ENTRO

EASTERN NILE POWER TRADE PROGRAM STUDY

AfDB

EDF – Generation and Engineering Division
73 373
Le Bourget du Lac Cedex
France
Tel: +33-4-79 60 60 60
Fax: +33-4-79 60 62 35
eMail: pierre.brun@edf.fr
http://www.edf.fr

ANALYSIS IN PERMANENT STATE

OF

THE INTERCONNECTED SYSTEM

VOL 3.4.2

OPTION 2
Ethiopia to Egypt 690 MW
Ethiopia to Sudan 1200 MW

FINAL REPORT

Scott Wilson
Kanthack House, Station Road,
Ashford, Kent TN 23 1 PP
England
Tel: +44 (0) 1233 658200
Fax: +44 (0) 1233 658209
eMail: alan.bates@scottwilson.com
http://www.scottwilson.com

with participation of:

- EPS (Egypt)
- Tropics (Ethiopia)
- YAM (Sudan)

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1 PRESENTATION

In this Option 2, the power exchanges between Ethiopia, Sudan and Egypt were:

- Ethiopia exports 690 MW to Egypt (as in Option 1)
- Ethiopia exports 1200 MW to Sudan

The duration of the power exchanges between Ethiopia and Sudan and between Ethiopia and Egypt are respectively 8600 hours and 7800 hours per year.

The study of Option 1 showed that the transmission cost between Ethiopia and Sudan was less expensive in AC technology than in DC technology. This transmission cost between Ethiopia and Egypt was equivalent for the two technologies.

So, in this Option 2, two main alternatives were examined: one AC alternative and one AC and DC alternative.

- Alternative 1: Three 500 kV circuits Mandaya - Rabak and a 500 kV double circuit line Merowe - Nag Hamadi.
- Alternative 2: A 500 kV AC double circuit line Mandaya - Rabak and one single pole DC link Mandaya - Nag Hamadi. For the DC link two voltage levels, 600 kV and 800 kV, were examined. For this alternative, the power exchange from Ethiopia to Sudan flowed over the AC line and the power exchange from Ethiopia to Egypt flowed over the DC link.

2 STUDY OF ALTERNATIVE 1

2.1 DESCRIPTION OF THE INTERCONNECTION

The interconnection between Ethiopia, Sudan and Egypt includes:

- A 500/400 kV substation located on Mandaya HPP site, equipped with three 500/400 kV 660 MVA transformers. This transformation is composed by nine 220 MVA single-phase units + one 220 MVA single-phase unit as a spare part.
- Three 500 kV AC circuits between Mandaya HPP and Rabak 500 kV substation. The length of the line is 570 km. The three circuits are equipped at each end by one 230 MVAr reactor to energize the line in good condition and to control the voltage profile in operation.
- A 500 kV AC double circuit line between Merowe HPP and Nag Hammadi 500 kV substation. The total length of the line is 1120 km. To control the voltage profile along the line and to facilitate the energizing of the line, an intermediate switching substation is installed in the middle of the line, close to the border between Sudan and Egypt. The two sections of the line are equipped at each end by one 230 MVAr reactor. Moreover, one 230 MVAr reactor is connected on the 500 kV bus bar of the intermediate switching substation, to facilitate the energizing of the line.

2.2 STATIC ANALYSIS OF THE BEHAVIOUR OF THE INTERCONNECTED SYSTEM

2.2.1 Unit commitment in Ethiopia

Name	installed power (MW)	Installed capacity (MW)			Generated power (MW)		
		Nber of units	Pmax	Total	Nber of units	P gen	Total
GIGEL GEBE III							
phase I	4 x 226	4	226	904	4	200	800
phase II	4 x 226	4	226	904	4	200	800
BELES	4 x 105	4	115	460	4	80	320
TEKEZE	4 x 75	4	75	300	3	60	180
GIGEL GEBE II	4 x 105	4	105	420	4	80	320
NECHE	2 x 21.3	2	21.5	43	2	15	30
AWASH II	2 x 16	2	16	32	2	12	24
AWASH III	2 x 16	2	16	32	2	12	24
KOKA	3 x 14	3	14.33	42.99	3	10	30
GIGEL GEBE I	3 x 65.7	3	65.7	197.1	3	55	165
FINCHAA	3 x 33.3	3	33.3	99.9	2	25	50
FINCHAA	1 x 32	1	38	38	1	25	25
MELKA WAKENA	4 x 38.25	4	38.25	153	3	25	75
TIS ABAY I	3 x 3.8	3	3.8	11.4	3	3	9
TIS ABAY II	2 x 36	2	34	68	2	25	50
SOR	2 x 2.5	2	2.5	5	2	2	4
MANDAYA		8	250	2000	8	212.5	1700
YAYU COAL	1 x 100	2	50	100	1	40	40
				5810			4646

Table 2-1 Unit commitment in Ethiopia

2.2.2 In normal condition (see Paragraph 5)

About 2004 MW flowed from Ethiopia to Sudan and Egypt:

- 1667 MW over the three 500 kV circuits Mandaya - Rabak
- 337 MW over the 220 kV double circuit line Gedaref - Gonder.

About 720 MW flowed from Merowe to Nag Hammadi 500 kV substation.

The total losses on the interconnection lines amounted to 110 MW, 84 MW between Ethiopia and Sudan and 26 MW between Sudan and Egypt.

The losses reached 5.8 % of the 1900 MW net power exchange.

The voltage profile along the interconnection link was satisfactory. The following values were obtained:

Bus	Vn (kV)	Vsol (kV)	Vsol/Vn (%)
NAG HAMMADI	500	512.5	102.5
MEROWE	500	524.9	105
MERINGAN	500	512.1	102.4
HASAHEISA	500	514.4	102.9
RABAK	500	511.4	102.3
MANDAYA	500	511.2	102.2
MANDAYA	400	414.2	103.6
GEDAREF	220	222	100.9
GONDER	230	230	100

Table 2-2 Voltage profile on the interconnection substations. Alternative 3

About 250 MVAr flowed from Rabak to supply the reactors connected at the Rabak end, and about 90 MVAr flowed from the line to Mandaya substation to feed the reactive losses in the transformation.

About 110 MVAr flowed from the line to the substation of Merowe and about 25 MVAr flowed from Nag Hamadi to supply the reactive compensation of the line.

The analysis was mainly focused on the Sudanese system because the whole imported power flowed over the network from Rabak 500/220 kV substation.

<u>Sudan</u>

The behaviour of the Sudanese transmission system was satisfactory; the power exchange coming from Mandaya to Rabak discharged the network. The flow over the 500 kV lines Hasaheisa - Kabashi was reduced to about 150 MW in place of 920 MW without power exchange.

About 760 MW flowed from Rabak to Meringan over the 500 kV line Meringan - Rabak that was the most loaded line (41 % of its nominal rating) and about 415 MW flowed from Meringan to Hasaheisa over the 500 kV line (23 % of its nominal rating)

The most loaded transformers were at Meringan and Markhiat, respectively 56 % and 55 % loaded.

The flows through the 500/220 kV transformers and over the 500 kV lines are displayed on paragraph 3.

Rabak area

A part of the power exchange, about 45 %, coming from Mandaya flowed over the 500 kV link Rabak - Meringan - Hasaheisa to supply the local demand. About 330 MW flowed from Rabak to Markhiat (20 %). About 230 MVA flowed through the Rabak transformation (14 %). The remaining part flowed to Markhiat and Nyala on the 500 kV system.

The 220 kV under laying system was affected, but no overload occurred on the 220 kV system. The most loaded lines Mashkur - Rabak were 50 % loaded.

Gedaref area:

The 220 kV lines were loaded below 30 % of their nominal rating.

Merowe and Port Sudan area:

The 500 kV lines were loaded below 20 % of their nominal rating (18.1 % for the two 500 kV lines Atbara - Port Sudan)

2.2.3 In N-1 situation

2.2.3.1 Interconnection

2.2.3.1.1 The 220 kV interconnection Gedaref - Gonder

<u>Tripping of one of the two 230 kV circuits Gonder - Shehedi</u>

In normal situation, about 340 MW flowed over the two circuits.

Following the tripping, 90 % of the initial power flowed over the remaining circuit that was overloaded by 11 % of its nominal rating (93 % of its emergency rating).

The voltage profile along the interconnection was slightly affected: the voltage reached 218 kV at Gedaref (-4 %).

Remedial action: tripping of one circuit of the 220 kV double circuit line Gedaref - Shehedi. The remaining line Gedaref - Shehedi was 98 % loaded.

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

In normal situation, about 310 MW flowed over the two circuits.

Following the tripping, 90 % of the initial power flowed over the remaining circuit that was 76 % loaded. The behaviour of the system was satisfactory.

The voltage profile along the interconnection was slightly affected: the voltage reached 216 kV at Gedaref (-3 %)

2.2.3.1.2 The 500 kV interconnection

Tripping of one circuit of the three 500 kV circuits Mandaya - Rabak

The behaviour of the interconnected system was acceptable. No overload occurred on the interconnection link (500 kV and 220 kV) and the voltage profile was within the limits.

About 98 % of the initial flow was transferred on the two remaining 500 kV circuits, that were 44 % loaded. The remaining part of the power flowed over the 220 kV interconnection Gedaref - Gonder that was 74 % loaded.

The double circuit 230 kV line Bahir Dar - Gonder was 78 % loaded.

The voltage profile was affected along the interconnection link: the voltage dropped at Rabak from 511 kV to 496 kV (-3 %) and at Gedaref from 222 kV to 210 kV (-5 %).

Tripping of one of the three 500/400 kV transformers at Mandaya

Following the tripping, the remaining transformer would be overloaded by 26 % of its nominal rating (and by 5 % of its emergency rating)

To overcome this constraint, two or three 250 MW units of Mandaya HPP should be automatically tripped. The loss of generation in the interconnected system would be compensated by the delivery of the primary reserve. The power exchange would be reduced to about 400 MW until the replacement of the faulted single-phase element by the spare element. This problem should be investigated by the study in transient state.

Another solution could be to equip Mandaya 500/400 kV substation with three 810 MVA transformers instead of 660 MVA (10 x 270 MVA single-phase transformers)

Tripping of one of the two circuits of the 500 kV double circuit line between Merowe and the intermediate substation

Following the tripping, the behaviour of the system was acceptable. The remaining circuit was 40 % loaded. The dynamic behaviour of the interconnected system will be investigated by the study in transient state.

2.2.3.2 Sudan (see paragraph 5)

The power imported by the interconnection with Ethiopia and Egypt had positive effect on the behaviour of the Sudanese system in N-1 situation: the power exchange discharged the 220 kV Sudanese system close to the interconnection point. No overload occurred on the 500 kV and 220 kV system whatever the tripped equipment.

2.3 TRANSIENT ANALYSIS OF THE BEHAVIOUR OF THE INTERCONNECTED SYSTEM

The international literature concerning the inter-area oscillations, indicates that an inter-area oscillation mode is acceptably damped if the damping coefficient is close to 5% and it is well damped if the damping coefficient is higher than 5%.

The fault describe is a three phase short-circuit normally cleared by opening of the faulted circuit following the normal operation of the protection.

2.3.1 Short-circuit on the 500 kV interconnection Egypt - Sudan at Nag Hammadi

In case of short circuit on one of the two 500 kV interconnection circuits at Nag Hammadi (cleared in 100 ms by the tripping of the faulted circuit NH500 - Intermediate station), the interconnected system remains stable.

The flow at the intermediate substation on the remaining circuit Nag Hammadi - Intermediate Substation increased from 350 to 700 MW, reaching transiently 763 MW.
The damping coefficient of the power oscillations on the interconnection is 5.4 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
NH500	514 kV	508 kV	506 kV
Merowe	523 kV	530 kV	520 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
NH HPP	50.4 Hz	49.7 Hz
High Dam	50.22 Hz	49.81 Hz
Isna	50.15 Hz	49.82 Hz
Merowe	50.15 Hz	49.95 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.2 Short-circuit on the 500 kV interconnection Egypt - Sudan at Merowe

In case of short circuit on one of the two 500 kV interconnection circuits at Merowe (cleared in 120 ms by the tripping of the faulted circuit Merowe - Intermediate substation), the interconnected system remains stable.

The flow at Merowe on the remaining circuit Merowe - Intermediate substation increased from 360 to 732 MW, reaching transiently 1014 MW.
The damping coefficient of the power oscillations on the interconnection is 8.8 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
NH500	514 kV	516 kV	509 kV
Merowe	523 kV	540 kV	516 kV
Markhiat	512.5 kV	530 kV	509.5kV
Atbara	518 kV	536 kV	515.5 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Merowe	50.52 Hz	49.81 Hz
Dal	50.45 Hz	49.63 Hz
Roseires	50.4 Hz	49.75 Hz
Garri GT	50.4 Hz	49.85 Hz
Fula GT	50.37 Hz	49.82 Hz
Port Sudan	50.3 Hz	49.81 Hz
High Dam	50.08 Hz	49.93 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.3 Short-circuit at Nag Hammadi on one of the two 500 kV circuits Nag Hammadi - High Dam

In case of short circuit on one of the two 500 kV circuit Nag Hammadi - High Dam (cleared in 100 ms by the tripping of the faulted circuit HD500 - NH500), the interconnected system remains stable.

The flow on the remaining circuit High Dam - Nag Hammadi increased from 343 to 621 MW, reaching transiently 1012 MW.
The damping coefficient of the power oscillations on the remaining circuit High Dam - Nag Hammadi is 7 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
HD500	525 kV	525 kV	522 kV
NH500	514 kV	505.5 kV	504.5 kV
Merowe	523 kV	529 kV	522 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
NH PS	50.4 Hz	49.7 Hz
High Dam	50.23 Hz	49.81 Hz
Isna	50.15 Hz	49.82 Hz
Merowe	50.15 Hz	49.97 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.4 Short-circuit at Nag Hammadi on the 500 kV circuit Nag Hammadi - Assiut

In case of short circuit on the 500 kV circuits Nag Hammadi - Assiut (cleared in 100 ms by the tripping of the faulted circuit NH500 - Assiut), the interconnected system remains stable.

The flow on the tripped circuit was 41 MW.
The flow on the remaining circuit Nag Hammadi - Sohag decreased from 47 to 30 MW, reaching transiently 336 MW.
The damping coefficient of the power oscillations on the remaining circuit Nag Hammadi - Assiut is 8.9 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
High Dam	525 kV	527 kV	523 kV
NH500	514 kV	508 kV	507 kV
Merowe	523 kV	530 kV	522.5 kV
Assiut	521 kV	520 kV	517 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
NH PS	50.4 Hz	49.7 Hz
High Dam	50.23 Hz	49.82 Hz
Isna	50.15 Hz	49.82 Hz
Merowe	50.15 Hz	49.97 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2

2.3.5 Short-circuit at Merowe on one of the two 500 kV circuits Merowe - Markhiat

In case of short circuit on one of the two 500 kV circuit Merowe - Markhiat at Merowe (cleared in 120 ms by the tripping of faulted circuit Merowe - Markhiat), the interconnected system remains stable.

