansion Plan

Ethiopian generation expansion plan

Commissioning Date	Hydro Project	Capacity MW	Average Generation GWh
2016	Halele Worabesa	420	2 245
2017			
2018			
2019			
2020	Madaya + Baro I + II + Genji	2700	16 509
2021	Geba I + II	368	1 788
2022	Chemoga Yeda + Genale III	534	1 415
2023	Genale IV	256	
2024			
2025	Karadobi	1 600	6 000

Table 2: Ethiopian Generation Expansion Plan

Sudan Generation Expansion Plan

Year	Thermal Plant			Hydro Electric Plant	
	Plant Name	Installed Capacity (MW)	Net Capacity (MW)	Plant Name	Installed Capacity (MW)
2015	Khartoum North ST's (U1&U2) Retired Khartoum North GT's (U3&U4) Retired 1 x Coal Fired Steam	-60 -47 400	-55 -34 380	Low Dal	340
2016				Kajbar	300
2017	1 x Crude Oil Fired Steam 1 x CCGT (6FA based)	250 214	238 208		
2018	1 x Coal Fired Steam	400	380		
2019	1 x CCGT (6FA based) 1 x Crude Oil Fired Steam	214 250	208 238	Dagesh	285
2020	2 x Crude Oil Fired Steam Southern Diesels	1,000 109	950 101	Fula 1	720
2021	1 x Coal Fired Steam	600	570		
2022				Shukoli	210
2023	1 x CCGT (9E based) Khartoum North ST's (U3&U4) Retired	352 -120	342 -102		
2024	1 x OCGT (6FA)	61	60	Lakki	210
2025	1 x Crude Oil Fired Steam	500	475		
2026	1 x CCGT (9E based)	352	342	Bedden	400
2027	2 x CCGT (9E based) 1 x Coal Fired Steam	705 600	683 570		
2028	Garri 1 CCGT's Retired	-220	-164		
2029	2 x CCGT (9EC based)	941	912		
2030	2 x CCGT (9EC based)	941	912		

Table 3: Sudanese Generation Expansion Plan

1.3.3 POWER EXCHANGES

According to the economic study, the Ethiopian System exports:

- 2 000 MW to Egypt
- 1 200 MW to Sudan.
- 1 200 MW to Kenya
- 50 MW to Djibouti

Taking into account the losses in the interconnection which reach:

- 150 MW on the DC interconnections between Egypt and Sudan
- 174 MW on the AC interconnections between Ethiopia and Sudan

The total generation in Ethiopia amounts to 8 737 MW to satisfy the power exchanges and the peak demand.

The unit commitment of Egypt, Ethiopia and Sudan is displayed in Appendix 1 “Unit commitment”.

1.3.4 PLANNING CRITERIA

The planning criteria of the three countries, used in Phase I and Phase II, are recalled hereafter.

1.3.4.1 Egypt

The operational voltage limits are:

In normal condition: The voltage at each bus bar must be kept within 95 % and 105 % of its nominal value.

In emergency condition: (in N-1 or N-2 situations) The voltage at each bus bar must be kept within 90 % and 105 % of its nominal value.

For the analysis of the Egyptian Transmission Master Plan, the following operating rules could be adopted:

In normal conditions: The flows must be kept below the thermal rating of each network element. The generators must operate within their reactive capabilities (generation and absorption).

In emergency situation: (in N-1 or N-2 situations) The emergency thermal rating of any equipment should not be exceeded. The value of the emergency rating for lines and transformers should be specified when necessary.

In transient state: The power system must remain stable following a three-phase to ground fault normally cleared by operation of the protection. The generators must operate in synchronism without sustained oscillations, power and voltage oscillations must be quickly damped.

Frequency limits:

Under frequency load shedding scheme: threshold of the first stage 49.2 Hz

Over frequency limit: 51 Hz (High Dam Generators)

1.3.4.2 Ethiopia

The operational limits, in normal and emergency situations, are described hereafter.

In normal condition: The flows must be kept below the thermal limit of each network element. The voltage at each bus bar must be kept within 95% and 105% of its nominal value. The 230kV system can be operated up to 245kV (106.5%). The generators must operate within their reactive capabilities (generation and absorption).

In emergency situation: (outage of one element:) The flows are allowed to increase up to 120% of the thermal rating of each element. The voltage dip can reach 10% of the nominal value.

In transient state: The power system must remain stable following a three-phase or a single-phase to ground fault. The generators must operate in synchronism without sustained oscillations, power and voltage oscillations must be quickly damped.

Frequency limits:

Under frequency load shedding scheme: threshold of the first stage 48.6 Hz

Over frequency limit: 52 Hz

1.3.4.3 Sudan

The operational limits, in normal and emergency situations, are described hereafter.

In normal conditions: The flows must be kept below the thermal rating of each network element. The voltage at each bus bar must be kept within 95% and 105% of its nominal value. The generators must operate within their reactive capabilities (generation and absorption).

In emergency situation: (outage of one element:)The thermal rating of any equipment should not be exceeded. The voltage should be kept within 90% and 105 % of its nominal value

In transient state: The power system must remain stable following a three-phase to ground fault cleared within 120 ms. The generators must operate in synchronism without sustained oscillations, power and voltage oscillations must be quickly damped.

Frequency limits:

Under frequency load shedding scheme: threshold of the first stage 49.2 Hz

Over frequency limit: 52 Hz (3s)

2 STUDY OF THE INTERCONNECTED SYSTEM IN PERMANENT STATE FOR THE PEAK LOAD 2025/2026

2.1 STUDY IN NORMAL SITUATION

2.1.1 ANALYSIS OF THE BEHAVIOUR OF THE INTERCONNECTION

2.1.1.1 Analysis of the AC interconnection

The behaviour of the whole interconnected system was satisfactory. The power flow over the lines were below their thermal rating, the voltage profile was within the limits and the units close the interconnection operated within their reactive capacity.

The total flow over the 500 kV and the 200kV interconnections between Ethiopia and Sudan amounted to about 3 521 MW

- 2 x 100 MW flowed from Gonder passing into Shehedi to Gedaref on the 220 kV interconnection
- 4 x 830 MW flowed from Mandaya to Kosti on the 500 kV interconnection

Sudan received 3347 MW :

- 2 x 95 MW arrived at Gedaref from the 220 kV interconnection (phase-shift of the transformer : 38°)
- 4 x 789 MW arrived at Kosti from the 500 kV interconnection

and exported 2150 MW to Egypt through the AC/DC converter station in Kosti

The losses on the AC interconnection amounted to 173.8 MW on the AC interconnection (Ethiopia - Sudan).

The voltage profile was satisfactory, and displayed in the following table :

Substations	Voltage (kV)
Mandaya 400 kV	417.3
Mandaya 500 kV	524.7
Kosti	520
Nag Hammadi	510
Gonder	234.7
Gedaref	224.2

Table 4: Voltage profile along the interconnection

At Mandaya HPP, 7 units were in operation, they generated 1 700 MW and 340 MVAr. The SVC of Kosti and Nag Hammadi generated respectively 73 MVAr and 214 MVAr.

About 88 MVAr were provided by the interconnection at Mandaya. At Kosti substation, about 132 MVAr flowed from Kosti to supply the reactive compensation of the line. Taking into account, the reactive compensation of the four circuits, the interconnected system supplied about 44 MVAr to the 500 kV interconnection.

2.1.1.2 Analysis of the DC interconnection

At Nag Hammadi, the AC / DC converter station provided 2 000 MW and absorbed 180 MVAr taking into account the capacitor filters.

The SVC supplied this reactive consumption and sent about 35 MVAr to the Egyptian System to support the voltage profile at Nag Hammadi.

At Kosti, The AC / DC converter station absorbed 2 154 MW and 78 MVAr taking into account the capacitor filters.

The SVC supplied this reactive consumption.

2.1.2 ANALYSIS OF THE BEHAVIOUR OF THE EGYPTIAN NETWORK CLOSE TO NAG HAMMADI

The active flow over the lines belonging to the 500 kV network of the Upper Nil area are displayed in the following table:

Circuit	Nb of circuits	Flow / Circuit (MW)	Loading (%)
From High Dam to Nag Hammadi	2	196	10.6
Nag Hammadi to Assiut	1	171	10.5
Nag Hammadi to Sohag	1	307	18
Samalut to Assiut	2	303	17.4
Kurimat to Samalut	2	791	44.8
Samalut from S.Giza	1	274	21.9

Table 5: Loading of the Egyptian 500kV network H.D. – Cairo

The transmission lines closed to the interconnection point Nag Hammadi were lightly loaded.

The balance point between the flows from the south (HD & Interconnection) and from the north (Kurimat & Cairo) is Assiut.

At Nag Hammadi, about 750 MW flowed through the four 285 MVA 500 / 132 kV transformers and 1 160 MW over the three 750 MVA 500 / 220 kV transformers.

The voltage profile in the substations of the Upper Nil area is displayed in the following table:

Substations	Voltage (kV)
High Dam 500 kV	525
Nag Hammadi 500 kV	510
Sohag 500 kV	508
Assiut 500 kV	512
Samalut 500 kV	516
Kurimat 500 kV	525

Table 6: Voltage profile In the Upper Nil Area

2.1.3 ANALYSIS OF THE BEHAVIOUR OF THE ETHOPIAN NETWORK CLOSE TO MANDAYA

The active flow over the 400 kV circuits between Addis Ababa and Mandaya are displayed in the following table:

Circuit	Nb of circuits	Flow/Circuit (MW)	Loading (%)
Karadobi to Ghedo	2	551	50
Ghedo to Sebeta	2	271	37
Ghedo to Ghimbi	2	274	39.4
Metu to Ghimbi	3	377	51
Ghimbi to Mandaya	3	552	76

Table 7: Loading of the Ethiopian 400kV network between Mandaya and Addis Ababa

The lines Karadobi – Ghedo and Ghimbi – Mandaya were heavily loaded (more than 50%). About 1 630 MW flowed through the four 510 MVA 400/500 kV transformers (81%) of Mandaya substation.

The voltage profile in the substations between Addis Ababa and Mandaya is displayed in the following table:

Substations	Voltage (kV)
Sebeta 400 kV	411
Karadobi 400 kV	417
Ghedo 400 kV	418
Metu 400 kV	419
Ghimbi 400 kV	419
Mandaya 400 kV	417

Table 8: Voltage profile In Mandaya area

The flows over the 230 kV circuits connected to Gonder are displayed in the following table:

Circuit	Nb of circuits	Flow/Circuit (MW)	Loading (%)
Bahir Dar to Gonder	2	154	55
Hummera to Gonder	1	8	16

Table 9: Loading of the 230kV circuits connected to Gonder

2.1.4 *Analysis of the behaviour of the Sudanese Network close to Kosti.*

The active flow over the 500 kV circuits connecting Kosti to the Sudanese System is displayed in the following table:

Circuit	Nb of circuits	Flow/Circuit (MW)	Loading (%)
Kosti to Jebel Aulia	1	379	21
Kosti to Meringan	2	672	35
Fula to Kosti	2	288	22
Meringan to Hassa Heisa	1	575	30
Gedaref to Meringan	1	14	5

Table 10: Loading of the Sudanese 500kV circuits connected to Kosti

With a second 500kV circuit Kosti-Meringan, the network was not excessively loaded to supply the 220kV system.

About 184 MW flowed through the two 300 MVA 500/220 kV transformers at Kosti.

The voltage profile in the substations in Kosti area is displayed in the following table:

Substations	Voltage (kV)
Fula 500 kV	523
Gedaref 500 kV	519
Hassa Heisa 500 kV	515
Jebel Aulia 500 kV	518
Meringan 500 kV	516

Table 11: Voltage profile In the Kosti area

2.2 STUDY IN N-1 SITUATION FOR THE 2025 / 2026 PEAK PERIOD

2.2.1 N-1 SITUATION ON THE INTERCONNECTION

2.2.1.1 Tripping of one of the two 230 kV circuits Gonder - Shehedi

Following the tripping, the behaviour of the interconnection was satisfactory, no overload occurred. About 87% of the initial flow was transferred on the remaining circuit that was 63% loaded (174 MW, 0.443kA).
The phase-shift transformer was not activated, the angle remained equal to 38°

The voltage profile was not significantly affected

2.2.1.2 Tripping of one of the two 220 kV circuits Shehedi - Gedaref

Following the tripping, the behaviour of the interconnection was satisfactory, no overload occurred. About 86% of the initial flow was transferred on the remaining circuit that was 43% loaded (164 MW, 0.432kA).
The phase-shift transformer was not activated, the angle remained equal to 38°

The voltage profile was not significantly affected

2.2.1.3 Tripping of the phase-shift transformer at Gedaref

Following the tripping, no overload occurred but the voltage profile was not acceptable on the 220kV interconnection.

All the power exchange flowed over the four 500kV circuits that were 47% loaded (886MW, 0.991kA).

The voltage profile on the 220kV interconnection was too high, it reached:

- 246.2kV at Shehedi (+7%)
- 249.5kV at Gedaref (+13.4%)

Taking into account the reactive compensation of the line that amount to 60MVAr (4 X 15MVAr reactors). To overcome this constraint, it would be necessary to connect one 20MVAr reactor to the Geradef 220kV busbar following the tripping of the phase-shift transformer. Resulting of the simulation in transient state, one 20MVAr shunt reactor allowed to reach a voltage equal to 244kV at Gedaref which is below the 245kV limit of the equipment. It could be also possible to disconnect the two 220kV circuits Gedaref - Shehedi.

2.2.1.4 Tripping of one of the four 500 kV circuits Mandaya - Kosti

Following the tripping, the behaviour of the interconnection was satisfactory, no overload occurred.

About 3 600MW flowed over the interconnection, 3 306MW over the three remaining 500kV circuits and 290MW on the 220kV interconnection. The losses on the interconnection increased by 40%.

The voltage profile was slightly affected on the interconnection. The voltage deep reached:

- 3.5kV at Mandaya
- 9kV at Kosti.

The SVC connected to Kosti, operated at its maximum value (492MVAr).

By increasing the angle of the phase-shift transformer at Gedaref, it would be possible to reduce the flow over the 220kV interconnection to about 240MW.

2.2.1.5 Tripping of one of the four 400/500 kV transformers at Mandaya substation

Following the tripping, the three remaining 510MVA transformer were overloaded by 7%, which is acceptable in N-1 situation (20% acceptable overload).

The flow over the 220kV interconnection increased by 4% (104MW instead of 100MW).

The voltage profile was not significantly affected.

2.2.1.6 Tripping of one of the 2 DC poles

The tripping of one of the 2 DC circuits (pole or converter station) is examined in dynamic part of the report.

2.2.2 N-1 SITUATION IN EGYPT CLOSE TO THE INTERCONNECTION POINT : NAG HAMMADI

The purpose of this analysis is to assess the impact of the injection of 2000 MW power exchange at Nag Hammadi on the 500kV transmission system of the Upper Nile area in N-1 situation. The following situations were examined:

- Tripping of one of the two 500 kV circuits High Dam - Nag Hammadi
- Tripping of the 500 kV circuit Nag Hammadi - Sohag
- Tripping of the 500 kV circuit Nag Hammadi - Assiut
- Tripping of one of the two the 500 kV circuits Kurimat – Samalut
- Tripping of the Static Var Compensator (SVC) connected to Nag Hammadi

Whatever the tripped circuit in the 500 kV system in the Upper Nile Valley, the behaviour of the system was satisfactory. For the tripping of one 500kV circuit connected to Nag Hammadi, the flow over the remaining circuits remained below 30% of their nominal rating.

The worst case appeared for the tripping of one of the two 500kV circuits Kurimat – Samalut that supplied the Upper Nile area, the remaining circuit was 70% loaded.

Whatever the tripped circuit, the voltage profile was not significantly affected thanks to the 300MVAr SVC connected to Nag Hammadi. The maximum voltage drop reached 3.6%.

The tripping of one of the two DC poles is examined in the chapter devoted to the transient state analysis.

The detailed results are displayed in Appendix.

2.2.3 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT : MANDAYA

The purpose of this analysis is to assess the impact of the export of 3200 MW from Ethiopia on the 400kV transmission system located between Mandaya HPP and Addis-Ababa area in N-1 situation. The following situations were examined:

- Tripping of one of the three 400 kV circuits Mandaya – Ghimbi
- Tripping of one of the two 400kV circuits Karadobi - Ghedo
- Tripping of one of the two 400 kV circuits Ghimbi - Ghedo
- Tripping of one the two 400 kV circuits Ghedo - Sebeta
- Tripping of one the two 400 kV circuits Debre Markos – Sululta
- Tripping of one the two 230 kV circuits Bahir Dar – Gonder

For two out of the six N-1 situations examined, some constraints appeared on the Ethiopian System:

- The tripping of one of the two circuits Karadobi – Ghedo induced unacceptable 26% overload on the remaining circuit
- The tripping of one of the three circuits Ghimbi – Mandaya circuits induced acceptable 13% overload on the two remaining circuits

To operate the transmission system in a satisfactory way, it is proposed:

- To equipped the double circuit line Karadobi – Ghedo with three 450mm² bundle conductors.
- To adapt the unit commitment at Mandaya HPP and to decreased the phase-shift transformer angle of Gedaref following the tripping of Ghimbi – Mandaya.

With such improvement, the behaviour of the Ethiopian System was satisfactory whatever the tripped circuit.

The detailed results are displayed Appendix.

2.2.4 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The purpose of this analysis is to assess the impact of the import of 3200 MW from Ethiopia on the 500kV transmission system connected to Kosti in N-1 situation. The following situations were examined:

- Tripping of the 500 kV circuit Kosti - Jebel Aulia
- Tripping of one the two 500 kV circuits Kosti - Meringan
- Tripping of one of the two 500 kV circuits Kosti - Fula
- Tripping of the SVC in Kosti

One second 500kV circuit Kosti – Gedaref was necessary to discharge the power arriving from the 500kV interconnection and from Fula TPP. The year of commissioning of this second circuit will depend on the installation of new generating units in Fula area.

With two 500kV circuits in operation between Kosti and Gedaref, the behaviour of the Sudanese system close to the interconnection was satisfactory in N-1 situation. Following the tripping of one of the 500 kV circuit connected to Kosti, the power flow over the transmission system remained far below the thermal limit of the circuits. The voltage profile was not significantly affected thanks to the 500MVAr SVC connected to Kosti.

The tripping of one of the two DC poles is examined in the chapter devoted to the transient state analysis.

The detailed results are displayed Appendix.

3 STUDY OF THE SHORT-CIRCUIT POWER

Three-phase to ground and one-phase to ground short-circuit calculations were performed taking into account the following assumptions:

- V = 1.1 Vn
- Impedance of generator = X"d (sub transient reactance)

All the units were assumed to be in operation.

At Nag Hammadi, the ratio "short circuit power / installed power of the ACDC station" was equal to 4.8 that allows satisfactory operation of the converter station.

At Kosti, the ratio "short circuit power / installed power of the ACDC station" was equal to 6.6 that allows satisfactory operation of the converter station.

The results are displayed Appendix.

4 STUDY OF THE INTERCONNECTED SYSTEM IN TRANSIENT STATE FOR THE 2025/ 2026 PEAK PERIOD

4.1.1 PRESENTATION

The study examined the impact on the interconnected system of a fault located on the AC and DC interconnection and on the VHV circuits connected to the interconnection point Nag Hammadi in Egypt, Mandaya in Ethiopia and Kosti in Sudan.

The fault consisted in three phase to ground short circuit for the AC system and blocking or the tripping of a pole for the DC system. The fault was cleared by tripping of the faulted element following the normal operation of the protection.

For the AC interconnection, the fault is successively located at each end of the line.

4.1.2 N-1 SITUATION ON THE INTERCONNECTION

Following the tripping of one of the four 500 kV circuits between Mandaya and Kosti or one of the four 500/400 kV transformers at Mandaya, the behaviour of the system was satisfactory, no overload occurred on the system, Ethiopian and Sudanese systems operated in synchronism, no major disturbance appeared in Egypt. The interconnected system was able to exchange 3200 MW, even with one 500 kV circuit out of operation.

The tripping of one of the two DC poles did not induce any loss of synchronism in Ethiopia and Sudan. The frequency surge, due to the reduction of half of the power exported to Egypt (1000 MW out of 2000 MW), induced a frequency surge in Ethiopia and Sudan below 1%. The system frequency recovered a value close to 50.15 Hz 15 seconds after the fault.

In Egypt the frequency decreased down to 49.84 Hz and recovered a value close 49.88 Hz 15 seconds after the fault.

The temporary blocking of the AC/DC converter stations, due to a commutation fault of the converters or a short circuit in the vicinity of Kosti and Nag Hammadi, did not induce major disturbance in the three systems. Voltage surge and frequency surge in Sudan and Ethiopia remained far below the acceptable limits in transient state. In Egypt, the frequency decline reached 0.2%.

4.1.3 N-1 SITUATION IN EGYPT CLOSE TO THE INTERCONNECTION POINT : NAG HAMMADI

The power imported from Ethiopia supplied the local demand in Nag Hammadi area. Therefore, the power flows over the 500 kV circuits of the Upper Nile network were far below their rating. Whatever the location of the fault and the tripped circuit, the behaviour of the system was satisfactory, no overload occurred, the generators operated in synchronism, all the oscillations were totally damped in 15 seconds.

Following the tripping of the largest unit in operation at Abu Kir generating 615MW, the system frequency decreased to 49.88Hz and recovered a value equal to 49.94Hz in 20 seconds.

4.1.4 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT : MANDAYA

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Ethiopian network close to Mandaya. The generators operated in synchronism with the Sudanese generators, the voltage oscillations were well damped.

Following the tripping of 2 units of Mandaya, the behaviour of the interconnected system was satisfactory, Ethiopia and Sudan operated in synchronism. The Ethiopia-Sudan frequency dropped to 49.78 Hz, before recovering to 49.94 Hz.

4.1.5 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Sudanese network close to Kosti. Whatever the location of the fault and the tripped circuit, the generators operated in synchronism with the Ethiopian generators, all the oscillations were totally damped in less than 15 seconds.

Following the tripping of the largest steam unit in operation at Port Sudan, generating 579MW, the system frequency dropped to 49.7 Hz, before recovering to 49.92 Hz.

5 CONCLUSION

5.1 GENERAL

To demonstrate that it was possible to export 3200 MW from Ethiopia to Sudan and Egypt, the operation of the interconnected system was simulated in year 2025 for the period of the annual peak load demand.

Simulations were carried out in permanent state to calculate the power flows over the transmission system, the voltage profile and the active and reactive generation of the generators. Contingency situations, consisting in the tripping of one element belonging to the interconnection and to the network feeding Mandaya, Kosti and Nag Hammadi substations, were examined. Whatever the situation, the Interconnected System must be able to satisfy the power exchanges and operate within the acceptable limits.

Simulations were also performed in transient state to verify that the System was able to recover an acceptable situation without loss of synchronism of any generator or sustained oscillations.

The results of the simulations are presented hereafter.

5.2 RESULTS

Whatever the situation, Ethiopia can export 2000 MW to Egypt and 1200 MW to Sudan. The 220 kV interconnection equipped with one 350 MVA phase shift transformer at Gedaref can operate in parallel with the 500 kV link and transmit about 200MW in normal situation.

5.2.1 CONCERNING THE INTERCONNECTION ITSELF, THE MAIN POINTS CAN BE UNDERLINED.

Following the tripping of one of the four 500 kV circuits between Mandaya and Kosti or one of the four 500/400 kV transformers at Mandaya, the behaviour of the system was satisfactory, no overload occurred on the system, Ethiopian and Sudanese systems operated in synchronism, no major disturbance appeared in Egypt. The interconnected system was able to exchange 3200 MW, even with one 500 kV circuit out of operation.

The tripping of one of the two DC poles did not induce any loss of synchronism in Ethiopia and Sudan. The frequency surge, due to the reduction of half of the power exported to Egypt (1000 MW out of 2000 MW), induced a frequency surge in Ethiopia and Sudan below 1%. The system frequency recovered a value close to 50.15 Hz 15 seconds after the fault.

In Egypt the frequency decreased down to 49.84 Hz and recovered a value close 49.88 Hz 15 seconds after the fault.

The temporary blocking of the AC/DC converter stations, due to a commutation fault of the converters or a short circuit in the vicinity of Kosti and Nag Hammadi, did not induce major disturbance in the three systems. Voltage surge and frequency surge in Sudan and Ethiopia remained below the acceptable limits in transient state. In Egypt, the frequency decline reached 0.2%.

5.2.2 *CONCERNING THE EGYPTIAN SYSTEM, THE FOLLOWING POINTS CAN BE UNDERLINED.*

The power imported from Ethiopia supplied the local demand in Nag Hammadi area. Therefore, the power flows over the 500 kV circuits of the Upper Nile network were far below their rating. Whatever the location of the fault and the tripped circuit, the behaviour of the system was satisfactory, no overload occurred, the generators operated in synchronism, all the oscillations were totally damped in 15 seconds.

5.2.3 *CONCERNING THE ETHIOPIAN SYSTEM THE FOLLOWING POINTS CAN BE UNDERLINED.*

Ethiopia can export 3200 MW to Sudan and in normal situation and following the tripping of any 400 kV and 230 kV circuit in the vicinity of Mandaya and Gonder. Whatever the fault, the Ethiopian system operated within the acceptable limits in N-1 condition.

To discharge the generation of Karadobi HPP, that amounts to 1600 MW, it is proposed to equip the 400 kV double circuit line between Karadobi and Ghedo with three 450 mm2 bundle conductors. With such equipment, no overload occurred on the remaining circuit when one circuit Karadobi- Ghedo was tripped.

Following a short circuit, the behaviour of the system was satisfactory, the generators operated in synchronism with the Sudanese generators, voltage oscillations were well damped.

5.2.4 *CONCERNING THE SUDANESE SYSTEM THE FOLLOWING POINTS CAN BE UNDERLINED.*

The Sudanese system can import 3200 MW from Ethiopia over the 500 kV and 220 kV interconnections operating in parallel and feed the 2000 MW AC/DC converter station at Kosti.

The behaviour of the system was satisfactory in normal and in N-1 situation.

To discharge the power generated by Fula TPP that added to the 1000 MW arriving at Kosti from Ethiopia, one second 500 kV circuit must be in operation between Kosti and Meringan. This second circuit avoid unacceptable overloads of the under laying 220 kV network in case of tripping of the first 500 kV circuit. This second circuit will have to be commissioned in phase with the increase of installed power in Fula TPP.

With such equipment, whatever the location of the fault and the tripped circuit, the behaviour of the system was satisfactory, no overload occurred, the generators operated in synchronism, all the oscillations were totally damped in less than 15 seconds.

APPENDIX

1 LOAD FLOW RESULTS – PEAK LOAD 2025 / 2026

1.1 INITIAL SYSTEM – NORMAL SITUATION

1.1.1 EGYPTIAN NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
A.Z.500	BASII500	-845.71	-41.96	846.75	950.2	1.62	-6.26	2020.7	46.9
A.Z.500	HELIO500	1979.82	93.27	1982.01	2224.1	8.37	7.44	4000.0	55.6
A.Z.500	N.DELTA500*	-1243.72	-52.74	1244.84	1396.9	11.98	82.89	2000.0	69.8
A.Z.500	SUEZ500	-941.13	-73.19	943.97	1059.3	8.12	-3.60	2049.6	51.7
A.Z.500	SUEZ500	-941.13	-73.19	943.97	1059.3	8.12	-3.60	2049.6	51.7
A.Z.500	TEB.500	159.75	-215.77	268.47	301.3	0.39	-92.46	2020.7	14.9
ABKIR500	KAFR.Z500	436.64	161.83	465.67	512.4	1.66	-72.35	2000.0	25.6
ABKIR500	KAFR.Z500	436.64	161.83	465.67	512.4	1.66	-72.35	2000.0	25.6
ABKIR500	N.DELTA500*	-171.81	-96.18	196.90	216.7	0.47	-210.63	2000.0	10.8
AKABA400	S_AQA400***	-98.85	-25.37	102.05	148.1	0.01	-5.12	2562.0	5.7
AKABA400	S_AQA400***	-98.85	-25.37	102.05	148.1	0.01	-5.12	2562.0	5.7
AMOUS500	SUEZ500	508.02	69.93	512.81	563.5	0.43	-15.71	2049.6	27.5
AMOUS500	SUEZ500	508.02	69.93	512.81	563.5	0.43	-15.71	2049.6	27.5
AMOUS500	TABA500	5.16	-43.43	43.74	48.1	0.14	-247.80	2049.6	2.3
AUST500	N.H.500	-170.27	-68.88	183.68	207.1	0.50	-198.90	1963.0	10.5
AUST500	SAML500	-301.79	-93.03	315.81	356.0	1.06	-130.87	1963.0	17.4
AUST500	SAML500	-301.79	-93.03	315.81	356.0	1.06	-130.87	1963.0	17.4
AUST500	SOHAG500	-4.17	8.56	9.52	10.7	0.04	-111.01	1960.0	0.5
BASII500	A.Z.500	847.33	35.70	848.08	948.6	1.62	-6.26	2020.7	46.9
BASII500	C.W.500	-1182.38	-203.03	1199.68	1341.9	0.94	5.33	2020.7	66.4
BASII500	KAFR.Z500	-292.44	33.09	294.31	329.2	0.71	-84.85	2000.0	16.5
BASII500	KAFR.Z500	-292.44	33.09	294.31	329.2	0.71	-84.85	2000.0	16.5
C.W.500	BASII500	1183.32	208.36	1201.52	1340.1	0.94	5.33	2020.7	66.4
C.W.500	CAIRO500	-477.77	433.05	644.82	719.2	0.51	-8.77	2020.7	36.2
CAIRO500	C.W.500	478.28	-441.81	651.12	731.5	0.51	-8.77	2020.7	36.2
CAIRO500	KRIMA500	-13.03	-215.45	215.84	242.5	0.24	-134.66	1963.0	12.4
CAIRO500	NOBAR500	-3562.59	202.02	3568.31	4009.0	49.61	553.02	4041.5	99.2
CAIRO500	NOBAR500	-1781.29	101.01	1784.15	2004.5	24.80	276.51	2020.7	99.2
CAIRO500	S.GIZA500	553.80	-9.39	553.88	622.3	3.35	-88.03	1700.0	36.6
CAIRO500	S.GIZA500	553.80	-9.39	553.88	622.3	3.35	-88.03	1700.0	36.6
D1H.D.5	H.D.500	-196.18	22.53	197.47	217.1	0.00	0.00	2049.6	10.6
D1H.D.5	N.H.500	196.18	-22.92	197.51	217.2	0.92	-234.13	2049.6	15.9

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
D2H.D.5	H.D.500	-196.18	22.53	197.47	217.1	0.00	0.00	2049.6	10.6
D2H.D.5	N.H.500	196.18	-22.92	197.51	217.2	0.92	-234.13	2049.6	15.9
DABAA500	SALOUM500	227.32	-129.56	261.65	288.9	1.26	-292.89	2000.0	14.4
DABAA500	SKRIR500	2126.35	-47.61	2126.88	2348.5	20.28	99.02	4000.0	58.7
DABAA500	SKRIR500	1063.18	-23.80	1063.44	1174.2	10.14	49.51	2000.0	58.7
H.D.500	D1H.D.5	196.18	-22.53	197.47	217.1	0.00	0.00	2049.6	10.6
H.D.500	D2H.D.5	196.18	-22.53	197.47	217.1	0.00	0.00	2049.6	10.6
HELIO500	A.Z.500	-1971.44	-85.83	1973.31	2229.5	8.37	7.44	4000.0	55.6
HELIO500	TEB.500	-710.40	-370.23	801.09	905.1	2.68	-17.69	1750.0	51.7
KAFR.Z500	ABKIR500	-434.98	-234.18	494.01	556.2	1.66	-72.35	2000.0	25.6
KAFR.Z500	ABKIR500	-434.98	-234.18	494.01	556.2	1.66	-72.35	2000.0	25.6
KAFR.Z500	BASII500	293.15	-117.94	315.98	355.8	0.71	-84.85	2000.0	16.5
KAFR.Z500	BASII500	293.15	-117.94	315.98	355.8	0.71	-84.85	2000.0	16.5
KRIMA500	CAIRO500	13.27	80.79	81.87	90.0	0.24	-134.66	1963.0	12.4
KRIMA500	SAML500	790.77	10.01	790.83	869.5	7.88	-59.84	1963.0	44.8
KRIMA500	SAML500	790.77	10.01	790.83	869.5	7.88	-59.84	1963.0	44.8
KRIMA500	TEB.500	1003.87	-16.50	1004.01	1103.9	4.66	2.68	2020.7	54.6
N.DELTA500*	A.Z.500	1255.70	135.64	1263.00	1388.7	11.98	82.89	2000.0	69.8
N.DELTA500*	ABKIR500	172.28	-114.45	206.83	227.4	0.47	-210.63	2000.0	10.8
N.H.500	AUST500	170.78	-130.02	214.64	243.0	0.50	-198.90	1963.0	10.5
N.H.500	D1H.D.5	-195.26	-211.20	287.63	325.6	0.92	-234.13	2049.6	15.9
N.H.500	D2H.D.5	-195.26	-211.20	287.63	325.6	0.92	-234.13	2049.6	15.9
N.H.500	N.H500_ACDC**	-1996.94	180.36	2005.07	2269.9	0.01	0.09	6384.0	35.6
N.H.500	SOHAG500	307.23	-42.09	310.10	351.1	0.86	-99.27	1960.0	17.9
N.H500_ACDC**	N.H.500	1996.95	-180.27	2005.07	2270.0	-	-	6384.0	-
N.OCTO_500	S.GIZA500	-186.95	-194.99	270.13	314.1	0.61	-120.74	1700.0	18.5
NOBAR500	CAIRO500	3612.19	351.00	3629.21	4004.5	49.61	553.02	4041.5	99.2
NOBAR500	CAIRO500	1806.10	175.50	1814.60	2002.2	24.80	276.51	2020.7	99.2
NOBAR500	SKRIR500	-4070.46	546.56	4106.99	4531.7	55.80	405.81	6062.2	74.8
S.GIZA500	CAIRO500	-550.45	-78.64	556.04	631.8	3.35	-88.03	1700.0	36.6
S.GIZA500	CAIRO500	-550.45	-78.64	556.04	631.8	3.35	-88.03	1700.0	36.6
S.GIZA500	N.OCTO_500	187.56	74.25	201.72	229.2	0.61	-120.74	1700.0	18.5
S.GIZA500	SAML500	274.39	-180.43	328.40	373.1	1.20	-156.88	1700.0	21.9
S_AQA400	AKABA400***	98.86	20.25	100.92	146.3	0.01	-5.12	2562.0	5.7
S_AQA400	AKABA400***	98.86	20.25	100.92	146.3	0.01	-5.12	2562.0	5.7
S_AQA400	S_TAB400***	-197.73	-40.51	201.83	292.7	0.34	-79.66	2562.0	11.4
S_TAB400	S_AQA400***	198.06	-39.16	201.90	292.3	0.34	-79.66	2562.0	11.4
S_TAB400	TABSW400***	-198.06	39.16	201.90	292.3	0.11	-9.57	2562.0	11.5
SALOUM500	DABAA500	-226.06	-163.33	278.89	311.8	1.26	-292.89	2000.0	14.4
SALOUM500	TOBROK500	107.99	11.28	108.58	121.4	0.25	-159.01	2020.0	6.0
SAML500	AUST500	302.86	-37.84	305.21	341.4	1.06	-130.87	1963.0	17.4
SAML500	AUST500	302.86	-37.84	305.21	341.4	1.06	-130.87	1963.0	17.4
SAML500	KRIMA500	-782.89	-69.85	786.00	879.1	7.88	-59.84	1963.0	44.8
SAML500	KRIMA500	-782.89	-69.85	786.00	879.1	7.88	-59.84	1963.0	44.8
SAML500	S.GIZA500	-273.19	23.56	274.21	306.7	1.20	-156.88	1700.0	21.9
SKRIR500	DABAA500	-2106.07	146.63	2111.17	2336.5	20.28	99.02	4000.0	58.7

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
SKRIR500	DABAA500	-1053.03	73.31	1055.58	1168.3	10.14	49.51	2000.0	58.7
SKRIR500	NOBAR500	4126.26	-140.76	4128.66	4569.4	55.80	405.81	6062.2	74.8
SOHAG500	AUST500	4.21	-119.57	119.65	136.0	0.04	-111.01	1960.0	0.5
SOHAG500	N.H.500	-306.36	-57.18	311.65	354.2	0.86	-99.27	1960.0	17.9
SUEZ500	A.Z.500	949.25	69.59	951.79	1048.9	8.12	-3.60	2049.6	51.7
SUEZ500	A.Z.500	949.25	69.59	951.79	1048.9	8.12	-3.60	2049.6	51.7
SUEZ500	AMOUS500	-507.59	-85.64	514.76	567.3	0.43	-15.71	2049.6	27.5
SUEZ500	AMOUS500	-507.59	-85.64	514.76	567.3	0.43	-15.71	2049.6	27.5
TABA500	AMOUS500	-5.02	-204.36	204.43	230.3	0.14	-247.80	2049.6	2.3
TABSW400	S_TAB400***	198.17	-48.73	204.08	295.7	0.11	-9.57	2562.0	11.5
TEB.500	A.Z.500	-159.35	123.31	201.49	222.3	0.39	-92.46	2020.7	14.9
TEB.500	HELIO500	713.08	352.54	795.47	877.7	2.68	-17.69	1750.0	51.7
TEB.500	KRIMA500	-999.21	19.18	999.39	1102.7	4.66	2.68	2020.7	54.6
TOBROK500	SALOUM500	-107.74	-170.30	201.52	229.6	0.25	-159.01	2020.0	6.0

*N.Delta 500 has been replaced by W.Domatia 500 kV, in the latest 2015 Egyptian data
** N.H500_ACDC : DC/AC converter station in Nag Hammadi
*** Egypt exported 200 MW to Jordan

Table appendix 1.1-1 - Power flow on the Egyptian 400 and 500 kV lines

Substation.	V sol [pu]	V sol [kV]
A.Z.500	1.029	514.5
ABKIR500	1.048	524
AMOUS500	1.049	524.5
AUST500	1.031	515.5
BASII500	1.043	521.5
C.W.500	1.042	521
CAIRO500	1.032	516
DABAA500	1.044	522
H.D.500	1.05	525
HELIO500	1.033	516.5
KAFR.Z500	1.047	523.5
KRIMA500	1.050	525
N.DELTA500	1.050	525
N.H.500	1.019	509.5
N.OCT500	1.028	514
NH500_ACDC	1.019	509.5
NOBAR500	1.043	521.5
S.GIZA500	1.031	515.5
SALOUM500	1.024	512
SAML500	1.034	517
SKRIR500	1.041	520.5
SOHAG500	1.017	508.5
SUEZ500	1.047	523.5

Substation.	V sol [pu]	V sol [kV]
TABA500	1.024	512
TEB.500	1.043	521.5
TOBROK500	1.012	506
TABSW400	0.996	398.4

Table appendix 1.1-2 - Voltage of the Egyptian 500 kV substations

1.1.2 Ethiopian Network

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
1MANDAS81	2RABAK81*	829.37	-187.25	850.25	935.7	40.94	-235.58	2128.0	44.0
1MANDAS81	2RABAK81*	829.37	-187.25	850.25	935.7	40.94	-235.58	2128.0	44.0
1MANDAS81	2RABAK81*	829.37	-187.25	850.25	935.7	40.94	-235.58	2128.0	44.0
1MANDAS81	2RABAK81*	829.37	-187.25	850.25	935.7	40.94	-235.58	2128.0	44.0

* Rabak was replaced by Kosti

Table appendix 1.1-3 - Power flow on the 500 kV Interconnection

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1B.DAR3S71	1BELESS71	-218.53	25.47	220.01	302.9	0.76	-34.92	1010.0	30.0
1B.DAR3S71	1BELESS71	-218.53	25.47	220.01	302.9	0.76	-34.92	1010.0	30.0
1B.DAR3S71	1D.MARS71	107.20	-63.18	124.44	171.3	0.54	-120.66	1010.0	17.0
1BARO2S71	1BAROS71	439.80	-37.91	441.43	607.1	0.90	-43.30	2020.0	29.9
1BAROS71	1BARO2S71	-438.89	-5.39	438.93	604.6	0.90	-43.30	2020.0	29.9
1BAROS71	1GENJIS71	-205.19	6.23	205.29	282.8	0.20	-11.02	1010.0	28.0
1BAROS71	1METUS71	411.72	-35.34	413.23	569.2	1.32	-20.29	1515.0	37.6
1BAROS71	1METUS71	411.72	-35.34	413.23	569.2	1.32	-20.29	1515.0	37.6
1BELESS71	1B.DAR3S71	219.29	-60.39	227.45	313.6	0.76	-34.92	1010.0	30.0
1BELESS71	1B.DAR3S71	219.29	-60.39	227.45	313.6	0.76	-34.92	1010.0	30.0
1D.MARS71	1B.DAR3S71	-106.67	-57.48	121.17	167.5	0.54	-120.66	1010.0	17.0
1D.MARS71	1KARADS71	-207.10	34.22	209.91	290.2	0.42	-21.60	1010.0	28.7
1D.MARS71	1KARADS71	-207.10	34.22	209.91	290.2	0.42	-21.60	1010.0	28.7
1D.MARS71	1SULULS71	335.35	-35.61	337.23	466.2	6.15	-93.04	1010.0	46.2
1D.MARS71	1SULULS71	335.35	-35.61	337.23	466.2	6.15	-93.04	1010.0	46.2
1GEBAS71	1METUS71	343.01	-38.08	345.12	475.2	1.38	-20.82	1010.0	47.1
1GENALE3S71	1GENALE4S71	-238.23	-29.66	240.07	332.2	1.07	-41.78	1010.0	32.9
1GENALE3S71	1W.SODS71	477.31	-75.73	483.28	668.7	16.12	-62.24	1010.0	66.2
1GENALE4S71	1GENALE3S71	239.30	-12.12	239.61	329.7	1.07	-41.78	1010.0	32.9
1GENJIS71	1BAROS71	205.39	-17.25	206.12	283.8	0.20	-11.02	1010.0	28.0
1GG2S71	1GGOS71	13.04	12.40	18.00	24.8	0.01	-25.59	1010.0	5.5
1GG2S71	1GIBE3S71	44.46	18.76	48.25	66.4	0.22	-90.60	1010.0	6.6
1GG2S71	1SEBETS71	341.36	-34.29	343.08	472.0	5.75	-85.53	1010.0	47.2

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1GGOS71	1GG2S71	-13.03	-38.00	40.17	55.4	0.01	-25.59	1010.0	5.5
1GHEDOS71	1GHIMBIS71	271.97	-89.23	286.24	395.2	3.50	-98.24	1010.0	39.1
1GHEDOS71	1GHIMBIS71	271.97	-89.23	286.24	395.2	3.50	-98.24	1010.0	39.1
1GHEDOS71	1KARADS71	-544.47	58.30	547.59	756.0	5.59	-22.31	1515.0	49.9
1GHEDOS71	1KARADS71	-544.47	58.30	547.59	756.0	5.59	-22.31	1515.0	49.9
1GHEDOS71	1SEBETS71	271.68	3.60	271.70	375.1	2.36	-63.53	1010.0	37.1
1GHEDOS71	1SEBETS71	271.68	3.60	271.70	375.1	2.36	-63.53	1010.0	37.1
1GHIMBIS71	1GHEDOS71	-268.47	-9.01	268.62	370.3	3.50	-98.24	1010.0	39.1
1GHIMBIS71	1GHEDOS71	-268.47	-9.01	268.62	370.3	3.50	-98.24	1010.0	39.1
1GHIMBIS71	1MANDAS71	550.86	-60.49	554.17	763.8	8.52	-10.23	1010.0	75.6
1GHIMBIS71	1MANDAS71	550.86	-60.49	554.17	763.8	8.52	-10.23	1010.0	75.6
1GHIMBIS71	1MANDAS71	550.86	-60.49	554.17	763.8	8.52	-10.23	1010.0	75.6
1GHIMBIS71	1METUS71	-372.48	29.95	373.68	515.1	4.02	-44.53	1010.0	51.0
1GHIMBIS71	1METUS71	-372.48	29.95	373.68	515.1	4.02	-44.53	1010.0	51.0
1GHIMBIS71	1METUS71	-372.48	29.95	373.68	515.1	4.02	-44.53	1010.0	51.0
1GIBE3S71	1GG2S71	-44.24	-109.36	117.97	165.4	0.22	-90.60	1010.0	6.6
1GIBE3S71	1W.SODS71	154.57	-66.52	168.27	236.0	0.50	-44.68	1010.0	23.4
1GIBE3S71	1W.SODS71	154.57	-66.52	168.27	236.0	0.50	-44.68	1010.0	23.4
1KALITS71	1SEBETS71	-270.75	-9.39	270.91	381.5	0.72	-18.59	1010.0	37.8
1KALITS71	1SEBETS71	-270.75	-9.39	270.91	381.5	0.72	-18.59	1010.0	37.8
1KALITS71	1W.SODS71	-227.65	-52.85	233.70	329.1	3.46	-136.61	1010.0	34.0
1KALITS71	1W.SODS71	-227.65	-52.85	233.70	329.1	3.46	-136.61	1010.0	34.0
1KARADS71	1D.MARS71	207.52	-55.83	214.90	297.4	0.42	-21.60	1010.0	28.7
1KARADS71	1D.MARS71	207.52	-55.83	214.90	297.4	0.42	-21.60	1010.0	28.7
1KARADS71	1GHEDOS71	550.06	-80.61	555.94	769.5	5.59	-22.31	1515.0	49.9
1KARADS71	1GHEDOS71	550.06	-80.61	555.94	769.5	5.59	-22.31	1515.0	49.9
1MANDAS71	1GHIMBIS71	-542.34	50.26	544.66	753.5	8.52	-10.23	1010.0	75.6
1MANDAS71	1GHIMBIS71	-542.34	50.26	544.66	753.5	8.52	-10.23	1010.0	75.6
1MANDAS71	1GHIMBIS71	-542.34	50.26	544.66	753.5	8.52	-10.23	1010.0	75.6
1METUS71	1BAROS71	-410.40	15.06	410.67	566.4	1.32	-20.29	1515.0	37.6
1METUS71	1BAROS71	-410.40	15.06	410.67	566.4	1.32	-20.29	1515.0	37.6
1METUS71	1GEBAS71	-341.63	17.26	342.07	471.8	1.38	-20.82	1010.0	47.1
1METUS71	1GHIMBIS71	376.50	-74.47	383.80	529.3	4.02	-44.53	1010.0	51.0
1METUS71	1GHIMBIS71	376.50	-74.47	383.80	529.3	4.02	-44.53	1010.0	51.0
1METUS71	1GHIMBIS71	376.50	-74.47	383.80	529.3	4.02	-44.53	1010.0	51.0
1SEBETS71	1GG2S71	-335.62	-51.24	339.50	476.8	5.75	-85.53	1010.0	47.2
1SEBETS71	1GHEDOS71	-269.32	-67.13	277.56	389.8	2.36	-63.53	1010.0	37.1
1SEBETS71	1GHEDOS71	-269.32	-67.13	277.56	389.8	2.36	-63.53	1010.0	37.1
1SEBETS71	1KALITS71	271.47	-9.20	271.62	381.5	0.72	-18.59	1010.0	37.8
1SEBETS71	1KALITS71	271.47	-9.20	271.62	381.5	0.72	-18.59	1010.0	37.8
1SEBETS71	1SULULS71	-98.77	82.62	128.77	180.9	0.23	-28.08	1010.0	17.9
1SULULS71	1D.MARS71	-329.20	-57.43	334.17	473.0	6.15	-93.04	1010.0	46.2
1SULULS71	1D.MARS71	-329.20	-57.43	334.17	473.0	6.15	-93.04	1010.0	46.2
1SULULS71	1SEBETS71	99.00	-110.69	148.51	210.2	0.23	-28.08	1010.0	17.9
1W.SODS71	1GENALE3S71	-461.19	13.48	461.39	644.8	16.12	-62.24	1010.0	66.2
1W.SODS71	1GIBE3S71	-154.07	21.84	155.61	217.5	0.50	-44.68	1010.0	23.4

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1W.SODS71	1GIBE3S71	-154.07	21.84	155.61	217.5	0.50	-44.68	1010.0	23.4
1W.SODS71	1KALITS71	231.11	-83.76	245.82	343.5	3.46	-136.61	1010.0	34.0
1W.SODS71	1KALITS71	231.11	-83.76	245.82	343.5	3.46	-136.61	1010.0	34.0

Table appendix 1.1-4 - Power flow on the Ethiopian 400 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1GONDES61	1SHEHES61	101.91	-18.38	103.56	257.0	2.47	-17.55	690.0	37.2
1GONDES61	1SHEHES61	101.91	-18.38	103.56	257.0	2.47	-17.55	690.0	37.2

Table appendix 1.1-5 - Power flow on the Ethiopian-Sudan 220 kV lines

Substation.	V sol [pu]	V sol [kV]
1B.DAR3S71	1,05	419,36
1BARO2S71	1,05	419,78
1BAROS71	1,05	419,16
1BELESS71	1,05	418,69
1D.MARS71	1,04	417,65
1GEBAS71	1,05	419,28
1GENALE3S71	1,04	417,24
1GENALE4S71	1,05	419,64
1GENJIS71	1,05	419,38
1GG2S71	1,05	419,62
1GGOS71	1,05	418,8
1GHEDOS71	1,05	418,21
1GHIMBIS71	1,05	418,87
1KALITS71	1,02	409,98
1KARADS71	1,04	417,13
1MANDAS71	1,04	417,35
1METUS71	1,05	418,63
1SEBETS71	1,03	411,06
1SULULS71	1,02	407,89
1W.SODS71	1,03	413,13
1MANDAS81	1,05	524,65

Table appendix 1.1-6 - Voltage of the Ethiopian substations

1.1.3 SUDANESE NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
2ATBARS81	2KABASS81	370.24	-166.64	406.01	448.8	4.11	-285.50	2128.0	21.1
2ATBARS81	2KABASS81	370.24	-166.64	406.01	448.8	4.11	-285.50	2128.0	20.1
2ATBARS81	2MEROWS81	-205.47	-130.75	243.55	269.2	1.04	-260.27	2128.0	12.6
2ATBARS81	2P.SUD81	-391.31	-185.98	433.26	478.9	7.28	-435.01	2128.0	24.3
2ATBARS81	2P.SUD81	-391.31	-185.98	433.26	478.9	7.28	-435.01	2128.0	24.3
2BAGERS81	2H.HEI81	152.07	9.56	152.37	169.4	0.28	-107.09	2128.0	8.0
2BAGERS81	2H.HEI81	152.07	9.56	152.37	169.4	0.28	-107.09	2128.0	8.0
2BAGERS81	2J.AULIAS81	39.17	39.84	55.87	62.1	0.02	-43.97	2128.0	2.9
2BAGERS81	2KABASS81	-264.30	-36.14	266.76	296.6	0.58	-83.06	2128.0	13.9
2BAGERS81	2KABASS81	-264.30	-36.14	266.76	296.6	0.58	-83.06	2128.0	13.9
2BORS81	2JUBAS81	-251.06	-10.74	251.29	277.1	1.13	-167.74	2128.0	13.0
2BORS81	2JUBAS81	-251.06	-10.74	251.29	277.1	1.13	-167.74	2128.0	13.0
2BORS81	2MALAKAS81	215.55	-225.41	311.89	343.9	1.73	-390.03	2128.0	16.2
2BORS81	2MALAKAS81	215.55	-225.41	311.89	343.9	1.73	-390.03	2128.0	16.2
2FULA81	2NYALA81	414.94	-146.88	440.17	485.9	7.30	-362.64	2128.0	24.8
2FULA81	2NYALA81	414.94	-146.88	440.17	485.9	7.30	-362.64	2128.0	22.8
2FULA81	2RABAK81*	288.09	-320.82	431.18	475.9	4.93	-599.80	2128.0	22.4
2FULA81	2RABAK81*	288.09	-320.82	431.18	475.9	4.93	-599.80	2128.0	22.4
2GEDARE81	2MERIN81	18.20	-74.57	76.76	84.8	0.07	-247.54	2128.0	4.0
2GEDARE81	2P.SUD81	-386.47	-312.35	496.91	549.2	11.65	-696.00	2128.0	25.8
2H.HEI81	2BAGERS81	-151.79	-116.65	191.44	214.6	0.28	-107.09	2128.0	8.0
2H.HEI81	2BAGERS81	-151.79	-116.65	191.44	214.6	0.28	-107.09	2128.0	8.0
2H.HEI81	2MERIN81	-574.58	0.35	574.58	644.2	1.99	-42.62	2128.0	30.3
2J.AULIAS81	2BAGERS81	-39.15	-83.82	92.51	103.2	0.02	-43.97	2128.0	2.9
2J.AULIAS81	2MARKHS81	-124.87	-2.16	124.88	139.3	0.13	-80.08	2128.0	6.5
2J.AULIAS81	2RABAK81*	-373.80	-134.76	397.35	443.1	4.99	-322.61	2128.0	20.8
2JUBAS81	2BORS81	252.19	-156.99	297.06	330.1	1.13	-167.74	2128.0	13.0
2JUBAS81	2BORS81	252.19	-156.99	297.06	330.1	1.13	-167.74	2128.0	13.0
2JUBAS81	2RUMBEKS81	402.16	-139.90	425.80	473.2	5.79	-312.18	2128.0	22.2
2KABASS81	2ATBARS81	-366.13	-118.87	384.94	427.3	4.11	-285.50	2128.0	21.1
2KABASS81	2ATBARS81	-366.13	-118.87	384.94	427.3	4.11	-285.50	2128.0	20.1
2KABASS81	2BAGERS81	264.88	-46.92	269.00	298.6	0.58	-83.06	2128.0	13.9
2KABASS81	2BAGERS81	264.88	-46.92	269.00	298.6	0.58	-83.06	2128.0	13.9
2KABASS81	2MARKHS81	351.60	109.87	368.37	408.9	0.55	-36.52	2128.0	20.0
2MALAKAS81	2BORS81	-213.82	-164.62	269.85	296.5	1.73	-390.03	2128.0	16.2
2MALAKAS81	2BORS81	-213.82	-164.62	269.85	296.5	1.73	-390.03	2128.0	16.2
2MARKHS81	2J.AULIAS81	125.00	-77.92	147.30	164.6	0.13	-80.08	2128.0	6.5
2MARKHS81	2KABASS81	-351.05	-146.39	380.35	424.9	0.55	-36.52	2128.0	20.0
2MARKHS81	2MEROWS81	-462.00	-154.78	487.23	544.3	8.20	-324.09	2128.0	25.8
2MARKHS81	2MEROWS81	-462.00	-154.78	487.23	544.3	8.20	-324.09	2128.0	25.8
2MERIN81	2GEDARE81	-18.13	-172.97	173.91	194.6	0.07	-247.54	2128.0	4.0
2MERIN81	2H.HEI81	576.57	-42.97	578.17	646.8	1.99	-42.62	2128.0	30.3
2MERIN81	2RABAK81*	-663.27	-29.02	663.90	742.7	7.46	-102.98	2128.0	35.2

2MERIN81	2RABAK81*	-663.27	-29.02	663.90	742.7	7.46	-102.98	2128.0	34.9
2MEROWS81	2ATBARS81	206.51	-129.52	243.77	268.0	1.04	-260.27	2128.0	12.6
2MEROWS81	2MARKHS81	470.20	-169.31	499.75	549.5	8.20	-324.09	2128.0	25.8
2MEROWS81	2MARKHS81	470.20	-169.31	499.75	549.5	8.20	-324.09	2128.0	25.8
2NYALA81	2FULA81	-407.64	-215.77	461.22	527.2	7.30	-362.64	2128.0	24.8
2NYALA81	2FULA81	-407.64	-215.77	461.22	527.2	7.30	-362.64	2128.0	22.8
2P.SUD81	2ATBARS81	398.59	-249.03	469.99	517.3	7.28	-435.01	2128.0	24.3
2P.SUD81	2ATBARS81	398.59	-249.03	469.99	517.3	7.28	-435.01	2128.0	24.3
2P.SUD81	2GEDARE81	398.12	-383.65	552.89	608.5	11.65	-696.00	2128.0	25.8
2RABAK_5ACDC**	2RABAK81*	-2153.62	-78.24	2155.04	2392.8	0.02	0.10	6384.0	37.5
2RABAK81*	2FULA81	-283.16	-278.99	397.51	441.4	4.93	-599.80	2128.0	22.4
2RABAK81*	2FULA81	-283.16	-278.99	397.51	441.4	4.93	-599.80	2128.0	22.4
2RABAK81*	2J.AULIAS81	378.80	-187.86	422.82	469.5	4.99	-322.61	2128.0	20.8
2RABAK81*	2MERIN81	670.73	-73.96	674.79	749.2	7.46	-102.98	2128.0	35.2
2RABAK81*	2MERIN81	670.73	-73.96	674.79	749.2	7.46	-102.98	2128.0	34.9
2RABAK81*	2RABAK_5ACDC**	2153.64	78.34	2155.06	2392.7	0.02	0.10	6384.0	37.5
2RUMBEKS81	2JUBAS81	-396.37	-172.28	432.19	490.7	5.79	-312.18	2128.0	22.2
2RUMBEKS81	2WAUS81	207.55	-208.31	294.06	333.9	1.69	-366.51	2128.0	15.7
2WAUS81	2RUMBEKS81	-205.86	-158.20	259.62	294.3	1.69	-366.51	2128.0	15.7

* Rabak was replaced by Kosti

** RABAK500_ACDC : DC/AC converter station in Kosti

Table appendix 1.1-7 - Power flows on the Sudanese 500 kV lines

From bus	To bus	P [MW]	Q [MVAr]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAr]	Ampacity (Norm.) [A]	Loading [%]
2GEDARS61	1SHEHE61	-97.13	-10.58	97.70	251.1	2.27	-27.76	972.0	25.8
2GEDARS61	1SHEHE61	-97.13	-10.58	97.70	251.1	2.27	-27.76	972.0	25.8

Table appendix 1.1-8 - Power flows on the 220 kV interconnection Ethiopia - Sudan

Substation	V sol [pu]	V sol [kV
2ATBARS81	1,04	522,3
2BAGERS81	1,04	519,2
2BORS81	1,05	523,6
2FULA81	1,05	523,1
2GEDARE81	1,04	522,4
2H,HEI81	1,03	515
2J,AULIAS81	1,04	517,8
2JUBAS81	1,04	519,5
2KABASS81	1,04	520,1
2MALAKAS81	1,05	525,4
2MARKHS81	1,03	516,8
2MERIN81	1,03	516,1
2MEROWS81	1,05	525,1
2NYALA81	1,01	505,1
2P,SUD81	1,05	524,6

2RABAK_5ACDC**	1,04	520
2RABAK81*	1,04	520
2RUMBEKS81	1,02	508,5
2WAUS81	1,02	509,3

* Rabak was replaced by Kosti
** RABAK500_ACDC : DC/AC converter station in Kosti

Table appendix 1.1-9 - Voltage of the 500 kV Sudanese substations

1.2 INITIAL SYSTEM – N-1 SITUATION

1.2.1 EGYPTIAN NETWORK

The active flow over the lines belonging to the 500 kV network of the Upper Nil area are displayed in the following table:

Circuit	Nb of circuits	Flow / Circuit (MW)	Loading (%)
From High Dam to Nag Hammadi	2	196	10.6
Nag Hammadi to Assiut	1	171	10.5
Nag Hammadi to Sohag	1	307	18
Samalut to Assiut	2	303	17.4
Kurimat to Samalut	2	791	44.8
S.Giza to Samalut	1	274	21.9

Table appendix 1.22-1: Loading of the Egyptian 500kV network H.D. – Cairo

At Nag Hammadi, about 750 MW (loading 71%) flowed through the four 285 MVA 500 / 132 kV transformers and 1 160 MW (loading 54%) over the three 750 MVA 500 / 220 kV transformers.

The voltage profile in the substations of the Upper Nil area is displayed in the following table:

Substations	Voltage (kV)
High Dam 500 kV	525
Nag Hammadi 500 kV	510
Sohag 500 kV	508
Assiut 500 kV	512
Samalut 500 kV	516
Kurimat 500 kV	525

Table appendix 1.22-2: Voltage profile In the Upper Nil Area

1.2.1.1 Tripping of one of the two circuits High Dam - Nag Hammadi

Following the tripping of the circuit, the behaviour of the system was satisfactory, no overload occurred on the transmission system.

About 82% of the initial power flowed over the remaining circuit that was 27% loaded (0.55kA, 356MW).

At Nag Hammadi the voltage dropped from 510 to 492kV (Voltage dip 3.6%). The 300MVAr SVC connected to Nag Hammadi generated its maximum output.

High Dam HPP generated 680 MVAr, 65% of its maximum reactive output, to keep the initial voltage at its set point (1.05 pu).

In High Dam substation, the flow through the 500/220 kV transformation increased by 45 MW, and the flow through the 500/132 kV transformation increased by 14 MW.

1.2.1.2 Tripping of the 500kV circuit Nag Hammadi - Sohag

Following the tripping of the circuit, the behaviour of the system was satisfactory, no overload occurred on the transmission system.

About 60% of the initial power flowed over the 500kV circuit Nag Hammadi – Assiut that was 21% loaded.

The remaining part of the power flowed through the 500/220kV transformation and 500/132kV transformation of Nag Hammadi that were respectively 59% and 73% loaded.

The flow through the 500/220kV transformer of Sohag decreased of about 50MVA, loading 60% instead of 70% initially.

Thanks to the SVC that generated 283MVAr instead of 213MVAr in normal situation, the voltage at Nag Hammadi remained equal to 510kV. The voltage at Sohag dropped down to 496kV (voltage drop 12kV).

1.2.1.3 Tripping of the 500kV circuit Nag Hammadi - Assiut

Following the tripping of the circuit, the behaviour of the system was satisfactory, no overload occurred on the transmission system.

About 67% of the initial power flowed over the 500kV circuit Nag Hammadi – Sohag that was 25% loaded.

The remaining part of the power flowed through the 500/220kV transformation and 500/132kV transformation of Nag Hammadi that were respectively 56% and 72% loaded.

The flow through the 500/220kV transformer of Sohag decreased of about 10MVA, loading 68% instead of 70% initially.

The SVC that generated 300MVAr, its maximum output, was not able to keep the initial value at Nag Hammadi which the voltage dropped to 504kV. The voltage at Sohag dropped down to 502kV (voltage drop 6kV) and the voltage at Assiut dropped down to 507kV (voltage drop 5kV).

1.2.1.4 Tripping of one of the two circuits Kurimat - Samalut

Following the tripping of the circuit, the behaviour of the system was satisfactory, no overload occurred on the transmission system.

About 55% of the initial power flowed over the remaining 500kV circuit Kurimat – Samalut and 31% over the 500kV circuit South Giza – Samalut that were respectively loaded 70% and 36% loaded.

The SVC that generated 300MVAr, its maximum output, can keep a voltage close to the initial value at Nag Hammadi which was 509kV. The voltage at Samalut dropped down to 506kV (voltage drop 10kV).

1.2.1.5 Tripping of the SVC at Nag Hammadi

In normal situation, the SVC generated 213 MVAr. Following its tripping, the voltage profile was slightly affected. It is displayed hereafter.

Substation	Initial voltage (kV)	Final Voltage (kV)
Nag Hammadi	510	496
Assiut	512	505
Samalut	516	512

Table appendix 1.22-3: Voltage profile In the Nag Hammadi area

1.2.1.6 Conclusion

Whatever the tripped circuit in the 500 kV system in the Upper Nile Valley, the behaviour of the system was satisfactory. For the tripping of one 500kV circuit connected to Nag Hammadi, the flow over the remaining circuits remained below 30% of their nominal rating.

The worst case appeared for the tripping of one of the two 500kV circuits Kurimat – Samalut that supplied the upper Nile area, the remaining circuit was 70% loaded.

Whatever the tripped circuit, the voltage profile was not significantly affected thanks to the 300MVAr SVC connected to Nag Hammadi. The maximum voltage drop reached 3.6%.

1.2.2 ETHIOPIAN NETWORK

1.2.2.1 The power flows over the Ethiopian system in normal situation

The flow over the lines connecting the 500kV interconnection and the 220kV interconnection to the Ethiopian bulk are displayed hereafter.

Circuit	Nb of circuits	Flow/Circuit (MW)	Loading (%)
Karadobi to Ghedo	2	551	50
Ghedo to Sebeta	2	271	37
Ghedo to Ghimbi	2	274	39.4
Metu to Ghimbi	3	377	51
Ghimbi to Mandaya	3	552	76

Table appendix 1.22-4: Loading of the Ethiopian 400kV network between Mandaya and Addis Ababa

The voltage profile in the substations between Addis Ababa and Mandaya is displayed in the following table:

Substations	Voltage (kV)
Sebeta 400 kV	411
Karadobi 400 kV	417
Ghedo 400 kV	418
Metu 400 kV	419
Ghimbi 400 kV	419
Mandaya 400 kV	417

Table appendix 1.22-5: Voltage profile in Mandaya area

The flows over the 230 kV circuits connected to Gonder are displayed in the following table:

Circuit	Nb of circuits	Flow/Circuit (MW)	Loading (%)
Bahir Dar to Gonder	2	154	55
Hummera to Gonder	1	8	16

Table appendix 1.22-6: Loading of the 230kV circuits connected to Gonder

1.2.2.2 Tripping of one of the two 400kV circuit Karadobi – Ghedo

Following the tripping, the flow over the remaining circuit reached 914 MW (1.26 kA), that is higher than the thermal rating equal to 1.01 kA of one 400kV line equipped with two 450mm^2 bundle conductors. To avoid any overload of the remaining circuit, it is proposed to equipped the double circuit line Karadobi – Ghedo with three 450mm^2 bundle conductors.