The flow on the remaining circuit Merowe - Markhiat increased from 213 to 311 MW, reaching transiently 439 MW.
The flow on the Merowe - Atbara increased from 150 to 246 MW, reaching transiently 416 MW.
The damping coefficient of the power oscillations on the interconnection and the line Merowe - Markhiat is 10.8 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
NH500	514 kV	518 kV	513.5 kV
Merowe	523 kV	550 kV	521 kV
Markhiat	512.5 kV	529 kV	506kV
Atbara	518 kV	540 kV	515.5 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Merowe	50.52 Hz	49.81 Hz
Dal	50.45 Hz	49.48 Hz
Roseires	50.4 Hz	49.75 Hz
GarriGT	50.4 Hz	49.8 Hz
Fula GT	50.31 Hz	49.8 Hz
Port Sudan	50.28 Hz	49.81 Hz
High Dam	50.12 Hz	49.91 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2

2.3.6 Short-circuit at Merowe on the 500 kV line Merowe - Atbara

In case of short circuit on single 500 kV line Merowe - Atbar (cleared in 120 ms by the tripping of the line), the interconnected system remains stable.

The initial flow on the Merowe - Atbara circuit was 150 MW.
The flow on each of the two 500 kV circuit Merowe - Markhiat increased from 213 to 278 MW, reaching transiently 439 MW.
The damping coefficient of the power oscillations on the interconnection and the line Merowe - Markhiat is 10.8 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
NH500	514 kV	518 kV	513.5 kV
Merowe	523 kV	550 kV	519 kV
Markhiat	512.5 kV	531.5 kV	508kV
Atabara	518 kV	528 kV	509 kV
Port Sudan	522 kV	538 kV	519 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Merowe	50.52 Hz	49.81 Hz
Dal	50.45 Hz	49.45 Hz
Roseires	50.23 Hz	49.75 Hz
Garri GT	50.34 Hz	49.83 Hz
Fula GT	50.32 Hz	49.82 Hz
Port Sudan	50.25 Hz	49.85 Hz
High Dam	50.12 Hz	49.91 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2

2.3.7 Short-circuit on the 500 kV interconnection Ethiopia - Sudan at Rabak

In case of short circuit on one of the three 500 kV interconnection circuits at Rabak (cleared in 120 ms by the tripping of the faulted circuit Rabak - Mandaya), the interconnected system remains stable.

The flow on the remaining 2 circuits Mandaya - Rabak increased from 556 to 807 MW, reaching transiently 921 MW.
The flow on each of the 220 kV circuits Gonder - Gedaref increased from 167 to 194 MW, reaching transiently 222 MW.
The damping coefficient of the power oscillations on the interconnection is 10.2 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Nag Hammadi	514 kV	519 kV	514 kV
Merowe	523 kV	538 kV	522 kV
Markhiat	512.5 kV	531.5 kV	508kV
Rabak	507 kV	511 kV	492 kV
Mandaya 500	509 kV	520 kV	503.5 kV
Mandaya 400	408 kV	420 kV	403 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Kost	50.29 Hz	49.82 Hz
Garri GT	50.28 Hz	49.86 Hz
Gedaref	50.25 Hz	49.85 Hz
Fula ST	50.22 Hz	49.82 Hz
Senar	50.2 Hz	49.87 Hz
Roseires	50.19 Hz	49.86 Hz
Mandaya	50.58 Hz	49.76 Hz
Tekeze	50.42 Hz	49.76 Hz
Gibe III	50.36 Hz	49.8 Hz
Merowe	50.13 Hz	49.9 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2

2.3.8 Short-circuit at Rabak on the 500 kV line Rabak - Markhiat

In case of short circuit on500 kV line Rabak - Markhiat (cleared in 120 ms by the tripping of the faulted circuit), the interconnected system remained stable.

The flow on the interconnection is not significantly affected: the flow on each of the two 220 kV interconnection circuits increased by 6 MW, and the flow on each of the three 500 kV interconnection circuits decreased by 4 MW.
The initial flow from Rabak to Markhiat reached 298 MW.
The flow on the circuit Rabak - Meringan increased from 713 to 928 MW, reaching transiently 1190 MW.
The flow through the 500/220 kV transformers in Rabak increased from 118 to 152 MW, reaching transiently 172 MW.
The damping coefficient of the power oscillations on the interconnection is 11.3 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Nag Hammadi	514 kV	518 kV	514 kV
Merowe	523 kV	540 kV	522 kV
Rabak	507 kV	515 kV	500 kV
Markhiat	507 kV	525 kV	510 kV
Mandaya	509 kV	531 kV	507 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Mandaya	50.57 Hz	49.75 Hz
Gibe III	50.3 Hz	49.82 Hz
Fula ST	50.3 Hz	49.77 Hz
Kosti	50.3 Hz	49.83 Hz
Merowe	50.14 Hz	49.83 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2

2.3.9 Short-circuit at Rabak on the 500 kV line Rabak - Meringan

In case of short circuit on line Rabak - Meringan (cleared in 120 ms by the tripping of the faulted circuit), the interconnected system remained stable.

The flow on the interconnection Sudan - Egypt is not affected. The volume of the flow on the interconnection between Ethiopia and Sudan is not affected.
The flow on each of the three 500 kV interconnection circuits between Ethiopia and Sudan is reduced by 17 MW, whereas the flow on each of the two 220 kV interconnection circuits

increased by 24 MW, reaching 192 MW.
The initial flow from Rabak to Meringan reached 713 MW.
The flow on the 500 kV circuit Rabak - Markhiat increased from 298 to 694 MW, reaching transiently 902 MW.
The flow through the 500/220 kV transformers (300 MVA each) in Rabak increased from 118 to 242 MW, reaching transiently 271 MW.
The damping coefficient of the power oscillations on the interconnection is 11.1 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Nag Hammadi	514 kV	518 kV	513 kV
Merowe	523 kV	539 kV	521 kV
Rabak	507 kV	514 kV	498 kV
Meringan	507 kV	517 kV	504 kV
Mandaya	509 kV	524 kV	507 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Mandaya	50.57 Hz	49.72 Hz
Gibe III	50.33 Hz	49.82 Hz
Fula ST	50.35 Hz	49.73 Hz
Kosti	50.33 Hz	49.81 Hz
Merowe	50.13 Hz	49.86 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2

2.3.10 Short-circuit on the 500 kV interconnection Ethiopia - Sudan at Mandaya

In case of short circuit on one of the three 500 kV interconnection circuits at Mandaya (cleared in 120 ms by the tripping of the faulted circuit Rabak - Mandaya), the interconnected system remains stable.

The flow on each of the remaining two 500 kV circuits Mandaya - Rabak increased from 556 to 807 MW, reaching transiently 992 MW.
The flow on each of the two 220 kV circuits Gonder - Gedaref increased from 167 to

194 MW, reaching transiently 246 MW.
The damping coefficient of the power oscillations on the interconnection is 9.5 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Nag Hammadi	514 kV	519 kV	514 kV
Merowe	523 kV	545 kV	522 kV
Markhiat	512.5 kV	531.5 kV	508kV
Rabak	507 kV	521 kV	493 kV
Mandaya 500	509 kV	560 kV	498 kV
Mandaya 400	408 kV	453 kV	403 kV
Debre Markos	411 kV	431 kV	407 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Mandaya	50.69 Hz	49.61 Hz
Tekeze	50.51 Hz	49.55 Hz
Gibe III	50.45 Hz	49.64 Hz
Fula ST	50.3 Hz	49.75 Hz
Kosti	50.22 Hz	49.75 Hz
Roseires	50.27 Hz	49.73 Hz
Merowe	50.13 Hz	49.9 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2

2.3.11 Tripping of one of the three 400/500 kV transformers in Mandaya following a short-circuit

In case of short circuit on one of the three 400/500 kV transformers at Mandaya (cleared in 120 ms by the tripping of the faulted transformer), the interconnected system remained stable.

The flow on the remaining two transformers increased from 557 to 831 MW, reaching transiently 1061 MW.
The flow on each of the three 500 kV circuits Mandaya - Rabak decreased from 556 to 553 MW.

The flow on each of the two 220 kV circuits Gonder - Gedaref increased from 167 to 172 MW. The damping coefficient of the power oscillations on the interconnection is 11.6 %.

The frequency variations are similar to those in case of short-circuit in Mandaya on one of the 3 circuits Mandaya - Rabak.

The transient over-voltages are similar those in case of short-circuit in Mandaya on one of the 3 circuits Mandaya - Rabak. It reached 12 % in Mandaya 400 and 500 kV.

The 2 remaining 660 MVA 400/500 kV transformers are 26 % overloaded. Two solutions are possible :

1. to increase the rated power of these transformers from 220 to 270 MVA (single phase), enabling the N-1 criteria without overload

2. to trip 2 units in Mandaya, reducing the flow through the transformers, and the power exchange exported from Ethiopia

<u>Tripping of 2 units in Mandaya</u>

The tripping of one of the three 400/500 kV transformers at Mandaya entailed the tripping of 2 units of Mandaya.

The flow on the remaining two transformers increased from 557 to 659 MW, reaching transiently 973 MW.

The volume of export from Ethiopia reduced from 2002 to 1624 MW:

The flow on each of the three 500 kV circuits Mandaya - Rabak decreased from 556 to 439 MW.
The flow on each of the two 220 kV circuits Gonder - Gedaref decreased from 167 to 154 MW.

The flow on the interconnection Merowe - Nag Hammadi is reduced from 690 MW to 424 MW.

The export from Egypt to Libya is reduced from 200 to 171 MW.

The export from Egypt to Jordan and Syria is reduced from 200 to 125 MW.

The frequency dipped to 49.94 Hz, before recovering at 49.96 Hz.

The figures are presented in Appendix 2 M6 Vol3.4 §2

2.3.12 Short-circuit at Mandaya on one of the two 400 kV circuits Mandaya - Debre Markos

In case of short circuit on one of the two 400 kV circuits at Mandaya (cleared in 100 ms by the tripping of the faulted circuit Mandaya - Debre Markos), the interconnected system remained stable.

The flow on the interconnection is not affected.
The flow on the remaining 400 kV circuit Mandaya - Debre Markos increased from 11 to 20 MW, reaching transiently 444 MW.
The damping coefficient of the power oscillations on the interconnection is 11.6 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Nag Hammadi	514 kV	516 kV	514 kV
Merowe	523 kV	543 kV	523 kV
Rabak	507 kV	559 kV	507 kV
Mandaya 500	509 kV	577 kV	508.5 kV
Mandaya 400	408 kV	459 kV	407 kV
Debre Markos	411 kV	430 kV	411 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Mandaya	50.61 Hz	49.4 Hz
Tekeze	50.31 Hz	49.63 Hz
Gibe III	50.2 Hz	49.8 Hz
Fula ST	50.35 Hz	49.7 Hz
Kosti	50.25 Hz	49.75 Hz
Merowe	50.16 Hz	49.83 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.13 Short-circuit on the 220 kV interconnection Ethiopia - Sudan at Gedaref

In case of short circuit on one of the two 220 kV interconnection circuits Gedaref - Shehedi (cleared in 120 ms by the tripping of the faulted circuit), the interconnected system remained stable.

The flow on the interconnection Sudan - Egypt is not affected. The volume of the flow on the interconnection between Ethiopia and Sudan is not affected.
The flow on the remaining circuit Gedaref - Shehedi increased from 154 to 260 MW (416 to 734 A - rating 972 A), reaching transiently 274 MW.
The flow on each of the 3 circuits Mandaya - Rabak increased from 556 to 573 MW, reaching transiently 596 MW.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Gedaref	221 kV	223 kV	220 kV
Gonder	229 kV	232 kV	229 kV

The voltage is not affected by the short-circuit and the tripping of the line Gedaref - Gonder

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Gedaref	50.8 Hz	49.1 Hz
Tish Abay	50.24 Hz	49.83 Hz
Beles	50.21 Hz	49.83 Hz
Roseires	50.1 Hz	49.9 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.14 Short-circuit on the 220 kV interconnection Ethiopia - Sudan at Gonder

In case of short circuit on one of the 2 circuits Gonder - Shehedi (cleared in 100 ms by the tripping of the faulted circuit), the interconnected system remained stable.

The flow on the interconnection Sudan - Egypt is not affected. The volume of the flow on the interconnection between Ethiopia and Sudan is not affected.
The flow on the remaining circuit Gedaref - Shehedi increased from 168 to 300 MW (430 to 767 A - normal rating 690 A, emergency rating : 828 A), reaching transiently 328 MW.
The flow on each of the 3 circuits Mandaya - Rabak increased from 556 to 570 MW, reaching

transiently 604 MW.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Gedaref	221 kV	223 kV	219 kV
Gonder	229 kV	232 kV	227 kV

The voltage is not affected by the short-circuit and the tripping of the line Gedaref - Gonder

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Beles	50.28 Hz	49.76 Hz
Tish Abay 2	50.26 Hz	49.76 Hz
Gedaref	50.05 Hz	49.9 Hz
Roseires	50.06 Hz	49.93 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.15 Tripping of the main unit in Egypt

In case of the tripping of the main unit in Egypt (650 MW Steam unit in Sidi Krir, generating 614 MW), the interconnected system remained stable.

The volume of export from Ethiopia increased from 2002 to 2072 MW:
- the flow on each of the three 500 kV circuits Mandaya - Rabak increased from 557 to 578 MW
- the flow on each of the two 220 kV circuits Gonder - Gedaref decreased from 167 to 172 MW

The flow on the interconnection Merowe - Nag Hammadi increased from 690 MW to 906 MW.

The export from Egypt to Libya decreased from 200 to 153 MW.

The export from Egypt to Jordan and Syria decreased from 200 to 87 MW.

The frequency dripped to 49.89 Hz, before recovering to 49.94 Hz.

The voltage profile is not significantly affected.

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.16 Tripping of the main unit in Sudan

In case of the tripping of the main unit in Sudan (400 MW Steam unit in Port Sudan, generating 367 MW), the interconnected system remained stable.

The volume of export from Ethiopia increased from 2002 to 2072 MW:
- the flow on each of the three 500 kV circuits Mandaya - Rabak increased from 557 to 578 MW h
- the flow on each of the two 220 kV circuits Gonder - Gedaref decreased from 167 to 172 MW

The flow on the interconnection Merowe - Nag Hammadi decreased from 690 MW to 906 MW.

The export from Egypt to Libya decreased from 200 to 153 MW.

The export from Egypt to Jordan and Syria decreased from 200 to 87 MW.

The frequency dipped to 49.89 Hz, before recovering to 49.94 Hz.

The voltage profine is not significantly affected.

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.17 Tripping of the main 2 units in Ethiopia

In case of the tripping of the main 2 units in Ethiopia (two 250 MW units in Mandaya, generating 425 MW), the interconnected system remained stable.

The volume of export from Ethiopia is decreased from 2002 to 1620 MW:
- the flow on each of the 500 kV Mandaya - Rabak decreased from 557 to 440 MW
- the flow on each of the two 220 kV interconnection Gonder - Gedaref decreased from 167 to 150 MW

The flow on the interconnection Merowe - Nag Hammadi decreased from 690 MW to 414 MW.

The export from Egypt to Libya decreased from 200 to 172 MW.

The export from Egypt to Jordan and Syria decreased from 200 to 128 MW.

The frequency dipped to 49.93 Hz, before recovering to 49.96 Hz.

The figures are presented in Appendix 2 M6 Vol3.4 §2.