The voltage profile was not significantly affected, the voltage deep at Ghedo reached 1.5kV.

The total flow over the 220kV interconnection increased by 22MW (2 X 111MW instead of 2 X 100MW).

1.2.2.3 Tripping of one of the two 400 kV circuits Debre Markos - Sululta

The initial flow on each circuit Debre Markos - Sululta reached 336 MW (loading of 46%)

Following the tripping of one circuit of the line, the behaviour was acceptable. No overload occurred on the transmission system. The flow on the two 230 kV circuits Ghedo to Gefersa increased from 2 X 191 to 2 X 201 MW (from 70 to 73% of loading).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 208 MW.

Voltage variation on the following substations is displayed hereafter:

Substation	Initial voltage (kV)	Final Voltage (kV)
1B.DAR3S71	420	420
1D.MARS71	418	417
1SULULS61	408	401
1SEBETS71	411	406
1GHEDOS71	418	416

Table appendix 1.22-7: Tripping of one circuit Debre Markos Sululta Voltage profile In Mandaya area

1.2.2.4 Tripping of one of the two 400 kV circuits Sebeta - Ghedo

The initial flow on each circuit Ghedo - Sebeta reached 271 MW (loading of 37%)

Following the tripping of one circuit, the flow on the remaining circuit increased to 431 MW (loading 59%).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 233 MW.

Voltage variation on the following substations

Substation	Initial voltage (kV)	Final voltage (kV)
1GHIMBIS71	419	419
1GHEDOS71	418	418
1SEBETS71	411	406

Table appendix 1.22-8: Tripping of one circuit Sebeta Ghedo Voltage profile In Mandaya area

1.2.2.5 Tripping of one of the two 400 kV circuits Ghedo - Ghimbi

The initial flow on each circuit Ghedo - Ghimbi reached 274 MW (loading of 39%)

Following the tripping of one circuit, the flow on the remaining circuit increased to 505 MW (loading 70%).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 233 MW.

The voltage profile was not affected.

1.2.2.6 Tripping of one of the three 400 kV circuit Ghimbi - Mandaya

The initial flow on each Ghimbi - Mandaya circuit reached 552 MW (loading of 76%)

Following the tripping of one circuit, the two remaining circuits were overloaded by 13% which is acceptable in N-1 situation. The flow on each circuit reached 823 MW (1.143kA).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 200 to 224 MW.

To recover a situation without constraint, it would be possible to increase the generation at Mandaya and reduce the generation at Baro HPP or / and to increase the flow over the 2230kV interconnection by reduction of the angle of the phase-shift transformer.

One 200 MW increase of generation output of Mandaya allowed to reduce the flow over the two circuits down to 725 MW (1kA, loading 99.4%)

A combination of the two actions, increase of Mandaya generation and decrease of the phase-shifter angle would allow to recover an acceptable situation.

The voltage profile was not affected.

1.2.2.7 Tripping of one of the two 230 kV circuits Bahir Dar - Gonder

The initial flow on each circuit Bahir Dar - Gonder reached 154 MW (loading of 55%)

Following the tripping of one circuit, the flow on the remaining circuit reached 262 MW (loading of 91%).

The flow over the 220 kV Ethiopia - Sudan interconnection decreased from 200 to 161 MW.

The voltage profile was not significantly affected, the voltage deep reached 4kV at Gonder.

1.2.2.8 Conclusion

For two out of the six N-1 situations examined, some constraints appeared on the Ethiopian System:

- The tripping of one of the two circuits Karadobi – Ghedo induced unacceptable 26% overload on the remaining circuit
- The tripping of one of the three circuits Ghimbi – Mandaya circuits induced acceptable 13% overload on the two remaining circuits

To operate the transmission system in a satisfactory way, it is proposed:

- To equipped the double circuit line Karadobi – Ghedo with three 450mm² bundle conductors.
- To adapt the unit commitment at Mandaya HPP and to decreased the phase-shift transformer angle of Gedaref following the tripping of Ghimbi – Mandaya.

With such improvement, the behaviour of the Ethiopian System was satisfactory whatever the tripped circuit.

1.2.3 SUDANESE NETWORK

The flow over the 500kV lines connecting Kosti to the Sudanese bulk are displayed hereafter.

Circuit	Nb of circuits	Flow/Circuit (MW)	Loading (%)
Kosti to Jebel Aulia	1	379	21
Kosti to Meringan	2	672	35
Fula to Kosti	2	288	22
Meringan to Hassa Heisa	1	575	30
Gedaref to Meringan	1	14	5

Table appendix 1.22-9: Loading of the Sudanese 500kV circuits connected to Kosti

About 180MW flow through the two 300MVA 500/220 kV transformers in Kosti.

The voltage profile in the substations in Kosti area is displayed in the following table:

Substations	Voltage (kV)
Fula 500 kV	523
Gedaref 500 kV	519
Hassa Heisa 500 kV	515
Jebel Aulia 500 kV	518
Meringan 500 kV	516

Table appendix 1.22-10: Voltage profile In the Kosti area

1.2.3.1 Tripping of the 500 kV circuit Kosti - Jebel Aulia

Following the tripping of the circuit, the behaviour of the system was satisfactory, no overload occurred on the transmission system.

About 80% of the initial power flowed over the two 500kV circuits Kosti Meringan that were 43% loaded.

The flow through the 500/220 kV transformation of Kosti increased by 60 MW (20% of the initial flow).

The flow over the 220kV interconnection increased by 14MW, 214MW instead of 200MW.

The voltage at Kosti substation was not affected, the SVC increasing its reactive output from 74 to 192 MVAr.

The voltage dip reached 2kV at Jebel Aulia.

1.2.3.2 Tripping of one of the two 500 kV circuits Kosti - Meringan

Following the tripping of the circuit, the behaviour of the system was satisfactory, no overload occurred on the transmission system.

About 63% of the initial power flowed over the remaining 500kV circuit Kosti Meringan that were 57% loaded and 22% flowed over Kosti - J.Aulia that was 28% loaded.

The flow through the 500/220 kV transformation of Kosti increased by 84 MW (13% of the initial flow).

The flow over the 220kV interconnection increased by 28MW, 228MW instead of 200MW.

The voltage at Kosti substation is not affected, the SVC increasing its reactive output from 74 to 148 MVAr.

The voltage dip reached 5kV at Meringan.

Remark:

With only one 500kV in operation between Kosti and Meringan, the tripping of this sole circuit would induce unacceptable overload on the 220kV underlying system and on the 500/220kV transformation of Kosti:

- 856MW flowed over the two 220kV circuits Kosti Mashkur that were 10% overloaded
- 346MVA flowed through each Kosti transformer that was 15% overloaded
- The phase-shift transformer at Gedaref was loaded at its maximum rating 350MVA.

1.2.3.3 Tripping of one of the two 500 kV circuits Kosti - Fula

Following the tripping of the circuit, the behaviour of the system was satisfactory, no overload occurred on the transmission system.

About 71% of the initial power flowed over the remaining 500kV circuit Fula Kosti that was 30% loaded. The remaining part of the power flowed on the 220kV underlying system, the 500/220kV transformation of Kosti was discharged by 50MW (17% of the initial flow). The remaining part of the power flowed over the 500/220kV loop Fula – Wau – Juba – Malakal – Rank.

The voltage at Kosti (SVC) and Fula (generation plants) substation is not affected, the SVC increasing its reactive output from 74 to 192 MVAr.

1.2.3.4 Tripping of the SVC at Kosti

In normal situation, the SVC generated 74 MVAr. The tripping of the SVC did not entail significant voltage variations. They are displayed hereafter.

Substation	Initial voltage (kV)	Final Voltage (kV)
Kosti	520	518
Meringan	516	514
J. Aulia	518	517

Table appendix 1.22-11: Voltage profile In the Kosti area

The SVC at Kosti is necessary to avoid an excessive voltage drop in Kosti area following the tripping of one of the four circuits of the 500kV interconnection.

1.2.3.5 Conclusion

One second 500kV circuit Kosti – Gedaref was necessary to discharge the power arriving from the 500kV interconnection and from Fula TPP. The year of commissioning of this second circuit will depend on the installation of new generating units in Fula area.

With two 500kV circuits in operation between Kosti and Gedaref, the behaviour of the Sudanese system close to the interconnection was satisfactory in N-1 situation. Following the tripping of one of the 500 kV circuit connected to Kosti, the power flow over the transmission system remained far below the thermal limit of the circuits. The voltage profile was not significantly affected thanks to the 500MVAr SVC connected to Kosti.

2 RESULTS OF THE TRANSIENT STATE ANALYSIS PERFORMED AT PEAK LOAD 2025/2026

2.1 STUDY OF A FAULT LOCATED ON THE INTERCONNECTION

2.1.1 TRIPPING OF ONE OF THE 2 POLES OF THE DC INTERCONNECTION AT KOSTI

Event : Time = 0 : Tripping of one of the 2 poles of the DC interconnection (ΔP = 1075MW, ΔQ = 645MVAr)

Time = 300ms: Disconnection of half of the capacitor banks of the filters (ΔQ = 560MVAr)

Following the tripping of one of the 2 poles of the DC interconnection, the behaviour of Ethiopia and Sudan interconnected together by the AC links was satisfactory.

Following the reduction of the transmitted power by half of its initial value, the frequency of Ethiopia and Sudan increased up to 50.45 Hz, before stabilizing around 50.15 Hz, 15 seconds after the tripping of the pole, resulting of the activation of the primary regulation of the generation governors

Before the disconnection of the filters, there was a voltage surge of about 10% at Kosti and Mandaya 500kV substations. Due to the automatic voltage regulator, the voltage profile recovered an acceptable value 10 seconds after the fault. The voltage reached 1.054 p.u (527kV). at Kosti and 1.066 p.u. (533kV) at Mandaya. It would be necessary to modify the set point of the generator at Mandaya HPP and of the SVC at Kosti to keep the voltage below the 1.05 p.u. voltage limit.

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	565 kV	527 kV
Mandaya	525 kV	551 kV	533 kV

Table appendix 2.11-1 Voltage Variation on Nodes

The flow on the four 500kV circuits Mandaya - Kosti decreased from 830 to 750 MW and from 100 to 75MW over each of the two 230kV circuit Gonder – Shehedi.

The corresponding figures are displayed in M1 - 2025 Appendix Stability Study

2.1.2 TRIPPING OF ONE OF THE 2 POLES OF THE DC INTERCONNECTION AT NAG HAMMADI

Event : Time = 0 : Tripping of one of the 2 poles of the DC interconnection (ΔP = 1000MW, ΔQ = 600MVAr)

Time = 300ms: Disconnection of half of the capacitor banks of the filters (ΔQ = 490MVAr)

Following the tripping of one of the 2 poles of the DC interconnection, the behaviour of Egyptian system was satisfactory.

Following the reduction of the imported power, by half of its initial value, the frequency of Egypt decreased down to 49.84Hz, before stabilizing around 49.88Hz, 20 seconds after the tripping of the pole, resulting of the activation of the primary regulation of the generation governors

Before the disconnection of the filters, there was a voltage surge of about 6% at Nag Hammadi 500kV substation. The voltage profile recovered an acceptable value 10 seconds after the fault. The voltage reached 508kV. at Nag Hammadi. The SVC at Nag Hammadi generated 255MVAr to sustain the voltage profile.

There was a shortage og generation in Nag Hammadi area, the flow came from the north. About 200MW flowed over the line Assiut Nag Hammadi and 20MW over the line Sohag Nag Hammadi.

The corresponding figures are displayed in M1 - 2025 Appendix Stability Study

2.1.3 *TRANSITORY BLOCKING OF THE CONVERTER STATION*

Event: A fault on the commutation of the converter at Kosti station or Nag Hammadi station induced a temporary blocking of the converter station.

The power exchange was reduced to zero during 300 ms. After this period, the converter stations operated normally and the power exchange recovered its initial value.

During the blocking, the capacitor banks of the filters remained connected on the system.

2.1.3.1 Analyze of the system behaviour in Ethiopian and Sudan

The behaviour of the interconnected system was satisfactory. Sudan and Ethiopia operated in synchronism.

Due to the excess of reactive power generated by the filters, there was a voltage surge at Kosti and Mandaya. The voltage reached:

- 595kV at Kosti
- 575kV at Mandaya

The voltage profile recovered its initial value 7 seconds after the blocking

The interruption of the power exchange induced in Sudan and Ethiopia a frequency surge of 0.6% (50.3Hz)

The system frequency recovered its initial value in 14 seconds.

The power oscillations appeared on the AC interconnection, they were totally damped in 6 seconds.

2.1.3.2 Analyze of the system behaviour in Egypt

The behaviour of the Egyptian system was satisfactory, all the units operated in synchronism.

Following the disturbance, voltage oscillation appeared on the substations close to Nag Hammadi.

They were totally damped on about 20 seconds. The maximum voltage surge reached 6.5% at Nag Hammadi.

There was a frequency drop of 0.1Hz. The system frequency oscillations were completely damped in 18 seconds.

The corresponding figures are displayed in M1 - 2025 Appendix Stability Study

2.1.4 SHORT-CIRCUIT ON ONE OF THE FOUR MANDAYA - KOSTI CIRCUITS, ON KOSTI SIDE

Event : a 3 phase short-circuit at Kosti end, on one of the 4 circuits Mandaya – Kosti. It was cleared in 120 ms by opening of the two circuit breakers.

During the short circuit, the voltage was equal to 0 at Kosti that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. Three hundred ms after the clearing of the fault, the voltage at Kosti recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2 150MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 12 seconds. The voltage surge at Kosti reached 15% due to the excess of reactive power generated by the filters. The voltage dip at Kosti reached 16kV.

The power flow on the three remaining circuits oscillated and was stabilized in 12 seconds at 1080MW on each circuits.

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	522 kV	573 kV	504 kV
Mandaya	525 kV	555 kV	510 kV

Table appendix 2.11-2 Voltage Variation on Nodes

The reactive output of the SVC connected to Kosti oscillated according to the voltage oscillations and recovered a stable value equal to 400MVAr.

During the blocking of the converter station, the frequency surge reached 50.85Hz.

The system frequency recovered its initial value 12 seconds after the fault.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.1.5 SHORT-CIRCUIT ON ONE OF THE 4 MANDAYA - KOSTI CIRCUITS, ON MANDAYA SIDE

Event : a 3 phase short-circuit at Mandaya end, on one of the 4 circuits Mandaya – Kosti. It was cleared in 120 ms by opening of the two circuit breakers.

During the short circuit, the voltage dropped down below 0.6 p.u. at Kosti that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. Three hundred ms after the clearing of the fault, the voltage at Kosti recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2 150MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 7 seconds. The voltage surge at Mandaya reached 10.8%. The voltage dip at Kosti reached 16kV.

The power flow on the three remaining circuits oscillated and was stabilized in 8 seconds at 1080MW on each circuits.

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	522 kV	535 kV	504 kV
Mandaya	525 kV	554 kV	510 kV

Table appendix 2.11-3 Voltage Variation on Nodes

The reactive output of the SVC connected to Kosti oscillated according to the voltage oscillations and recovered a stable value equal to 400MVAr.

During the blocking of the converter station, the frequency surge reached 50.83Hz.

The system frequency recovered its initial value 10 seconds after the fault.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.1.6 FAULT ON ONE OF THE 4 MANDAYA 500/400 KV TRANSFORMERS

Event : a 3 phase short-circuit on one of the 4 transformers on the 500kV busbar side, it was cleared in 120 ms by opening of the 500kV and 400kV breakers.

During the short circuit, the voltage dropped down below 0.6 p.u. at Kosti that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. Three hundred ms after the clearing of the fault, the voltage at Kosti recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2 150MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 5 seconds. The voltage surge at Mandaya reached 14.7%.

The power flow over the 500kV interconnection decreased very slightly by about 2.5MW on each circuit.

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	520 kV	561 kV	520 kV
Mandaya	525 kV	575 kV	525 kV
Mandaya	417 kV	450 kV	416 kV

Table appendix 2.11-3 Voltage Variation on Nodes

During the blocking of the converter station, the frequency surge reached 50.81Hz.

The system frequency recovered its initial value 10 seconds after the fault.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.1.7 FAULT ON THE 220 KV INTERCONNECTION

Event : a 3 phase short-circuit on the phase-shift transformer on the 220kV busbar side, it was cleared in 120 ms by opening of the two 220kV breakers. The 220kV interconnection was opened, Gedaref was radialy connected to Shehedi Gonder without any flow.

The behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism. Following the clearing of the fault, there was a voltage surge of about 12% at

Gedaref busbar which voltage reached 258kV. The voltage decreased to 1.093 p.u. (250kV) which is unacceptable. It is necessary to increase the reactive compensation by connecting a shunt reactor on Gedaref busbar.

With 20MVAr reactor connected at Gedaref, the voltage recovered an acceptable value equal 1.06 p.u. (244kV).

Node	Initial voltage	Maximal voltage	Final voltage
Gonder	235 kV	252 kV	242 kV
Shehedi	232 kV	257 kV	245 kV
Gedaref	224 kV	258 kV	244 kV

Table appendix 2.11-4 Voltage Variation on Nodes

The power flow over the 500kV interconnection increased by 50MW on each circuit.

The system frequency recovered its initial value 10 seconds after the fault.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.2 EGYPTIAN NETWORK

Recall of the flows on the 500 kV backbone along the Nile Valley

From bus	To bus	N° of circuits	P [MW]	Loading %
H.D.500	N.H.500	2	267.0	18.5
N.H.500	AUST500	2	361.8	20.6
N.H.500	SOHAG500	1	446.0	26
SOHAG500	AUST500	1	215.8	13
AUST500	SAML500	2	46.6	4
SAML500	S.GIZA500	1	-88.5	9.2
SAML500	KRIMA500	1	-661.8	38

Table appendix 2.22-1 Power Flows on the 500kV Egyptian Backbone

2.2.1 SHORT-CIRCUIT ON ONE OF THE 2 CIRCUITS HIGH DAM - NAG HAMMADI, AT NAG HAMMADI SIDE

Event : a 3 phase short-circuit at Nag Hammadi end, on one of the two circuits High Dam – Nag Hammadi. It was cleared in 100 ms by opening of the two circuit breakers.

During the short circuit, the voltage dropped down below 0.6 p.u. at Nag Hammadi that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. Three hundred ms after the clearing of the fault, the voltage at Nag Hammadi recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2000MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the Egyptian system was satisfactory, all the units operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 10 seconds. The voltage surge due the reactive generation of the filters reached 8.5%. at Nag Hammadi. The final voltage dip at Nag Hammadi reached 9kV.

The power flow on the remaining circuit oscillated and was stabilized in 10 seconds at 355MW. The power surge reached 1080MW.

The reactive output of the SVC connected to Nag Hammadi oscillated according to the voltage oscillations and recovered a stable value equal to 300MVAr.

The system frequency oscillations were totally damped in 10 seconds after the fault.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.2.2 SHORT-CIRCUIT ON THE CIRCUIT NAG HAMMADI - SOHAG, AT NAG HAMMADI SIDE

Event : a 3 phase short-circuit at Nag Hammadi end, on the circuit Nag Hammadi - Sohag. It was cleared in 100 ms by opening of the two circuit breakers.

During the short circuit, the voltage dropped down below 0.6 p.u. at Nag Hammadi that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. Three hundred ms after the clearing of the fault, the voltage at Nag Hammadi recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2000MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the Egyptian system was satisfactory, all the units operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 10 seconds. The voltage surge due the reactive generation of the filters reached 12%. at Nag Hammadi. The final voltage dip at Nag Hammadi reached 2kV.

The power flow on the Nag Hammadi Assiut circuit oscillated and was stabilized in 10 seconds at 350MW. The power surge reached 680MW.

The reactive output of the SVC connected to Nag Hammadi oscillated according to the voltage oscillations and recovered a stable value equal to 260MVAr.

The system frequency oscillations were totally damped in 10 seconds after the fault.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.2.3 SHORT-CIRCUIT ON THE CIRCUIT NAG HAMMADI - ASSIUT, AT NAG HAMMADI SIDE

Event : a 3 phase short-circuit at Nag Hammadi end, on the circuit Nag Hammadi - Assiut. It was cleared in 100 ms by opening of the two circuit breakers.

During the short circuit, the voltage dropped down below 0.6 p.u. at Nag Hammadi that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. Three hundred ms after the clearing of the fault, the voltage at Nag Hammadi recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2000MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the Egyptian system was satisfactory, all the units operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 10 seconds. The voltage surge due the reactive generation of the filters reached 10.6%. at Nag Hammadi. The final voltage dip at Nag Hammadi reached 4kV.

The power flow on the Nag Hammadi Sohag circuit oscillated and was stabilized in 10 seconds at 436MW. The power surge reached 810MW.

The reactive output of the SVC connected to Nag Hammadi oscillated according to the voltage oscillations and recovered a stable value equal to 300MVAr.

The system frequency oscillations were totally damped in 10 seconds after the fault.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.2.4 TRIPPING OF THE 300MVAR SVC AT NAG HAMMADI

Event : The tripping of the 300MVAr SVC at Nag Hammadi generating 220MVAr.

Following the tripping, the behaviour of the system was satisfactory. At Nag Hammadi, the voltage declined from 510kV to 499kV and from 512kV to 507kV at Assiut. The lost of reactive generation was partially compensated by the increase of the reactive output of the High Dam generators, each unit increased by 8.5MVAr this reactive output. The reactive flow over the lines Assiut Nag Hammadi and Sohag Nag Hammadi was affected, the variation amounted to 110MVAr over the two circuits.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.2.5 TRIPPING OF EGYPTIAN LARGEST STEAM UNIT : 765 MVA

Event : the 765 MVA steam unit of Abu Kir was tripped, it generated 615 MW

Following the tripping of the largest steam unit in operation, the behaviour of the system was satisfactory.

The Egyptian frequency decreased to 49.88 Hz, before recovering to 49.94 Hz. The self regulation of the load was estimated to 143 MW in Egypt interconnected to Libya and Jordan.

The voltage was not significantly affected.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.3 ETHIOPIAN NETWORK

2.3.1 POWER FLOW OVER THE 400KV SYSTEM CONNECTED TO MANDAYA

The flow over the 400kV circuits are displayed in the following table:

Circuit	Nb of circuits	Flow/Circuit (MW)	Loading (%)
Karadobi to Ghedo	2	551	50
Ghedo to Sebeta	2	271	37
Ghedo to Ghimbi	2	274	39.4
Metu to Ghimbi	3	377	51
Ghimbi to Mandaya	3	552	76

Table appendix 2.32-2: Loading of the Ethiopian 400kV network between Mandaya and Addis Ababa

2.3.2 SHORT-CIRCUIT AT MANDAYA 400KV BUSBAR, ON ONE OF THE THREE 400 KV CIRCUITS GHIMBI - MANDAYA

Event : A 3 phase short-circuit at Mandaya end, on one of the 3 circuits Mandaya – Ghimbi. It was cleared in 100 ms by opening of the two circuit breakers.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

During the fault, the voltage at Kosti dropped close to 0.6 p.u. that induced a blocking of the ACDC converter station.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 8 seconds. The voltage surge at Mandaya reached 11.2%.

The power flow over the two remaining circuits Ghimbi Mandaya oscillated and was stabilized in 8 seconds at 817MW on each circuits.

Node	Initial voltage	Maximal voltage	Final voltage
Ghimbi	419 kV	442 kV	416 kV
Mandaya	417 kV	445 kV	414 kV
Rabak	520 kV	583 kV	520 kV

Table appendix 2.33-1 Voltage Variation on Nodes

Following a frequency surge of about 1%, the system frequency recovered its initial value 12 seconds after the fault.

The total power flow over the four 500kV circuits Mandaya – Kosti decreased by about 20MW that were transferred to the 220kV interconnection.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.3.3 SHORT-CIRCUIT AT KARADOBI 400KV BUSBAR, ON ONE OF THE TWO 400 KV CIRCUITS KARADOBI – GHEDO

Event : a 3 phase short-circuit at Karadobi end, on one of the two circuits Karadobi – Ghedo. It was cleared in 100 ms by opening of the two circuit breakers.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

The voltage at Kosti remained above 0.9 p.u. therefore the operation of the converter station was satisfactory, there was no blocking of the station. The power exchange on the DC interconnection was kept constant.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 8 seconds. The voltage surge at Karadobi reached 11% (444kV) and at Ghedo the voltage surge reached 9% (436kV). The voltage dip at Karadobi reached 3kV and at Ghedo the voltage dip reached 3kV.

The power flow on the remaining circuit oscillated and was stabilized in 8 seconds. From 546 MW the remaining circuit increased to 900MW.

Node	Initial voltage	Maximal voltage	Final voltage
Karadobi	417 kV	444 kV	414 kV
Ghedo	418 kV	436 kV	415 kV
Kosti	520 kV	537 kV	520 kV

Table appendix 2.33-2 Voltage Variation on Nodes

The total power flow over the four 500kV circuits Mandaya – Kosti decreased by about 20MW that were transferred to the 220kV interconnection.

Following a frequency surge of about 1.3%, the system frequency recovered its initial value 7 seconds after the fault.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.3.4 SHORT-CIRCUIT AT GONDER 230 KV BUSBAR, ON ONE OF THE TWO 330 KV CIRCUITS GONDER – BAHIR DAR

Event : a 3 phase short-circuit at Gonder end, on one of the two circuits Gonder – Bahir Dar. It was cleared in 100 ms by opening of the two circuit breakers.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

The power oscillations on the remaining Gonder Bahir Dar circuit were totally damped in 4 seconds. The transient power surge reached 280MW. The power flow stabilized at 260MW, below the thermal limit.

The total power flow over the 220kV interconnection was slightly affected, it decreased of about 40 MW that were transferred on the 500kV interconnection.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.3.5 *TRIPPING OF ETHIOPIA 2 UNITS : MANDAYA HPP UNITS*

Event : 2 units of Mandaya, the largest units in operation in the Ethiopian system were tripped. Their initial generation amounted 242.85MW.

Following the tripping of 2 units of Mandaya, the behaviour of the interconnected system was satisfactory, Ethiopia and Sudan operated in synchronism.

The power exchange to Egypt over the DC interconnection was kept constant. The tripping of generation was compensated by the activation of the primary reserve in Sudan and Ethiopia due to the operation of the speed governors and by the self regulation versus frequency of the load demand .

The Ethiopia-Sudan frequency dropped to 49.78 Hz, before recovering to 49.94 Hz.

The exportation of Ethiopia to Sudan was affected by the tripping of generation in Ethiopia.

The power flow over the 500kV interconnection decreased by 292MW (757MW instead of 830MW on each circuit). The flow on the 220kV interconnection was not significantly affected, due to the location of the tripped units, the power flow decreased by only 2MW.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.4 *SUDANESE NETWORK*

Recall of the flow on the Sudanese 500 kV system around Kosti

From bus	To bus	N° of circuit	P [MW]	Loading %
2RABAK81*	1MANDAY81	4	-787.4	44
2RABAK81*	2FULA81	2	-100.4	17.8
2RABAK81*	2J.AULIAS81	1	303.5	19.3
2RABAK81*	2MERIN81	1	696.8	36.3
2BAGERS81	2H.HEI81	2	214.0	11.4
2BAGERS81	2J.AULIAS81	1	-78.4	5.3
2GEDARE81	2MERIN81	1	114.1	6.5
2H.HEI81	2MERIN81	1	-297.4	21.7

* Rabak was replaced by Kosti

Table appendix 2.44-1 Power Flows on the 500kV Sudanese Network

2.4.1 SHORT-CIRCUIT ON ONE OF THE TWO 500 KV CIRCUITS KOSTI - FULA, AT KOSTI SIDE

Event : a 3 phase short-circuit at Kosti end, on one of the 2 circuits Kosti – Fula. It was cleared in 120 ms by opening of the two circuit breakers.

During the short circuit, the voltage was equal to 0 at Kosti that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. One hundred ms after the clearing of the fault, the voltage at Kosti recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2 150MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 8 seconds. The voltage surge at Kosti reached 18% due to the excess of reactive power generated by the filters. The final voltage dip at Kosti reached 5 kV.

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	522 kV	588 kV	517 kV
Fula	523 kV	546 kV	520 kV

Table appendix 2.44-2 Voltage Variation on Nodes

The reactive output of the SVC connected to Kosti oscillated according to the voltage oscillations and recovered a stable value equal to 145MVAr.

The power flow on the remaining circuit oscillated and was stabilized in 12 seconds at 500MW.

During the blocking of the converter station, the frequency surge reached 50.84Hz.

The system frequency recovered its initial value 14 seconds after the fault. Power oscillations occurred on the 500 and 220kV AC interconnection, they were totally damped in 8 seconds.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.4.2 SHORT-CIRCUIT AT KOSTI ON ONE OF THE TWO 500KV CIRCUITS KOSTI - MERINGAN

Event : a 3 phase short-circuit at Kosti end, on one of the two 500kV circuits Kosti – Meringan. It was cleared in 120 ms by opening of the two circuit breakers.

During the short circuit, the voltage was equal to 0 at Kosti that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. One hundred ms after the clearing of the fault, the voltage at Kosti recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2 150MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 7 seconds. The voltage surge at Kosti reached 19% due to the excess of reactive power generated by the filters. The final voltage dip at Kosti reached 3kV.

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	522 kV	595 kV	519 kV
Meringan	518 kV	550 kV	512 kV

Table appendix 2.44-3 Voltage Variation on Nodes

The reactive output of the SVC connected to Kosti oscillated according to the voltage oscillations and recovered a stable value equal to 103MVAr.

During the blocking of the converter station, the frequency surge reached 50.84Hz.

The system frequency recovered its initial value 14 seconds after the fault. Power oscillations occurred on the 500 and 220kV AC interconnection, they were totally damped in 8 seconds.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.4.3 SHORT-CIRCUIT ON THE 500 KV CIRCUIT KOSTI - JEBEL AULIA, AT KOSTI SIDE

Event : a 3 phase short-circuit at Kosti end, on the circuit Kosti – Jebel Aulia. It was cleared in 120 ms by opening of the two circuit breakers.

During the short circuit, the voltage was equal to 0 at Kosti that induced a transitory blocking of the ACDC station. The power exchange on the DC interconnection was reduced to 0. One hundred ms after the clearing of the fault, the voltage at Kosti recovered a value close to the initial value. The ACDC converter station can operate properly and the power exchange recovered this initial 2 150MW level.

During the transitory blocking of the DC station, the capacitors bank of the filters remained connected.

Following the fault, the behaviour of the interconnected system was satisfactory, Ethiopian and Sudan operated in synchronism.

Following the clearing of the fault, voltage oscillations appeared, they were totally damped in 8 seconds. The voltage surge at Kosti reached 19% due to the excess of reactive power generated by the filters. The final voltage dip at Kosti reached 4kV.

Following the clearing of the fault, 79% of the Kosti – Jebel Aulia loading flowed through the two Kosti – Meringan circuits. The flow over the Kosti - Meringan circuits oscillated and was stabilized in 10 seconds.

Node	Initial voltage	Maximal voltage	Final voltage
Kosti	522 kV	595 kV	518 kV
Jebel Aulia	518 kV	544 kV	515 kV

The reactive output of the SVC connected to Kosti oscillated according to the voltage oscillations and recovered a stable value equal to 125MVAr.

During the blocking of the converter station, the frequency surge reached 50.84Hz.

The system frequency recovered its initial value 14 seconds after the fault. Power oscillations occurred on the 500 and 220kV AC interconnection, they were totally damped in 8 seconds.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.4.4 TRIPPING OF THE 500MVAR SVC AT KOSTI

Event : The tripping of the 500MVAr SVC at Kosti generating 80MVAr.

Following the tripping, the behaviour of the system was satisfactory. At Kosti, the voltage declined from 520kV to 517kV and from 525kV to 524kV at Mandaya. The lost of reactive generation was partially compensated by the increase of the reactive output of the generators close to Kosti. The reactive flow over the interconnection Mandaya Kosti was not significantly affected, the variation amounted to 9MVAr over each circuits.

The figures are displayed in M1 - 2025 Appendix Stability Study

2.4.5 TRIPPING OF THE LARGEST UNIT IN SUDAN : PORT-SUDAN 670MVA STEAM UNIT

Event : The 670MVA Steam Unit of Port-Sudan, the largest units in operation in the Sudan system was tripped. Its initial generation amounted 579MW.

Following the tripping of this unit of Port Sudan, the behaviour of the interconnected system was satisfactory, Ethiopia and Sudan operated in synchronism.

The power exchange to Egypt over the DC interconnection was kept constant. The tripping of generation was compensated by the activation of the primary reserve in Sudan and Ethiopia due to the operation of the speed governors and by the self regulation versus frequency of the load demand .

The Ethiopia-Sudan frequency dropped to 49.7 Hz, before recovering to 49.92 Hz.

The exportation of Ethiopia to Sudan was affected by the tripping of generation in Ethiopia.

The power flow over the 500kV interconnection increased by 200MW (880MW instead of 830MW on each circuit). The flow on the 220kV interconnection increased by 60MW.

The figures are displayed in M1 - 2025 Appendix Stability Study

3 SHORT-CIRCUIT POWER – 2025

3.1 *HYPOTHESIS*

Three-phase to ground and one-phase to ground short-circuit calculations were performed taking into account the following assumptions:

V = 1.1 Vn

Impedance of generator = X"d (sub transient reactance).

All the units were assumed to be in operation.

3.2 *SHORT-CIRCUIT POWER IN THE 132 / 220 / 500 KV SUBSTATIONS OF THE UPPER NILE VALLEY IN EGYPT*

Nom de barre	KV Pré déf, (Mult, = 1,10)	LLL I [A]	LLL S [MVA]	LG I [A]	LG S [MVA]
AUST500	550	14009	12132,1	12715	11011,5
H.D.500	550	12716	11012,4	13374	11582,2
KRIMA500	550	40550	35117,3	41492	35933,1
N.H.500	550	11227	9722,9	10187	8822,2
SAML500	550	19543	16924,7	17118	14824,6
SOHAG500	550	9103	7883,4	6920	5992,9
AUST220	242	25610	9758,7	24182	9214,6
H.D.220	242	21046	8019,6	21694	8266,5
KURIM220_1	242	43078	16414,9	43172	16450,7
N.H.220	242	20945	7981,1	19205	7318,1
SAML220	242	25500	9716,8	23380	8909
SOHAG220	242	10970	4180,1	9197	3504,5
ASU132	145,2	20596	4708,9	19950	4561,2
H.D.132II	145,2	22796	5211,9	22790	5210,5
H.D.132I	145,2	22796	5211,9	22790	5210,5
SAML132	145,2	22578	5162	21517	4919,4
SOHAG132	145,2	5236	1197,1	4562	1043

Table appendix 3.2-1 - Short Circuit Power in the Egyptian substations

The DC interconnection at Nag Hammadi did not affect the short-circuit level in the Egyptian system. At Nag Hammadi, the ratio "short circuit power / installed power of the ACDC station" was equal to 4.8 that allows satisfactory operation of the converter station.

3.3 SHORT-CIRCUIT POWER IN ETHIOPIA IN THE SUBSTATIONS BETWEEN MANDAYA AND ADDIS ABABA

Nom de barre	KV Pré déf, (Mult, = 1,10)	LLL I [A]	LLL S [MVA]	LG I [A]	LG S [MVA]
1MANDAS81	550	15103	13080	17405	15073
1B.DAR3S71	440	6765	4687	6522	4519
1GENJIS71	440	9114	6314	9351	6479
1MANDAS71	440	16289	11285	17350	12020
1SEBETS71	440	15438	10696	12575	8712
1GIBE3S71	440	18279	12664	20690	14335
1BARO2S71	440	9595	6648	10580	7330
1KARADS71	440	16773	11621	19352	13408
1GHEDOS71	440	15479	10724	12708	8804
1BAROS71	440	11161	7733	12211	8460
1SULULS71	440	11968	8292	9274	6425
1BELESS71	440	6108	4232	6672	4623
1GEBAS71	440	8215	5692	8506	5893
1GHIMBIS71	440	15593	10803	13786	9551
1METUS71	440	12613	8739	12713	8808
1B.DAR2S61	253	9763	3889	8990	3581
1D.DAW3S61	253	4141	1650	1684	671
1GEFERS61	253	15892	6331	12035	4794
1GONDES61	253	5953	2372	3124	1245
1SEBET1S61	253	18935	7543	15238	6070
1SEBET2S61	253	17999	7170	15164	6041
1GHEDOS61	253	10580	4215	9015	3591
1SHEHES61	253	5241	2088	1933	770
1SULULS61	253	16758	6676	13332	5311
1METUS61	253	5611	2235	5767	2297
1SHEHE61	242	5482	2089	2008	765
1SEBETS51	145.2	14772	3377	13330	3048
1GHEDOS51	145.2	2682	613	2617	598

Table appendix 3.3-1 - Short Circuit Power in the Ethiopian substations

3.4 SHORT-CIRCUIT POWER IN SUDAN IN THE SUBSTATIONS CLOSE TO KOSTI SUBSTATION

Nom de barre	KV Pré déf, (Mult, = 1,10)	LLL I [A]	LLL S [MVA]	LG I [A]	LG S [MVA]
2MERIN81	550	13544	11729	10319	8936,5
2GEDARE81	550	6183	5354,6	5328	4614,2
2RABAK81*	550	16321	14134	16981	14706
2H.HEI81	550	13109	11353	9838	8520
2J.AULIAS81	550	13312	11529	10776	9332,3
2MEROWS81	550	10724	9287,3	11978	10373
2FULA81	550	11113	9624,1	13405	11609
2RANKS61	242	10020	3818,1	6614	2520,3
2GEDARS62	242	10886	4148,1	11271	4294,8
2GEDARS61	242	8487	3234	1404	535
2FULAS61	242	16250	6192,1	19274	7344,4
2J.AULS61	242	22916	8732,2	18854	7184,3
2ROSEIS61	242	8772	3342,6	9999	3810,1
2MERINS61	242	21278	8108	16801	6402
2RABAKS61	242	19528	7441,2	22753	8670,1
2H.HEIS61	242	22124	8430,4	17155	6536,9

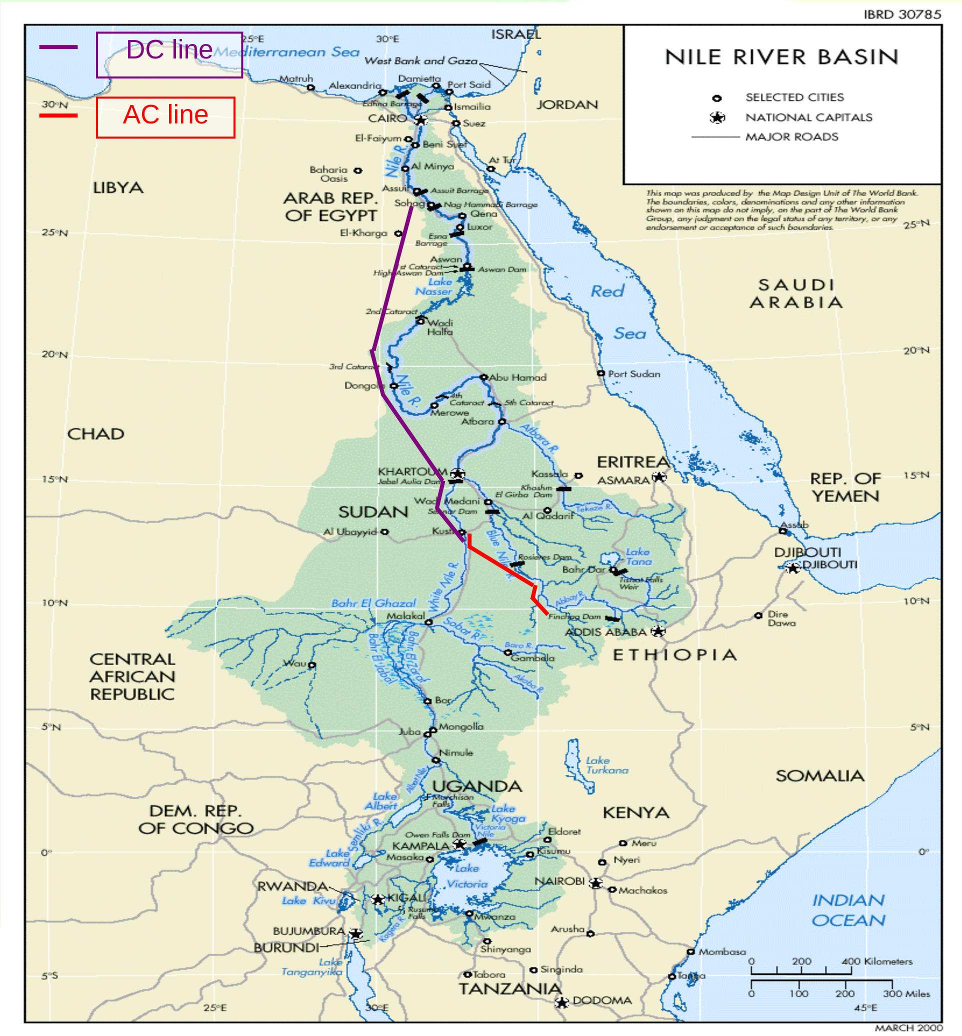
* Rabak was replaced by Kosti

Table appendix 3.4-1 - Short Circuit Power in the Sudanese substations

At Kosti, the ratio “short circuit power / installed power of the ACDC station“ was equal to 6.6 that allows satisfactory operation of the converter station.

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

EASTERN NILE POWER TRADE PROGRAM STUDY



M1 – 2030 – POWER STUDY

Electrical Power Systems
Engineering Company

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
CCG	Combined Cycle Gas turbine
DC	Direct Current
ENPTPS	Eastern Nile Power Trade Program Study
EDF	Electricité de France
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
GEP	Generation Expansion Plan
HPP	Hydro Power Plant
HD	High Dam
HV	High Voltage
HVDC	High Voltage Direct Current
NBI	Nile Basin Initiative
NH	Nag Hammadi
p.u	Per Unit
SC	Steering Committee
ST	Steam Turbine
SVC	Static Voltage Compensator
SW	Scott Wilson

EXECUTIVE SUMMARY

This report introduces the studies for the interconnected system for the peak load situation in 2030 in :

- Permanent state (normal and N-1 situations)
- Short circuit power
- Dynamic study

The main results are :

REGARDING THE INTERCONNECTION

The operation in parallel of the 500 and 220 kV AC interconnections has been studied and a phase shift transformer is required to operate the 220 kV interconnection, but the phase-shift angle is reduced to 20° due to the commissioning of Border and the reduction of the flow on the 220 kV interconnection, to optimized the losses.

The behaviour of the AC and DC interconnection is satisfying. The commissioning of Border improved the stability of the AC interconnection, the need of reducing the power on the DC interconnection in case of fault on the AC interconnection is no more required.

CONCERNING EGYPT

The behaviour of the Egyptian system is satisfactory in permanent and in transient states.

CONCERNING ETHIOPIA

The N-1 situation on the 400 kV backbone Mandaya - Ghimbi - Ghedo - Sebeta is satisfying. No over load occurs following the tripping of one of these circuits. The dynamic behaviour of the Ethiopian system is satisfying.

CONCERNING SUDAN

The behaviour of the Sudanese system is satisfactory, in case of tripping or short-circuit around Rabak/Kosti.

1 PRESENTATION OF THE INTERCONNECTED SYSTEM IN 2030

1.1 PRESENTATION

The impact of the interconnection between Egypt, Ethiopia and Sudan on these 3 systems has been investigated for the years 2020 (commissioning year of the interconnection) and 2025, presented in the corresponding reports.

This report presented the behaviour of the interconnected system for the year 2030. The model of the 2030 network included the development of the transmission system of the 3 countries.

The interconnection points are:

- Nag Hammadi for Egypt,
- Kosti for Sudan (initially located at Rabak (east side of the Nile), the line routing study located the interconnection substation in Sudan on the west side of the Nile river at Kosti),
- Mandaya for Ethiopia.

Concerning the network, the model was based on

- the data collected in Phase I, and updated during the April 08 meeting of Phase II in Cairo.
- the result of the study in 2020 and 2025 (adjunction of a phase shift transformer on the 220 kV interconnection, and adjunction of a 300 MVA SVC in Nag Hammadi)

Concerning the demand and the generation expansion plan, the data resulted of the economic study performed in Phase I.

1.2 DESCRIPTION OF THE TRANSMISSION SYSTEM IN 2030

1.2.1 DESCRIPTION OF THE INTERCONNECTION

The interconnection between the 3 countries selected at the beginning of Phase II, is made up of :

- An AC interconnection of 2 double 500 kV circuits between Mandaya (Ethiopia) and Kosti (Sudan) including :
  - A new substation, T.Border substation, is created on the AC interconnection between Mandaya and Kosti. Border HPP is radically connected to this new substation by a 500 kV double circuit line (70 km). Therefore, each 500 kV circuit Mandaya - Kosti is converted into 2 circuits : Mandaya - T.Border and T.Border - Kosti. The length of the interconnection remains equal to 544 km = 158 km between Mandaya and T.Border + 386 km between T.Border and Kosti.
  - The reactive compensation of Mandaya - T.Border circuit is made up of a 50 MVAr reactor at each side.
  - The reactive compensation of T.Border - Kosti circuit is made up of a 100 MVAr reactor at T.Border side and 75 MVAr reactor at Kosti side.

- o There is no additional compensation for 2030 scheme because all reactors will be re-allocated:
  - The two 100 MVAr reactors (two by 2x50 MVAR) initially connected at Kosti for the energization of the line in 2020 are converted in four 50 MVAR reactors to be shifted at T.Border side, on Mandaya - T.Border circuit.
  - The 150 MVAr reactor at Mandaya side is made up of a 100 MVAr reactor (to be shifted to T.Border side of T.Border - Kosti circuit), and a 50 MVAr one (remaining at Mandaya).
- A 500/400 kV substation located on Mandaya HPP site, equipped with four 500/400 kV 510 MVA transformers.
- The interconnection also included the existing 220 kV double circuit interconnection between Gonder (Ethiopia) and Gedaref (Sudan), equipped with a phase shift transformer at Gedaref side to limit the flow on this interconnection.
- A 600 kV DC interconnection between Kosti (Sudan) and Nag Hammadi (Egypt), made up of :
  - o AC/DC 2 x 1 075 MW converter station located at Kosti substation in Sudan, and a 500 MVAr SVC
  - o A 600 kV DC bipolar line between Kosti and Nag Hammadi. The total length of the line is about 1 665 km
  - o A DC/AC 2 x 1 075 MW converter station located at Nag Hammadi in Egypt, and a 300 MVAr SVC (requested for the intermediate load situation in 2020 – detailed in Report M1-2020 Power Study)

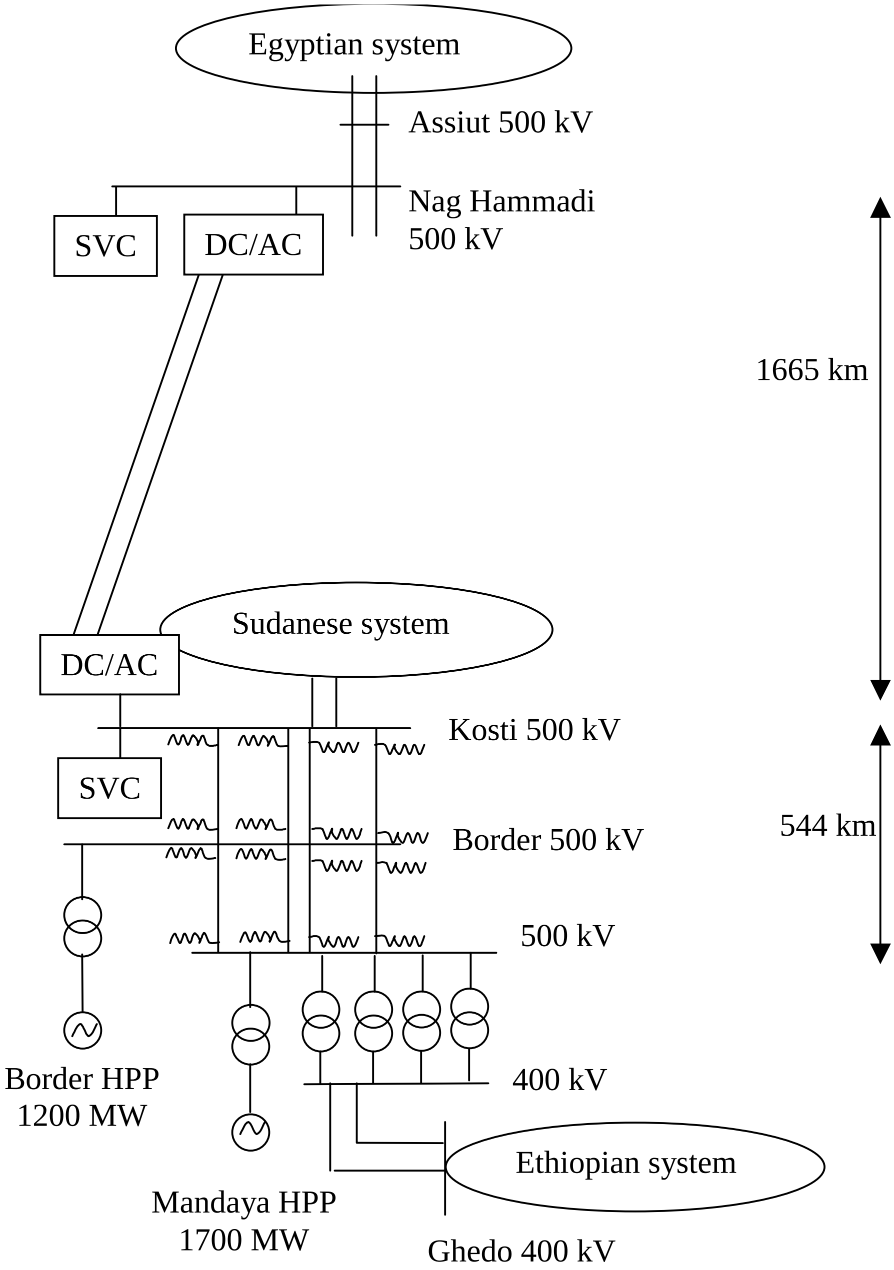


Figure 1: Interconnection Scheme in 2030

1.2.2 DESCRIPTION OF THE SYSTEM CLOSE TO THE INTERCONNECTION POINTS

1.2.2.1 Description of the Egyptian system close to Nag Hammadi

Nag Hammadi is located along the 500 kV double circuit backbone in the Nile valley, connecting High Dam HPP in the south to Kurimat and Cairo in the North, via Nag Hammadi, Assiut and Samalut substations.

In Nag Hammadi substation, two 500 kV circuits are connected to High Dam HPP in the south, and 2 are connected to Assiut substation in the North, one of them tapping in Sohag substation. Nag Hammadi substation included 500/220 kV and 500/132 kV transformations. A 300 MVAr SVC is also connected at Nag Hammadi substation (result of the 2020 network study).

1.2.2.2 Description of the Ethiopian system close to Border HPP and Mandaya HPP

T.Border 500kV substation is connected to Mandaya 500kV substation with four 500kV circuits. Border HPP is connected to T.Border substation with a 500 kV double circuit line.

Mandaya substation is connected to the 400 kV circuit in Addis Ababa with the following circuits :

- 3 circuits Mandaya - Ghimbi
- a double circuit Ghimbi - Ghedo
- 3 circuits Ghedo - Sebeta

Baro - Genji HPP, commissioned in 2020, are connected in 400 kV to Ghimbi, via Metu. (a third circuit is commissioned in 2021 between Ghimbi and Metu with the commissioning of Geba HPP)

1.2.2.3 Description of the Sudanese system in Kosti area

Concerning Kosti area, connection point of the interconnection to Ethiopia and Egypt, the 500 kV system includes :

- Two 500 kV circuits Kosti - Fula - Nyala (Western part)
- One 500 kV circuit Kosti - Jebel Aulia - Markhiat (along the White Nile river)
- Two 500 kV circuits Kosti - Meringan (between the Blue and the White Nile rivers)
- Two 500 kV circuits Meringan - Hasaheisa and two 500 kV circuits Hasaheisa - Bager - Kabashi (along the Blue Nile river)
- One 500 kV circuit Meringan - Gedaref - Port Sudan

Kosti substation included a 500/220 kV transformation.

1.3 DEMAND AND GENERATION BALANCE

1.3.1 LOAD DEMAND

In 2030, the most critical situation is the annual peak load period. This period was examined to assess the impact of the interconnection and the power exchanges on the transmission systems: the total demand is the sum of the annual peak of each of the 3 countries.

For this period, there is a risk of shortage of generation in the importing countries, so the transmission system must be able to operate with the maximum import (2000 MW for Egypt, and 1200 MW for Sudan).

The demand value for each country is displayed hereafter.

Peak demand* (MW)	2029/2030
Egypt	61 825
Ethiopia	5 506
Sudan	13 698

* These figures do not include the transmission losses

Table 1: Egyptian, Ethiopian and Sudanese 2029/2030 Load forecasts

1.3.2 GENERATION

The generation expansion plans were reviewed in Phase 1 (Module 3), and were presented in the Economic study. For Ethiopia, it was adapted in Module 6 of Phase 1, to take into account the anticipation of Mandaya HPP from 2024 to 2020 to meet the power exchange selected.

Name of the plant	Unit number	Plant site location	Type of generation unit	Installed capacity (MW)	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27
Sidi Krir	1	East Delta	CCGT	750	500	250																	
Kurimat (3)	1	Upper Egypt	CCGT	750	500	250																	
Nobaria (3)	1	West Delta	CCGT	750	500	250																	
Atfe	1	West Delta	CCGT	750	500	250																	
Sharm El-Sheik	1	West Delta	CCGT	750				750															
Alexandria Eas	1..2	West Delta	CCGT	750						500	500	500											
Combined Cycl	1..8		CCGT	750						500	500		500	500	500	1000	500	500	500	500	500		
Open Cycle GT 250 MW			OCGT	250																			
Abu Qir	1..2	West Delta	ST	650			650	650															
Suez	1	East Delta	ST	450					450														
Steam Units 45	1..16		ST	450						1350	450	450		450	450				450	900	900	1350	450
Cairo West Ext	1..2	Cairo	ST	350			700																
Tebbin	1..2	Cairo	ST	350		700																	
Ayoun Musa E>	1	Upper Egypt	ST	350				350															
Steam Units 65	1..22		ST	350					1300		650		1300	1300	1300	1300	650	1950	650	1300		1300	1300
Borg El-Arab			Solar/Therma	300									300		300								
Kurimat	1	Upper Egypt	Solar/Therma	150	150																		
Dabaa Nuclear	1..5		Nuclear	1000								1000					1000		1000		1000		1000
New Naga Han	4		Hydro	64	64																		
Assiut			Hydro	40					40														
Damietta			Hydro	13			13																
Zefta			Hydro	5.5				5.5															
Zafarana		East Delta	Wind	125	125																		

Table 2: Egyptian Generation Expansion Plan

For the years 2027 to 2030, additional plants have been supposed to be commissioned :

- Two 450 MW ST units
- Four 650 MW ST units

Commisioning Date	Hydro Project	Capacity MW	Average Generation GWh
2008	Gibe II	420	1 600
	Tekeze	300	1 200
2009	Beles	420	2 000
2010	Neshe	97	225
2011	Gibe III (I)		
2012	Gibe III (II)	1 870	6 240
2014			
2015			
2016	Halele Worabesa	420	2 245
2017			
2018			
2019			
2020	Mandaya + Baro I + II + Gengi	2 700	16 509
2021	Geba I + II	368	1 788
2022	Chemoga Yeda + Genale III	534	1 415
2023	Genale IV	256	
2024			
2025	Karadobi	1 600	6 000
2026			
2027			
2028			
2029	Aleltu E&W	565	
2030	Border	1 200	
Total		10 750	

Table 3: Ethiopian Generation Expansion Plan

Year	Thermal Plant			Hydro Electric Plant	
	Plant Name	Installed Capacity (MW)	Net Capacity (MW)	Plant Name	Installed Capacity (MW)
2015	Khartoum North ST's (U1&U2) Retired Khartoum North GT's (U3&U4) Retired 1 x Coal Fired Steam	-60 -47 400	-55 -34 380	Low Dal	340
2016				Kajbar	300
2017	1 x Crude Oil Fired Steam 1 x CCGT (6FA based)	250 214	238 208		
2018	1 x Coal Fired Steam	400	380		
2019	1 x CCGT (6FA based) 1 x Crude Oil Fired Steam	214 250	208 238	Dagesh	285
2020	2 x Crude Oil Fired Steam Southern Diesels	1,000 109	950 101	Fula 1	720
2021	1 x Coal Fired Steam	600	570		
2022				Shukoli	210
2023	1 x CCGT (9E based) Khartoum North ST's (U3&U4) Retired	352 -120	342 -102		
2024	1 x OCGT (6FA)	61	60	Lakki	210
2025	1 x Crude Oil Fired Steam	500	475		
2026	1 x CCGT (9E based)	352	342	Bedden	400
2027	2 x CCGT (9E based) 1 x Coal Fired Steam	705 600	683 570		
2028	Garri 1 CCGT's Retired	-220	-164		
2029	2 x CCGT (9EC based)	941	912		
2030	2 x CCGT (9EC based)	941	912		

Table 4: Sudanese Generation Expansion Plan

2 STUDY OF THE INTERCONNECTION FOR PEAK LOAD SITUATION 2029/2030

2.1 STUDY IN PERMANENT STATE OF THE INTERCONNECTION FOR PEAK LOAD PERIOD 2029 / 2030

2.1.1 NORMAL SITUATION

The interconnection

Ethiopia exported a total flow of 3446 MW over the 220 and the 500 kV interconnections :

- 2 x 69 = 138 MW flowed from Gonder on the 220 kV interconnection
- 4 x 827 = 3308 MW flow from T.Border on the 500 kV interconnection

Sudan received 3351 MW :

- 2 x 67 = 134 MW arrived at Gedaref from the 220 kV interconnection (phase-shift of the transformer : 20°)
- 4 x 804 = 3216 MW arrived at Kosti from the 500 kV interconnection

and exported 2 150 MW to Egypt at the AC/DC converter station in Kosti

The losses on the interconnection amounted to 94 MW on the AC interconnection (Ethiopia - Sudan): 4 x 22.3 = 89.4 MW on the 500 kV interconnection T.Border – Rabak (and 4 x 7.5 MW on Mandaya - T.Border), 2 x 2.34 = 4.7 MW on the 220 kV interconnection

The flow on the interconnection neighbouring circuits are displayed in Appendix A.1.1.

The voltage profile is satisfactory, and displayed in the following table :

Substations	Voltage (kV)
Border 500 kV	524.5
Mandaya 500 kV	525
Kosti	520
Nag Hammadi	510
Gonder	234.6
Gedaref	224.6

Table 5: Voltage profile in normal condition at the interconnection points

About 48 MVAr are sent to the interconnection at Border.

About 152 MVAr are supplied by the 500 kV Sudanese network at Kosti to feed partially the reactors of the interconnection, and 212 MVAr are supplied by the 500/220 kV transformation of Kosti (Steam Turbine connected in 220 kV).

Border HPP generated 1170 MW and absorbed 30 MVAr.

Interconnection Neighbouring circuits

Egypt :

Circuit	Nb of circuits	Flow (MW) per circuit	Loading (%)
Nag Hammadi from High Dam	2	90	15.2
Nag Hammadi to Assiut	1	90	4.1
Nag Hammadi to Sohag	1	130	10.1
Samalut to Assiut	2	391	22.7
Samalut from Kurimat	2	852	49.2
Samalut from S.Giza	1	465	33.6

Table 6: Loading of the Egyptian 500kV backbone H.D. – Cairo

The transmission lines closed to the interconnection point (Nag Hammadi) are lightly loaded.

The balance point between the flow from the south (HD & Interconnection) and from the north (Kurimat & Cairo) is located between Assiut And Sohag.

Ethiopia

The three circuits Ghimbi - Mandaya provided 485 MW to Mandaya and the four circuits T.Border - Mandaya provided 2 175 MW to T.Border substation.

Circuit	Nb of circuits	Flow (MW) per circuit	Loading (%)
Mandaya to T.Border	4	544	27.9
Ghimbi to Mandaya	3	162	23
Metu to Ghimbi	3	235	48.4
Ghimbi to Ghedo	2	281	39
Ghedo to Sebeta	3	438	60.6

Table 7: Loading of the Ethiopian 400kV backbone Mandaya - Addis Ababa

The 400 kV transmission lines located between Mandaya and Addis Ababa is heavily loaded.

Sudan

Circuit	Nb of circuits	Flow (MW) per circuit	Loading (%)
Kosti to Meringan	2	891.5	47
Kosti to Jabel Aulia	1	525	29
Fula to Kosti	2	314	23
Kosti transformation 500 to 220 kV	2	72	42.8

Table 8: Loading of the Sudanese 500kV circuits connected to Kosti

The 500 kV transmission network is not heavily loaded.

The SVC absorbed -13.6 MVAr in Kosti.

2.1.2 N-1 SITUATION ON THE INTERCONNECTION

2.1.2.1 Tripping of one of the two 220 kV circuits Gonder - Shehedi

The initial flow on each circuit Gonder - Shehedi reached 69.2 MW (loading of 27 %).
After the tripping, the flow on the remaining circuit increased to 120 MW (loading of 45.4 %). The importation in Gedaref from the 220 kV interconnection decreased from 134 to 115 MW. The flow on each 500 kV T.Border - Kosti circuit increased from 827 to 832 MW.

The voltage profile is not significantly affected: the voltage at Gonder and Gedaref decreased respectively from1.020 and 1.021 pu to 1.011 and 1.016 pu.

2.1.2.2 Tripping of one of the two 220 kV circuits Shehedi - Gedaref

The initial flow on each circuit Shehedi - Gedaref reached 68 MW (loading of 18 %).
After the tripping, the flow on the remaining circuit increased to 113.6 MW (loading of 29.4%). The flow on each 500 kV T.Border - Kosti circuit increased from 827 to 833.2 MW.

The voltage profile is not significantly affected: the voltage at Gonder increased from 1.02 to 1.022 and at Gedaref decreased from 1.021 pu to 1.018 pu.

2.1.2.3 Tripping of one of the four 500 kV circuits Border - Mandaya

The initial flow on each 500kV circuit T.Border - Mandaya reached 544 MW (loading of 27.9 %).

After the tripping, the flow on each remaining circuit increased to 722 MW (loading of 43.2 %). The importation in Gedaref from the 220 kV interconnection increased from 134 to 151 MW.

The SVC reactive power generation increased from -14 to 3 MVAr, Kosti voltage remained constant. Mandaya HPP increased its reactive output from -88.5 to 37 MVAr, to keep Mandaya voltage at 525 kV and Border HPP increased it from -30.5 MVAr to 33.6 MVAr to keep T.Border voltage close to 524 kV. The reactive output of Kosti CCG remained constant.

Due to Mandaya HPP, Border HPP and the SVC in Kosti, the voltage profile is not affected.

2.1.2.4 Tripping of one of the four 500 kV circuits T.Border - Kosti

The initial flow on each 500 kV circuit T.Border - Kosti reached 827 MW (loading of 43.2 %). After the tripping, the flow on each remaining circuit increased to 1099.5 MW (loading of 57.3 %). The importation in Gedaref from the 220 kV interconnection increased from 134 to 171 MW.

The SVC reactive power generation increased from -14 to 294 MVAr, and Kosti CCG increased its reactive output from 446 MVAr to 483 MVAr. Kosti voltage dropped by less than 1%, from 520 to 519.5 kV.

Border HPP increased its reactive output from -30 MVAr to 116 MVAr, to keep Border voltage above 520 kV: the voltage dropped from 524.5 to 523 kV.

Due to Border HPP, Kosti CCG and the SVC in Kosti, the voltage profile is not significantly affected.

2.1.2.5 Tripping of one of the four 400/500 kV transformers at Mandaya substation

The initial flow on each 400/500 kV transformer of Mandaya reached 120.6 MW (loading of 23.2 %). After the tripping, the flow on each remaining transformer increased to 160 MW (loading of 31.4%). The flow on each 500 kV circuit lightly decreased from 544 to 543.4 MW.

The flow on the double circuit line Gonder - Shehedi increased from 138.5 MW to 140.6 MW (loading of 27.4 %).

The voltage profile is not affected.

2.1.2.6 Tripping of one of the 2 DC poles

The tripping of one of the 2 DC circuits (pole or converter station) was studied in dynamic part of the report. See the results in Appendix A.2.1.1

2.1.3 N-1 SITUATION IN EGYPT CLOSE TO THE INTERCONNECTION POINT : NAG HAMMADI

The purpose of this study is to assess the impact of the injection of 2 000 MW in Nag Hammadi. The following cases have been simulated :

- Tripping of one of the two 500 kV circuits High Dam - Nag Hammadi
- Tripping of the 500 kV circuit Nag Hammadi - Sohag
- Tripping of the 500 kV circuit Nag Hammadi - Assiut
- Tripping of one of the two 500kV circuits Assiut - Samalut
- Tripping of one of the two 500 kV circuits Kurimat - Samalut
- Tripping of the 500kV circuit S.Giza - Samalut

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), the flows on the remaining circuits were below their rating.

The tripping of one of the DC poles was studied in dynamic.