2.3.18 Conclusion

Several faults were simulated on each of the interconnections (500 kV Egypt - Sudan, and 500 and 200 kV Ethiopia - Sudan), and on the neighbouring circuits, normally cleared by the opening of the faulted circuit. The behaviour of the system was satisfactory : the oscillations were well damped (damping coefficient from 5.4 to 11.6 % - a damping over 5 % being considered as well damped by international standards), no loss of synchronism occurred. The voltage profile was not significantly affected.

2.4 COST OF THIS AC ALTERNATIVE 1

2.4.1 Investment cost

ALTERNATIVE AC Rabak	Size	Length (km) Quantity	Investment cost (k$/km)			Total cost (k$)		
			i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
500 kV AC double circuit line	4 x 280 mm²	570	438	456	420	249 592	259 738	239 446
500 kV AC single circuit line	4 x 280 mm²	570	261	271	250	148 633	154 675	142 591
Reactor (MVAr)	230	6	75	77	73	103 155	105 846	100 464
Mandaya Substation								
500 kV line bay DBB		3	2 530	2 596	2 464	7 590	7 788	7 392
500/400 kV transformer	220 MVA	10	4 387	4 502	4 273	30 710	31 511	29 908
500 kV transformer bay DBB		3	2 231	2 289	2 173	4 462	4 578	4 346
400 kV transformer bay DBB		3	1 323	1 357	1 288	2 645	2 714	2 576
Rabak substation								
500 kV line bay DBB		3	2 530	2 596	2 464	7 590	7 788	7392
Total substation equipement								
Total line						**554 376**	**574 638**	**534 115**

Table 2-3 - Investment cost of alternative 1 between Ethiopia and Sudan

ALTERNATIVE AC Merowe – Nag Hamadi	Size	Length (km) Quantity	Investment cost (k$/km)			Total cost (k$)		
			i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Merowe - Intermediate								
500 kV AC double circuit line	4 x 280 mm²	560	438	456	420	245 213	255 181	235 245
Reactor (MVAr)	230	4	75	77	73	68 784	70 579	66 990
Merowe Substation								
500 kV line bay DBB		2	2 530	2 596	2464	5 060	5 192	4 928
Intermediate substation								
installation		1	2 300	2 360	2 240	2 300	2 360	2 240
500 kV line bays		4	2 530	2 596	2464	10 120	10 384	9 856
Reactor (MVAr)	230	1	75	77	73	17 193	17 641	16 744
Reactor Bay		1	1 127	1 156	1 098	1 127	1 156	1 098
Nag Hamadi substation								
500 kV line bay (one and half)		2	3 335	3 422	3248	6 670	6 844	6 496
Section Intermediate - Nag Hamadi								
500 kV AC double circuit line	3 x 500 mm²	560	438	456	420	245 213	255 181	235 245
Reactor (MVAr)	215	4	75	77	73	64 297	65 974	62 620
Total substation equipment								
Total line						**665 976**	**690 492**	**641 461**

Table 2-4 - Investment cost of alternative 1 between Sudan and Egypt

2.4.2 Transmission cost

Mandaya - Rabak	O & M cost (k$)	Investment Cost (k$)	Annuity cost (k$)	Cost of losses (k$)	Total Annuity Cost (k$)	Transmission cost ($/MWh)	Add trans. Cost Ethiopia-Sudan	Total Trans cost
I=10%	6 244	554 376	55 914	28 557	90 715	6.2	1.1	7.3
i=12%	6 244	574 638	69 196	28 557	103 997	7.1	1.1	8.2
i=8%	6 244	534 115	43 660	28 557	78 461	5.3	1.1	6.5

Table 2-5 - Transmission cost between Ethiopia and Sudan

Merowe - Nag Hammadi	O & M cost (k$)	Investment Cost (k$)	Annuity cost (k$)	Cost of losses (k$)	Total Annuity Cost (k$)	Transmission cost ($/MWh)
I=10%	7 040	665 976	67 170	11 889	86 099	16.0
i=12%	7 040	690 492	83 147	11 889	102 076	19.0
i=8%	7 040	641 461	52 435	11 889	71 364	13.3

Table 2-6 - Transmission cost between Sudan and Egypt (Nag Hammadi)

Total Transmission Cost ($/MWh)	i=10%	i=12%	i=8%
Connection point Nag Hammadi	22.2	26.0	18.6

Table 2-7 - Transmission cost between Ethiopia and Egypt (Nag Hammadi)

3 STUDY OF ALTERNATIVE 2

3.1 DESCRIPTION

The interconnection between Ethiopia, Sudan and Egypt includes:

- A 500/400 kV substation located on Mandaya HPP site, equipped with two 500/400 kV 510 MVA transformers. This transformation is composed by six 170 MVA single-phase units + one 170 MVA single-phase unit as a spare part.
- A 500 kV AC double circuit line between Mandaya HPP and Rabak 500 kV substation. The length of the line is 570 km. The two circuits are equipped at each end by one 230 MVAr reactor to energize the line in good condition and to control the voltage profile in operation.
- One 750 MW AC/DC converter station at Mandaya
- One 700 MW DC/AC converter station at Nag Hamadi
- One single pole DC line between Mandaya and Nag Hamadi.

There is no DC/AC taping station in Sudan.

The length of the DC line is equal to 2200 km. Two voltage levels were examined: 600 kV and 800 kV.

For the 600 kV, the DC line is equipped with bundle Canary conductors (total cross section: 6 x 456 mm²).

For the 800 kV, the DC line is equipped with 8 bundle Hawk conductors (total cross section: 8 x 241 mm²)

3.2 ANALYSIS OF THE BEHAVIOUR OF THE INTERCONNECTED SYSTEM

3.2.1 In normal condition

Ethiopia was interconnected to Sudan with one AC 500 kV double circuit line and one 220 kV double circuit line. The two systems operated in synchronism.

Ethiopia was interconnected directly to Egypt with a DC link.

As in alternative 1, the power imported by the interconnection with Ethiopia had positive effect on the behaviour of the Sudanese system: the power exchange discharged the 220 kV Sudanese system close to the interconnection point.

3.2.2 In N-1 situation

Following the tripping of one of the two 500 kV circuits between Mandaya and Rabak, the behaviour of the system was satisfactory. No overload occurred on the remaining circuit and on the 220 kV line Gonder - Gedaref operating in parallel (see Report M6 Vol3.4.1: total flow on the AC interconnection about 1400 MW)

Following the tripping of the DC link between Mandaya and Nag Hammadi, the two systems, Egypt and Ethiopia, operated separately. In the Egyptian system, the loss of the power exchange would be compensated by the delivery of the primary reserve without any adverse effect on the Egyptian system.

3.3 TRANSIENT ANALYSIS OF THE BEHAVIOUR OF THE INTERCONNECTED SYSTEM

3.3.1 Short-circuit on the 500 kV interconnection Ethiopia - Sudan at Mandaya

In case of short circuit on one of the two 500 kV interconnection circuits at Mandaya (cleared in 120 ms by the tripping of the faulted circuit Rabak - Mandaya), the interconnected system remains stable.

The flow on the remaining 500 kV circuit Mandaya - Rabak increased from 475 to 869 MW, reaching transiently 1148 MW.
The flow on each of the two 220 kV circuits Gonder - Gedaref increased from 149 to 190 MW (current increased from 379 to 488 A, rating 690 A), reaching transiently 237 MW.

The damping coefficient of the power oscillations on the interconnection is 12.2 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Merowe	512 kV	527 kV	511 kV
Rabak	512 kV	522 kV	501 kV
Mandaya 500	511 kV	540 kV	500 kV
Mandaya 400	407 kV	435 kV	404 kV
Debre Markos	412 kV	423 kV	409 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Mandaya	50.62 Hz	49.65 Hz
Tekeze	50.45 Hz	49.63 Hz
Gibe III	50.37 Hz	49.83 Hz
Fula ST	50.25 Hz	49.88 Hz
Kost	50.16 Hz	49.95 Hz
Merowe	50.17 Hz	49.94 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §3.

3.3.2 Short-circuit on the 500 kV interconnection Ethiopia - Sudan at Rabak

In case of short circuit on one of the two 500 kV interconnection circuits at Rabak (cleared in 120 ms by the tripping of the faulted circuit Rabak - Mandaya), the interconnected system remains stable.

The flow on the remaining 500 kV circuit Mandaya - Rabak increased from 475 to 867 MW, reaching transiently 1002 MW.
The flow on each of the two 220 kV circuits Gonder - Gedaref increased from 149 to

188 MW, reaching transiently 206 MW.
The damping coefficient of the power oscillations on the interconnection is 10.0 %.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Merowe	513 kV	522 kV	511 kV
Markhiat	507 kV	511 kV	503 kV
Rabak	512 kV	512 kV	501 kV
Mandaya 500	511 kV	512 kV	500 kV
Mandaya 400	408 kV	412 kV	404 kV

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Kost	50.31 Hz	49.96 Hz
Garri GT	50.31 Hz	49.94 Hz
Fula ST	50.26 Hz	49.932 Hz
Mandaya	50.38 Hz	49.95 Hz
Tekeze	50.35 Hz	49.92 Hz
Gibe III	50.3 Hz	49.95 Hz
Merowe	50.25 Hz	49.93 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §3.

3.3.3 Tripping of one of the two 400/500 kV transformers in Mandaya following a short-circuit

In case of short circuit on one of the two 400/500 kV transformers at Mandaya (cleared in 120 ms by the tripping of the faulted transformer), the interconnected system remained stable.

The flow on the remaining transformer increased from 475 to 932 MW, reaching transiently 1420 MW.
The flow on each of the two 500 kV circuits Mandaya - Rabak decreased from 475 to 466 MW.
The flow on each of the two 220 kV circuits Gonder - Gedaref increased from 149 to

156 MW.
The damping coefficient of the power oscillations on the interconnection is 10.7 %.

The frequency variations are similar to those in case of short-circuit in Mandaya on one of the 2 circuits Mandaya - Rabak.

Transient over-voltages are slightly higher than those in case of short-circuit in Mandaya on one of the two 500 kV circuits Mandaya - Rabak. It reached 11 % in Mandaya 500 and 9 % in Mandaya 400 kV and Rabak.

The remaining 510 MVA 400/500 kV transformer is 83 % overloaded. Two solutions are possible :

1. to add a third 510 MVA transformer, enabling the N-1 situation without overload. This solution is more optimal than increasing the rated power of these transformers from 170 to 310 MVA (single phase), enabling the N-1 criteria without overload.

2. to trip some units in Mandaya, reducing the flow through the remaining transformer, and the power exchange exported. The size of the transformer will define the number of units to trip. But the number of unit to trip is limited, not to trigger the load shedding scheme.

Tripping of 2 units in Mandaya

The tripping of one 400/500 kV transformer at Mandaya triggered the tripping of 2 units at Mandaya.
The flow on the remaining transformer increased from 475 to 755 MW, reaching transiently 1229 MW. The 510 MVA transformer remained 48 % overloaded. The tripping of a third unit at Mandaya (3 x 212.5 MW = 638 MW) would jeopardize the Ethiopian and Sudanese system, leading to the load shedding scheme activation. It is therefore recommended to add a third transformer.

The volume of export from Ethiopia to Sudan reduced from 1248 to 1050 MW:

The flow on each of the 500 kV Mandaya - Rabak decreased from 475 to 377 MW.
The flow on the 220 kV interconnection Gonder - Gedaref decreased from 149 to 148 MW.

The frequency dropped to 49.55 Hz, before recovering to 49.87 Hz.

The figures are presented in Appendix 2 M6 Vol3.4 §3.

3.3.4 Short-circuit on the 220 kV interconnection Ethiopia - Sudan at Gonder

In case of short circuit on one of the two 220 kV circuits Gonder - Shehedi (cleared in 120 ms by the tripping of the faulted circuit), the interconnected system remained stable.

The volume of the flow on the interconnection between Ethiopia and Sudan is not affected.

The flow on the remaining 220 kV circuit Gedaref - Shehedi increased from 149 to 268 MW (379 to 673 A - normal rating 690 A, emergency rating : 828 A), reaching transiently 300 MW.
The flow on each of the two 500 kV circuits Mandaya - Rabak increased from 475 to 490 MW, reaching transiently 537 MW.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Gedaref	226 kV	230 kV	225 kV
Gonder	234 kV	239 kV	233 kV

The voltage is not affected by the short-circuit and the tripping of the line Gedaref - Gonder

Generator frequency variation

Generator	Maximal frequency	Minimal frequency
Beles	50.3 Hz	49.7 Hz
Tish Abay 2	50.3 Hz	49.7 Hz
Gedaref	50.06 Hz	49.9 Hz

The figures are presented in Appendix 2 M6 Vol3.4 §3.

3.3.5 Tripping of the DC interconnection

The tripping of the interconnection can be the tripping of any of its element : line or convector station. The tripping of the DC line is followed by the tripping of the compensation associated with the converter station at Mandaya 400 kV and at Nag Hammadi 500 kV. This tripping is simulated 1 second after the tripping of the interconnection, to simulate the attempt of automation to restore the operating of the faulted element.

After the tripping of the converter station in Nag Hammadi, the system recovered correctly.

Egypt side

The 280 Mvar capacitor banks (2/3 compensation for the reactive consumption of the converter station -) associated to the convector station are disconnected 1 s after the tripping of the line or blocking of one pole.

The export from Egypt to Libya decreased from 200 to 113 MW. The 50 MW primary reserve are delivered, the remaining difference is due to the frequency dependency of the load.

The export from Egypt to Jordan (and Syria) decreased from 200 to 23 MW. The 100 MW primary reserve are delivered, the remaining difference is due to the frequency dependency of the load.

The frequency dipped to 49.79 Hz, before recovering to 49.82 Hz.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Nag Hammadi	503 kV	518 kV	503 kV

The voltage profile is not significantly affected.

Ethiopian and Sudan side

The 300 Mvar capacitor banks (2/3 compensation for the reactive consumption of the converter station -) associated to the convector station are disconnected 1 s after the tripping of the line or blocking of one pole. 2 units of Mandaya (2 x 212.5 MW) were also tripped 1 s after the incident on the DC interconnection.

The volume of export from Ethiopia decreased from 1248 to 1470 MW:
- the flow on each of the two 500 kV Mandaya - Rabak increased from 475 to 575 MW
- the flow on each of the two 220 kV interconnection Gonder - Gedaref decreased from 149 to 160 MW

The frequency raised to 50.34 Hz, before recovering to 50.08 Hz.

Voltage variation

Node	Initial voltage	Maximal voltage	Final voltage
Mandaya 500	510 kV	539 kV	510 kV
Mandaya 400	407 kV	435 kV	409 kV
Rabak	508 kV	515 kV	505 kV

Without the tripping of two units of Mandaya :

1. the frequency raised up to 50.5 Hz, before stabilising at 50.17 Hz

2. the exchange from Ethiopia to Sudan increased from 1248 to 1734 MW, wit a peak at 1942 MW :
   - the flow on each of the two 500 kV circuits increased from 475 to 691 MW, with a peak at 775 MW
   - the flow on each of the two 220 kV circuits increased from 149 to 176 MW, with a peak at 196 MW

This peak exchange is due to the slow dynamic of hydropower plant (Ethiopia) compared to the one of thermal plant (majority of Sudan generation plan).

The figures are presented in Appendix 2 M6 Vol3.4 §3.

3.3.6 Tripping of the main unit in Sudan

In case of the tripping of the main unit in Sudan (400 MW Steam unit in Port Sudan, generating 367 MW), the interconnected system remained stable.

The volume of export from Ethiopia increased from 1248 to 1468 MW:
- the flow on each of the two 500 kV circuits Mandaya - Rabak increased from 475 to 568 MW
- the flow on each of the two 220 kV circuits Gonder - Gedaref decreased from 149 to 166 MW

The frequency dropped to 49.63 Hz, before recovering to 49.9 Hz.

The voltage profile is not significantly affected.

The figures are presented in Appendix 2 M6 Vol3.4 §3.

3.3.7 Tripping of the main unit in Ethiopia

In case of the tripping of the main 2 units in Ethiopia (two 250 MW units in Mandaya, generating 425 MW), the interconnected system remained stable.

The volume of export from Ethiopia decreased from 1248 to 1048 MW:
- the flow on each of the two 500 kV circuits Mandaya - Rabak decreased from 475 to 382 MW
- the flow on each of the two 220 kV circuits Gonder - Gedaref decreased from 149 to 142 MW

The frequency dropped to 49.55 Hz, before recovering to 49.87 Hz.

The voltage profile is not significantly affected.

The figures are presented in Appendix 2 M6 Vol3.4 §3.

3.3.8 Conclusion

Several faults were simulated on each of the interconnections (DC interconnection Ethiopia - Egypt, and 500 and 200 kV interconnections Ethiopia - Sudan), and on the neighbouring circuits, normally cleared by the opening of the faulted circuit. The behaviour of the system was satisfactory : the oscillations were very well damped (damping coefficient over 10 % - a damping over 5 % being considered as well damped by international standards), no loss of synchronism occurred. The voltage profile was not significantly affected.

A third 510 MVA transformer is requested at Mandaya for N-1 situation.

3.4 COST OF THE ALTERNATIVE 2

3.4.1 Investment cost

3.4.1.1 AC section between Mandaya and Rabak

AC line between Mandaya and Rabak	Size	length (km) Quantity	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%
500 kV AC double circuit line	4 x 280 mm²	570	356	202 920	438	456	420	249 592	259 738	239 446
Reactor (MVAr)	234	4	65	60 881	75	77	73	70 013	71 839	68 186
Mandaya Substation										
500 kV line bay DBB		2	2 200	4 400	2 530	2 596	2 464	5 060	5 192	4 928
500/400 kV transformer	170 MVA	10	3 204	32042	3685	3781	3589	36848	37809	35887
500 kV transformer bay DBB		2	1 940	3 880	2 231	2 289	2 173	4 462	4 578	4 346
400 kV transformer bay DBB		2	1 150	2 300	1 323	1 357	1 288	2 645	2 714	2 576
Rabak substation										
500 kV line bay DBB		2	2 200	4 400	2 530	2 596	2 464	5 060	5 192	4 928
Total transformer				38 222						
Total substation equipment				69 681				**124 088**	**127 325**	**120 851**
Total line				202 920				**249 592**	**259 738**	**239 446**
TOTAL				**310 822**				**373 679**	**387 062**	**360 296**

Table 3-1 - Investment cost of section AC in Alternative 2

3.4.1.2 DC section between Mandaya and Nag Hamadi

DC link +/- 600 kV	Size	Length (km) Quantity	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 Mandaya - Nag Hamadi monopole		2200	256	563200	320	335	307	704 000	737 792	675 840
AC/DC converter station Mandaya mono	754	1	143	107653	184	194	176	138 872	146 408	132 413
AC/DC converter station Nag Hamadi mono	706	1	143	100817	184	194	176	130 054	137 111	124 005
sub total substation				**208 470**				**268 926**	**283 519**	**256 418**
sub total line				**563 200**				**704000**	**737 792**	**675 840**
total				**771 670**				**972 926**	**1 021 311**	**932 258**

Table 3-2 - Investment cost of section +/- 600 kV DC link in Alternative 2

DC LINK +/- 800 KV	Size	Length (km) Quantity	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 Mandaya - Nag Hamadi monopole		2 200	233	513 395	292	306	280	641 744	672 547	616 074
AC/DC converter station Mandaya mono	754	1	159	119 956	205	216	196	154 744	163 140	147 546
AC/DC converter station Nag Hamadi mono	706	1	159	112 339	205	216	196	144 917	152 781	138 177
sub total substation				**232 295**				**299 660**	**315 921**	**285 723**
sub total line				**513 395**				**641 744**	**672 547**	**616 074**
total				**745 690**				**941 404**	**988 468**	**901 797**

Table 3-3 - Investment cost of section +/- 800 kV DC link in Alternative 2

3.4.2 Transmission cost

3.4.2.1 Between Ethiopia and Sudan

AC 500 kV double circuit line	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Transmission Cost ($/MWh)**		
	i=10%	i=12%	i=8%		Joule losses	Permanent losses	i=10%	i=12%	i=8%
Mandaya - Rabak	25174	31277	19573	2029	17544	599	5.9	6.8	5.1
substations Mandaya+Rabak	12515	15332	9879	2158	985				

Table 3-4 - AC Transmission cost between Ethiopia and Sudan in Alternative 2

3.4.2.2 Between Ethiopia and Egypt

+/- 600 KV DC	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Transmission Cost ($/MWh)**		
	i=10%	i=12%	i=8%		Joule losses	Permanent losses	i=10%	i=12%	i=8%
Mandaya - Nag Hamadi	71 005	88 842	55 245	5 632	10 569	1 272	**23.3**	**27.8**	**19.3**
AC/DC converter station	29 627	36 149	24 021	2 919	2 733	1 535			

Table 3-5 - +/- 600 kV DC Transmission cost between Ethiopia and Egypt in Alternative 2

+/- 800 KV DC	Annuity Cost (k$)			M &O Cost (k$)	Cost of Losses (k$)		**Transmission Cost ($/MWh)**		
	i=10%	i=12%	i=8%		Joule losses	Permanent losses	i=10%	i=12%	i=8%
Mandaya - Nag Hamadi	64 726	80 986	50 360	5 134	8 415	7 323	**23.4**	**27.8**	**19.6**
AC/DC converter station	33 013	40 280	26 766	3 252	2 733	1 535			

Table 3-6 - +/- 800 kV DC Transmission cost between Ethiopia and Egypt in Alternative 2

4 CONCLUSION

To export 1200 MW from Ethiopia to Sudan and 690 MW from Ethiopia to Egypt, two alternatives of interconnection have been examined:

- Alternative 1: AC solution with three 500 kV circuits between Ethiopia and Sudan and a 500 kV double circuit between Sudan and Egypt.

- Alternative 2: AC+DC solution with one AC 500 kV double circuit line between Ethiopia and Sudan and one DC (600 or 800 kV) single pole line between Ethiopia and Egypt.

The investment cost of the two Alternatives are displayed in the following tables:

Alternative 1 AC	Total cost (k$)		
	i=10%	i=12%	i=8%
Total Mandaya - Rabak	554 376	574 638	534 115
Total Merowe – Nag Hamadi	665 976	690 492	641 461
Total	1 220 352	1 265 130	1 175 576

Table 4-1 - Investment cost of Alternative 1

Alternative 2 Mixte AC+DC	Total cost (k$)		
	i=10%	i=12%	i=8%
Total Mandaya - Rabak	373 679	387 062	360 296
Total DC link +/- 600 kV	972 926	1 021 311	932 258
Total DC link +/- 800 kV	941 404	988 468	901 797
Total AC + DC 600	1 346 605	1 408 373	1 292 554
Total AC + DC 800	1 315 083	1 375 530	1 262 093

Table 4-2 - Investment cost of Alternative 2

The AC alternative is less expensive than the AC+DC mix alternative by 8.7 %.

The transmission costs have been calculated assuming the followings:

- Duration of power exchange 7800 hours to Egypt, 8600 hours to Sudan
- Cost of losses: 40 $/MWh

The results are displayed on the following tables:

Transmission cost ($/MWh)		
I=10%	I=12%	I=8%
7.3	8.2	6.5

Table 4-3 - Transmission cost between Ethiopia and Sudan Alternative 1

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
22.2	26	18.6

Table 4-4 - Transmission cost between Ethiopia and Egypt (Nag Hammadi) Alternative 1

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
5.9	6.8	5.1

Table 4-5 - AC Transmission cost between Ethiopia and Sudan in Alternative 2

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
23.3	27.8	19.3

Table 4-6 - +/- 600 kV DC Transmission cost between Ethiopia and Egypt in Alternative 2

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
23.4	27.8	19.6

Table 4-7 - +/- 800 kV DC Transmission cost between Ethiopia and Egypt in Alternative 2

Between Ethiopia and Sudan, the transmission cost of the AC+DC mix alternative is less expensive than those of the AC alternative.

Between Ethiopia and Egypt, the transmission cost of the AC+DC mix alternative is slightly more expensive than the AC alternative.

5 RESULTS OF THE SIMULATIONS: ALTERNATIVE 1

5.1 IN NORMAL CONDITION

5.1.1 Transformers

Transformers	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Loading (%)	Taping (%)
MANDAY871	1980	-1669.04	85.72	1671.24	84.4	98.76
ATBARY862	300	91.44	33.86	97.51	32.5	100
ATBARY861	300	91.44	33.86	97.51	32.5	100
FULAY861	300	25.71	-21.19	33.31	11.1	100
FULAY862	300	25.71	-21.19	33.31	11.1	100
H.HEIY863	300	141.52	51.21	150.5	50.2	97.52
H.HEIY862	300	141.52	51.21	150.5	50.2	97.52
H.HEIY861	300	141.52	51.21	150.5	50.2	97.52
H.HEIY864	300	141.52	51.21	150.5	50.2	97.52
KABASY862	300	16.23	1.59	16.31	5.4	102.48
KABASY861	300	16.23	1.59	16.31	5.4	102.48
MARKHY862	1200	608.66	248.76	657.53	54.8	96.28
MARKHY861	300	152.16	62.19	164.38	54.8	96.28
MERINY861	600	332.67	29.58	333.98	55.7	100
MEROWY862	300	-40.64	-64.84	76.52	25.5	105
MEROWY861	150	-20.32	-32.42	38.26	25.5	105
NYALAY863	300	231.87	-2.29	231.88	77.3	100
NYALAY862	150	115.94	-1.14	115.94	77.3	100
NYALAY861	150	115.94	-1.14	115.94	77.3	100
P.SUDY863	300	20.76	14.57	25.36	8.5	100
P.SUDY862	300	20.76	14.57	25.36	8.5	100
P.SUDY861	300	20.76	14.57	25.36	8.5	100
RABAKY862	300	114.13	-15.88	115.23	38.4	100
RABAKY861	300	114.13	-15.88	115.23	38.4	100

Table 5-1 - 500/220 kV transformers and the Mandaya transformation

5.1.2 Lines

Lines	From bus	To bus	Un (kV)	P (MW)	Q (MVAr)	S (MVA)	I (kA)	Active losses (MW)	Reactive losses (MVAr)]	Rating (kA)	Loading (%)
MANDA81RABAK	1MANDAS81	2RABAK81	500	555.75	-269.15	617.5	0.7	18.95	-425.83	2.13	32.8
MANDA82RABAK	1MANDAS81	2RABAK81	500	1111.51	-538.29	1234.99	1.39	37.89	-851.66	4.26	32.8
ATBAR82KABAS	2ATBARS81	2KABASS81	500	154.92	-172.17	231.6	0.26	0.73	-317.97	2.13	12.1
DAL81NAG	2DALS81	3NAG81	500	701.34	-579.75	909.94	1.01	10.9	-1032.04	4.26	23.6
FULA81RABAK	2FULA81	2RABAK81	500	-282.1	-253.25	379.1	0.43	5.13	-575.91	2.13	20

FULA82NYALA	2FULA81	2NYALA81	500	234.91	-185.1	299.07	0.34	2.38	-402.47	2.13	15.8
ATBAR81KABAS	2KABASS81	2ATBARS81	500	-154.19	-145.8	212.21	0.24	0.73	-317.97	2.13	11.1
H.HEI81KABAS	2KABASS81	2H.HEI81	500	70.94	-47.06	85.13	0.09	0.15	-196.64	2.13	4.4
H.HEI82KABAS	2KABASS81	2H.HEI81	500	70.94	-47.06	85.13	0.09	0.15	-196.64	2.13	4.4
MARKH81KABAS	2MARKHS81	2KABASS81	500	-115.06	-176.02	210.29	0.23	0.15	-40.54	2.13	11
HASA81MERIN	2MERIN81	2H.HEI81	500	416.88	-144.47	441.2	0.5	1.14	-50.55	2.13	23.4
ATBAR81MEROW	2MEROWS81	2ATBARS81	500	29.15	-83.48	88.42	0.1	0.04	-235.47	2.13	4.6
DAL81MEROW	2MEROWS81	2DALS81	500	719.32	-616.28	947.21	1.04	14.73	-1116.95	4.26	24.5
MARKH81MEROW	2MEROWS81	2MARKHS81	500	153.82	-174.9	232.92	0.26	0.91	-395.91	2.13	12
MARKH82MEROW	2MEROWS81	2MARKHS81	500	153.82	-174.9	232.92	0.26	0.91	-395.91	2.13	12
FULA81NYALA	2NYALA81	2FULA81	500	-232.53	-217.37	318.31	0.36	2.38	-402.47	2.13	17.1
ATBAR82P.SUD	2P.SUD81	2ATBARS81	500	237.57	-255.59	348.95	0.39	2.6	-477.64	2.13	18.1
ATBAR81P.SUD	2P.SUD81	2ATBARS81	500	237.57	-255.59	348.95	0.39	2.6	-477.64	2.13	18.1
MARKH81RABAK	2RABAK81	2MARKHS81	500	336.2	-254.1	421.42	0.48	5.01	-396.19	2.13	22.4
MERIN81RABAK	2RABAK81	2MERIN81	500	757.15	-121.95	766.91	0.87	9.84	-75.32	2.13	40.7
D.MAR71MANDA	1MANDAS71	1D.MARS71	400	11.52	-83.07	83.86	0.12	0.01	-170.62	1.01	11.6
D.MAR72MANDA	1MANDAS71	1D.MARS71	400	11.52	-83.07	83.86	0.12	0.01	-170.62	1.01	11.6
GONDE62SHEHE	1GONDES61	1SHEHES61	230	168.68	-34.99	172.27	0.43	7.02	-1.96	0.69	62.7
GONDE61SHEHE	1GONDES61	1SHEHES61	230	168.68	-34.99	172.27	0.43	7.02	-1.96	0.69	62.7
A.ZAB61FULA	2A.ZABS61	2FULAS61	220	-15.19	1.89	15.31	0.04	0.07	-24.88	0.97	4
A.ZAB62FULA	2A.ZABS61	2FULAS61	220	-15.19	1.89	15.31	0.04	0.07	-24.88	0.97	4
ALGHO61BARBA	2ALGHOS61	2BARBAS61	220	-74.5	-35	82.31	0.21	0.23	-4.03	0.97	22.1
ALGHO62BARBA	2ALGHOS61	2BARBAS61	220	-74.5	-35	82.31	0.21	0.23	-4.03	0.97	22.1
ATBAR62SHEND	2ATBAS61	2SHENDIS61	220	11.78	-21.07	24.14	0.06	0.03	-29.12	0.97	6.4
ATBAR61SHEND	2ATBAS61	2SHENDIS61	220	11.78	-21.07	24.14	0.06	0.03	-29.12	0.97	6.4
ATBAR61BARBA	2ATBAS61	2BARBAS61	220	58.17	37.06	68.97	0.18	0.24	-6.34	0.97	18.2
ATBAR62BARBA	2ATBAS61	2BARBAS61	220	58.17	37.06	68.97	0.18	0.24	-6.34	0.97	18.2
ATBAR61Z	2ATBAS61	Z	220	-51.37	-37.57	63.64	0.16	0.84	-44.81	0.97	16.8
ATBAR62Z	2ATBAS61	Z	220	-51.37	-37.57	63.64	0.16	0.84	-44.81	0.97	16.8
BAGER61GIAD	2BAGER61	2GIADS61	220	119.77	-27.32	122.84	0.32	0.5	-0.46	0.67	47.1
BAGER63GIAD	2BAGER61	2GIADS61	220	157.61	-41.47	162.97	0.42	0.78	-1.01	0.97	43.3
BARBA61SHERE	2BARBAS61	2SHERES61	220	-91.29	-22.58	94.04	0.24	0.97	-13.07	0.97	25.1
BARBA62SHERE	2BARBAS61	2SHERES61	220	-91.29	-22.58	94.04	0.24	0.97	-13.07	0.97	25.1
DEBBA61M.TOW	2DEBBAS61	2M.TOWS61	220	10.35	-3.52	10.93	0.03	0.05	-31.9	0.97	2.8
DEBBA62M.TOW	2DEBBAS61	2M.TOWS61	220	10.35	-3.52	10.93	0.03	0.05	-31.9	0.97	2.8
DEBBA61DONGO	2DEBBAS61	2DONGOS61	220	-15.35	1.02	15.38	0.04	0.15	-37.71	0.97	4
A.ZAB61DEBET	2DEBETS61	2A.ZABS61	220	2.31	-4.22	4.81	0.01	0	-14.1	0.97	1.2
A.ZAB62DEBET	2DEBETS61	2A.ZABS61	220	2.31	-4.22	4.81	0.01	0	-14.1	0.97	1.2
DEBBA62DONGO	2DONGOS61	2DEBBAS61	220	15.5	-38.73	41.71	0.11	0.15	-37.71	0.97	11
DONGO61KARMA	2DONGOS61	2KARMAS61	220	-108.5	-4.77	108.6	0.28	0.8	-7.36	0.97	28.5
E.DAE61NYALA	2E.DAE61	2NYALA61	220	61.55	-5.59	61.81	0.16	0.92	-33.29	0.97	16.1
E.DAE62NYALA	2E.DAE61	2NYALA61	220	61.55	-5.59	61.81	0.16	0.92	-33.29	0.97	16.1