The detailed results are displayed in Appendix A.1.2.1

2.1.4 N-1 SITUATION IN ETHIOPIA CLOSE TO THE INTERCONNECTION POINT: MANDAYA

The purpose of this study is to assess the impact of the interconnection close to Border: at Mandaya and around Addis Ababa. The following cases have been simulated :

- Tripping of one of the three 400 kV circuits Mandaya - Ghimbi
- Tripping of one of the two 400 kV circuits Ghimbi - Ghedo
- Tripping of one the three 400 kV circuits Ghedo - Sebeta
- Tripping of one of the two 400 kV circuits Debre Markos - Sululta

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), the flow on the remaining circuits remained within the rating.

The detailed results are displayed in Appendix A.1.2.2

2.1.5 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The purpose of this study is to assess the impact of the interconnection in Nag Hammadi. The following cases have been simulated :

- Tripping of the 500 kV circuit Kosti - Jebel Aulia
- Tripping of one of the two 500 kV circuits Kosti - Meringan
- Tripping of one of the two 500 kV circuits Kosti - Fula
- Tripping of the SVC in Kosti

The situation after the tripping of each of these elements was satisfactory. The voltage remained within the acceptable limits (+5/-10%), the flow on the remaining circuits remained within the rating.

The tripping of one of the DC poles was studied in dynamic.

The detailed results are displayed in Appendix A.1.2.3

2.2 STUDY OF THE SHORT-CIRCUIT POWER

Three-phase to ground and one-phase to ground short-circuit calculations were performed taking into account the following assumptions:

- V = 1.1 Vn
- Impedance of generator = X”d (sub transient reactance)

The short-circuit power of the Egyptian system is compliant with the 40 kA limitation on the 220 and 500 kV system.

The short-circuit power of the Sudanese system is compliant with the 40 kA limitation on the 220 and 500 kV system.

The results are displayed in Appendix 3

2.3 DYNAMIC STUDY OF THE INTERCONNECTION FOR PEAK LOAD PERIOD 2029 / 2030

2.3.1 N-1 SITUATION ON THE INTERCONNECTION

The behaviour of the system in case of tripping of one of the 2 poles is also acceptable for the 3 systems.

In case of short-circuit on one of the 500 kV interconnection Kosti - Border - Mandaya, Ethiopia and Sudan kept the synchronism.

In case of short-circuit on one of the 220 kV interconnection Gonder - Shehedi - Gedaref, Ethiopia and Sudan kept the synchronism.

See the results in Appendix A.2.1

2.3.2 N-1 SITUATION IN EGYPT CLOSE TO THE INTERCONNECTION POINT : NAG HAMMADI

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Egyptian network close to Nag Hammadi and High Dam. The voltage and the frequency recovered correctly. The disturbances causes on the Ethiopia-Sudan system were also acceptable.

The tripping of the main steam unit (765 MVA) was acceptable for the system.

See the results in Appendix A.2.2

2.3.3 N-1 SITUATION IN ETHIOPIA CLOSE TO BORDER AND MANDAYA

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Ethiopian network close to Border and Mandaya HPP. The voltage and the frequency recovered correctly. The disturbances causes on the Egyptian system were also acceptable.

The behaviour of the system following the tripping of 2 Ethiopian main units (Mandaya 266 MVA, initial output 2 x 212.5 MW) was acceptable.

See the results in Appendix A.2.3

2.3.4 N-1 SITUATION IN SUDAN CLOSE TO THE INTERCONNECTION POINT : KOSTI

The behaviour of the interconnected system was satisfactory in case of short-circuit on the Sudanese network close to Kosti. The voltage and the frequency recovered correctly. The disturbances causes on the Egyptian system were also acceptable.

The behaviour of the system following the tripping of Sudan main unit (Port Sudan 670 MVA, initial output 558 MW) was acceptable.

See the results in Appendix A.2.4

Appendix 1. LOAD FLOW RESULTS – PEAK LOAD SITUATION 2029/2030

A.1.1. Initial system – Normal situation

A.1.1.1 EGYPTIAN NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
A.Z.500	HELIO500	2151.78	67.99	2152.85	2412.0	9.84	26.98	4000.0	60.3
A.Z.500	N.DELTA500*	-1225.48	-38.21	1226.07	1373.6	11.59	77.01	2000.0	68.7
A.Z.500	SUEZ500	-1356.99	23.67	1357.19	1520.6	16.88	125.12	2049.6	74.2
A.Z.500	SUEZ500	-1356.99	23.67	1357.19	1520.6	16.88	125.12	2049.6	74.2
A.Z.500	TEB.500	306.59	-147.21	340.10	381.0	0.76	-86.60	2020.7	18.9
ABKIR500	KAFR.Z500	834.35	119.92	842.93	927.4	5.13	-25.22	2000.0	46.4
ABKIR500	KAFR.Z500	834.35	119.92	842.93	927.4	5.13	-25.22	2000.0	46.4
ABKIR500	N.DELTA500	257.88	-120.34	284.58	313.1	1.06	-202.53	2000.0	15.7
AMOUS500	SUEZ500	579.25	23.10	579.71	637.1	0.55	-13.91	2049.6	31.1
AMOUS500	SUEZ500	579.25	23.10	579.71	637.1	0.55	-13.91	2049.6	31.1
AMOUS500	TABA500	10.15	-43.91	45.07	49.5	0.14	-247.77	2049.6	2.4
AUST500	N.H.500	-45.22	-55.55	71.63	81.1	0.07	-201.96	1963.0	4.1
AUST500	N.H.500	-45.22	-55.55	71.63	81.1	0.07	-201.96	1963.0	4.1
AUST500	SOHAG500	47.78	-31.38	57.16	64.7	0.03	-110.77	1960.0	3.3
BASII500	A.Z.500	912.03	-107.07	918.30	1030.4	1.90	-1.98	2020.7	51.0
BASII500	C.W.500	-341.17	-7.90	341.26	382.9	0.08	-7.96	2020.7	18.9
BASII500	KAFR.Z500	-713.95	25.64	714.41	801.6	3.99	-35.51	2000.0	40.1
BASII500	KAFR.Z500	-713.95	25.64	714.41	801.6	3.99	-35.51	2000.0	40.1
CAIRO500	C.W.500	-946.21	-633.25	1138.56	1293.8	1.62	7.85	2020.7	64.0
CAIRO500	KRIMA500	90.41	-299.03	312.40	355.0	0.69	-127.09	1963.0	18.1
CAIRO500	NOBAR500	-3007.29	49.65	3007.70	3417.7	35.99	352.05	4041.5	84.6
CAIRO500	NOBAR500	-1503.64	24.82	1503.85	1708.9	17.99	176.03	2020.7	84.6
CAIRO500	S.GIZA500	481.11	-30.33	482.07	547.8	2.57	-95.99	1700.0	32.2
CAIRO500	S.GIZA500	481.11	-30.33	482.07	547.8	2.57	-95.99	1700.0	32.2
DABAA500	SALOUM500	223.00	-100.13	244.45	271.2	1.28	-286.41	2000.0	13.6
DABAA500	SKRIR500	2143.78	-7.97	2143.79	2378.5	20.84	111.20	4000.0	59.5
DABAA500	SKRIR500	1071.89	-3.98	1071.90	1189.3	10.42	55.60	2000.0	59.5
H.D.500	D1H.D.5	90.58	20.03	92.77	102.0	0.00	0.00	2049.6	5.0
H.D.500	D2H.D.5	90.58	20.03	92.77	102.0	0.00	0.00	2049.6	5.0
HELIO500	TEB.500	-517.58	-240.87	570.88	643.6	1.35	-35.67	1750.0	36.8
N.H.500	D1H.D.5	-90.03	-256.60	271.94	310.9	0.55	-236.81	2049.6	15.2
N.H.500	D2H.D.5	-90.03	-256.60	271.94	310.9	0.55	-236.81	2049.6	15.2
N.H.500	SOHAG500	130.29	-114.44	173.41	198.3	0.19	-107.42	1960.0	10.1
N.H500_ACDC**	N.H.500	1999.99	-200.82	2010.04	2298.1	0.01	0.10	6384.0	36.0
N.OCTO_500	S.GIZA500	-265.74	-247.52	363.16	430.3	1.27	-108.34	1700.0	25.3
NOBAR500	SKRIR500	-3695.50	401.49	3717.25	4143.3	46.59	278.47	6062.2	68.3
S.GIZA500	SAML500	464.72	-180.24	498.45	571.0	3.26	-126.27	1700.0	33.6
SALOUM500	TOBROK500	105.95	-35.25	111.66	126.8	0.17	-156.78	2020.0	6.3

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
SAML500	AUST500	391.31	-61.75	396.16	446.5	1.78	-119.39	1963.0	22.7
SAML500	AUST500	391.31	-61.75	396.16	446.5	1.78	-119.39	1963.0	22.7
SAML500	KRIMA500	-851.83	-99.51	857.62	966.6	9.48	-36.96	1963.0	49.2
SAML500	KRIMA500	-851.83	-99.51	857.62	966.6	9.48	-36.96	1963.0	49.2
TEB.500	KRIMA500	-532.78	-138.45	550.47	611.3	1.39	-44.70	2020.7	30.3
S_AQA400***	AKABA400	100.01	20.07	102.01	147.9	0.01	-5.11	2562.0	5.8
S_AQA400***	AKABA400	100.01	20.07	102.01	147.9	0.01	-5.11	2562.0	5.8
S_TAB400***	S_AQA400	200.37	-39.46	204.22	295.6	0.34	-79.60	2562.0	11.5
TABSW400	S_TAB400	200.49	-49.00	206.39	299.1	0.11	-9.54	2562.0	11.7

*N.Delta 500 has been replaced by W.Domatia 500 kV, in the latest 2015 Egyptian data
** N.H500_ACDC : DC/AC converter station in Nag Hammadi
*** Egypt exported 200 MW to Jordan

Table appendix 1.1 -1 -Power flow on the Egyptian 400 and 500 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
SALOUM500	TOBROK500	105.95	-35.25	111.66	126.8	0.17	-156.78	2020.0	6.3
SALOUM220	TOBROK220	47.27	-15.89	49.87	129.2	0.32	-28.93	1207.2	10.7
SALOUM220	TOBROK220	47.27	-15.89	49.87	129.2	0.32	-28.93	1207.2	10.7

The power flow exported from Egypt to Libya reached 200 MW

Table appendix 1.1 -2 - Power flow exported from Egypt to Libya

Substation	V sol [pu]	V sol [kV]
A.Z.500	1,031	515,5
ABKIR500	1,050	525
AMOUS500	1,051	525,5
AUST500	1,020	510
BASII500	1,029	514,5
C.W.500	1,029	514,5
CAIRO500	1,016	508
D1H.D.5	1,050	525
D2H.D.5	1,050	525
DABAA500	1,041	520,5
H.D.500	1,050	525
HELIO500	1,024	512
KAFR.Z500	1,030	515
KRIMA500	1,051	525,5
N.DELTA500	1,050	525
N.H.500	1,010	505
N.H500_ACDC	1,010	505
N.OCTO_500	0,974	487
NOBAR500	1,036	518
S.GIZA500	1,008	504
SALOUM500	1,017	508,5
SAML500	1,025	512,5
SKRIR500	1,036	518
SOHAG500	1,017	508,5
SUEZ500	1,049	524,5
TABA500	1,025	512,5
TEB.500	1,040	520
TOBROK500	1,007	503,5
TABSW400	0,996	398,4

Table appendix 1.1 -3 - Voltage of the Egyptian 500 kV substation

A.1.1.2 ETHIOPIAN NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1BORDERS81	1T.BORDES81	583.22	-77.66	588.36	647.4	1.91	-43.34	2128.0	30.4
1BORDERS81	1T.BORDES81	583.22	-77.66	588.36	647.4	1.91	-43.34	2128.0	30.4
1T.BORDES81	1MANDAS81	-536.46	-55.85	539.36	593.6	7.51	-209.22	2128.0	27.9
1T.BORDES81	1MANDAS81	-536.46	-55.85	539.36	593.6	7.51	-209.22	2128.0	27.9
1T.BORDES81	1MANDAS81	-536.46	-55.85	539.36	593.6	7.51	-209.22	2128.0	27.9
1T.BORDES81	1MANDAS81	-536.46	-55.85	539.36	593.6	7.51	-209.22	2128.0	27.9
1T.BORDES81	2RABAK81*	826.61	-126.42	836.22	920.3	22.34	-138.54	2128.0	43.2
1T.BORDES81	2RABAK81*	826.61	-126.42	836.22	920.3	22.34	-138.54	2128.0	43.2
1T.BORDES81	2RABAK81*	826.61	-126.42	836.22	920.3	22.34	-138.54	2128.0	43.2
1T.BORDES81	2RABAK81*	826.61	-126.42	836.22	920.3	22.34	-138.54	2128.0	43.2

* Rabak was replaced by Kosti

Table appendix 1.1 -4 - Power flow on the Ethiopian 500 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1BORDERS81	1T.BORDES81	583.22	-77.66	588.36	647.4	1.91	-43.34	2128.0	30.4
1BORDERS81	1T.BORDES81	583.22	-77.66	588.36	647.4	1.91	-43.34	2128.0	30.4
1T.BORDES81	1MANDAS81	-536.46	-55.85	539.36	593.6	7.51	-209.22	2128.0	27.9
1T.BORDES81	1MANDAS81	-536.46	-55.85	539.36	593.6	7.51	-209.22	2128.0	27.9
1T.BORDES81	1MANDAS81	-536.46	-55.85	539.36	593.6	7.51	-209.22	2128.0	27.9
1T.BORDES81	1MANDAS81	-536.46	-55.85	539.36	593.6	7.51	-209.22	2128.0	27.9
1T.BORDES81	2RABAK81	826.61	-126.42	836.22	920.3	22.34	-138.54	2128.0	43.2
1T.BORDES81	2RABAK81	826.61	-126.42	836.22	920.3	22.34	-138.54	2128.0	43.2
1T.BORDES81	2RABAK81	826.61	-126.42	836.22	920.3	22.34	-138.54	2128.0	43.2
1T.BORDES81	2RABAK81	826.61	-126.42	836.22	920.3	22.34	-138.54	2128.0	43.2
1B.DAR3S71	1BELESS71	-224.49	11.36	224.78	310.0	0.78	-34.65	1010.0	30.7
1B.DAR3S71	1BELESS71	-224.49	11.36	224.78	310.0	0.78	-34.65	1010.0	30.7
1B.DAR3S71	1D.MARS71	61.22	-55.88	82.89	114.3	0.18	-122.84	1010.0	11.3
1BAROS71	1BARO2S71	-492.35	-12.57	492.52	678.9	1.13	-41.48	2020.0	33.6
1BAROS71	1GENJIS71	-209.17	-1.51	209.17	288.3	0.20	-10.95	1010.0	28.5
1BAROS71	1METUS71	445.48	0.79	445.48	614.1	1.55	-17.89	1515.0	40.5
1BAROS71	1METUS71	445.48	0.79	445.48	614.1	1.55	-17.89	1515.0	40.5
1D.MARS71	1KARADS71	-298.02	11.24	298.23	413.3	0.84	-18.36	1010.0	40.9
1D.MARS71	1KARADS71	-298.02	11.24	298.23	413.3	0.84	-18.36	1010.0	40.9
1D.MARS71	1SULULS71	369.38	-8.56	369.48	512.1	7.63	-79.65	1010.0	50.7
1D.MARS71	1SULULS71	369.38	-8.56	369.48	512.1	7.63	-79.65	1010.0	50.7
1GEBAS71	1METUS71	289.27	-28.40	290.66	401.6	0.98	-23.58	1010.0	39.8
1GENALE3S71	1GENALE4S71	-244.14	-24.67	245.38	339.5	1.12	-41.35	1010.0	33.6
1GENALE3S71	1W.SODS71	489.18	-69.42	494.08	683.7	16.94	-55.53	1010.0	67.7
1GG2S71	1GIBE3S71	29.09	-9.50	30.60	42.2	0.08	-91.98	1010.0	4.2
1GGOS71	1GG2S71	20.42	-57.09	60.63	83.9	0.02	-25.33	1010.0	8.3

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1GHEDOS71	1GHIMBIS71	-280.87	-27.40	282.20	394.0	3.84	-93.57	1010.0	39.0
1GHEDOS71	1GHIMBIS71	-280.87	-27.40	282.20	394.0	3.84	-93.57	1010.0	39.0
1GHEDOS71	1KARADS71	-377.45	-11.60	377.63	527.2	4.01	-41.52	1010.0	52.2
1GHEDOS71	1KARADS71	-377.45	-11.60	377.63	527.2	4.01	-41.52	1010.0	52.2
1GHEDOS71	1SEBETS71	438.35	8.19	438.42	612.1	6.20	-32.46	1010.0	60.6
1GHEDOS71	1SEBETS71	438.35	8.19	438.42	612.1	6.20	-32.46	1010.0	60.6
1GHEDOS71	1SEBETS71	438.35	8.19	438.42	612.1	6.20	-32.46	1010.0	60.6
1GHIMBIS71	1MANDAS71	161.57	-43.07	167.21	231.9	0.74	-68.22	1010.0	23.0
1GHIMBIS71	1MANDAS71	161.57	-43.07	167.21	231.9	0.74	-68.22	1010.0	23.0
1GHIMBIS71	1MANDAS71	161.57	-43.07	167.21	231.9	0.74	-68.22	1010.0	23.0
1GHIMBIS71	1METUS71	-352.08	14.97	352.40	488.7	3.60	-46.98	1010.0	48.4
1GHIMBIS71	1METUS71	-352.08	14.97	352.40	488.7	3.60	-46.98	1010.0	48.4
1GHIMBIS71	1METUS71	-352.08	14.97	352.40	488.7	3.60	-46.98	1010.0	48.4
1GIBE3S71	1W.SODS71	186.49	-13.30	186.96	260.7	0.67	-43.55	1010.0	25.8
1GIBE3S71	1W.SODS71	186.49	-13.30	186.96	260.7	0.67	-43.55	1010.0	25.8
1KALITS71	1SEBETS71	-375.55	-59.69	380.27	546.1	1.45	-12.20	1010.0	54.1
1KALITS71	1SEBETS71	-375.55	-59.69	380.27	546.1	1.45	-12.20	1010.0	54.1
1KALITS71	1SEBETS71	-375.55	-59.69	380.27	546.1	1.45	-12.20	1010.0	54.1
1SEBETS71	1GG2S71	-294.94	-89.69	308.27	439.2	4.60	-92.08	1010.0	43.5
1SEBETS71	1SULULS71	-102.23	75.31	126.98	180.9	0.23	-27.27	1010.0	17.9
1W.SODS71	1KALITS71	215.10	-49.27	220.67	309.2	3.08	-135.97	1010.0	30.6
1W.SODS71	1KALITS71	215.10	-49.27	220.67	309.2	3.08	-135.97	1010.0	30.6

Table appendix 1.1 -5 - Power flow on the Ethiopian 400 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
1GONDES61	1SHEHES61	69.24	-30.76	75.77	186.5	1.19	-22.63	690.0	27.0
1GONDES61	1SHEHES61	69.24	-30.76	75.77	186.5	1.19	-22.63	690.0	27.0

Table appendix 1.1 -6 - Power flow on the Ethiopian-Sudan 220 kV lines

From bus	To bus	Sn nominal [MVA]	P [MW]	Q [MVAR]	S [MVA]	I [A]	Loading [%]
1MANDAS71	1MANDAS81	510	141.64	-2.73	141.66	197	27.8
1MANDAS71	1MANDAS81	510	141.64	-2.73	141.66	197	27.8
1MANDAS71	1MANDAS81	510	141.64	-2.73	141.66	197	27.8
1MANDAS71	1MANDAS81	510	141.64	-2.73	141.66	197	27.8

Table appendix 1.1 -7 - Power flow on the Ethiopian 400/500 kV transformers

Substation	V sol [pu]	V sol [kV]
1MANDAS81	1,051	525,5
1T.BORDES81	1.049	524.5
1B.DAR3S71	1,047	418,8
1BARO2S71	1,049	419,6
1BAROS71	1,047	418,8
1BELESS71	1,047	418,8
1D.MARS71	1,041	416,4
1GEBAS71	1,045	418
1GENALE3S71	1,043	417,2
1GENALE4S71	1,049	419,6
1GENJIS71	1,048	419,2
1GG2S71	1,047	418,8
1GGOS71	1,043	417,2
1GHEDOS71	1,034	413,6
1GHIMBIS71	1,041	416,4
1KALITS71	1,035	414
1KARADS71	1,005	402
1MANDAS71	1,043	417,2
1METUS71	1,038	415,2
1SEBETS71	1,043	417,2
1SULULS71	1,013	405,2
1W.SODS71	1,006	402,4

Table appendix 1.1 -8 - Voltage of the 400 and 500 kV Ethiopian substations

A.1.1.3 SUDANESE NETWORK

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Norm.) [A]	Loading %
2ATBARS81	2KABASS81	374.86	-179.15	415.47	466.0	4.35	-275.50	2128.0	21.9
2BAGERS81	2H.HEI81	137.03	52.45	146.72	165.4	0.32	-103.34	2128.0	7.8
2BAGERS81	2H.HEI81	137.03	52.45	146.72	165.4	0.32	-103.34	2128.0	7.8
2BAGERS81	2J.AULIAS81	100.34	65.12	119.62	134.8	0.08	-42.23	2128.0	6.3
2BAGERS81	2KABASS81	-314.46	-78.58	324.13	365.3	0.85	-78.38	2128.0	17.2
2BAGERS81	2KABASS81	-314.46	-78.58	324.13	365.3	0.85	-78.38	2128.0	17.2
2BORS81	2JUBAS81	-426.66	-80.69	434.22	486.3	3.07	-146.04	2128.0	22.9
2BORS81	2MALAKAS81	343.61	-171.51	384.04	430.1	4.50	-343.38	2128.0	20.2
2FULA81	2NYALA81	496.64	-129.92	513.35	565.7	10.44	-331.27	2128.0	26.6
2FULA81	2RABAK81*	314.20	-317.18	446.46	492.0	5.85	-591.80	2128.0	23.1
2FULA81	2RABAK81*	314.20	-317.18	446.46	492.0	5.85	-591.80	2128.0	23.1
2GEDARE81	2MERIN81	-82.56	-168.38	187.53	217.2	0.25	-229.95	2128.0	10.2
2GEDARE81	2P.SUD81	-451.12	-305.68	544.93	631.2	16.82	-609.17	2128.0	29.7
2H.HEI81	2MERIN81	-758.04	50.08	759.69	867.1	3.62	-24.27	2128.0	40.7
2J.AULIAS81	2MARKHS81	-101.15	-32.52	106.25	120.2	0.08	-78.38	2128.0	5.7
2J.AULIAS81	2RABAK81*	-525.30	-130.88	541.36	612.6	10.06	-267.26	2128.0	28.8
2JUBAS81	2RUMBEKS81	427.54	-81.37	435.21	483.2	6.84	-295.05	2128.0	22.7
2KABASS81	2ATBARS81	-370.51	-96.34	382.83	428.9	4.35	-275.50	2128.0	20.2
2MARKHS81	2KABASS81	-566.92	-200.90	601.47	680.5	1.45	-26.82	2128.0	32.0
2MERIN81	2RABAK81*	-884.75	-85.68	888.89	1013.6	13.68	-38.33	2128.0	47.6
2MEROWS81	2ATBARS81	163.84	-66.84	176.95	194.5	0.77	-259.12	2128.0	9.1
2MEROWS81	2MARKHS81	473.15	-134.92	492.01	540.9	8.43	-316.89	2128.0	25.4
2MEROWS81	2MARKHS81	473.15	-134.92	492.01	540.9	8.43	-316.89	2128.0	25.4
2NYALA81	2FULA81	-486.20	-201.35	526.24	603.2	10.44	-331.27	2128.0	28.3
2P.SUD81	2ATBARS81	498.40	-206.33	539.42	593.5	11.47	-386.53	2128.0	27.9
2P.SUD81	2ATBARS81	498.40	-206.33	539.42	593.5	11.47	-386.53	2128.0	27.9
2RABAK_5ACDC**	2RABAK8*1	-2149.99	-78.38	2151.42	2388.7	0.02	0.09	6384.0	37.4
2RABAK81*	2MERIN81	898.43	47.35	899.68	998.9	13.68	-38.33	2128.0	46.9
2RUMBEKS81	2WAUS81	198.68	-172.64	263.21	304.9	1.61	-348.34	2128.0	14.3

* Rabak was replaced by Kosti

* RABAK_5ACDC : AC/DC converter station in Kosti

Table appendix 1.1 -9 - Power flows on the Sudanese 500 kV lines

From bus	To bus	P [MW]	Q [MVAr]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAr]	Ampacity (Norm.) [A]	Loading [%]
2GEDARS61	1SHEHE61	-66.91	-8.55	67.45	173.4	1.09	-32.61	972.0	17.8
2GEDARS61	1SHEHE61	-66.91	-8.55	67.45	173.4	1.09	-32.61	972.0	17.8

Table appendix 1.1 -10 - Power flows on the 220 kV interconnection Ethiopia - Sudan

Power imported from Ethiopia

Power flow arriving from Ethiopia to Sudan:

- 500 kV interconnection : 4 x 804.3MW =3217 MW
- 220 kV interconnection : 2 x 67MW =134 MW

Total : 3351 MW

Among these 3351 MW, 2150 MW are absorbed by the AC/DC converter station in Rabak (hypothesis : losses on the DC lines and converter stations = 150 MW). 1200 MW are for the Sudanese system.

To limit the flow and avoid an overload on the 220 kV interconnection, a phase-shift transformer has been installed at Gedaref substation.

Substation	V sol [pu]	V sol [kV
2ATBARS81	1,029	514,5
2BAGERS81	1,025	512,5
2BORS81	1,031	515,5
2FULA81	1,048	524
2GEDARE81	0,997	498,5
2H.HEI81	1,012	506
2J.AULIAS81	1,02	510
2JUBAS81	1,04	520
2KABASS81	1,031	515,5
2MALAKAS81	1,017	508,5
2MARKHS81	1,021	510,5
2MERIN81	1,013	506,5
2MEROWS81	1,05	525
2NYALA81	1,007	503,5
2P.SUD81	1,049	524,5
2RABAK_5ACDC*	1,04	520
2RABAK81*	1,04	520
2RUMBEKS81	0,997	498,5
2WAUS81	0,988	494

* Rabak was replaced by Kosti

Table appendix 1.1 -11 - Voltage of the 500 kV Sudanese substations

A.1.2. Initial system – N-1 situation

A.1.2.1 EGYPTIAN NETWORK

Recall of the flows on the 500 kV backbone along the Nile Valley

From bus	To bus	N° of circuits	P [MW] per circuit	Loading %
H.D.500	N.H.500	2	90	15.2
N.H.500	AUST500	1	65	5.6
N.H.500	SOHAG500	1	147	10.5
SOHAG500	AUST500	1	-27	3.3
AUST500	SAML500	2	-391	22.7
SAML500	S.GIZA500	1	180	33.6
SAML500	KRIMA500	2	-852	49.2

Table appendix 1.2 -1 - Power flow on the Egyptian 500 kV lines

A.1.2.1.1 TRIPPING OF ONE OF THE 2 CIRCUITS HIGH DAM - NAG HAMMADI

The initial flow on each of the 2 circuits High Dam - Nag Hammadi reached 90 MW, total 180 MW (15.2 % of loading). High Dam HPP generated initially 580 MVAr.

The situation after the tripping of the line is satisfactory. The flow on the remaining circuit reached 164 MW (16.5 % of loading – load report of 86 % of the initial flow). High Dam HPP generated 557 MVAr, to keep the voltage at its set point (1.01 pu).

In High Dam substation, the flow on the 500/220 kV transformation increased by 10 MW, and the flow on the 500/132 kV transformation increased by 6 MW.

The voltage in Nag Hammadi remained at 1.01 p.u.

A.1.2.1.2 TRIPPING OF THE CIRCUIT NAG HAMMADI - SOHAG

The initial flow on the circuit Nag Hammadi - Sohag reached 147 MW (10.5 % of loading).

The flow on the circuit Nag Hammadi - Assiut increased from 65 MW to 152 MW (respectively 5.6 % and 9.7 %of loading - load report of 59 %).

The flow on the circuit Sohag - Assiut increased from -27 MW (3.3 % of loading) to 130 MW.

In Nag Hammadi substation, the flow on the 500/220 kV transformation increased by 50 MW, and the flow on the 500/132 kV transformation increased by 8 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
Nag Hammadi	1.01	1.01
Sohag	1.015	1.017
Assiut	1.016	1.02

Table appendix 1.2 –2 Voltage Variation of Egyptian substations

The situation after the tripping of the line is satisfactory.

A.1.2.1.3 TRIPPING OF THE CIRCUIT NAG HAMMADI - ASSIUT

The initial flow on the circuit Nag Hammadi - Assiut reached 65 MW (5.6 % of loading).

The flow on the circuit Nag Hammadi - Sohag increased from 147 MW to 192 MW (10.5 % to 12.1 %of loading - load report of 69 %).

In Nag Hammadi substation, the flow on the 500/220 kV transformation increased by 14 MW, and the flow on the 500/132 kV transformation increased by 4 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
Nag Hammadi	1.01	1.009
Sohag	1.015	1.01
Assiut	1.016	1.008

Table appendix 1.2 –3 Voltage Variation of Egyptian substations

The situation after the tripping of the line is satisfactory.

A.1.2.1.4 TRIPPING OF ONE OF THE TWO CIRCUITS ASSIUT - SAMALUT

The initial flow on each of the two circuits Assiut - Samalut reached -391 MW, total -783 MW (22.7 % of loading).

The flow on the remaining circuit reached -684MW (39.6% of the nominal rating - 75% of load report)

The flow on the circuit South Giza - Samalut decreased from 465 MW to 460 MW (33.6 % to 32.7%of loading).

The flow on the two circuits Kurimat - Samalut decreased from 1704 MW to 1696MW (loading of 49.6%)

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
South Giza	1.008	1.006
Samalut	1.023	1.017
Assiut	1.016	1.002

Table appendix 1.2 –4 Voltage Variation of Egyptian substations

The voltage profile was slightly affected.

A.1.2.1.5 TRIPPING OF THE CIRCUIT SAMALUT – SOUTH GIZA

The initial flow on the circuit Samalut - South Giza reached 465 MW (33.6 % of loading).

The flow on each of the two circuits Kurimat - Samalut increased from –852 MW to -1044 MW (49.2 % to 60.5%of loading - load report of 83 %).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
South Giza	1.008	0.995
Samalut	1.023	1.019
Assiut	1.016	1.014

Table appendix 1.2 –5 Voltage Variation of Egyptian substations

The voltage profile was slightly affected.

A.1.2.1.6 TRIPPING OF ONE OF THE TWO CIRCUITS KURIMAT - SAMALUT

The initial flow on each the two circuits Kurimat - Samalut reached 852 MW, total 1 704 MW (49.4 % of loading).

The flow on the remaining circuit reached 1312 MW (77.6% of the nominal rating - 77% of load report)

The flow on the circuit South Giza - Samalut increased from 465 MW to 722 MW (33.5 % to 49.6 %of loading).

The flow on the two circuits Cairo - South Giza increased from 963 MW to 575 MW (32.2 % to 38.6 %of loading).

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
South Giza	1.008	0.997
Samalut	1.023	0.998
Assiut	1.016	1

Table appendix 1.2 –6 Voltage Variation of Egyptian substations

A.1.2.1.7 CONCLUSION

Whatever the tripped line in the 500 kV system in the Upper Nile Valley, the behaviour of the system is satisfactory. The flow remained far below the thermal limit, and the voltage remained within the limits (+5/-10 %).

A.1.2.2 ETHIOPIAN NETWORK

Recall of the flow on the Ethiopian 400 kV system between Addis Ababa and Mandaya

From bus	To bus	N° of circuit	P (MW) per circuit	Loading (%)
1MANDAS71	1GHIMBIS71	3	162	23
1GHIMBIS71	1GHEDOS71	2	281	39
1GHIMBIS71	1METUS71	3	-352	48.4
1GHEDOS71	1SEBETS71	3	438	60.6

Table appendix 1.2 –7 Power flow on the Ethiopian 400 kV lines

A.1.2.2.1 TRIPPING OF ONE OF THE TWO 400 KV CIRCUITS DEBRE MARKOS - SULULTA

The initial flow on each of the two circuits Debre Markos - Sululta reached 369 MW, total 739 MW (loading of 50.7°%)

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system. The flow on the remaining circuit increased from 369 MW to 505 MW (loading of 69.6%, loading report of 68.3%). The flow on the two 230 kV circuits Ghedo to Gefersa increased from 393 to 413 MW (from 71.7 to 75.6 % of loading).

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 134 to 140 MW.