EID.B62GARRI	2EID.BS61	2GARRIS61	220	-77.92	-23.58	81.41	0.21	0.52	-9.98	0.97	21.8
EID.B61GARRI	2EID.BS61	2GARRIS61	220	-77.92	-23.58	81.41	0.21	0.52	-9.98	0.97	21.8
F.ZON62GARRI	2F.ZON	2GARRIS61	220	-139.69	-25.14	141.93	0.36	0.13	-0.44	0.97	37.5
F.ZON62KABAS	2F.ZON	2KABASS61	220	83.4	25.03	87.08	0.22	0.27	-4.15	0.97	23
F.ZON61KABAS	2F.ZON	2KABASS61	220	83.4	25.03	87.08	0.22	0.27	-4.15	0.97	23
E.DAEI61FULA	2FULAS61	2E.DAE61	220	73.43	-39.71	83.48	0.21	1.85	-47.19	0.97	21.7
E.DAEI62FULA	2FULAS61	2E.DAE61	220	73.43	-39.71	83.48	0.21	1.85	-47.19	0.97	21.7
GAMOE61J.AUL	2GAMOES61	2J.AULS61	220	-8.4	36.68	37.63	0.1	0.09	-7.45	0.97	9.9
GAMOE62J.AUL	2GAMOES61	2J.AULS61	220	-8.4	36.68	37.63	0.1	0.09	-7.45	0.97	9.9
F.ZON61GARRI	2GARRIS61	2F.ZON	220	139.82	24.7	141.99	0.36	0.13	-0.44	0.97	37.4
ETHIO-SUDAN	2GEDARS61	1SHEHE61	220	-154.85	42.78	160.65	0.42	6.78	-5.4	0.97	43
GEDAR62GIRBA	2GEDARS61	2GIRBAS61	220	88.99	-30.38	94.04	0.24	1.56	-21.27	0.97	25.2
GEDAR61GIRBA	2GEDARS61	2GIRBAS61	220	88.99	-30.38	94.04	0.24	1.56	-21.27	0.97	25.2
SUD-ETHI2	2GEDARS61	1SHEHE61	220	-154.85	42.78	160.65	0.42	6.78	-5.4	0.97	43
GETEI61MASHK	2GETEIS61	2MASHKS61	220	-65.49	29.47	71.81	0.19	0.45	-10.08	0.97	19.2
GETEIS62MASH	2GETEIS61	2MASHKS61	220	-65.49	29.47	71.81	0.19	0.45	-10.08	0.97	19.2
BAGER62GIAD	2GIADS61	2BAGER61	220	-119.26	26.87	122.25	0.32	0.5	-0.46	0.67	46.9
GIAD63H.HEI	2GIADS61	2H.HEIS61	220	22.42	-36.85	43.13	0.11	0.16	-20.09	0.97	11.4
GIAD61H.HEI	2GIADS61	2H.HEIS61	220	17.55	-26.58	31.85	0.08	0.1	-13.82	0.67	12.2
GIAD62H.HEI	2GIADS61	2H.HEIS61	220	17.55	-26.58	31.85	0.08	0.1	-13.82	0.67	12.2
GIRBA61KASSA	2GIRBAS61	2KASSAS61	220	57.38	-6.32	57.73	0.15	0.3	-11.94	0.97	15.4
GIRBA62KASSA	2GIRBAS61	2KASSAS61	220	57.38	-6.32	57.73	0.15	0.3	-11.94	0.97	15.4
GIRBA61HALFA	2GIRBAS61	2HALFAS61	220	11.51	-6.17	13.06	0.03	0.01	-11.67	0.97	3.5
GIRBA62HALFA	2GIRBAS61	2HALFAS61	220	11.51	-6.17	13.06	0.03	0.01	-11.67	0.97	3.5
H.HEI61MERIN	2H.HEIS61	2MERINS61	220	-16.33	28.91	33.21	0.08	0.11	-7.32	0.67	12.6
H.HEI62MERIN	2H.HEIS61	2MERINS61	220	-16.33	28.91	33.21	0.08	0.11	-7.32	0.67	12.6
H.HEI63MERIN	2H.HEIS61	2MERINS61	220	-20.25	38.5	43.5	0.11	0.17	-10.68	0.97	11.4
HAWAT61SINGE	2HAWATS61	2SINGERS61	220	-27.31	-8.12	28.5	0.07	0.09	-18.2	0.97	7.5
HAWAT62SINGE	2HAWATS61	2SINGERS61	220	-27.31	-8.12	28.5	0.07	0.09	-18.2	0.97	7.5
GEDAR61HAWAT	2HAWATS61	2GEDARS61	220	0.8	3.41	3.5	0.01	0.03	-22.31	0.97	0.9
GEDAR62HAWAT	2HAWATS61	2GEDARS61	220	0.8	3.41	3.5	0.01	0.03	-22.31	0.97	0.9
J.AUL61GETEI	2J.AULS61	2GETEIS61	220	-65.22	22.52	69	0.18	0.27	-6.95	0.97	18.4
J.AUL62GETEI	2J.AULS61	2GETEIS61	220	-65.22	22.52	69	0.18	0.27	-6.95	0.97	18.4
GIAD62J.AUL	2J.AULS61	2GIADS61	220	-92.95	6.23	93.15	0.24	0.42	-5.47	0.97	24.8
GIAD61J.AUL	2J.AULS61	2GIADS61	220	-92.95	6.23	93.15	0.24	0.42	-5.47	0.97	24.8
EID.B61KABAS	2KABASS61	2EID.BS61	220	60.89	6.97	61.29	0.16	0.15	-5.41	0.97	16.3
EID.B62KABAS	2KABASS61	2EID.BS61	220	60.89	6.97	61.29	0.16	0.15	-5.41	0.97	16.3
DONGO62KARMA	2KARMAS61	2DONGOS61	220	109.3	-2.59	109.33	0.28	0.8	-7.36	0.97	28.5
AROMA61KASSA	2KASSAS61	2AROMA	220	32.1	3.48	32.29	0.08	0.09	-11.52	0.97	8.7
BAGER63KILOX	2KILOXS61	2BAGER61	220	30.44	-55.53	63.33	0.16	0.11	-3.98	0.97	16.9
KILOX61BAGER	2KILOXS61	2BAGER61	220	24.23	-40.99	47.62	0.12	0.07	-2.71	0.67	18.4
KILOX62BAGER	2KILOXS61	2BAGER61	220	24.23	-40.99	47.62	0.12	0.07	-2.71	0.67	18.4

EID.B61KILOX	2KILOXS61	2EID.BS61	220	-88.3	16.84	89.89	0.23	0.15	-2.14	0.97	24
EID.B63KILOX	2KILOXS61	2EID.BS61	220	-88.3	16.84	89.89	0.23	0.15	-2.14	0.97	24
EID.B62KILOX	2KILOXS61	2EID.BS61	220	-88.3	16.84	89.89	0.23	0.15	-2.14	0.97	24
KARMA62L.DAL	2L.DAL61	2KARMAS61	220	87.71	-11.31	88.44	0.22	0.97	-17.09	0.97	22.8
KARMA61L.DAL	2L.DAL61	2KARMAS61	220	87.71	-11.31	88.44	0.22	0.97	-17.09	0.97	22.8
M.TOW62MEROW	2M.TOWS61	2MEROWS61	220	-0.2	23.39	23.39	0.06	0.03	-7.21	0.97	6.1
MAHAD61MARKH	2MAHADS61	2MARKHS61	220	-135.11	-9.1	135.42	0.34	0.33	-1.55	0.97	35.1
MAHAD62MARKH	2MAHADS61	2MARKHS61	220	-135.11	-9.1	135.42	0.34	0.33	-1.55	0.97	35.1
MAHAD63MARKH	2MAHADS61	2MARKHS61	220	-135.11	-9.1	135.42	0.34	0.33	-1.55	0.97	35.1
MANAG61MERIN	2MANAGS61	2MERINS61	220	-99.72	-74.74	124.62	0.33	1.37	-6.68	0.97	34.4
GAMOE62MARKH	2MARKHS61	2GAMOES61	220	76.66	71.12	104.57	0.26	0.56	-5.56	0.97	27
GAMOE61MARKH	2MARKHS61	2GAMOES61	220	76.66	71.12	104.57	0.26	0.56	-5.56	0.97	27
MARSH61MANAG	2MASHKS61	2MANAGS61	220	106.9	10.04	107.38	0.28	1.62	-12.22	0.97	28.9
MASHK62RABA	2MASHKS61	2RABAKS61	220	-185.39	3.53	185.42	0.48	5.12	0.89	0.97	49.8
MASHK61RABAK	2MASHKS61	2RABAKS61	220	-185.39	3.53	185.42	0.48	5.12	0.89	0.97	49.8
MERIN61SENNA	2MERINS61	2SENNAS61	220	-44.11	8.45	44.91	0.12	0.27	-10.42	0.67	17.2
MERIN62SENNA	2MERINS61	2SENNAS61	220	-44.11	8.45	44.91	0.12	0.27	-10.42	0.67	17.2
M.TOW61MEROW	2MEROWS61	2M.TOWS61	220	0.24	-30.59	30.6	0.08	0.03	-7.21	0.97	8
KARMA61MEROW	2MEROWS61	2KARMAS61	220	-30.79	-30.29	43.19	0.11	0.4	-65.68	0.97	11.4
KARMA62MEROW	2MEROWS61	2KARMAS61	220	-30.79	-30.29	43.19	0.11	0.4	-65.68	0.97	11.4
FASHE61NYALA	2NYALA61	2FASHE61	220	35.28	-19.6	40.36	0.1	0.27	-31.04	0.97	10.8
FASHE62NYALA	2NYALA61	2FASHE61	220	35.28	-19.6	40.36	0.1	0.27	-31.04	0.97	10.8
ZALIN61NYALA	2NYALA61	2ZALIN61	220	113.19	-12.54	113.88	0.3	3.14	-21.35	0.97	30.4
ZALIN62NYALA	2NYALA61	2ZALIN61	220	113.19	-12.54	113.88	0.3	3.14	-21.35	0.97	30.4
E.RAH62OBEID	2OBEIDS61	2E.RAHS61	220	-33.33	7.98	34.27	0.09	0.03	-4.15	0.97	8.9
E.RAH61OBEID	2OBEIDS61	2E.RAHS61	220	-33.33	7.98	34.27	0.09	0.03	-4.15	0.97	8.9
DEBET61OBEID	2OBEIDS61	2DEBETS61	220	2.33	-22.48	22.6	0.06	0.02	-18.27	0.97	5.9
DEBET62OBEID	2OBEIDS61	2DEBETS61	220	2.33	-22.48	22.6	0.06	0.02	-18.27	0.97	5.9
P.SUT61P.SUD	2P.SUT61	2P.SOUDS61	220	152.91	-5.61	153.01	0.39	0.15	-0.39	0.97	39.8
P.SUT62P.SUD	2P.SUT61	2P.SOUDS61	220	152.91	-5.61	153.01	0.39	0.15	-0.39	0.97	39.8
RABAK62RANK	2RABAKS61	2RANKS61	220	-20.79	-23.32	31.24	0.08	0.08	-22.63	0.97	8.2
RABAK61RANK	2RABAKS61	2RANKS61	220	-20.79	-23.32	31.24	0.08	0.08	-22.63	0.97	8.2
RANK61ROSEI	2RANKS61	2ROSEIS61	220	-40.37	-9.69	41.52	0.1	0.34	-32.95	0.97	10.8
RANK62ROSEI	2RANKS61	2ROSEIS61	220	-40.37	-9.69	41.52	0.1	0.34	-32.95	0.97	10.8
SENNA62SINGE	2SENNAS61	2SINGERS61	220	-58.47	-5.27	58.7	0.15	0.44	-9.6	0.67	22.6
SENNA61SINGE	2SENNAS61	2SINGERS61	220	-58.47	-5.27	58.7	0.15	0.44	-9.6	0.67	22.6
F.ZON62SHEND	2SHENDIS61	2F.ZON	220	-8.76	-1.45	8.88	0.02	0.03	-23.85	0.97	2.3
F.ZON61SHEND	2SHENDIS61	2F.ZON	220	-8.76	-1.45	8.88	0.02	0.03	-23.85	0.97	2.3
A.HAM61SHERE	2SHERES61	2A.HAM	220	7.52	-18.48	19.95	0.05	0.02	-21.98	0.97	5.2
A.HAM62SHERE	2SHERES61	2A.HAM	220	7.52	-18.48	19.95	0.05	0.02	-21.98	0.97	5.2
GIRBA61SHOWA	2SHOWAS61	2GIRBAS61	220	-20	-10	22.36	0.06	0.04	-13.93	0.97	6
ROSEI62SINGE	2SINGERS61	2ROSEIS61	220	-115.31	0.91	115.31	0.3	2.91	-5.63	0.67	44

ROSEI61SINGE	2SINGERS61	2ROSEIS61	220	-115.31	0.91	115.31	0.3	2.91	-5.63	0.67	44
P.SUT61SUAK	2SUAKI61	2P.SUT61	220	-114	-54	126.14	0.33	1.5	-8.15	0.97	33.9
RABAK62U.RAW	2U.RAWS61	2RABAKS61	220	-87.02	3.48	87.09	0.22	2.41	-36.45	0.97	22.8
RABAK61U.RAW	2U.RAWS61	2RABAKS61	220	-87.02	3.48	87.09	0.22	2.41	-36.45	0.97	22.8
E.RAH61U.RAW	2U.RAWS61	2E.RAHS61	220	33.52	-28.48	43.98	0.11	0.16	-16.34	0.97	11.5
E.RAH62U.RAW	2U.RAWS61	2E.RAHS61	220	33.52	-28.48	43.98	0.11	0.16	-16.34	0.97	11.5
L.DAL61W.HAL	2W.HALS61	2L.DAL61	220	-24.03	-21.74	32.41	0.08	0.13	-37.03	0.97	8.4
GENEI61ZALIN	2ZALIN61	2GENEI61	220	130.04	9.5	130.39	0.35	2.98	-8.85	0.97	35.8

Table 5-2 - 500 kV and 220 kV lines

5.1.3 Voltage profile

Bus	Vn (kV)	V sol (kV)	Vsol/Vn (%)
2MEROWS81	500	524.9	105.0
3NAG81	500	524.6	104.9
2P.SUD81	500	522.6	104.5
2DALS81	500	522.3	104.5
2ATBARS81	500	520.6	104.1
2KABASS81	500	520.2	104.0
2MARKHS81	500	516.8	103.4
2H.HEI81	500	514.4	102.9
2FULA81	500	513.7	102.7
2MERIN81	500	512.1	102.4
2RABAK81	500	511.4	102.3
1MANDAS81	500	511.2	102.2
2NYALA81	500	504.2	100.8
1MANDAS71	400	414.2	103.6
Z	220	233.5	106.2
2DEBETS61	220	230.2	104.6
2DEBBAS61	220	230.0	104.6
2L.DAL61	220	230.0	104.5
1GONDES61	230	230.0	100.0
2A.ZABS61	220	229.9	104.5
2MARKHS61	220	229.8	104.5
2ROSEIS61	220	229.6	104.3
2MAHADS61	220	229.1	104.1
2RANKS61	220	229.1	104.1
2OBEIDS61	220	228.8	104.0
2E.RAHS61	220	228.7	104.0
2P.SUT61	220	228.4	103.8
2E.DAE61	220	228.2	103.7
2FULAS61	220	228.2	103.7

2P.SOUDS61	220	228.2	103.7
2W.HALS61	220	228.0	103.6
2KARMAS61	220	227.8	103.5
2A.HAM	220	227.8	103.5
2U.RAWS61	220	227.3	103.3
2M.TOWS61	220	227.1	103.2
1SHEHES61	230	227.0	98.7
2SHERES61	220	227.0	103.2
2H.HEIS61	220	226.8	103.1
2RABAKS61	220	226.7	103.0
2SHENDIS61	220	226.1	102.8
2DONGOS61	220	226.1	102.8
2MEROWS61	220	225.8	102.6
2ATBAS61	220	225.4	102.4
X	230	225.3	98.0
2GAMOES61	220	225.2	102.4
2GARRIS61	220	225.1	102.3
2SINGERS61	220	224.8	102.2
2F.ZON	220	224.7	102.2
2HAWATS61	220	224.2	101.9
2MERINS61	220	223.9	101.8
2GIADS61	220	223.8	101.7
2BAGER61	220	223.5	101.6
2J.AULS61	220	223.2	101.5
2KABASS61	220	223.1	101.4
2SENNAS61	220	223.1	101.4
2BARBAS61	220	222.8	101.3
2GETEIS61	220	222.6	101.2
2EID.BS61	220	222.2	101.0
2NYALA61	220	222.2	101.0
2KILOXS61	220	222.1	101.0
2GIRBAS61	220	222.0	100.9
2GEDARS61	220	222.0	100.9
2HALFAS61	220	221.8	100.8
2FASHE61	220	221.3	100.6
2SHOWAS61	220	221.3	100.6
2ALGHOS61	220	221.1	100.5
2SUAKI61	220	221.0	100.5
2MASHKS61	220	221.0	100.4
2KASSAS61	220	220.9	100.4
2AROMA	220	219.5	99.8
1SHEHE61	220	219.4	99.7
2ZALIN61	220	216.4	98.4
2MANAGS61	220	215.5	97.9
2GENEI61	220	209.1	95.0

Table 5-3 - Voltage profile

5.2 ANALYSIS OF N-1 SITUATIONS

5.2.1 Tripping of one of the two 500/220 kV transformers at Meringan

The behaviour of the system was satisfactory.

No over load occurred on the 220 kV transmission system.

The remaining transformer was 73 % loaded.

5.2.2 Tripping of the 500 kV line Meringan - Rabak

The behaviour of the system was satisfactory.

A part of the initial flow was transferred through the 500/220 kV transformer at Rabak that were 85 % loaded and over the 220 kV lines Mashkur - Rabak that were 82 % loaded (50 % in normal condition). The remaining part flowed over the 500 kV line Rabak - Markhiat that was 42 % loaded.

The voltage profile was slightly affected (-2 % at Hasaheisa).

5.2.3 Tripping of one of the two 220 kV circuits Mashkur - Rabak

The behaviour of the system was satisfactory.

Following the tripping, the remaining 220 kV circuit was 74 % loaded.

The voltage profile was not affected.

5.2.4 Conclusion

The power imported by the interconnection with Ethiopia and Egypt had positive effect on the behaviour of the Sudanese system in N-1 situation: the power exchange discharged the 220 kV Sudanese system close to the interconnection point. No overload occurred on the 500 kV and 220 kV system whatever the tripped equipment.

ENTRO

EDF – Generation and Engineering Division
73 373
Le Bourget du Lac Cedex
France
Tel: +33-4-79 60 60 60
Fax: +33-4-79 60 62 35
eMail: pierre.brun@edf.fr
http://www.edf.fr

EASTERN NILE POWER TRADE PROGRAM STUDY

AfDB

Analysis of the network expansion plan

VOL 3.4 - INTERCONNECTION

APPENDIX 2

Transient Stability Study
on Option 2 :
Ethiopia to Sudan : 1200 MW
Ethiopia to Egypt : 690 MW

15 November 2007

Scott Wilson
Kanthack House, Station Road,
Ashford, Kent TN 23 1 PP
England
Tel: +44 (0) 1233 658200
Fax: +44 (0) 1233 658209
eMail: alan.bates@scottwilson.com
http://www.scottwilson.com

with participation of:

EPS (Egypt)
Tropics (Ethiopia)
YAM (Sudan)

LIST OF APPENDICES

1 Transient stability analysis hypothesis

The volume of primary reserve set as followed :

- Libya : 50 MW
- Jordan and Syria : 100 MW
- Egypt : 284 MW (104 MW on hydropower plants + 180 MW on thermal plants)
- Sudan : 264 MW (140 MW on hydropower plants + 124 MW on thermal power plants)
- Ethiopia : 456 MW (hydropower plant only)

Load voltage and frequency dependency coefficients

	dP/dV	dP/df	dQ/dV	dQ/df
Egypt	0.83	1.46	4.01	-0.88
Ethiopia	0.94	1.26	3.67	-1.29
Sudan	0.79	1.53	4.14	-0.72

Load of Libya, Jordan ans Syria

The 2015 peak load forcast for Libya reached 7100 MW.
The 2015 peak load forcast for Jordan and Syria reached 15000 MW.

Calculation of the damping magnitude of the power oscillations

The power oscillations evolve according to the formula :

$$\mathbf{A.e^{-\alpha t}.cos(\omega t+\varphi)} \quad \text{with } \omega=2\pi f_x$$

From the curves it is possible to measure the frequency, f_x of the oscillations. (generally a low value close to 0.3Hz or 0.5Hz)
The apparent damping coefficient D of the oscillation mode is equal to :

$$\mathbf{D}=\frac{\alpha}{\sqrt{(\alpha^2+\beta^2)}} \quad \text{with } \beta = 2\pi f$$

and α is like that $e^{-\alpha t}=0.05$ with ***t*** is the damping duration.

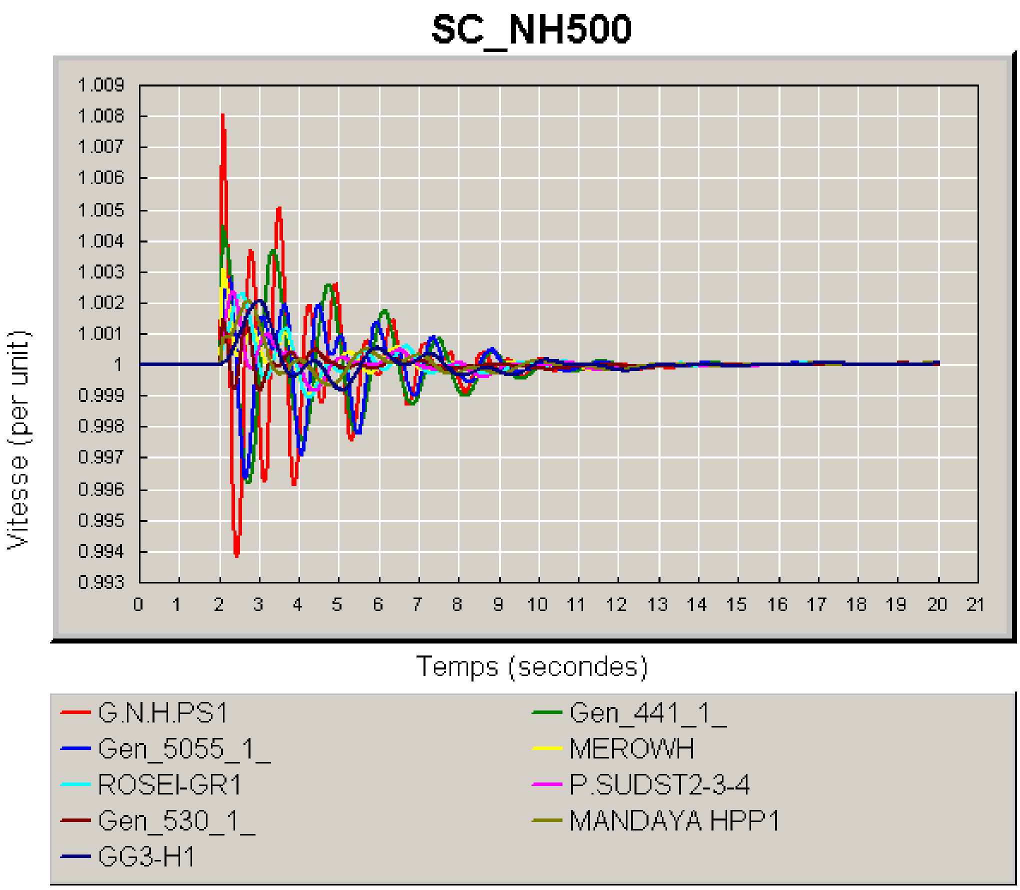
The international literature concerning the inter-area oscillations, indicates that an inter-area oscillation mode is acceptably damped if the damping coefficient is close to 5% and it is well damped if the damping coefficient is higher than 5%.

According to the above formula, the apparent damping coefficient for the average frequency was estimated from the curves and the results.