Voltage variation on the following substations:

Substation	Initial voltage (pu)	Final voltage (pu)
1B.DAR3S71	1.047	1.046
1D.MARS71	1.041	1.041
1GHEDOS71	1.034	1.026
1SEBETS71	1.043	1
1SULULS71	1.013	0.985

Table appendix 1.2 –8 Voltage Variation of Ethiopian substations

A.1.2.2.2 TRIPPING OF ONE OF THE THREE 400 KV CIRCUITS SEBETA - GHEDO

The initial flow on each circuit Ghedo - Sebeta reached 438 MW, total 1 315 MW (loading of 60.6%)

The flow on the remaining circuit reached 601 MW (loading of 83.6% - load report of 68.5%)

The flow over the 220 kV Ethiopia - Sudan interconnection decreased from 134 to 127 MW

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.041	1.04
1GHEDOS71	1.034	1.03
1SEBETS71	1.043	1

Table appendix 1.2 –9 Voltage Variation of Ethiopian substations

The voltage profile was not significantly affected.

A.1.2.2.3 TRIPPING OF ONE OF THE TWO 400 KV CIRCUITS GHEDO - GHIMBI

The initial flow on each circuit Ghedo - Ghimbi reached -281 MW, total 562 MW (loading of 39°%)

The flow over the remaining circuit reached -50 6MW – loading of 70.4% - load report of 90%).

The flow over the 220 kV Ethiopia - Sudan interconnection decreased from 134 to 102.6 MW

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.041	1.038
1GHEDOS71	1.034	1.029
1SEBETS71	1.043	1.01

Table appendix 1.2 –10 Voltage Variation of Ethiopian substations

The voltage profile was not significantly affected.

A.1.2.2.4 TRIPPING OF ONE OF THE THREE 400 KV CIRCUIT GHIMBI - MANDAYA

The initial flow on each circuit Ghimbi - Mandaya reached 162 MW, total 485 MW (loading of 23°%)

The flow over the two remaining circuits reached 479 MW (loading of 33.3% - load report of 98.75%)

The flow over the 220 kV Ethiopia - Sudan interconnection increased from 134 to 140 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1GHIMBIS71	1.041	1.042
1GHEDOS71	1.034	1.034
1SEBETS71	1.043	1.013

Table appendix 1.2 –11 Voltage Variation of Ethiopian substations

The voltage profile was not significantly affected.

A.1.2.2.5 TRIPPING OF ONE OF THE TWO 230 KV CIRCUITS BAHIR DAR - GONDER

The initial flow on each circuit Bahir Dar - Gonder reached 151 MW (loading of 54.1°%)

Following the tripping of the line, the flow on the remaining circuit reached 212 MW (loading of 74.4 % - load report of 68.8%).

The flow over the 220 kV Ethiopia - Sudan interconnection decreased from 134 to 41 MW.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
1B.DARS61	1.043	1.042
1GONDERS61	1.02	1.012

Table appendix 1.2 –12 Voltage Variation of Ethiopian substations

The voltage profile was not affected.

A.1.2.2.6 CONCLUSION

The behaviour of the Ethiopian system is satisfactory, in case of tripping of one of the 400 kV circuit on the 400 kV backbone between Mandaya and Addis Ababa area. The flow remained far below the thermal limit, and the voltage remained within the limits (+5/-10 %).

A.1.2.3 SUDANESE NETWORK

Recall of the flow on the Sudanese 500 kV system around Kosti

From bus	To bus	N° of circuit	P [MW] per circuit	Loading %
2RABAK81	1T.BORDES81	4	827	43.2
2RABAK81	2FULA81	2	314	23.1
2RABAK81	2J.AULIAS81	1	525	28.8
2RABAK81	2MERIN81	2	892	47.9
2BAGERS81	2H.HEI81	2	137	7.8
2BAGERS81	2J.AULIAS81	1	100	6.3
2GEDARE81	2MERIN81	1	-83	10.2
2H.HEI81	2MERIN81	1	-758	40.7

* Rabak was replaced by Kosti

Table appendix 1.2 –13 Power flow on the Sudanese 500 kV lines

A.1.2.3.1 TRIPPING OF THE 500 KV CIRCUIT KOSTI - JEBEL AULIA

The initial flow on Kosti - J.Aulia reached 525 MW (loading of 28.8%)

The flow on each circuit Kosti - Meringan increased from 885 to 1114MW (from 47.6 to 60.6% of loading).

The flow on the 500/220 kV transformation of Kosti decreased by 54MW.

The voltage at Kosti substation is not affected, the SVC increasing its reactive output from -14 to 151 MVAr.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
Kosti	1.04	1.04
J. Aulia	1.02	1.013

Table appendix 1.2 –14 Voltage Variation of Sudanese substations

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.1.2.3.2 TRIPPING OF ONE OF THE TWO 500 KV CIRCUITS KOSTI - MERINGAN

The initial flow on each of the two circuits Kosti - Meringan reached 892 MW, total 1 783 MW (loading of 47.9°%)

The flow on Kosti - J.Aulia increased from 525 to 725 MW (from 28.8 to 39.2% of loading).

The flow on the two circuits Fula - Kosti decreased from 628 to 612 MW (from 23.1 to 22.8% of loading).

The flow on the 500/220 kV transformation of Kosti increased by 100 MW.

The voltage at Kosti substation is not affected, the SVC increasing its reactive output from -14 to 99 MVAr.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
Kosti	1.04	1.04
Meringan	1.013	0.991
J. Aulia	1.02	1.012

Table appendix 1.2 –15 Voltage Variation of Sudanese substations

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.1.2.3.3 TRIPPING OF ONE OF THE TWO 500 KV CIRCUITS KOSTI - FULA

The initial flow on the two circuits Kosti - Fula reached 624 MW (loading of 23.1°%)

The flow on the remaining circuit Kosti - Fula increased from 624 to 543 MW (from 23.1% to 32.1% of loading, loading report of 97.9%).

The flow on the 500/220 kV transformation of Kosti decreased by 52 MW.

The voltage at Kosti (SVC) and Fula (generation plants) substation is not affected, the SVC increasing its reactive output from -14 to 156 MVAr.

Voltage variation on the following substations

Substation	Initial voltage (pu)	Final voltage (pu)
Kosti	1.04	1.04
Fula	1.048	1.04
Nyala	1.007	0.993

Table appendix 1.2 –16 Voltage Variation of Sudanese substations

Following the tripping of the line, the behaviour was acceptable. No overload occurred on the transmission system.

A.1.2.3.4 TRIPPING OF THE SVC AT KOSTI

In normal situation, the SVC reactive power generation is close to 0. The tripping of the SVC did not entail significant voltage variation. The voltage at Kosti increased from 1.04 to 1.041.

A.1.2.3.5 CONCLUSION

The behaviour of the Sudanese system is satisfactory, in case of tripping of one of the 500 kV circuit connected to Kosti. The flow remained far below the thermal limit, and the voltage remained within the limits (+5/-10 %).

Appendix 2. DYNAMIC RESULTS – PEAK LOAD 2029/2030

A.2.1. Interconnection

A.2.1.1 TRIPPING OF ONE OF THE 2 POLES OF THE DC INTERCONNECTION

In case of tripping of one of the 2 poles of the DC interconnection, the behaviour of the system is satisfactory.

Event : a tripping of one of the 2 poles of the DC interconnection, and disconnection of half of the capacitor banks in each of the HVDC converter station 300 ms after.

Following the reduction of the transmitted power by half of its initial value :

- For the Ethiopia - Sudan system, the frequency raised to 50.35 Hz, before stabilizing around 50.14 Hz, after activation of the primary regulation of the generation governors
- For the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 49.8 Hz, after activation of the primary regulation of the generation governors with spinning reserve, and the self regulation of the load (estimated to 360 MW).

Libya contributed with about 50 MW of its primary reserve, and around 63 MW of self regulation of the load
Jordan and Syria contributed with about 100 MW of primary reserve, and about 112 MW of self regulation of the load

Node	Initial voltage	Maximal voltage	Final voltage
NH500	505 kV	525 kV	502.5 kV
Kosti 500	520 kV	549.5 kV	522.7 kV
T.Border 500	524.5 kV	546.5 kV	527.9 kV
Mandaya 500	525.5 kV	540.5 kV	527.5 kV

Table appendix 2.1 –1 Voltage Variation of interconnection Nodes

The flow on each of the 4 circuits T.Border - Kosti decreased from 827 MW to 773 MW.

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.1.2 SHORT-CIRCUIT ON ONE OF THE 4 T.BORDER - KOSTI CIRCUITS, ON KOSTI SIDE

In case of short-circuit at Kosti on the interconnection, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on one of the 4 circuits T.Border - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) led to a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before recovering its initial value 300 ms after the tripping of the line.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Following the tripping of the 500kV line T.Border - Kosti:

- For the Ethiopia - Sudan system, the frequency raised to 50.7 Hz, before stabilizing around 49.96 Hz, after activation of the primary regulation of the generation governors
- For the Egyptian system and the neighbouring countries, the frequency dropped and stabilized around 50 Hz.

Node	Initial voltage	Maximal voltage	Final voltage
N.H.	505 kV	535.6 kV	505.1 kV
T.Border	524.5 kV	547.45 kV	517.9 kV
Kosti	520 kV	537.3 kV	517.85 kV
Mandaya	525.5 kV	547.45 kV.	517.95 kV

Table appendix 2.1 –2 Voltage Variation of interconnection Nodes

The flow on each of the remaining 3 circuits T.Border - Kosti reached 1 216 MW, before stabilizing at 1 079 MW.

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.1.3 SHORT-CIRCUIT ON ONE OF THE 4 T.BORDER - KOSTI CIRCUITS, ON T.BORDER SIDE

In case of short-circuit at T.Border on the interconnection line T.Border - Kosti, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at T.Border end, on one of the 4 circuits T.Border - Kosti, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0.45 pu) led to a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Generator	Maximal frequency	Minimal frequency
Border	50.8 Hz	49.5 Hz
Mandaya	50.7 Hz	49.6 Hz
Gibe 3	50.3 Hz	49.9 Hz
Kosti	50.4 Hz	49.85 Hz
Fula ST	50.3 Hz	49.8 Hz

Table appendix 2.1 –3 Voltage Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
T.Border	524.5 kV	571.4 kV	0 kV	517.9 kV
Kosti	520 kV	525.9 kV	253.6 kV	513.3 kV
Mandaya	525.5 kV	572.95 kV	182.3 kV	522.4 kV

Table appendix 2.1 –4 Voltage Variation of interconnection nodes

The flow on the remaining 3 circuits T.Border - Kosti reached 1 300 MW, before stabilizing at 1 080 MW.

The figures are displayed in M1-2030_Appendix_Stability_Study

A.2.1.4 SHORT-CIRCUIT ON ONE OF THE 4 T.BORDER - MANDAYA CIRCUITS, ON BORDER SIDE

In case of short-circuit at Border on one of the 4 T.Border - Mandaya circuits, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at T.Border end, on one of the 4 circuits T.Border - Mandaya, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0.44 pu) led to a transitory blocking of commutation of the inverter station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Generator	Maximal frequency	Minimal frequency
Border	50.8 Hz	49.6 Hz
Mandaya	50.7 Hz	49.6 Hz
Gibe 3	50.3 Hz	49.9 Hz
Kost	50.4 Hz	49.8 Hz
Fula ST	50.3 Hz	49.8 Hz

Table appendix 2.1 –5 Voltage Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
T.Border	524.5 kV	573.7 kV	0 kV	521.6 kV
Kosti	520 kV	551.6 kV	253.6 kV	519.2 kV
Mandaya	525.5 kV	569 kV	182.3 kV	522.8 kV

Table appendix 2.1 –6 Voltage Variation of interconnection nodes

The flow on each of the remaining 3 circuits T.Border - Mandaya reached 787 MW, before stabilizing at 696 MW.

The figures are displayed in M1-2030_Appendix_Stability_Study

A.2.1.5 SHORT-CIRCUIT ON ONE OF THE 4 T.BORDER-MANDAYA CIRCUITS, ON MANDAYA SIDE

In case of short-circuit at Mandaya on one of the 4 T.Border - Mandaya circuits, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Mandaya end, on one of the 4 circuits T.Border - Mandaya, cleared in 120 ms by the opening of the circuit breakers.

The voltage in Kosti reached 0.64p.u. There was no transitory blocking of commutation of the inverter station at Kosti.

Generator	Maximal frequency	Minimal frequency
Border	50.6 Hz	49.4 Hz
Mandaya	50.8 Hz	49.3 Hz
Gibe 3	50.25 Hz	49.8 Hz
Kost	50.3 Hz	49.8 Hz
Fula ST	50.2 Hz	49.8 Hz

Table appendix 2.1 –7 Voltage Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
T.Border	524.5 kV	591 kV	171 kV	521.4 kV
Kosti	520 kV	568 kV	320.24 kV	519 kV
Mandaya	525.5 kV	588 kV	0 kV	522.8 kV

Table appendix 2.1 –8 Voltage Variation on interconnection nodes

The flow on each of the remaining 3 circuits T.Border - Mandaya reached 838 MW, before stabilizing at 698 MW.

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.1.6 FAULT ON ONE OF THE 4 MANDAYA 500/400 KV TRANSFORMERS

In case of short-circuit at Mandaya 500 kV on one of the four 500/400 kV transformers at Mandaya, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at the 500 kV side of one of the four 500/400 kV transformer at Mandaya substation, cleared in 120 ms by the opening of the circuit breakers.

The voltage in Kosti reached 0.64 p.u. There was no transitory blocking of commutation of the inverter station at Kosti.

Generator	Maximal frequency	Minimal frequency
Border	50.6 Hz	49.3 Hz
Mandaya	50.8 Hz	49.3 Hz
Baro	50.5 Hz	49.5 Hz
Kost	50.3 Hz	49.8 Hz

Table appendix 2.1 –9 Voltage Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
TBorder	524.5 kV	598.9 kV	170.9 kV	524.9 kV
Kosti	520 kV	569.5 kV	320.2 kV	520.3 kV
Mandaya 500	525.5 kV	594.8 kV	0	525.6 kV
Mandaya 400	417 KV	459.5 kV	52.9 kV	415.3 kV

Table appendix 2.1 –8 Voltage Variation on interconnection nodes

The flow on each of the remaining 3 transformers reached 391 MW, before stabilizing at 150.5 MW.

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.1.7 FAULT ON THE 220 KV INTERCONNECTION

In case of short-circuit at Gedaref 220 kV, on the 220 kV phase-shift transformer, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Gedaref 220 kV side on one of the two 220 kV interconnection circuits, cleared in 120 ms by the opening of the circuit breakers.

The DC interconnection is not affected.

Generator	Maximal frequency	Minimal frequency
Border	49.99 Hz	49.99 Hz
Mandaya	49.99 Hz	49.99 Hz
Gedaref H	50.46 Hz	49.49 Hz

Table appendix 2.1 –10 Voltage Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
Border	524.5 kV	536.1 kV	496.3 kV	522.8 kV
Kosti	520 kV	536 kV	469.8 kV	518.3 kV
Mandaya	525.5 kV	534.8 kV	507.4 kV	524.4 kV
Gonder 220 kV	224.4 kV	234.5 kV	135.7 kV	230.9 kV

Table appendix 2.1 –11 Voltage Variation on interconnection nodes

The flow on the 500 kV interconnection line T.Border – Kosti, reached 881 MW, before stabilizing at 853 MW.

The figures are displayed in M1–2030_Appendix_Stability_Study.

A.2.2. Egyptian Network

Recall of the flows on the 500 kV backbone along the Nile Valley

From bus	To bus	Nb of circuits	P(MW)	Loading %
H.D.500	N.H.500	2	90	15.2
N.H.500	AUST500	1	65	5.6
N.H.500	SOHAG500	1	147	10.5
SOHAG500	AUST500	1	-27	3.3
AUST500	SAML500	2	391	22.7
SAML500	S.GIZA500	1	180	33.6
SAML500	KRIMA500	2	-852	49.2

Table appendix 2.2 –1 Power Flows on the 500 kV Egyptian Lines

A.2.2.1 SHORT-CIRCUIT OF ONE OF THE 2 CIRCUITS HIGH DAM - NAG HAMMADI, AT HIGH DAM SIDE

In case of short-circuit in High Dam, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at High Dam end, on one of the 2 circuits High Dam - Nag Hammadi, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0.4 pu) led to a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	530.8 kV	524 kV
NH500	505 kV	530.5 kV	497.6 kV
Kosti	520 kV	572.1 kV	520.3 kV
T.Border	524.5 kV	563.3 kV	525 kV
Mandaya	525 kV	553.2 kV	525 kV

Table appendix 2.2 –2 Voltage Variation on interconnection nodes

The transitory over voltage in Kosti reached 14.4 %, the SVC absorbing 21 MVAr.

The flow on the remaining circuit High Dam - Nag Hammadi reached transiently a maximum value 1 200 MW, before recovering to 146 MW (initial value of 89 MW).

High dam reached transitory 50.4 Hz before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 2000 MW export toward Egypt led to a transitory over-frequency of 210 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 2 000 MW of import is smaller than 50 mHz.

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.2.2 SHORT-CIRCUIT ON ONE OF THE 2 CIRCUITS HIGH DAM - NAG HAMMADI, AT NAG HAMMADI SIDE

In case of short-circuit in Nag Hammadi, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Nag Hammadi end, on one of the 2 circuits High Dam - Nag Hammadi, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0 pu) led to a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 KV	532 kV	523.8 kV
NH500	505 kV	539.2 kV	497.6 kV

Table appendix 2.2 –3 Voltage Variation on nodes

The flow on the remaining circuit High Dam - Nag Hammadi reached transiently a maximum value 868 MW, before recovering to 165 MW (initial value of 89 MW).

High dam transitory frequency variations reached 240 mHz before recovering to 50 Hz. On Egypt side, the transitory frequency drop due to the transitory blocking of 2 000 MW of import is smaller than 60 mHz.

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.2.3 SHORT-CIRCUIT ON THE CIRCUIT NAG HAMMADI - SOHAG, AT NAG HAMMADI SIDE

In case of short-circuit in Nag Hammadi, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Nag Hammadi end, on Nag Hammadi - Sohag, cleared in 100 ms by the opening of the circuit breakers.

The voltage drop in Nag Hammadi (0 pu) led to a transitory blocking of commutation of the inverter station at Nag Hammadi. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	544.3 kV	526.7 kV
NH500	505 kV	551.6 kV	503.2 kV
Kosti	520 kV	572.1 kV	520.3 kV
T.Border	524.5 kV	563.3 kV	525 kV
Mandaya	525 kV	553.6 kV	525 kV

Table appendix 2.2 –4 Voltage Variation on nodes

The transitory over voltage in Kosti reached 14.4 %, the SVC absorbing at its maximum capacity : 22 MVAr.

The flow on the remaining circuit Nag Hammadi - Assiut reached transiently a maximum value 765 MW, before recovering to 156 MW (initial value of 65 MW).

High dam transitory frequency variations reached 345 mHz before recovering to 50 Hz. On the Ethiopia - Sudan side, the transitory blocking of the 2000 MW export toward Egypt led to a transitory over-frequency of 210 mHz. On Egypt side, the transitory frequency drop due to the transitory blocking of 2000 MW of import is smaller than 60 mHz.

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.2.4 TRIPPING OF EGYPT MAIN STEAM UNIT : 765 MVA

In case of tripping of Egypt main steam unit, the behavior of the system is satisfactory.

Event : the 625 MW steam unit of Sidi Krir is tripped (initial output : 614 MW).

The DC power flow is not affected. The Ethiopia-Sudan system remained unchanged.

The Egyptian frequency dropped to 49.89 Hz, before recovering to 49.92 Hz. The self regulation of the load is estimated to 145 MW in Egypt.

Libya contributed with 42 MW of its primary reserve, and around 31 MW of self regulation of the load.

Jordan and Syria contributed with 95 MW of its primary reserve, and about 35 MW of self regulation of the load

The voltage is not significantly affected.

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.3. Ethiopian network

Recall of the flow on the Ethiopian 400 kV system between Addis Ababa and Mandaya

From bus	To bus	N° of circuit	P (MW) per circuit	Loading (%)
1MANDAS71	1GHIMBIS71	3	162	23
1GHIMBIS71	1GHEDOS71	2	281	39
1GHIMBIS71	1METUS71	3	-352	48.4
1GHEDOS71	1SEBETS71	3	438	60.6

Table appendix 2.3 –1 Power Flows on the 400kV Ethiopian System

A.2.3.1 SHORT-CIRCUIT AT MANDAYA, ON ONE OF THE THREE 400 KV CIRCUITS GHIMBI - MANDAYA

In case of short-circuit at Mandaya side on one of the 3 Ghimbi - Mandaya, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Mandaya end, on one of the 3 circuits Mandaya - Ghimbi, cleared in 100 ms by the opening of the circuit breakers.

The voltage in Kosti reached 0.74 p.u. There was no transitory blocking of commutation of the inverter station at Kosti.

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	525.4 kV	525 kV
NH500	504.8 kV	505 kV	504.9 kV
Kosti	520 kV	547.7 kV	520.1 kV
T.Border	524.5 kV	567 kV	524.35 kV
Mandaya 500	525 kV	569.6 kV	524.5 kV
Mandaya 400	415.2 kV	446.7 kV	413.7 kV

Table appendix 2.3 –2 Voltage Variation of Ethiopian Substations

The transitory over voltage in Kosti reached 5.3 %, the SVC absorbing at its maximum capacity : 16 MVAr.

The flow on the two remaining circuits Mandaya - Ghimbi reached transiently a maximum value 736 MW, before recovering to 451 MW (initial value of 465 MW on the three circuits).

Generator	Maximal frequency	Minimal frequency
Genji	50.47 Hz	49.99 Hz
Kost	50.15 Hz	49.99 Hz
Border	50.29 Hz	49.99 Hz
Mandaya	50.47 Hz	49.99 Hz
Gibe 3	50.13 Hz	49.99 Hz

Table appendix 2.3 –3 Frequency Variation of Ethiopian Generators

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.3.2 TRIPPING OF ETHIOPIA MAIN 2 UNITS : MANDAYA HPP UNITS

In case of tripping of 2 units of Mandaya, the behavior of the system is satisfactory.

Event : 2 units of Mandaya (the main unit in Ethiopia) is tripped (initial output : 2 x 212.5 MW = 425 MW).

The DC power flow is not affected. The Egyptian system remained unchanged.

The Ethiopia-Sudan frequency dropped to 49.8 Hz, before recovering to 49.93 Hz.

The flow on each of the four 500 kV lines T.Border - Kosti decreased from 822 MW to at 747 MW.

The figures are displayed in M1-2030_Appendix_Stability_Study

A.2.4. Sudanese network

Recall of the flow on the Sudanese 500 kV system around Kosti

From bus	**To bus**	**Nb of circuit**	**P (MW)** per circuit	**Loading(%)%**
2RABAK81	1T.BORDES81	4	827	43.2
2RABAK81	2FULA81	2	314	23.1
2RABAK81	2J.AULIAS81	1	525	28.8
2RABAK81	2MERIN81	2	892	47.9
2BAGERS81	2H.HEI81	2	137	7.8
2BAGERS81	2J.AULIAS81	1	100	6.3
2GEDARE81	2MERIN81	1	-83	10.2
2H.HEI81	2MERIN81	1	-758	40.7

*Rabak was replaced by Kosti

Table appendix 2.4 –1 Power Flows on the 500 kV Sudanese System

A.2.4.1 SHORT-CIRCUIT ON ONE OF THE TWO 500 KV CIRCUITS KOSTI - FULA, AT KOSTI SIDE

In case of short-circuit on Kosti - Fula, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on one of the 2 circuits Kosti - Fula, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) led to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

In case of short-circuit on one of the 2 circuits Kosti - Fula, on Kosti side, the behaviour of the system is satisfactory.

Generator	Maximal frequency	Minimal frequency
Border	50.8 Hz	49.99 Hz
Mandaya	50.62 Hz	49.99 Hz
Gibe 3	50.34 Hz	49.99 Hz
Kost	50.47 Hz	49.99 Hz
Fula ST	50.45 Hz	49.99 Hz

Table appendix 2.4 –2 Voltage Variation of Generators

The flow on the remaining circuit Kosti - Fula reached a maximum of 893 MW, before stabilizing at 555 MW initial value of 317 MW).

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	505 kV	535.6 kV	458 kV	505.15 kV
T.Border	520 kV	553.9 kV	256.3 kV	524.1 kV
Kosti	524.5 kV	552.5 kV	0 kV	517.7 kV
Mandaya	525 kV	552.3 kV	335 kV	525 kV

Table appendix 2.4 –3 Voltage Variation of interconnection nodes

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.4.2 SHORT-CIRCUIT ON THE 500 KV CIRCUIT KOSTI - JEBEL AULIA, AT KOSTI SIDE

In case of short-circuit on Kosti - Jebel Aulia, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on the circuits Kosti - Jebel Aulia, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) led to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

The initial flow on Kosti - J.Aulia reached 525 MW (loading of 28.8°%)

The flow on the two circuits Kosti - Meringan increased transitory to 1 867 MW, before stabilizing at 1 114 MW.

Generator	Maximal frequency	Minimal frequency
Border	50.77 Hz	49.99 Hz
Mandaya	50.63 Hz	49.99 Hz
Gibe 3	50.39 Hz	49.99 Hz
Kost	50.51 Hz	49.99 Hz
Fula ST	50.45 Hz	49.99 Hz

Table appendix 2.4 –4 Frequency Variation of interconnection nodes

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	505 kV	535.6 kV	458 kV	505.1 kV
T.Border	520 kV	552 kV	256.2 kV	524.4 kV
Kosti	524.5 kV	552 kV	0 kV	518.2 kV
Kosti 220 kV	230 kV	236.5 kV	90.2 kV	229.1 kV
Mandaya	525 kV	550 kV	335 kV	525.4 kV

Table appendix 2.4 –5 Voltage Variation of interconnection nodes

The figures are displayed in M1–2030_Appendix_Stability_Study

A.2.4.3 SHORT-CIRCUIT ON THE 500 KV CIRCUIT KOSTI - MERINGAN, AT KOSTI SIDE

In case of short-circuit on Kosti - Meringan, the behavior of the system is satisfactory.

Event : a 3 phase short-circuit at Kosti end, on the circuits Kosti - Meringan, cleared in 120 ms by the opening of the circuit breakers.

The voltage drop in Kosti (0 pu) led to a transitory blocking of commutation of the rectifier station at Kosti. The flow on the DC interconnection is transitory reduced to 0, before starting its recovery to its initial value 300 ms after the clearing of the fault.

During the transitory blocking of the DC stations, the capacitors bank remained connected.

The flow on the remaining circuit Kosti - Meringan reached transiently a maximum value 2 200 MW, before recovering to 1 407 MW (initial value of 884 MW on each circuit).

The flow on Kosti - Jebel Aulia increased transitory to 1 220 MW, before stabilizing at 708 MW (initial value : 525 MW).

Generator	Maximal frequency	Minimal frequency
Border	50.77 Hz	49.99 Hz
Mandaya	50.63 Hz	49.94 Hz
Gibe 3	50.38 Hz	49.99 Hz
Kost	50.49 Hz	49.99 Hz
Fula ST	50.44 Hz	49.99 Hz

Table appendix 2.4 –6 Frequency Variation of Generators

Node	Initial voltage	Maximal voltage	Minimal voltage	Final voltage
NH500	505 kV	535.6 kV	459.6 kV	505 kV
T.Border	505 kV	553.9 kV	257.3 kV	525 kV
Kosti 500 kV	520 kV	547 kV	0 kV	519.4 kV
Kosti 220 kV	229 kV	233.3 kV	90.2 kV	229 kV
Mandaya	524.5 kV	552.2 kV	335 kV	525.7 kV

Table appendix 2.4 –7 Voltage Variation of interconnection nodes

The transitory over voltage in Kosti reached 8.4 % in 500 kV, and 2.8 % in 220 kV, the SVC absorbing about 1 MVAr.

The figures are displayed in M1–2030_Appendix_Stability_Study.

A.2.4.4 TRIPPING OF SUDAN MAIN UNIT : PORT SUDAN 670 MVA STEAM TURBINE

In case of tripping of Sudan main unit, the behavior of the system is satisfactory.

Event : the 670 MVA steam unit of Port-Sudan (the main unit in Sudan) is tripped (initial output : 530 MW).

The DC power flow is not affected. The Egyptian system remained unchanged.

The Ethiopia-Sudan frequency dropped to 49.7 Hz, before recovering to 49.9 Hz.

The flow on each of the four 500 kV lines T.Border - Kosti increased from 822 MW to at 857 MW

The figures are displayed in M1–2030_Appendix_Stability_Study.

Appendix 3. SHORT-CIRCUIT POWER - 2030

Three-phase to ground and one-phase to ground short-circuit calculations were performed taking into account the following assumptions:

- V = 1.1 Vn
- Impedance of generator = X"d (sub transient reactance)

The short-circuit power of the Egyptian system is compliant with the 40 kA limitation on the 220 and 500 kV system.

A.3.1. Short-circuit power in the 500/220/132 kV substations of the Nile Valley in Egypt

Busbar	KV. (Mult. = 1.10)	LLL		LG	
		I [A]	S [MVA]	I [A]	S [MVA]
AUST500	550.00	14862.0	12870.9	13172.0	11407.3
H.D.500	550.00	13838.0	11984.1	14180.0	12280.2
KRIMA500	550.00	43943.0	38055.8	43925.0	38040.2
N.H.500	550.00	11802.0	10220.8	10496.0	9089.8
S.GIZA500	550.00	20254.0	17540.5	15491.0	13415.6
SAML500	550.00	20338.0	17613.2	17516.0	15169.3
SOHAG500	550.00	9449.0	8183.1	7051.0	6106.3
AUST220	242.00	27838.0	10607.7	25464.0	9703.1
H.D.220	242.00	22551.0	8593.1	22737.0	8664.0
KURIM220_1	242.00	44521.0	16964.8	44164.0	16828.7
N.H.220	242.00	21845.0	8324.1	19701.0	7507.1
SAML220	242.00	26159.0	9967.9	23745.0	9048.1
SOHAG220	242.00	11204.0	4269.3	9306.0	3546.1
ASSIUT132	145.20	12205.0	2790.4	11089.0	2535.3
H.D.132I	145.20	24902.0	5693.4	24151.0	5521.7
H.D.132II	145.20	24902.0	5693.4	24151.0	5521.7
N.H2_132	145.20	26887.0	6147.2	25033.0	5723.3
SAML132	145.20	22868.0	5228.3	21691.0	4959.2

The short-circuit power of the other 132 and 220 kV substations in the Nile Valley is smaller than the one in these 500/220/132 kV substations, since there is no generation connected to these substations.