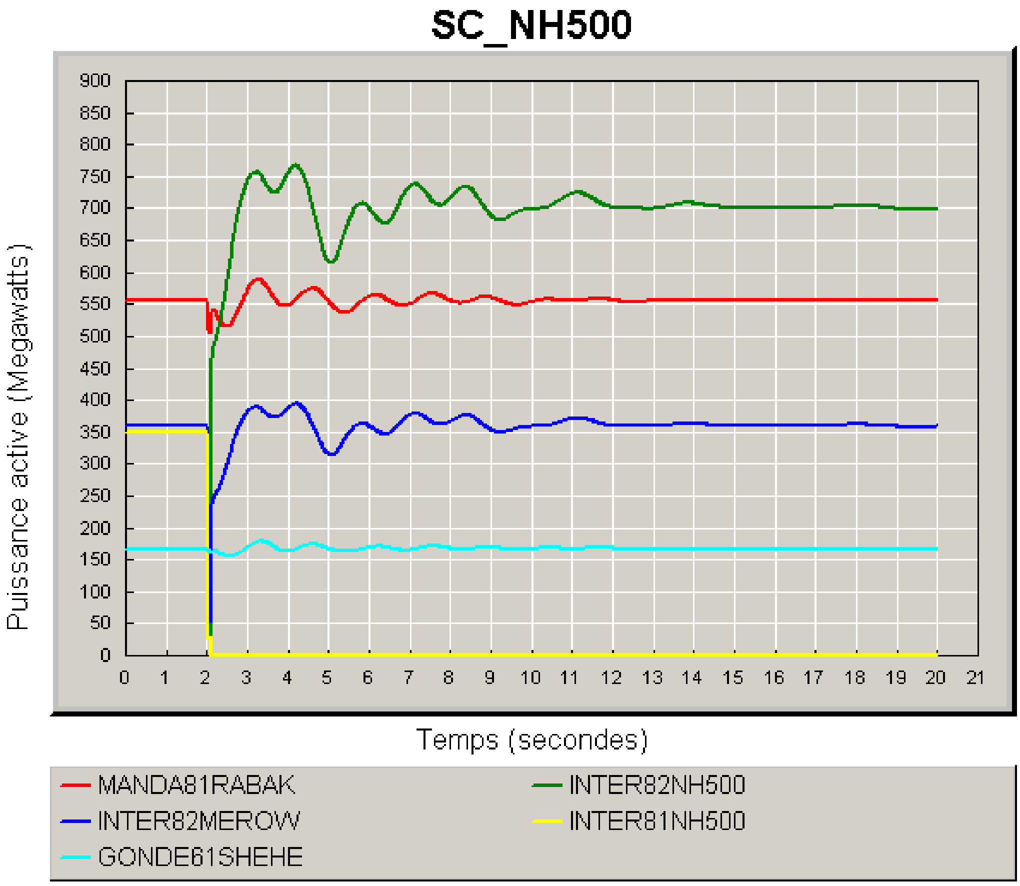
2 AC option

2.1 SHORT-CIRCUIT AT NAG HAMMADI ON NAG HAMMADI - INTERMEDIATE SUBSTATION

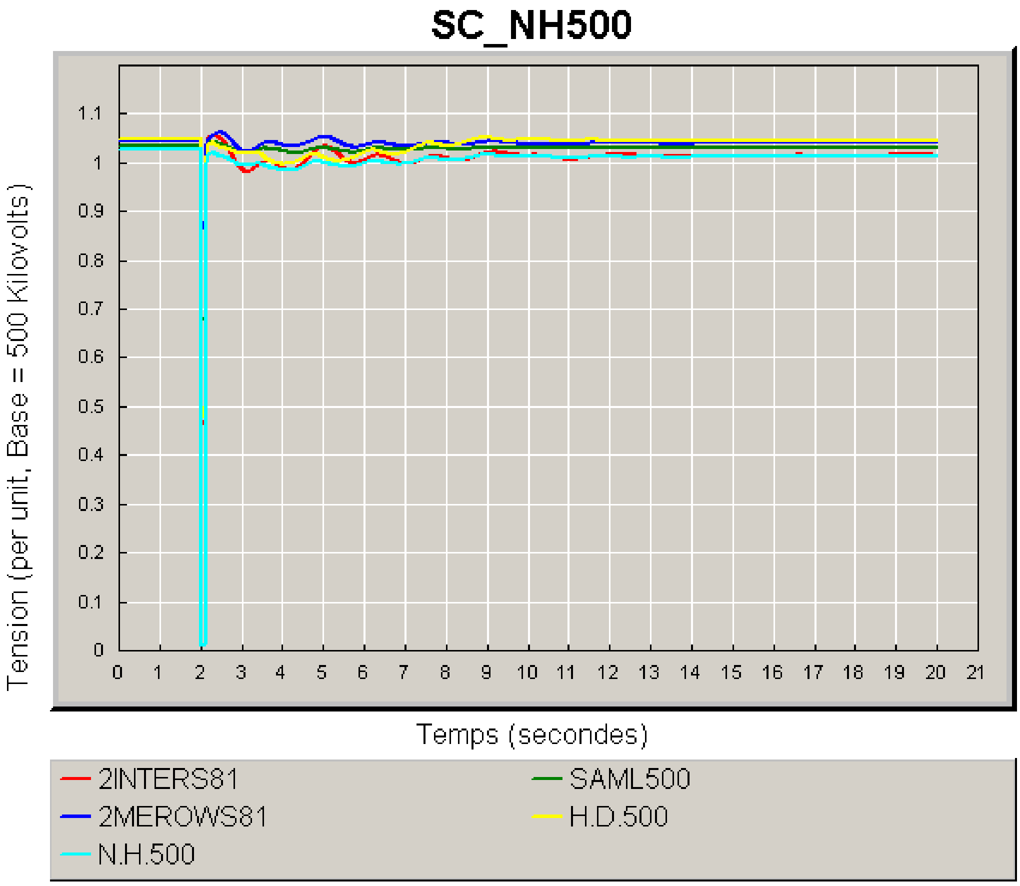
2.1.1 GENERATORS FREQUENCY VARIATION



2.1.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION

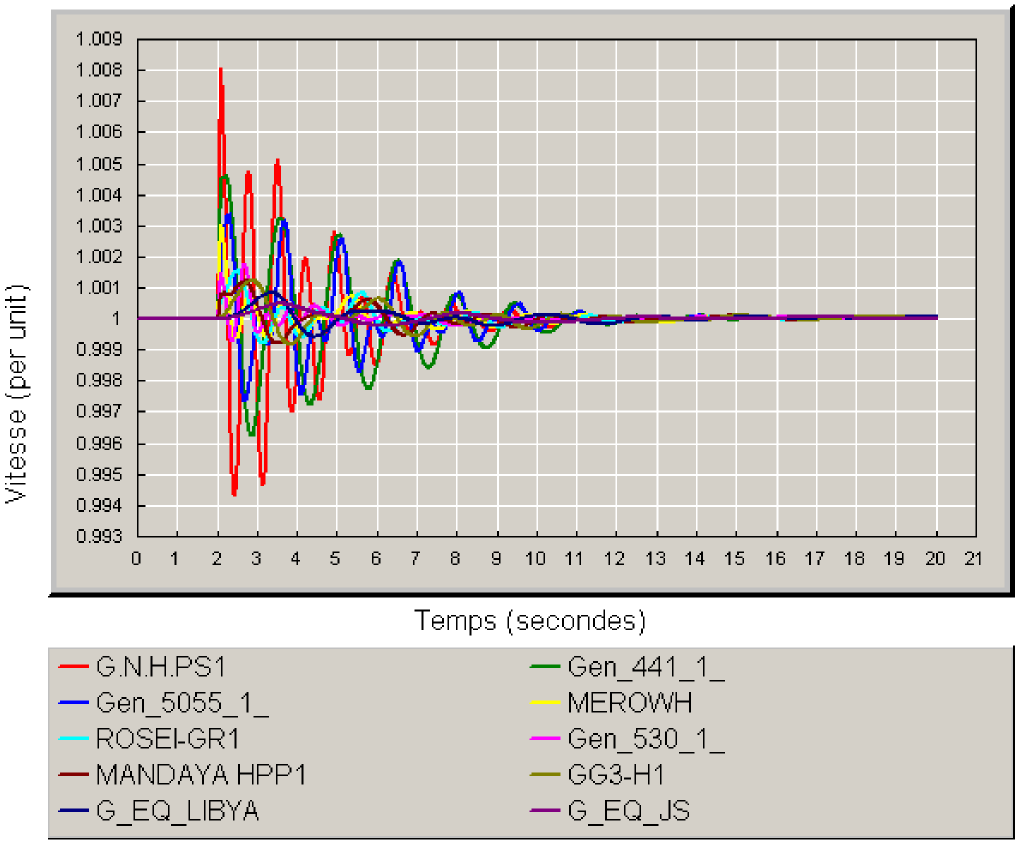


2.1.3 VOLTAGE VARIATION ON THE 500 KV



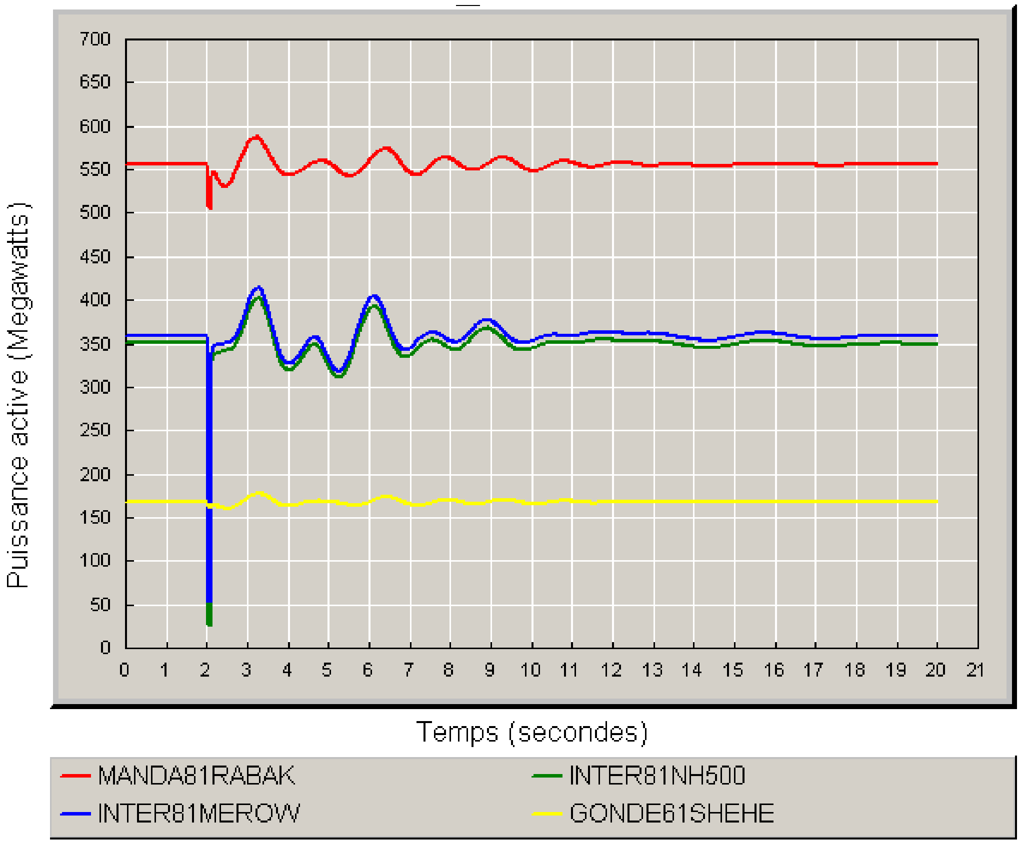
2.2 SHORT-CIRCUIT AT NAG HAMMADI ON NAG HAMMADI - HIGH DAM

2.2.1 GENERATORS FREQUENCY VARIATION

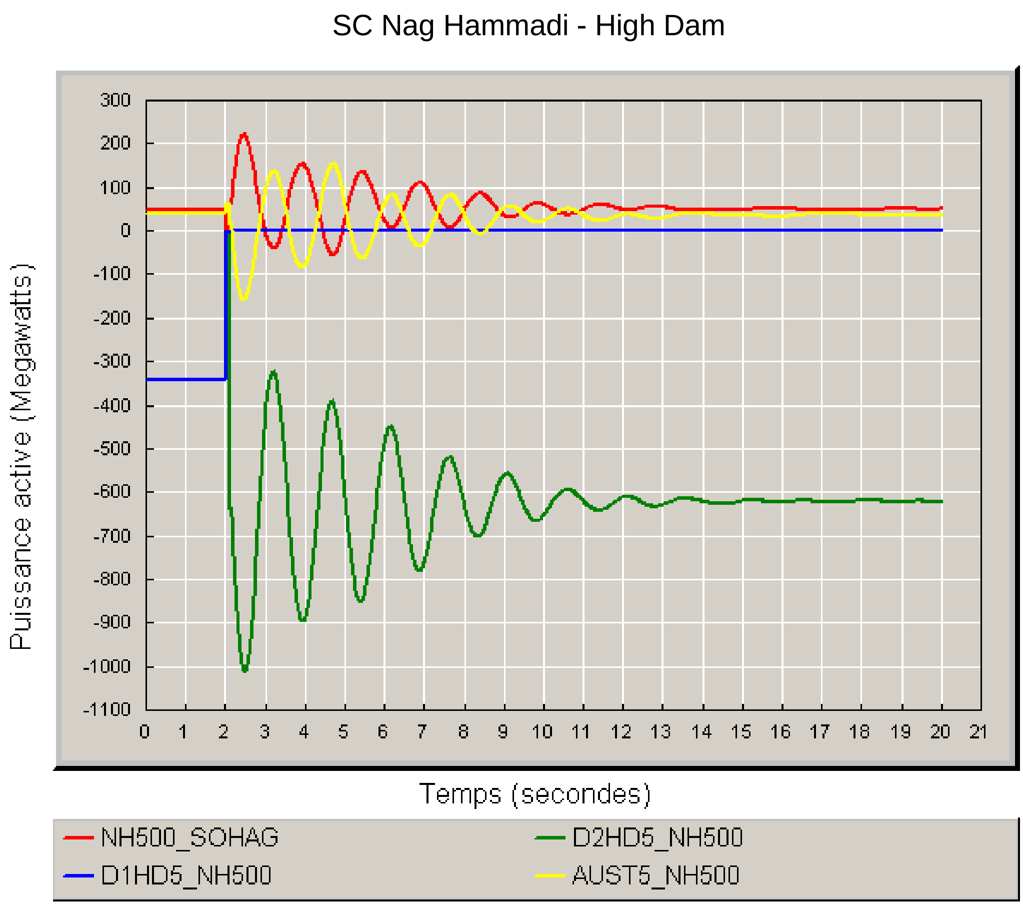


2.2.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION

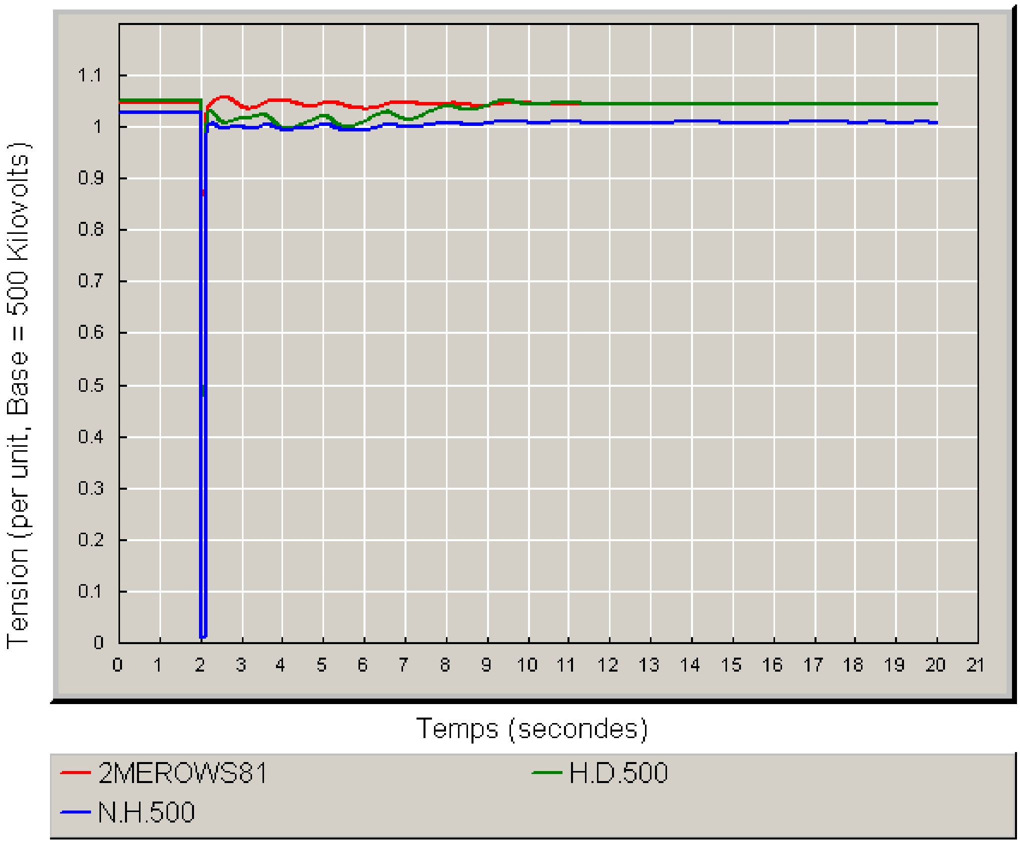