Table appendix 3.1 -1 - Short Circuit Power in the Egyptian substations

A.3.2. Short-circuit power in Ethiopia along the network between Mandaya and Addis Ababa

Busbar	KV. (Mult. = 1.10)	LLL		LG	
		I [A]	S [MVA]	I [A]	S [MVA]
1BORDERS81	550.00	16980.0	14705.1	17402.0	15070.6
1MANDAS81	550.00	20690.0	17918.1	22276.0	19291.6
1T.BORDES81	550.00	20349.0	17622.8	17148.0	14850.6
1BARO2S71	440.00	11378.0	7882.9	11958.0	8284.7
1BAROS71	440.00	13325.0	9231.8	13854.0	9598.3
1GENJIS71	440.00	10606.0	7348.1	10348.0	7169.3
1GHEDOS71	440.00	17778.0	12317.0	13841.0	9589.3
1GHIMBIS71	440.00	18190.0	12602.4	15093.0	10456.7
1MANDAS71	440.00	20160.0	13967.3	20269.0	14042.8
1METUS71	440.00	14855.0	10291.8	14154.0	9806.2
1SEBETS71	440.00	18540.0	12844.9	14828.0	10273.1
1GHEDOS61	11533.0	4594.4	9533.0	3797.7	11533.0
1GONDES61	6136.0	2444.4	3157.0	1257.7	6136.0
1METUS61	6012.0	2395.0	6044.0	2407.8	6012.0
1SEBET1S61	21719.0	8652.2	16976.0	6762.8	21719.0
1SEBET2S61	20286.0	8081.4	16839.0	6708.2	20286.0
1SHEHES61	5357.0	2134.1	1943.0	774.0	5357.0
1SULULS61	19357.0	7711.3	15332.0	6107.8	19357.0
1GHEDOS51	145.2	2715.0	620.7	2641.0	603.8
1SEBETS51	145.2	17578.0	4018.9	15566.0	3558.9

Table appendix 3.2 -1 - Short Circuit Power in the Ethiopian substations

A.3.3. Short-circuit power in Sudan in the south part, around Kosti substation

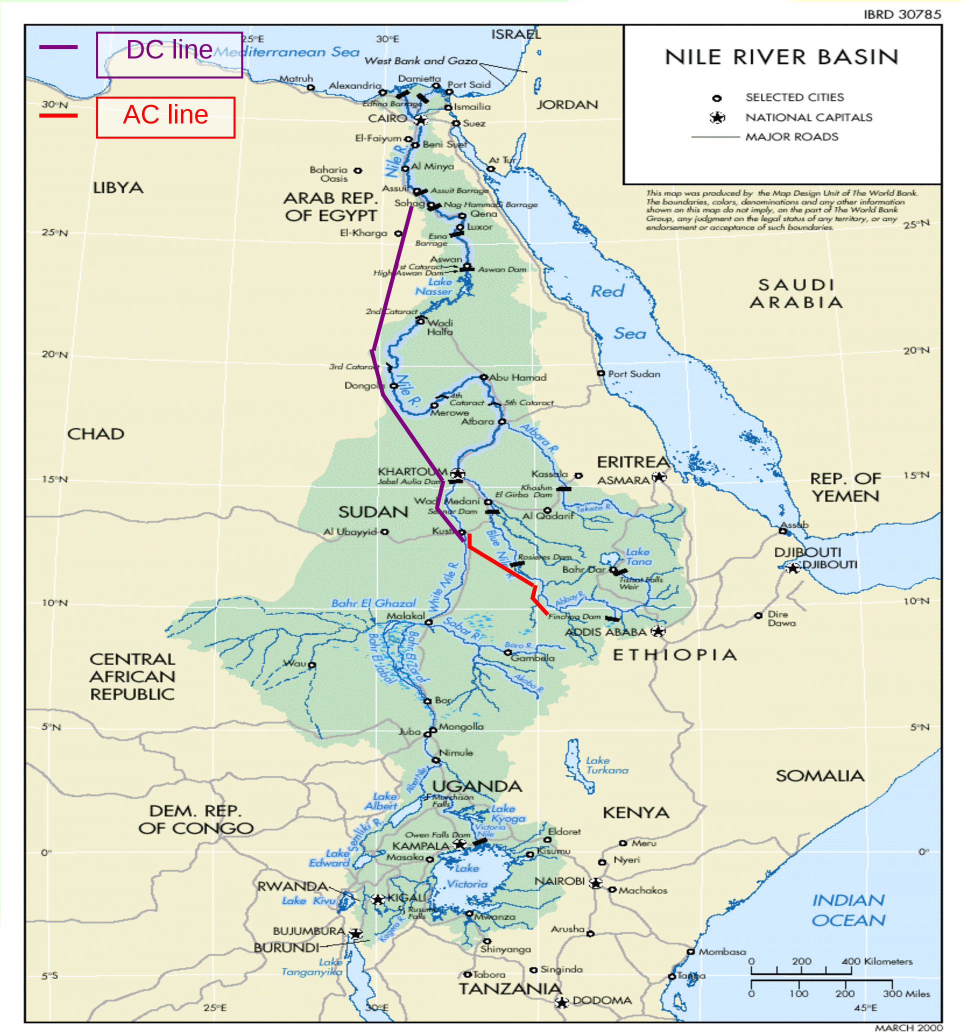
Busbar	KV (Mult. = 1.10)	LLL		LG	
		I [A]	S [MVA]	I [A]	S [MVA]
2FULA81	550.00	13972.0	12100.1	16606.0	14381.2
2GEDARE81	550.00	6615.0	5728.8	5538.0	4796.0
2H.HEI81	550.00	15604.0	13513.5	10873.0	9416.3
2J.AULIAS81	550.00	15677.0	13576.7	11913.0	10317.0
2MERIN81	550.00	16327.0	14139.6	11375.0	9851.0
2RABAK81*	550.00	22806.0	19750.6	21505.0	18623.9
2FULAS61	242.00	18364.0	6997.6	21258.0	8100.4
2GEDARS61	242.00	8842.0	3369.3	1411.0	537.7
2GEDARS62	242.00	11530.0	4393.5	11726.0	4468.2
2H.HEIS61	242.00	25009.0	9529.7	18452.0	7031.2
2J.AULS61	242.00	23041.0	8779.8	18525.0	7059.0
2MERINS61	242.00	23740.0	9046.2	17805.0	6784.6
2RABAKS61*	242.00	23949.0	9125.8	26480.0	10090.2
2RANKS61	242.00	10446.0	3980.5	6624.0	2524.1
2ROSEIS61	242.00	9510.0	3623.8	10622.0	4047.5
2SENNAS61	242.00	9604.0	3659.6	6487.0	2471.9

* Rabak was replaced by Kosti

Table appendix 3.3 -1 Short Circuit Power in the Sudanese substations

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

EASTERN NILE POWER TRADE PROGRAM STUDY



M1 - 2030 - TARGET NETWORK

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
CCG	Combined Cycle Gas turbine
DC	Direct Current
ENPTPS	Eastern Nile Power Trade Program Study
EDF	Electricité de France
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
GEP	Generation Expansion Plan
HPP	Hydro Power Plant
HD	High Dam
HV	High Voltage
HVDC	High Voltage Direct Current
NBI	Nile Basin Initiative
pu	per unit
ST	Steam Turbine
TPP	Thermal Power Plant

EXECUTIVE SUMMARY

This report introduces the 2030 networks for each of the 3 countries : Egypt, Ethiopia and Sudan.

1 INTRODUCTION OF THE TARGET NETWORK FOR THE THREE SYSTEMS IN 2030

To investigate the behaviour of the interconnection between Egypt, Ethiopia and Sudan for the years 2025/2026 and 2029/2030, it is necessary to determine the development of the transmission system of the 3 countries close to the connection points of the interconnections:

- Mandaya
- Rabak
- Nag Hammadi

The target network of the 3 systems has been elaborated for the year 2030. Concerning the network, the study was based on the data collected in Phase I, and updated during the April 08 meeting of Phase II in Cairo.

Concerning the demand and the generation expansion plan, input data are the results of the economic study performed in Phase I.

2 PROPOSED EXPANSION PLAN FOR THE EGYPTIAN SYSTEM

2.1 PRESENTATION

The analysis is focussed on the transmission system of the Upper Nile Valley, because it is mainly concerned by the connection of the DC interconnection. The expansion of the transmission system in this area is related to the supply of the increasing demand.

The target network was elaborated for the year 2030, and the expansion of the system was examined during the 2015 - 2030 period.

2.2 DEMAND SCENARIO

According to the result of Phase 1, the study in Phase II was performed for the medium demand scenario.

The peak demands for the studied years are the following ones :

Year	Peak demand (MW)
2020 / 2021	40 960
2025 / 2026	51 850
2029 / 2030	61 825

Table 1 :– Peak Demand for Egyptian System

Theses values include the transmission losses

The average growth rate of the demand during the 2015 - 2030 period reached 4.5 % a year.

It has been assumed that the growth rate in the Upper Nile Valley would be lower, a 2.2 % was retained.

With such hypothesis, the demand (without transmission losses) in the Upper Nile Valley (south of Kurimat) reached about 7 416 MW in 2030.

2.3 GENERATION EXPANSION PLAN

The following units (based on the Module 3 Phase 1) have been implemented for the simulations :

Name of the plant	Unit number	Plant site location	Type of generation unit	Installed capacity (MW)	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27
Sidi Krir	1	East Delta	CCGT	750	500	250																	
Kurimat (3)	1	Upper Egypt	CCGT	750	500	250																	
Nobaria (3)	1	West Delta	CCGT	750	500	250																	
Atfe	1	West Delta	CCGT	750	500	250																	
Sharm El-Sheik	1	West Delta	CCGT	750				750															
Alexandria Eas	1..2	West Delta	CCGT	750						500	500	500											
Combined Cycl	1..8		CCGT	750						500	500		500	500	500	1000	500	500	500	500	500		
Open Cycle GT 250 MW			OCGT	250																			
Abu Qir	1..2	West Delta	ST	650			650	650															
Suez	1	East Delta	ST	450					450														
Steam Units 45	1..16		ST	450						1350	450	450		450	450				450	900	900	1350	450
Cairo West Ext	1..2	Cairo	ST	350			700																
Tebbin	1..2	Cairo	ST	350		700																	
Ayoun Musa Ex	1	Upper Egypt	ST	350				350															
Steam Units 65	1..22		ST	350					1300		650		1300	1300	1300	1300	650	1950	650	1300		1300	1300
Borg El-Arab			Solar/Therma	300									300		300								
Kurimat	1	Upper Egypt	Solar/Therma	150	150																		
Dabaa Nuclear	1..5		Nuclear	1000								1000					1000		1000		1000		1000
New Naga Ham	4		Hydro	64	64																		
Assiut			Hydro	40					40														
Damietta			Hydro	13			13																
Zefta			Hydro	5.5				5.5															
Zafarana		East Delta	Wind	125	125																		

Table 2 :– GEP for Egyptian System

For the years 2027 to 2030, additional plants have been supposed to be commissioned :

- Two 450 MW ST units
- Four 650 MW ST units

The units commissioned between 2015 and 2030 were located in delta, canal, Alexandria and Cairo zones. In Kurimat (Upper Nile zone), a third CCG has been added, as well as two 650 MW ST units.

2.4 GENERATION / DEMAND BALANCE IN THE UPPER NILE VALLEY

The generation in the Upper Nile Valley is listed hereafter :

	Installed capacity (MW)	Generation (MW)
HD (HPP)	2100	1700
Aswan 1 (HPP)	345	280
Aswan 2 (HPP)	270	248
Isna (HPP)	90	72
Nag Hammadi (HPP)	64	60
Assiut (HPP)	40	34
Assiut (ST TPP)	600	482
Total	3509	2876

Table 3 : Generation/Demand Balance

The DC substation injected 2 000 MW at Nag Hammadi 500 kV bus bar.

The wind generation located on the Red Sea coast inject 400 MW in Qena 220 kV.

The Upper Nile valley presented a shortage of generation by about 2150 MW to supply its demand.

The following flow arriving at Samalut from the three 500 kV circuits from the north:

- 2 x 800 MW from Kurimat
- 590 MW from South Giza

Total flow : 2190 MW

The total generation and power injection over the network of the Upper Egypt zone reached 7460 MW, corresponding to the local demand and the transmission losses.

2.5 TRANSMISSION

The Egyptian 500 kV system was updated according to the information provided by ENTRO in April 2008 in Cairo.

The 500 kV system included in 2015:

A 500 kV loop in North Delta connecting the following substation Bassous - Kafr Zayed - Abu Kir - W.Domatia - Abu Zaabal (double circuit line between Bassous - Kafr Zayed - Abu Kir)

A 500 kV circuit from the Libyan border to Cairo 500, Saloum - Dabaa - Sidi Krir - Nobaria - Cairo

The Cairo loop is reinforced with the creation of two additional 500/220 kV substations in South Giza and New October, and an additional Abu Zaabal - Tebbin 500 kV circuit. The new substation in Heliopolis was included in the previous data

A 500 kV double circuit from Samalut to High Dam along the Upper Nile valley

Additional 500 kV reinforcement between 2015 and 2030 :

Due to the commissioning of nuclear power plant at Dabaa (4 units of 1000 MW by 2030), the circuit Daaba - Cairo is reinforced by two additional 500 kV circuits.

For 2030, the Cairo loop is reinforced by the following 500 kV circuits :

A second Cairo - South Giza circuit

A second Abu Zaabal - Heliopolis circuit

To face the increase of the demand in the Upper Nile Valley, an second circuit Kurimat - Samalut is necessary

Analysis of the behaviour of the proposed 500 kV system in the Upper Nile region

A load flow calculation was performed for the peak demand in 2030.

As described previously in § 4.1.3., about 2 200 MW flowed from the North (from Kurimat and South Giza) to Samalut. The following power flows arrived at Samalut from the north over the three 500 kV circuits :

- 590 MW from South Giza
- 2 x 800 MW from Kurimat

The second circuit Kurimat - Samalut is necessary to face the N-1 situation in case of tripping of the existing circuit.

The flow between Nag Hammadi and Assiut is close to 0. All the power generated in High Dam and Aswan HPP and the 2000 MW injected by the DC/AC converter station in Nag Hammadi is locally consumed.

3 PROPOSED EXPANSION PLAN FOR THE ETHIOPIAN SYSTEM

3.1 PRESENTATION

The expansion of the transmission system in Ethiopia is strongly related to the connection of new HPP commissioned during the 2015 - 2030 period.

The target network was elaborated for the year 2030, and the expansion of the system was examined during the 2015 - 2030 period.

3.2 DEMAND SCENARIO

According to the result of Phase 1, the study in Phase II was performed for the low demand scenario.

The peak demands for the studied years are the following ones :

Year	Peak demand (MW)
2020 / 2021	2604
2025 / 2026	3973
2029 / 2030	5506

Table 4 : Peak Demand for the Ethiopian System

Theses values include the transmission losses.

3.3 HYDRO POWER CONNECTION

The new dams and their commissioning dates are recalled hereafter :

Commisioning Date	Hydro Project	Capacity MW	Average Generation GWh
2008	Gibe II	420	1 600
	Tekeze	300	1 200
2009	Beles	420	2 000
2010	Neshe	97	225
2011	Gibe III (I)		
2012	Gibe III (II)	1 870	6 240
2014			
2015			
2016	Halele Worabesa	420	2 245
2017			
2018			
2019			
2020	Mandaya + Baro I + II + Gengi	2 700	16 509
2021	Geba I + II	368	1 788
2022	Chemoga Yeda + Genale III	534	1 415
2023	Genale IV	256	
2024			
2025	Karadobi	1 600	6 000
2026			
2027			
2028			
2029	Aleltu E&W	565	
2030	Border	1 200	
Total		10 750	

Table 5 :– Ethiopian generation expansion plan Tight pool - Ethiopia - Low demand projection Power exchange capacity : 1200/2000 MW

3.4 *PROPOSED HYDRO POWER PLANT CONNECTION*

The proposed connections for the HPP commissioned between 2016 and 2030 are detailed hereafter.

3.4.1 *HALALE WARABESSA (2016)*

According to the Ethiopian Power System Expansion Master Plan (June 2006), the following connection scheme was retained :

- one single 230 kV circuit (30 km) between Halele HPP (96 MW) and Warabesa HPP (326 MW)
- creation of a tapping station on the existing 230 kV line Gigel Gibe - Ghedo
- one single 230 kV circuit (5 km) between Warabesa and the new tapping station
- a double 230 kV circuit line between Warabesa and Ghedo (79 km)

3.4.2 *MANDAYA (2020)*

Mandaya should be connected to the Ethiopian system with at least two 400 kV circuits. As 1300 MW of new HPP are located 300 km south east of Mandaya and south of a line Mandaya - Ghedo - Sebata, it is proposed to connect Mandaya HPP by the south route, with a 400 kV double circuit line Mandaya - Ghimbi - Ghedo - Sebeta.

- Three 400 kV circuits 2 x 450 mm² from Mandaya to Ghimbi (120 km)
- A 400 kV double circuit 2 (or 3) x 450 mm² from Ghimbi to Ghedo (200 km)
- A single 400 kV circuit from Ghedo to Sebeta (133 km)
- A single 400 kV circuit Ghedo - Debre Markos (157 km)
  Karadobi could then be connected with a tapping substation on this circuit.

3.4.3 BARO I (2X100 MW) & II (3X167 MW) + GENJI (2X100 MW) (2020)

Baro 2 (West of Baro 1) and Genji (south of Baro 1) are radialy connected to Baro 1, with 400 kV circuits. Baro 1 is connected to Ghimbi, passing Metu, where Geba will be connected in 2021.

- one single 400 kV circuit (20 km) from Genji to Baro 1
- one double 400 kV circuit line (40 km) from Baro 2 to Baro 1. (double circuit for N-1 situation)
- a 400 kV double circuit line with 3 x 450 mm² conductors (55 km) from Baro 1 to Metu.
  With a double 2x450 mm² circuit line (1010 A) in N-1 situation : 900 MW/700 MVA = 28 % overload (without reactive flow

  A triple circuit line with 2 x 450 mm² would be ~30 % more expensive (Baro 1&2 + Genji = 900 MW)
- Metu - Ghimbi : 3 circuits 2 x 450 mm² (900 MW from Baro & Genji + 370 MW from Geba = 1270 MW). Also it is slightly more expensive than a 400 kV double circuit line 4 x 450 mm² (120 km), it is more flexible for operation. With a double 3x450 mm² circuit line (1515 A) in N-1 situation : 1270 MW/1050 MVA = 21 % overload (without reactive flow)

The closer existing connection point would be Gibe 400 kV substation (200 km as the crow flies), but would require a transmission reinforcement from Gibe to Addis Ababa, and the power flow would finely ends up from Addis towards Mandaya.

Metu substation should be created for the commissioning of Geba1&2, but as they are to be connected in 2021, it is better to build it for 2020. A 100 MVA 400/230 kV transformation could be installed.

3.4.4 GEBA 1&2 (370 MW) (2021)

- A single 400 kV circuit Geba 2 - Metu (30 km)
- A single 400 kV circuit Geba 2 - Geba 1

A connection to the 230 kV with reinforcement from Geba to Metu (with a 400/230 kV station in Metu) could also be possible.

3.4.5 CHEMOGA YEDA (280 MW) (2022)

According to the Ethiopian Power System Expansion Master Plan (June 2006), the following connection scheme was retained :

- a dedicated double 230 kV circuit line (39 km) from Chemoga Yeda 1 HPP (162 MW) to Debre Markos
- a 230 kV circuit (9 km) from Chemoga Yeda 1 to Chemoga Yeda 2 (118 MW).

3.4.6 GENALE 3 (254 MW) & 4 (257 MW) (2022 AND 2023)

These dams are located far south east of the network. In the master plan, they were dedicated to export power to Kenya, but the AC/DC substation would be located in Gibe III.

The location was not precise (based on GD3 and GD6 location, from the GD-6 Hydropower project report).

- a single 400 kV circuit from Genale 4 to Genale 3 (83 km) (from GD6 to GD3)
- a single 400 kV circuit from Genale 3 to W. Sodo (300 km).

3.4.7 KARADOBI (1600 MW) (2025)

Karadobi HPP is located closed to the 400 kV existing line Debre Markos - Ghedo. It is proposed to connected the HPP with tapping substation on the line Debre Markos - Ghedo

- Debre Markos - Karadobi :40 km
- Karadobi - Ghedo :117 km

An additional 400 kV circuit Debre Markos - Karadobi - Ghedo with a cross section of 2 x 450 mm².

3.4.8 ALALTU EAST (186 MW) & WEST (265 MW) (2029)

Alaltu HPP are located north of Addis, closed to the existing line Kombolcha - Cotobie. It is proposed to created a new substation closed to Chacha or Debre Birham, and to connect the HPP to the new substation. Additional circuits are required to export power toward the south.

- connection with tapping station on the existing 230 kV 2x 181 mm² Kombolcha - Cotobie around Chacha town or Debre Birham
- double 230 kV circuit line 2 x 181 mm² (100 km) Chacha - Cotobie
- connection from the HPP to the new substation

3.4.9 BORDER (1200 MW) (2030)

Border HPP is located at 50 km from the 500 kV interconnection between Ethiopia and Sudan. It is proposed to connect the new HPP with a double circuit to a new tapping station on the 2 double circuit lines Mandaya - Rabak

- a double 500 kV circuit line Border HPP - Tapping Border (50 km)

3.5 TRANSMISSION

The aim of studying the Ethiopian network reinforcements is not to establish an extension up to 2030 of the existing master plan (elaborated up to 2015) of the Ethiopian system, but to have a realistic base for the system, to be able to study the interconnection of Ethiopia with Sudan and Egypt.

Network reinforcements, in addition to the dam connections, are proposed hereafter.

Other proposed 400 kV reinforcements :

- Development of a 400 kV link around Addis Ababa
    - a 400 kV double circuit line Kaliti - Sebeta (40 km)
      A first circuit is necessary to face N-1 situation on a circuit Gibe - Sebeta or W.Sodo - Kaliti, after the connection of Gibe III. A additional (second) circuit is necessary in 2030.
    - a 400 kV single circuit Sebeta - Sululta (50 km)
- A second 400 kV circuit Ghedo - Sebeta (133 km)

4 PROPOSED EXPANSION PLAN FOR THE SUDANESE SYSTEM

4.1 PRESENTATION

The expansion of the transmission system of Sudan is described in the Long Term System Planning Study report from PB Power.

The network was described for the years 2015, 2020 and 2030.

4.2 DEMAND SCENARIO

According to the result of Phase 1, the study in Phase II was performed for the medium demand scenario.

The peak demands for the studied years are the following ones :

Year	Peak demand (MW)
2020 / 2021	9 243
2025 / 2026	11 412
2029 / 2030	13 698

These values include the transmission losses.

Table 6 : Peak Demand for Sudanese System

4.3 GENERATION EXPANSION PLAN

The following units (based on the Module 3 Phase 1) have been implemented for the simulations :

Year	Thermal Plant			Hydro Electric Plant	
	Plant Name	Installed Capacity (MW)	Net Capacity (MW)	Plant Name	Installed Capacity (MW)
2015	Khartoum North ST's (U1&U2) Retired Khartoum North GT's (U3&U4) Retired 1 x Coal Fired Steam	-60 -47 400	-55 -34 380	Low Dal	340
2016				Kajbar	300
2017	1 x Crude Oil Fired Steam 1 x CCGT (6FA based)	250 214	238 208		
2018	1 x Coal Fired Steam	400	380		
2019	1 x CCGT (6FA based) 1 x Crude Oil Fired Steam	214 250	208 238	Dagesh	285
2020	2 x Crude Oil Fired Steam Southern Diesels	1,000 109	950 101	Fula 1	720
2021	1 x Coal Fired Steam	600	570		
2022				Shukoli	210
2023	1 x CCGT (9E based) Khartoum North ST's (U3&U4) Retired	352 -120	342 -102		
2024	1 x OCGT (6FA)	61	60	Lakki	210
2025	1 x Crude Oil Fired Steam	500	475		
2026	1 x CCGT (9E based)	352	342	Bedden	400
2027	2 x CCGT (9E based) 1 x Coal Fired Steam	705 600	683 570		
2028	Garri 1 CCGT's Retired	-220	-164		
2029	2 x CCGT (9EC based)	941	912		
2030	2 x CCGT (9EC based)	941	912		

Table 7 : GEP for Sudanese System

4.4 TRANSMISSION EXPANSION PLAN

The transmission system of Sudan was extended according the Long Term System Planning Study report from PB Power.

Concerning Rabak area, connection point of the interconnection to Ethiopia and Egypt, the 500 kV system includes :

- Two 500 kV circuits Rabak - Fula - Nyala (Western part)
- One 500 kV circuit Rabak - Jebel Aulia - Markhiat (along the White Nile river)
- Two 500 kV circuits Rabak - Meringan (between the Blue and the White Nile rivers)
- One 500 kV circuit Meringan - Hasaheisa and two 500 kV circuits Hasaheisa - Bager - Kabashi (along the Blue Nile river)

- One 500 kV circuit Meringan - Gedaref - Port Sudan

Analyse of the behaviour in permanent state

A load flow calculation was performed for the 2030 peak load, the Sudanese system interconnected with Egypt and Ethiopia.

The imported power reached 3350 MW from Ethiopia (on the 220 and 500 kV interconnection). 2150 MW are exported via the AC/DC converter station toward Egypt. 1200 MW from Ethiopia are injected in Sudan.

Balance in Rabak :

Power arriving in Rabak :

- 1000 MW from Ethiopia (200 MW on the 220 kV interconnection. The 2000 MW to Egypt are converted locally)
- 2 x 345 MW arriving from Fula, exported by the western region
- 435 MW (one 472 MW combined cycled) + 330 MW (one 352 MW combined cycled) connected on the 500 kV voltage
  One additional 352 MW CC is connected on the 220 kV busbar, with the four Kosti units (4 x 115 MW), reducing the flow on the 500/220 kV transformer

Total : 2450 MW

Power flow exported from Rabak on the 500 kV system:

- Rabak - Jebel Aulia : 540 MW
- Rabak - Meringan : 2 x 890 MW
- Transformation 500/220 kV at Rabak : 2 x 60 MW

Total : 2450 MW

The 500 kV system connected to Rabak satisfied the N-1 criteria.

APPENDIX - LOAD FLOW RESULTS PEAK 2030 – NORMAL SITUATION

A. 1. Egyptian Network

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
A.Z.500	BASII500	-865.0	91.6	869.8	974.6	1.7	-4.8	2020.7	48.4
A.Z.500	HELIO500	1063.0	35.0	1063.5	1191.7	4.8	12.0	2000	59.6
A.Z.500	HELIO500	1063.0	35.0	1063.5	1191.7	4.8	12.0	2000	59.6
A.Z.500	N.DELTA500*	-1221.8	-40.9	1222.5	1369.8	11.5	76.0	2000	68.5
A.Z.500	SUEZ500	-1358.8	23.4	1359.0	1522.8	16.9	125.8	2049.6	74.3
A.Z.500	SUEZ500	-1358.8	23.4	1359.0	1522.8	16.9	125.8	2049.6	74.3
A.Z.500	TEB.500	287.6	-144.7	322.0	360.8	0.7	-87.8	2020.7	17.9
ABKIR500	KAFR.Z500	836.6	120.7	845.3	929.9	5.2	-24.8	2000	46.5
ABKIR500	KAFR.Z500	836.6	120.7	845.3	929.9	5.2	-24.8	2000	46.5
ABKIR500	N.DELTA500*	254.0	-120.5	281.2	309.3	1.0	-203.0	2000	15.5
AMOUS500	SUEZ500	579.2	24.4	579.7	637.0	0.6	-13.9	2049.6	31.1
AMOUS500	SUEZ500	579.2	24.4	579.7	637.0	0.6	-13.9	2049.6	31.1
AMOUS500	TABA500	10.2	-43.9	45.0	49.5	0.1	-247.8	2049.6	2.4
AUST500	N.H.500	-40.3	-5.1	40.6	47.1	0.2	-188.6	1963	2.4
AUST500	N.H.500	-40.3	-5.1	40.6	47.1	0.2	-188.6	1963	2.4
AUST500	SAML500	-390.6	-127.4	410.8	476.6	1.9	-112.3	1963	22.8
AUST500	SAML500	-390.6	-127.4	410.8	476.6	1.9	-112.3	1963	22.8
AUST500	SOHAG500	53.8	28.2	60.7	70.4	0.1	-103.8	1960	3.6
BASII500	C.W.500	-242.8	10.6	243.0	272.6	0.0	-8.6	2020.7	13.5
BASII500	KAFR.Z500	-714.5	27.6	715.0	802.2	4.0	-35.4	2000	40.1
BASII500	KAFR.Z500	-714.5	27.6	715.0	802.2	4.0	-35.4	2000	40.1
CAIRO500	C.W.500	-1044.1	-788.8	1308.6	1491.6	2.2	15.8	2020.7	73.8
CAIRO500	KRIMA500	24.6	-307.8	308.8	352.0	0.7	-127.0	1963	17.9
CAIRO500	NOBAR500	-1507.3	10.6	1507.3	1718.2	18.2	179.2	2020.7	85
CAIRO500	NOBAR500	-1507.3	10.6	1507.3	1718.2	18.2	179.2	2020.7	85
CAIRO500	NOBAR500	-1507.3	10.6	1507.3	1718.2	18.2	179.2	2020.7	85
CAIRO500	S.GIZA500	635.5	103.9	644.0	734.1	1.4	-20.4	1700	43.2
CAIRO500	S.GIZA500	635.5	103.9	644.0	734.1	1.4	-20.4	1700	43.2
D1H.D.5	H.D.500	-89.7	-150.1	174.9	192.5	0.0	0.0	2049.6	9.4
D1H.D.5	N.H.500	89.7	150.4	175.1	192.8	1.6	-214.3	2049.6	21.7
D2H.D.5	H.D.500	-89.7	-150.1	174.9	192.5	0.0	0.0	2049.6	9.4
D2H.D.5	N.H.500	89.7	150.4	175.1	192.8	1.6	-214.3	2049.6	21.7
DABAA500	SALOUM500	223.3	-100.0	244.7	271.6	1.3	-286.1	2000	13.6
DABAA500	SKRIR500	1072.3	-1.7	1072.3	1190.2	10.4	56.1	2000	59.5
DABAA500	SKRIR500	1072.3	-1.7	1072.3	1190.2	10.4	56.1	2000	59.5
DABAA500	SKRIR500	1072.3	-1.7	1072.3	1190.2	10.4	56.1	2000	59.5
HELIO500	TEB.500	-539.3	-236.1	588.7	663.8	1.4	-34.4	1750	37.9
KRIMA500	SAML500	808.0	122.5	817.2	899.0	8.7	-46.1	1963	47.5
KRIMA500	SAML500	808.0	122.5	817.2	899.0	8.7	-46.1	1963	47.5

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
KRIMA500	TEB.500	579.0	81.8	584.7	643.2	1.6	-41.4	2020.7	32.5
N.H.500	N.H500_ACDC**	-1999.9	346.2	2029.6	2406.1	-	-	-	-
N.H.500	SOHAG500	126.1	-136.2	185.6	220.0	0.2	-99.6	1960	11.2
N.OCTO_500	S.GIZA500	-346.9	-296.9	456.6	548.2	2.2	-94.1	1700	32.2
NOBAR500	SKRIR500	-1233.8	132.2	1240.9	1384.7	46.8	94.2	2020.7	68.5
NOBAR500	SKRIR500	-1233.8	132.2	1240.9	1384.7	46.8	94.2	2020.7	68.5
NOBAR500	SKRIR500	-1233.8	132.2	1240.9	1384.7	46.8	94.2	2020.7	68.5
S.GIZA500	SAML500	592.9	-125.9	606.1	696.0	5.1	-98.4	1700	40.9
SALOUM500	TOBROK500	106.2	-35.9	112.1	127.3	0.2	-156.7	2020	6.3
TOBROK500	SALOUM500	-106.0	-120.8	160.7	184.3	0.2	-156.7	2020	6.3

*N.Delta 500 has been replaced by W.Domatia 500 kV, in the latest 2015 Egyptian data
** N.H500_ACDC : DC/AC converter station in Nag Hammadi
*** Egypt exported 200 MW to Jordan

Table appendix 1.1 : Power flow on the Egyptian 400 and 500 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
AKABA400	S_AQA400***	-100.0	-25.2	103.1	149.6	0.0	-5.1	2562	5.8
AKABA400	S_AQA400***	-100.0	-25.2	103.1	149.6	0.0	-5.1	2562	5.8
S_AQA400	S_TAB400***	-200.0	-40.2	204.0	295.9	0.3	-79.6	2562	11.5
S_TAB400	TABSW400	-200.4	39.4	204.2	295.6	0.1	-9.5	2562	11.7

Table appendix 1.2 : Power flow exported from Egypt to Jordan & Syria

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
SALOUM500	TOBROK500	106.2	-35.9	112.1	127.3	0.2	-156.7	2020	6.3
SALOUM220	TOBROK220	47.3	-16.2	50.0	129.6	0.3	-28.9	1207.2	10.7
SALOUM220	TOBROK220	47.3	-16.2	50.0	129.6	0.3	-28.9	1207.2	10.7

The power flow exported from Egypt to Libya reached 200 MW

Table appendix 1.3 : Power flow exported from Egypt to Libya

Substation.	V sol [pu]	V sol [kVu]
A.Z.500	1.031	515.5
ABKIR500	1.05	525
AMOUS500	1.05	525
AUST500	0.995	497.5
BASII500	1.029	514.5
C.W.500	1.029	514.5
CAIRO500	1.013	506.5
D1H.D.5	1.049	524.5
D2H.D.5	1.049	524.5
DABAA500	1.04	520
H.D.500	1.049	524.5
HELIO500	1.024	512
KAFR.Z500	1.03	515
KRIMA500	1.05	525
N.DELTA500	1.05	525
N.H.500	0.974	487
N.OCTO_500	0.962	481
NOBAR500	1.035	517.5
S.GIZA500	1.006	503
SALOUM500	1.017	508.5
SAML500	1.012	506
SKRIR500	1.035	517.5
SOHAG500	0.984	492
SUEZ500	1.049	524.5
TABA500	1.025	512.5
TEB.500	1.04	520
TOBROK500	1.007	503.5

Table appendix 1.4 : Voltage of the Egyptian 500 kV substation

A. 2. Ethiopian Network

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
1BORDERS81	1T.BORDES781	538.5	-27.6	539.2	593.3	1.6	-46.1	2128	27.9
1BORDERS81	1T.BORDES781	538.5	-27.6	539.2	593.3	1.6	-46.1	2128	27.9
1MANDAS81	1T.BORDES781	563.4	-150.7	583.2	642.2	8.1	-202.2	2128	28.9
1MANDAS81	1T.BORDES781	563.4	-150.7	583.2	642.2	8.1	-202.2	2128	28.9
1MANDAS81	1T.BORDES781	563.4	-150.7	583.2	642.2	8.1	-202.2	2128	28.9
1MANDAS81	1T.BORDES781	563.4	-150.7	583.2	642.2	8.1	-202.2	2128	28.9
1T.BORDES781	2RABAK81	823.3	-103.5	829.7	915.5	22.4	-134.0	2128	43
1T.BORDES781	2RABAK81	823.3	-103.5	829.7	915.5	22.4	-134.0	2128	43
1T.BORDES781	2RABAK81	823.3	-103.5	829.7	915.5	22.4	-134.0	2128	43
1T.BORDES781	2RABAK81	823.3	-103.5	829.7	915.5	22.4	-134.0	2128	43

Table appendix 2.1 : Power flow on the Ethiopian 500 kV lines

From bus	To bus	P [MW]	Q [MVAR]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAR]	Ampacity (Nom.) [A]	Loading %
1B.DAR3S71	1BELESS71	-218.6	7.3	218.7	301.7	0.7	-35.0	1010	29.9
1B.DAR3S71	1BELESS71	-218.6	7.3	218.7	301.7	0.7	-35.0	1010	29.9
1B.DAR3S71	1D.MARS71	26.1	-52.1	58.3	80.4	0.0	-123.8	1010	8
1BAROS71	1BARO2S71	-231.3	-1.1	231.3	318.7	0.5	-21.2	1010	31.6
1BAROS71	1BARO2S71	-231.3	-1.1	231.3	318.7	0.5	-21.2	1010	31.6
1BAROS71	1GENJIS71	-199.2	8.2	199.4	274.7	0.2	-11.1	1010	27.2
1BAROS71	1METUS71	420.7	-13.0	420.9	579.9	1.4	-19.7	1515	38.3
1BAROS71	1METUS71	420.7	-13.0	420.9	579.9	1.4	-19.7	1515	38.3
1D.MARS71	1KARADS71	-324.4	10.9	324.6	450.0	1.0	-17.2	1010	44.6
1D.MARS71	1KARADS71	-324.4	10.9	324.6	450.0	1.0	-17.2	1010	44.6
1D.MARS71	1SULULS71	386.7	-7.7	386.8	536.2	8.4	-74.1	1010	53.1
1D.MARS71	1SULULS71	386.7	-7.7	386.8	536.2	8.4	-74.1	1010	53.1
1GEBAS71	1METUS71	334.1	-38.0	336.2	463.9	1.3	-21.2	1010	45.9
1GENALE3S71	1GENALE4S71	-223.5	-24.3	224.8	310.2	0.9	-43.0	1010	30.7
1GENALE3S71	1W.SODS71	447.6	-73.6	453.6	626.0	14.1	-77.8	1010	62
1GG2S71	1GGOS71	5.2	29.3	29.8	41.1	0.0	-25.4	1010	7.5
1GG2S71	1GIBE3S71	89.3	-18.2	91.1	125.6	0.3	-90.3	1010	12.4
1GG2S71	1SEBETS71	304.4	-1.9	304.4	419.7	4.8	-91.0	1010	44.1
1GHEDOS71	1GHIMBIS71	-241.4	-46.7	245.8	342.9	2.8	-102.1	1010	34
1GHEDOS71	1GHIMBIS71	-241.4	-46.7	245.8	342.9	2.8	-102.1	1010	34
1GHEDOS71	1KARADS71	-426.8	3.0	426.8	595.3	5.1	-33.1	1010	58.9
1GHEDOS71	1KARADS71	-426.8	3.0	426.8	595.3	5.1	-33.1	1010	58.9
1GHEDOS71	1SEBETS71	444.9	11.2	445.0	620.8	6.4	-31.2	1010	61.5
1GHEDOS71	1SEBETS71	444.9	11.2	445.0	620.8	6.4	-31.2	1010	61.5
1GHEDOS71	1SEBETS71	444.9	11.2	445.0	620.8	6.4	-31.2	1010	61.5
1GHIMBIS71	1MANDAS71	187.5	-62.5	197.7	272.9	1.0	-67.1	1010	27

1GHIMBIS71	1MANDAS71	187.5	-62.5	197.7	272.9	1.0	-67.1	1010	27
1GHIMBIS71	1MANDAS71	187.5	-62.5	197.7	272.9	1.0	-67.1	1010	27
1GHIMBIS71	1METUS71	-351.0	26.6	352.0	486.0	3.6	-47.6	1010	48.1
1GHIMBIS71	1METUS71	-351.0	26.6	352.0	486.0	3.6	-47.6	1010	48.1
1GHIMBIS71	1METUS71	-351.0	26.6	352.0	486.0	3.6	-47.6	1010	48.1
1GIBE3S71	1W.SODS71	181.7	-19.3	182.7	254.5	0.6	-44.0	1010	25.2
1GIBE3S71	1W.SODS71	181.7	-19.3	182.7	254.5	0.6	-44.0	1010	25.2
1KALITS71	1SEBETS71	-391.7	-56.7	395.8	568.3	1.6	-11.3	1010	56.3
1KALITS71	1SEBETS71	-391.7	-56.7	395.8	568.3	1.6	-11.3	1010	56.3
1KALITS71	1SEBETS71	-391.7	-56.7	395.8	568.3	1.6	-11.3	1010	56.3
1KALITS71	1W.SODS71	-188.5	-95.5	211.3	303.4	2.5	-141.0	1010	27.2
1KALITS71	1W.SODS71	-188.5	-95.5	211.3	303.4	2.5	-141.0	1010	27.2
1SEBETS71	1SULULS71	-129.7	84.7	154.9	220.7	0.3	-26.5	1010	21.9

Table appendix 2.2 : Power flow on the Ethiopian 400 kV lines

From bus	To bus	Sn nominal [MVA]	P [MW]	Q [MVAR]	S [MVA]	I [A]	Loading [%]
1MANDAS71	1MANDAS81	510	139.8	-17.0	140.8	194.3	27.7
1MANDAS71	1MANDAS81	510	139.8	-17.0	140.8	194.3	27.7
1MANDAS71	1MANDAS81	510	139.8	-17.0	140.8	194.3	27.7
1MANDAS71	1MANDAS81	510	139.8	-17.0	140.8	194.3	27.7

Table appendix 2.3 : Power flow on the Ethiopian 400/500 kV transformers

Substation.	V sol [pu]	V sol [kV]
1BORDERS81	1.049	524.5
1MANDAS81	1.049	524.5
1T.BORDES781	1.047	523.5
1B.DAR3S71	1.046	418.4
1BARO2S71	1.049	419.6
1BAROS71	1.048	419.2
1BELESS71	1.047	418.8
1D.MARS71	1.041	416.4
1GEBAS71	1.046	418.4
1GENALE3S71	1.046	418.4
1GENALE4S71	1.05	420.0
1GENJIS71	1.048	419.2
1GG2S71	1.047	418.8
1GGOS71	1.044	417.6
1GHEDOS71	1.035	414
1GHIMBIS71	1.045	418
1GIBE3S71	1.036	414.4
1KALITS71	1.005	402

1KARADS71	1.043	417.2
1MANDAS71	1.046	418.4
1METUS71	1.044	417.6
1SEBETS71	1.013	405.2
1SULULS71	1.005	402
1W.SODS71	1.032	412.8

Table appendix 2.4 : Voltage of the 400 and 500 kV Ethiopian substations

A. 3. Sudanese Network

From bus	To bus	P [MW]	Q [MVAr]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAr]	Ampacity (Nom.) [A]	Loading [%]
2ATBARS81	2KABASS81	384.8	-180.4	425.0	477.2	4.6	-272.5	2128	22.4
2ATBARS81	2KABASS81	384.8	-180.4	425.0	477.2	4.6	-272.5	2128	20.6
2ATBARS81	2MEROWS81	-138.9	-201.5	244.7	274.8	0.6	-260.4	2128	7.8
2ATBARS81	2P.SUD81	-509.5	-175.0	538.7	604.9	12.6	-375.1	2128	28.9
2ATBARS81	2P.SUD81	-509.5	-175.0	538.7	604.9	12.6	-375.1	2128	28.9
2BAGERS81	2H.HEI81	123.0	85.6	149.8	169.5	0.4	-101.7	2128	8
2BAGERS81	2H.HEI81	123.0	85.6	149.8	169.5	0.4	-101.7	2128	8
2BAGERS81	2J.AULIAS81	99.2	53.9	112.9	127.7	0.1	-42.0	2128	6
2BAGERS81	2KABASS81	-302.4	-116.9	324.2	366.8	0.8	-78.2	2128	17.2
2BAGERS81	2KABASS81	-302.4	-116.9	324.2	366.8	0.8	-78.2	2128	17.2
2BORS81	2JUBAS81	-300.8	-61.5	307.0	341.2	1.5	-162.9	2128	16
2BORS81	2JUBAS81	-300.8	-61.5	307.0	341.2	1.5	-162.9	2128	16
2BORS81	2MALAKAS81	245.8	-181.6	305.6	339.6	2.3	-372.3	2128	16
2BORS81	2MALAKAS81	245.8	-181.6	305.6	339.6	2.3	-372.3	2128	16
2FULA81	2NYALA81	499.0	-117.9	512.7	566.3	10.7	-325.0	2128	28.8
2FULA81	2NYALA81	499.0	-117.9	512.7	566.3	10.7	-325.0	2128	26.6
2FULA81	2RABAK81	350.4	-299.7	461.1	509.3	7.3	-569.4	2128	23.9
2FULA81	2RABAK81	350.4	-299.7	461.1	509.3	7.3	-569.4	2128	23.9
2GEDARE81	2MERIN81	-69.9	-175.3	188.7	220.7	0.2	-226.1	2128	10.4
2GEDARE81	2P.SUD81	-454.3	-308.6	549.1	642.4	17.3	-597.6	2128	30.2
2H.HEI81	2MERIN81	-794.7	64.1	797.3	916.6	4.1	-19.2	2128	43.1
2J.AULIAS81	2MARKHS81	-87.1	-58.0	104.6	118.8	0.1	-78.2	2128	5.6
2J.AULIAS81	2RABAK81	-542.2	-105.1	552.3	627.1	10.9	-254.3	2128	29.5
2JUBAS81	2RUMBEKS81	362.2	-133.7	386.1	428.3	4.7	-323.0	2128	20.1
2KABASS81	2MARKHS81	571.0	193.5	603.0	675.9	1.5	-26.3	2128	32.5
2MARKHS81	2MEROWS81	-457.6	-188.0	494.8	560.5	8.2	-318.9	2128	25
2MARKHS81	2MEROWS81	-457.6	-188.0	494.8	560.5	8.2	-318.9	2128	25
2MERIN81	2RABAK81	-894.5	-66.4	897.0	1030.8	14.2	-30.2	2128	47.9
2MERIN81	2RABAK81	-894.5	-66.4	897.0	1030.8	14.2	-30.2	2128	48.4
2RABAK81	1T.BORDES781	-800.9	-30.4	801.5	898.5	22.4	-134.0	2128	43
2RABAK81	1T.BORDES781	-800.9	-30.4	801.5	898.5	22.4	-134.0	2128	43
2RABAK81	1T.BORDES781	-800.9	-30.4	801.5	898.5	22.4	-134.0	2128	43
2RABAK81	1T.BORDES781	-800.9	-30.4	801.5	898.5	22.4	-134.0	2128	43
2RABAK81	2RABAK_5ACDC*	2150.0	229.2	2162.2	2424.0	-	-	-	-
2RUMBEKS81	2WAUS81	211.1	-172.4	272.6	309.9	1.8	-359.8	2128	14.6

* RABAK_5ACDC : AC/DC converter station in Rabak

Table appendix 3.1 : Power flows on the Sudanese 500 kV lines

From bus	To bus	P [MW]	Q [MVAr]	S [MVA]	I [A]	Losses P [MW]	Losses Q [MVAr]	Ampacity (Norm.) [A]	Loading [%]
2GEDARS61	1SHEHE61	-73.9	-4.2	74.0	190.1	1.4	-31.4	972	19.6
2GEDARS61	1SHEHE61	-73.9	-4.2	74.0	190.1	1.4	-31.4	972	19.6

Table appendix 3.2 : Power flows on the 220 kV interconnection Ethiopia - Sudan

Power imported from Ethiopia

Power flow arriving from Ethiopia to Sudan :

- 500 kV interconnection : 4 x 801 MW = 3 204 MW

- 220 kV interconnection : 2 x 74 MW = 148 MW

Total : 3351 MW

Among these 3351 MW, 2150 MW are absorbed by the AC/DC converter station in Rabak (hypothesis : losses on the DC lines and converter stations = 150 MW). 1200 MW are for the Sudanese system.

To limit the flow and avoid an overload on the 220 kV interconnection, a phase-shift transformer has been installed at Gedaref substation.

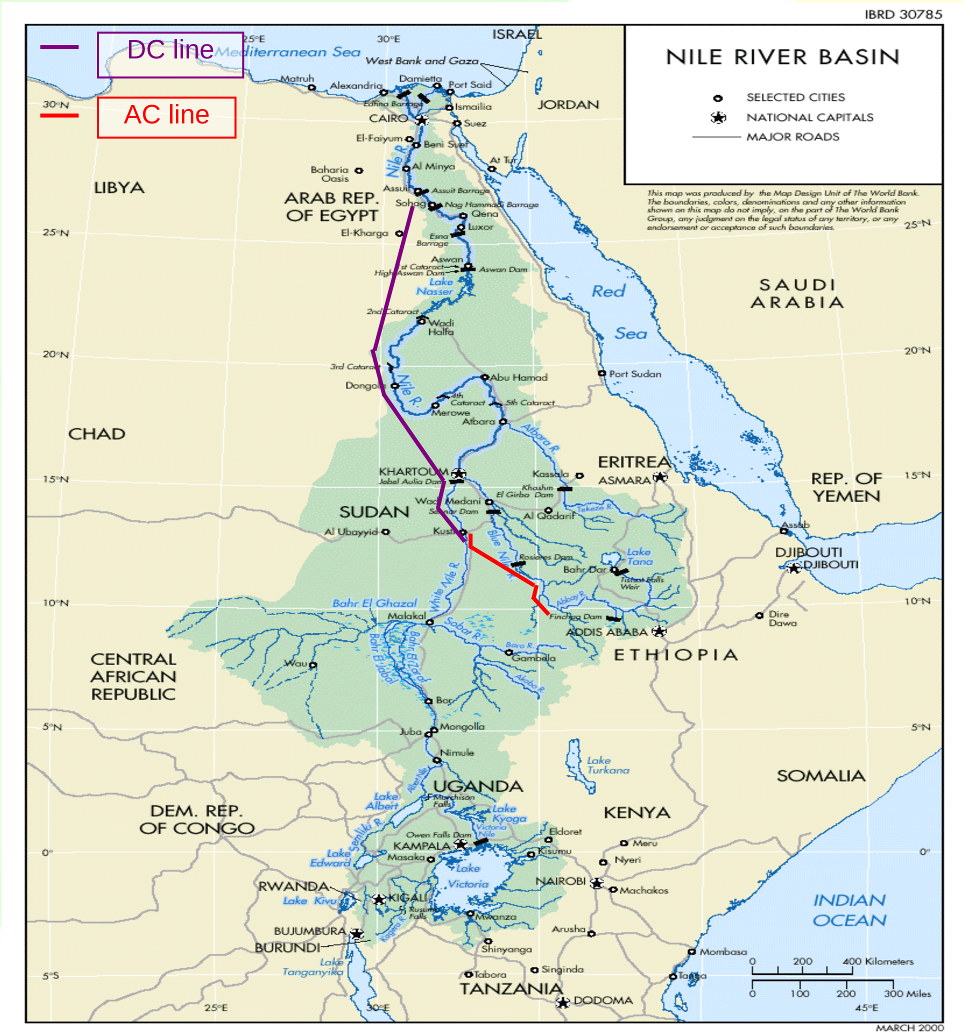
Substation.	V sol [pu]	V sol [kV]
2ATBARS81	1.028	514
2BAGERS81	1.021	510.5
2BORS81	1.039	519.5
2FULA81	1.045	522.5
2H.HEI81	1.004	502
2J.AULIAS81	1.017	508.5
2JUBAS81	1.041	520.5
2KABASS81	1.03	515
2MALAKAS81	1.027	513.5
2MARKHS81	1.019	509.5
2MERIN81	1.005	502.5
2MEROWS81	1.05	525
2NYALA81	1	500
2P.SUD81	1.05	525
2RABAK81	1.03	515
2RUMBEKS81	1.016	508
2WAUS81	1.004	502

Table appendix 3.3 : Voltage of the 500 kV Sudanese substations

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



M1 – DC LINK OPTIMIZATION

EPS Electrical Power Systems Engineering Company

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ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
DC	Direct Current
ENPTPS	Eastern Nile Power Trade Program Study
EDF	Electricité de France
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
HV	High Voltage
HVDC	High Voltage Direct Current
IDC	Interest During Construction
NBI	Nile Basin Initiative
OHL	Over Head Line
SW	Scott Wilson

EXECUTIVE SUMMARY

The optimization study for a DC interconnection provides with the selection of the DC voltage and with the cross-section of the conductors of this DC interconnection.

The optimization is based on an economic comparison between different solutions for DC voltages, HVDC stations, and OHL conductors.

The result of the study is :

- The selected voltage is the +/-600 kV DC.
- The conductor type, to be selected for the DC bipolar line, is the 6 x Curlew (overall cross section : 593 mm² / Al cross section : 525 mm²)

1 INTRODUCING DC LINK OPTIMIZATION

The selected scheme for the interconnection between the three countries included a DC transmission circuit between Kosti in Sudan (initially located at Rabak (east side of the Nile), the line routing study located the interconnection substation in Sudan on the West side of the Nile river at Kosti, and Nag Hammadi in Egypt.

The characteristics of the DC interconnection are the following ones :

- Length : 1 665 km
- Capacity : 2 000 MW
- Duration : 6 300 h/year

The global optimization study for a DC interconnection provides with the selection of the DC voltage and the cross-section OHL conductors of the DC interconnection.

It is based on an economic comparison between different voltage solutions. The cost, price and condition economical references for this optimization hypothesis are, for sake of consistency, the same as used for ENPTPS phase I study : $ 2006

An increase of the cross section of the conductor led to an increase of the investment cost, but a reduction of the losses, and therefore of the cost of the losses.

An increase of the DC voltage led to the reduction of the current, and therefore the cross section of the conductor, but entailed an increase of the height of the pylons, and an increase of the cost of the HVDC converter station. About losses, an increase of the DC voltage entailed an increase of the Coronna losses, but a reduction of the Joule losses.

For three voltage levels (500, 600 and 800 kV), cost calculations with different conductors were carried out to find the optimal solution for each DC voltage level.

2 COST CALCULATION

2.1 HYPOTHESIS

The cost presented hereafter only concerned the DC interconnection :

- HVDC substations
- HVDC bipolar line

The hypothesis for the calculation are the following ones :

1. Cost calculations expressed in US Dollar 2006
2. Discount rate = 10 %, with a sensitivity analysis for 8 and 12 %
3. The annual costs were calculated assuming the equipment life time as followed :
   - AC equipments : line and substation : 50 years
   - DC line : 50 years
   - AC / DC converter station : 25 years
4. The cost of losses is assumed to be an 2006 economical hypothesis 40 $/MWh, consistent with Phase I investment evaluations. The amount of losses on the interconnection lines was determined with load flows calculation.

2.2 PRESENTATION OF THE SOLUTIONS

All costs mentioned here above, are expressed in k$ 2006

2.2.1 500 KV SOLUTIONS

500 kV	6 x Curlew	8 x Canary	8 x Curlew
Investment cost HVDC bipolar line	849 150	892 856	940 725
Investment cost HVDC substations	2 x 286 130	2 x 283 505	2 x 280 880
Total investment cost	**1 421 411**	**1 459 867**	**1 502 485**
Total annual losses	45 570	40 488	36 325
Total annual cost	**207 263**	**206 304**	**206 716**

Table 1 : 500 kV solutions

2.2.2 600 kV SOLUTIONS

600 kV	8 x Grosbeak	6 x Canary	6 x Curlew	8 x Canary
Investment cost HVDC bipolar line	828 338	826 256	861 638	907 425
Investment cost HVDC substations	2 x 298 427	2 x 297 045	2 x 295 663	2 x 294 282
Total investment cost	**1 425 191**	**1 420 346**	***1 452 964***	**1 495 989**
Total annual losses	40 846	39 025	35 297	31 720
Total annual cost	**203 249**	**200 865**	**200 657**	**201 715**

Table 2 : 600 kV solutions

2.2.3 800 kV SOLUTIONS

800 kV	8 x Hawk	8 x Dove	8 x Grosbeak
Investment cost HVDC bipolar line	824 175	844 988	890 775
Investment cost HVDC substations	2 x 356 454	2 x 353 138	2 x 351 480
Total investment cost	**1 537 083**	**1 551 264**	**1 593 735**
Total annual losses	38 864	34 579	31 605
Total annual cost	**214 860**	**212 038**	**213 647**

Table 3 : 800 kV solutions

3 CONCLUSION

The selected voltage is the +/-600 kV DC.

The conductor type, to be selected for the DC bipolar line, is the 6 x Curlew (overall cross section : 593 mm² / Al cross section : 525 mm²)

Appendix 1. Network Equipment Cost

Equipment 500 kV	Size	Capital cost (k$)	Investment cost (k$)		
			I=10%	I=12%	I=8%
+/- 500 kV double pole OHL		k$/km	k$/km	k$/km	k$/km
Grosbeak	8 x 321 mm²	390	488	511	468
Canary	6 x 456 mm²	390	488	511	468
Curlew	6 x 525 mm²	408	510	534	490
Canary	8 x 456 mm²	429	536	562	515
Curlew	8 x 525 mm²	452	565	592	542
AC/DC converter station		k$/MW	k$/MW	k$/MW	k$/MW
for double pole	2000 MW	102	131	138	125

Table 4: 500 kV DC Transmission Equipment Unit Costs

Equipment 600 kV	Size	Capital cost (k$)	Investment cost (k$)		
			I=10%	I=12%	I=8%
+/- 600 kV double pole OHL		k$/km	k$/km	k$/km	k$/km
Hawk	8 x 241 mm²	368	460	482	442
Dove	8 x 282 mm²	377	471	494	452
Grosbeak	8 x 321 mm²	398	498	521	478
Canary	6 x 456 mm²	397	496	520	476
Curlew	6 x 525 mm²	414	518	542	497
Canary	8 x 456 mm²	436	545	571	523
AC/DC converter station		k$/MW	k$/MW	k$/MW	k$/MW
for double pole	2000 MW	107	138	146	132

Table 5: 600 kV DC Transmission Equipment Unit Costs

Equipment 800 kV	Size	Capital cost (k$)	Investment cost (k$)		
			I=10%	I=12%	I=8%
+/- 800 kV double pole OHL		k$/km	k$/km	k$/km	k$/km
Hawk	8 x 241 mm²	396	495	519	475
Dove	6 x 282.6 mm²	406	508	532	487
Grosbeak	6 x 321.8 mm²	428	535	561	514
AC/DC converter station		k$/MW	k$/MW	k$/MW	k$/MW
for double pole	2000 MW	129	166	175	158

Table 6: 800 kV DC Transmission Equipment Unit Costs

Note: Investment Cost includes Interest During Construction (IDC)

Appendix 2. Comparison for the 500, 600 and 800 kV DC solutions

The parameters used for the capital, investment and annual transmission cost calculation are the same one as those used in phase 1 :

Cost calculations expressed in US Dollar 2006

Discount rate = 10 %, with a sensitivity analysis for 8 and 12 %

The annual costs were calculated assuming the equipment life time as followed :

- AC equipments : line and substation : 50 years
- DC line : 50 years
- AC / DC converter station : 25 years

The losses on the interconnection were supplied by Ethiopia, the cost of losses was assumed to be 40 $/MWh. The amount of losses on the interconnection lines was determined with load flows calculation.

The annual transmission cost was calculated as the sum of the :

- investment cost
- operation and maintenance cost
- cost of the transmission losses

Appendix 3. 500 kV DC solutions

DC line 6 x Curlew (593 mm²)

Curlew : overall cross section : 593 mm² / Al cross section : 525 mm²

Total Al cross section : 3 150 mm²

DC +/- 500 kV RABAK - NH	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	6 x 525 mm²	1 665	408	679 320	510	534	490	849 150	889 909	815 184
AC/DC converter station Kosti	2180	1	102	221 806	131	138	125	286 130	301 657	272 822
AC/DC converter station NH	2180	1	102	221 806	131	138	125	286 130	301 657	272 822
Total				**1 122 933**				**1 421 411**	**1 493 223**	**1 360 828**

Table 7: 500 kV - 6 x Curlew Line - Capital and Investment Costs

500 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	85 645	107 160	66 635	6 793	33 636	758	**207 263**	242 656	176 325
AC/DC converter station	63 045	76 922	51 115	6 211	6 592	4 583			

Table 8: 500 kV - 6 x Curlew Line - Annual Transmission costs

DC line 8 x Canary (515 mm²)

Canary: overall cross section : 515 mm² / Al cross section : 456 mm²

Total Al cross section : 3 648 mm²

DC +/- 500 kV KOSTI - NH	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	8 x 456 mm²	1 665	429	714 285	536	562	515	892 856	935 713	857 142
AC/DC converter station Kosti	2 160	1	102	219 772	131	138	125	283 505	298 889	270 319
AC/DC converter station NH	2 160	1	102	219 772	131	138	125	283 505	298 889	270 319
Total				**1 153 828**				**1 459 867**	**1 533 492**	**1 397 780**

Table 9: 500 kV - 8 x Canary Line - Capital and Investment Costs

500 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	90 053	112 675	70 065	7 143	28 773	642	**206 304**	242 677	174 496
AC/DC converter station	62 466	76 217	50 646	6 154	6 532	4 541			

Table 10: 500 kV - 8 x Canary Line - Annual Transmission Costs

DC line 8 x Curlew (593 mm²)

Curlew : overall cross section : 593 mm² / Al cross section : 525 mm²

Total Al cross section : 4 200 mm²

DC +/- 500 kV KOSTI - NH	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	8 x 525 mm²	1 665	452	752 580	565	592	542	940 725	985 880	903 096
AC/DC converter station Kosti	2 140	1	102	217 737	131	138	125	280 880	296 122	267 816
AC/DC converter station NH	2 140	1	102	217 737	131	138	125	280 880	296 122	267 816
Total				**1 188 053**				**1 502 485**	**1 578 123**	**1 438 728**

Table 11: 500 kV - 8 x Curlew Line - Capital and Investment costs

500 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	94 881	118 716	73 822	7 526	24 712	642	**206 716**	244 174	173 946
AC/DC converter station	61 888	75 511	50 177	6 097	6 471	4 499			

Table 12: 500 kV - 8 x Curlew Line - Annual Transmission Costs

Appendix 4. 600 kV DC solutions

DC line 8 x Grosbeak (374 mm²)

Grosbeak : overall cross section : 374 mm² / Al cross section : 321 mm²

Total Al cross section : 2 574 mm²

DC +/- 600 kV KOSTI - NH	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	8 x 321 mm²	1 665	398	662 670	498	521	478	828 338	868 098	795 204
AC/DC converter station Kosti	2 160	1	107	231 338	138	146	132	298 427	314 620	284 546
AC/DC converter station NH	2 160	1	107	231 338	138	146	132	298 427	314 620	284 546
Total				**1 125 347**				**1 425 191**	**1 497 338**	**1 364 297**

Table 13: 600 kV - 8 x Grosbeak Line - Capital and Investment costs

600 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	83 545	104 533	65 002	6 627	28 314	1 459	**203 249**	238 711	172 264
AC/DC converter station	65 754	80 228	53 312	6 477	6 532	4 541			

Table 14: 600 kV - 8 x Grosbeak Line - Annual Transmission Costs

DC line 6 x Canary (515 mm²)

Canary : overall cross section : 515 mm² / Al cross section : 456 mm²

Total Al cross section : 2 736 mm²

DC +/- 600 kV KOSTI - NH	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	6 x 456 mm²	1 665	397	661 005	496	520	476	826 256	865 917	793 206
AC/DC converter station Kosti	2 150	1	107	229 997	138	146	132	297 045	313 164	283 229
AC/DC converter station NH	2 150	1	107	230 267	138	146	132	297 045	313 164	283 229
Total				**1 121 375**				**1 420 346**	**1 492 244**	**1 359 664**

Table 15: 600 kV - 6 x Canary Line - Capital and Investment costs

600 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	83 336	104 271	64 839	6 610	26 369	1 634	**200 865**	236 207	169 984
AC/DC converter station	65 450	79 857	53 065	6 445	6 502	4 520			

Table 16: 600 kV - 6 x Canary Line - Annual Transmission Costs

DC line 6 x Curlew (593 mm²)

Curlew : overall cross section : 593 mm² / Al cross section : 525 mm²

Total Al cross section : 3 150 mm²

DC +/- 600 kV KOSTI - NH	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	6 x 525 mm²	1 665	414	689 310	518	542	497	861 638	902 996	827 172
AC/DC converter station Kosti	2 140	1	107	229 196	138	146	132	295 663	311 707	281 912
AC/DC converter station NH	2 140	1	107	229 196	138	146	132	295 663	311 707	281 912
Total				1 147 703				1 452 964	1 526 410	1 390 995

Table 17: 600 kV - 6 x Curlew Line - Capital and Investment costs

600 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	86 904	108 736	67 615	6 893	22 810	1 517	**200 657**	236 829	169 042
AC/DC converter station	65 145	79 485	52 818	6 417	6 471	4 499			

Table 18: - 600 kV - 6 x Curlew Line - Annual Transmission Costs

DC line 8 x Canary (515 mm²)

Canary : overall cross section : 515 mm² / Al cross section : 456 mm²

Total Al cross section : 3 648 mm²

DC +/- 600 kV KOSTI - NH	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	8 x 456 mm²	1 665	436	725 940	545	571	523	907 425	950 981	871 128
AC/DC converter station Kosti	2 130	1	107	226 985	138	146	132	294 282	310 251	280 594
AC/DC converter station NH	2 130	1	107	228 125	138	146	132	294 282	310 251	280 594
Total				**1 181 129**				**1 495 989**	**1 571 482**	**1 432 316**

Table 19: 600 kV - 8 x Canary Line - Capital and Investment Costs

600 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	91 522	114 514	71 208	7 259	19 576	1 225	**201 715**	238 980	169 132
AC/DC converter station	64 841	79 114	52 571	6 373	6 441	4 478			

Table 20: 600 kV - 8 x Canary Line - Annual transmission Costs

Appendix 5. 800 kV DC solutions

DC line 8 x Hawk (281 mm²)

Hawk : overall cross section : 281 mm² / Al cross section : 241 mm²

Total Al cross section : 1 928 mm²

DC link +/- 800 kV	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	8 x 281 mm²	1 665	396	659 340	495	519	475	824 175	863 735	791 208
AC/DC converter station Kosti	2 150	1	129	276 321	166	175	158	356 454	375 796	339 875
AC/DC converter station NH	2 150	1	129	276 321	166	175	158	356 454	375 796	339 875
Total				**1 211 982**				**1 537 083**	**1 615 328**	**1 470 957**

Table 21: 800 kV - 8 x Hawk Line - Capital and Investment Costs

800 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	83 126	104 008	64 676	6 593	20 783	7 059	**214 860**	253 031	181 548
AC/DC converter station	78 540	95 828	63 678	7 737	6 502	4 520			

Table 22: 800 kV - 8 x Hawk Line - Annual Transmission Costs

DC line 8 x Dove (328 mm²)

Dove : overall cross section : 328 mm² / Al cross section : 282 mm²

Total Al cross section : 2 256 mm²

DC link +/- 800 kV	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	8 x 282 mm²	1 665	406	675 990	508	532	487	844 988	885 547	811 188
AC/DC converter station Kosti	2 130	1	129	273 750	166	175	158	353 138	372 301	336 713
AC/DC converter station NH	2 130	1	129	273 750	166	175	158	353 138	372 301	336 713
Total				**1 223 491**				**1 551 264**	**1 630 148**	**1 484 614**

Table 23: 800 kV - 8 x Dove Line - Capital and Investment Costs

800 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	permanent	i=10%	i=12%	i=8%
Kosti - NH	85 225	106 635	66 309	6 760	17 768	5 893	**212 038**	250 576	178 399
AC/DC converter station	77 809	94 937	63 086	7 665	6 441	4 478			

Table 24: 800 kV - 8 x Dove Line - Annual Transmission coSts

DC line 8 x Grosbeak (374 mm²)

Grosbeak : overall cross section : 374 mm² / Al cross section : 321 mm²

Total Al cross section : 2 574 mm²

DC link +/- 800 kV	Size	Length (km)	Capital cost (k$)	Total capital cost (k$)	Investment cost (k$/km)			Total cost (k$)		
					i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Kosti - NH bipole	8 x 321.8	1 665	428	712 620	535	561	514	890 775	933 532	855 144
AC/DC converter station Kosti	2 120	1	129	272 465	166	175	158	351 480	370 553	335 132
AC/DC converter station NH	2 120	1	129	272 465	166	175	158	351 480	370 553	335 132
Total				**1 257 551**				**1 593 735**	**1 674 638**	**1 525 409**

Table 25: - 800 kV - 8 x Grosbeak Line - Capital and Investment Costs

800 kV	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Total annual cost (k$)**		
	i=10%	i=12%	i=8%		Joule	Permanent	i=10%	i=12%	i=8%
Kosti - NH	89 843	112 413	69 902	7 126	15 603	5 134	**213 647**	253 264	179 052
AC/DC converter station	77 444	94 491	62 790	7 629	6 411	4 457			

Table 26: 800 kV - 8 x Grosbeak Line - Annual Transmission Costs