SC Nag Hammadi - High Dam



2.2.3 POWER FLOW VARIATION ON NAG - HAMMADI - HIGH DAM

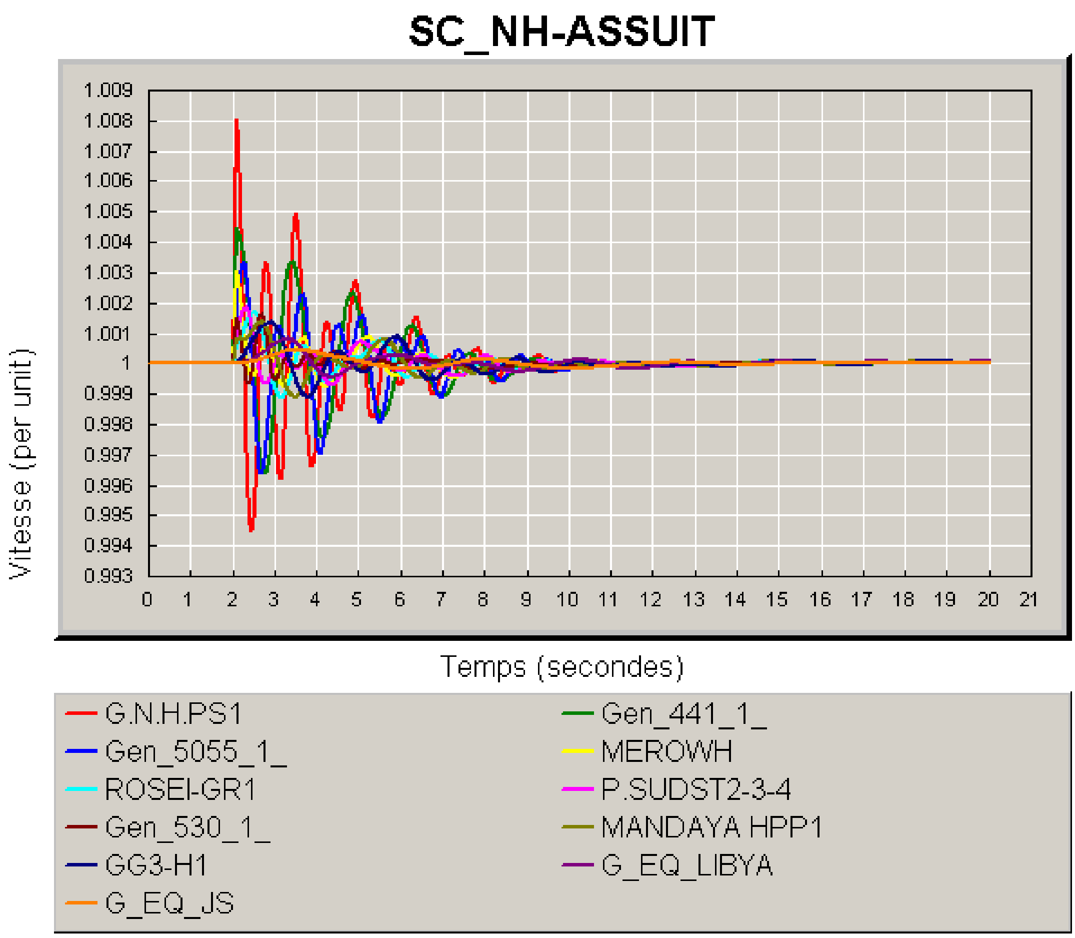


2.2.4 VOLTAGE VARIATION ON THE 500 KV

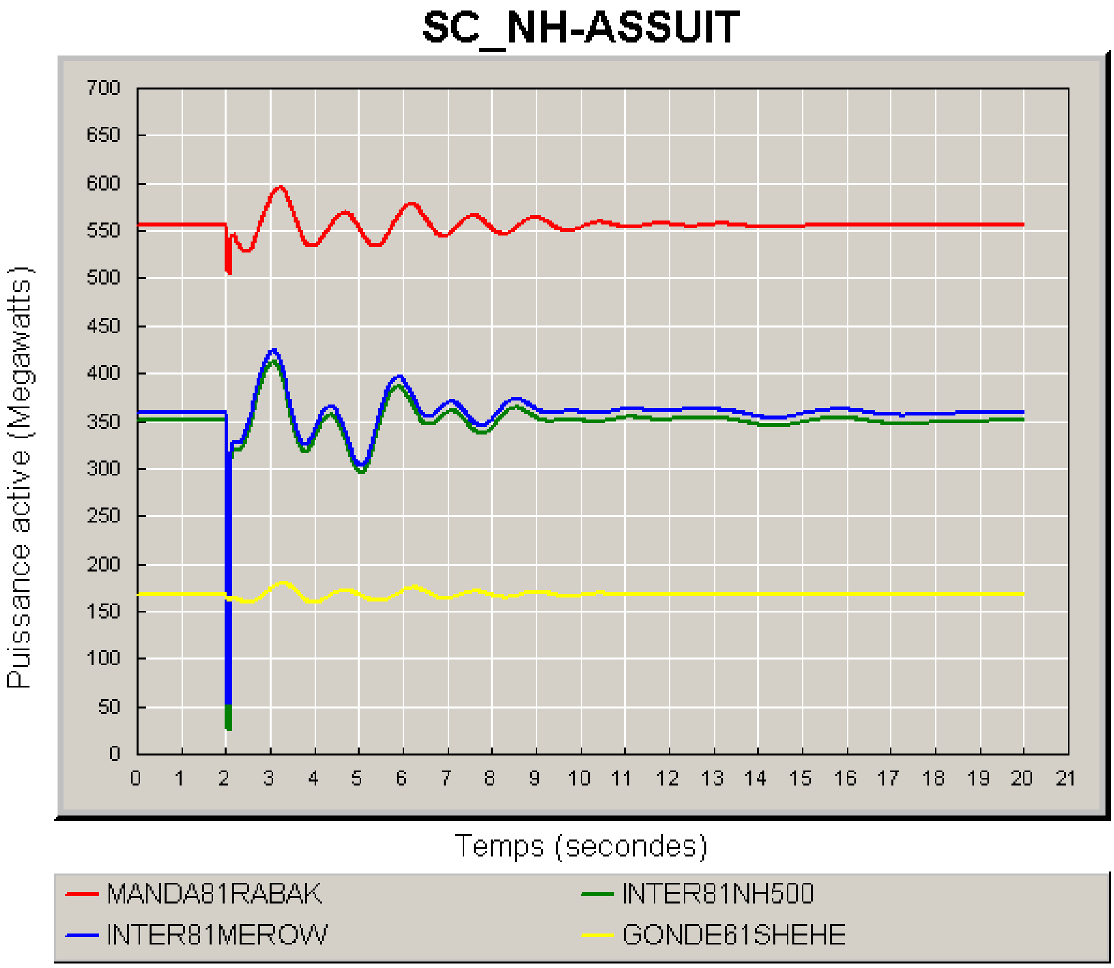


2.3 SHORT-CIRCUIT AT NAG HAMMADI ON NH500 - ASSIUT

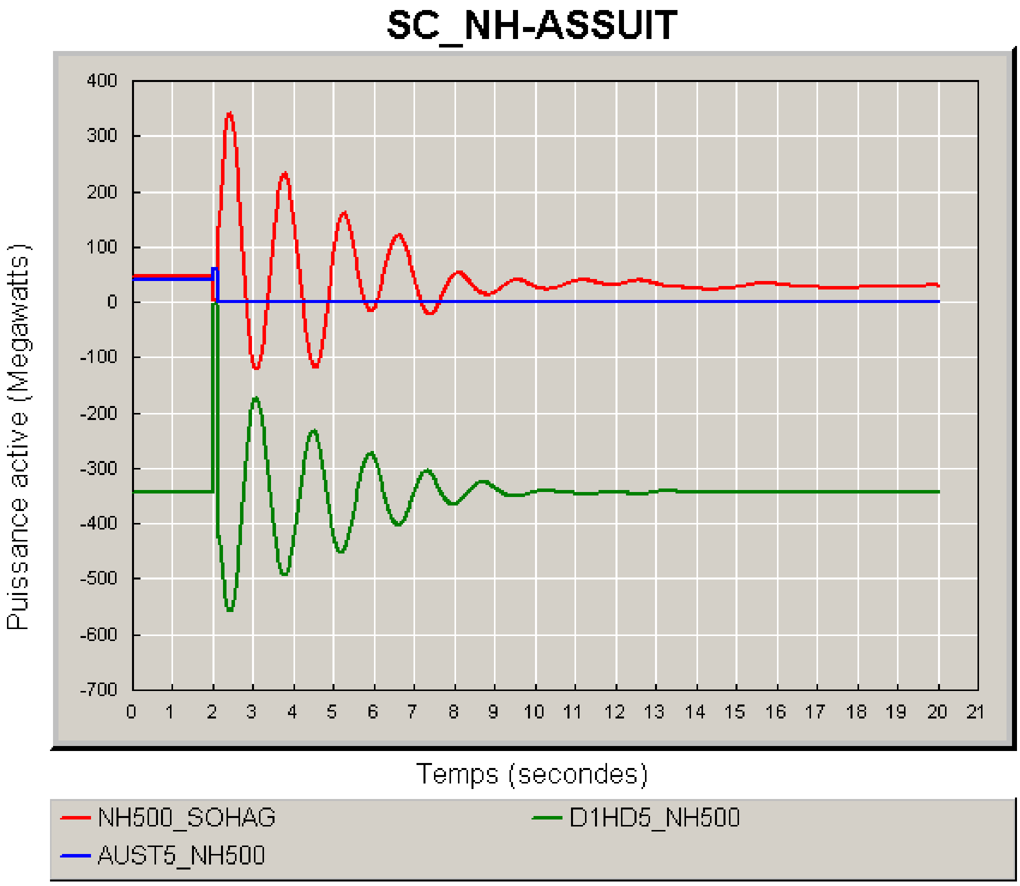
2.3.1 GENERATORS FREQUENCY VARIATION



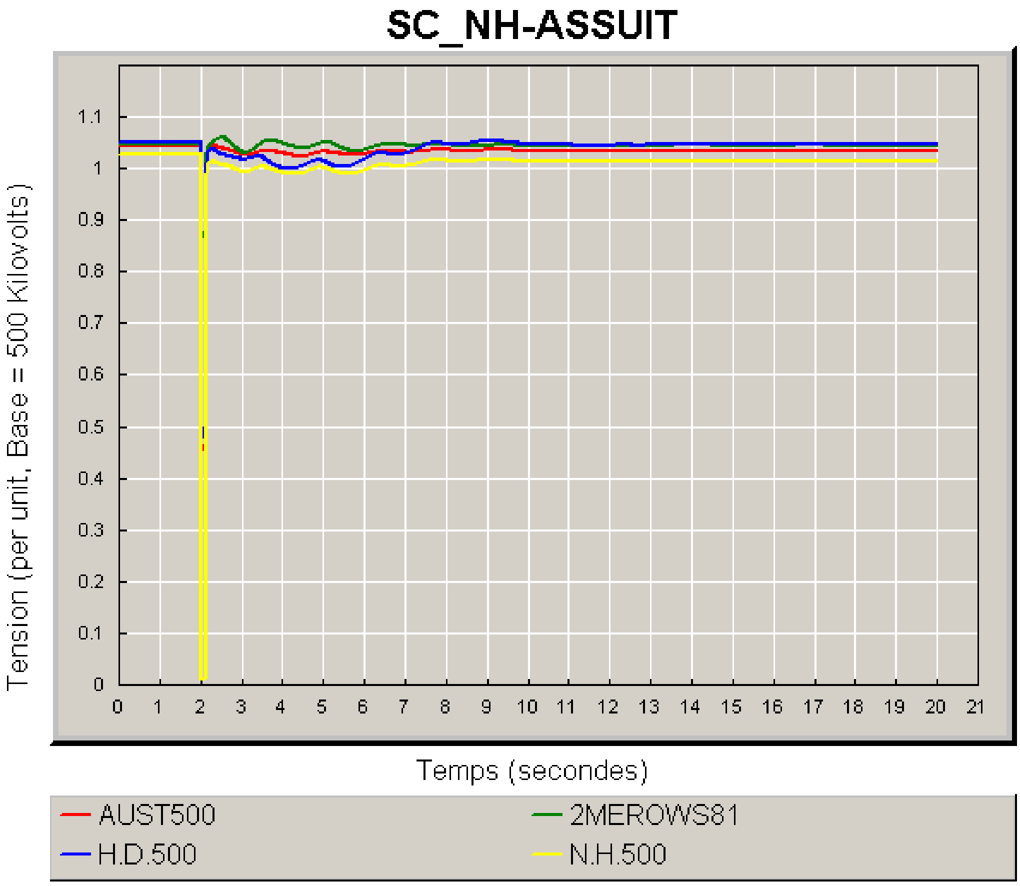
2.3.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



2.3.3 POWER FLOW VARIATION ON THE CIRCUIT HIGH DAM - NAG HAMMADI - ASSIUT

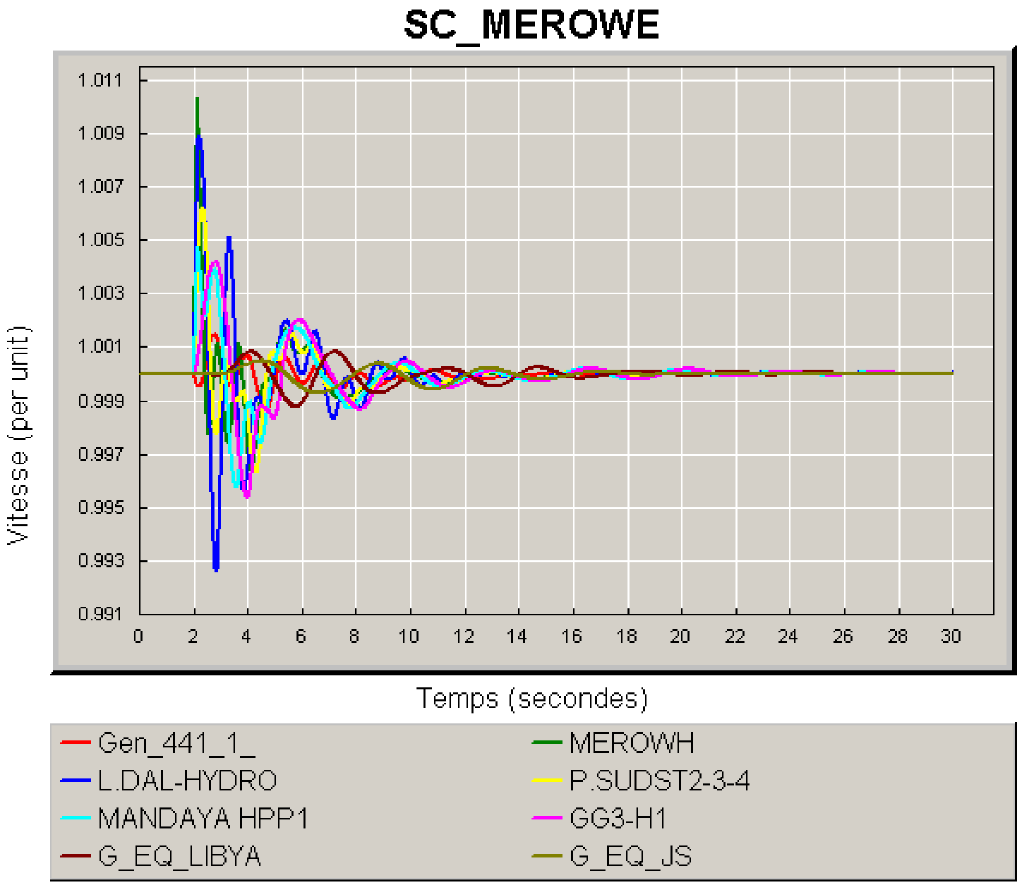


2.3.4 VOLTAGE VARIATION ON THE 500 KV

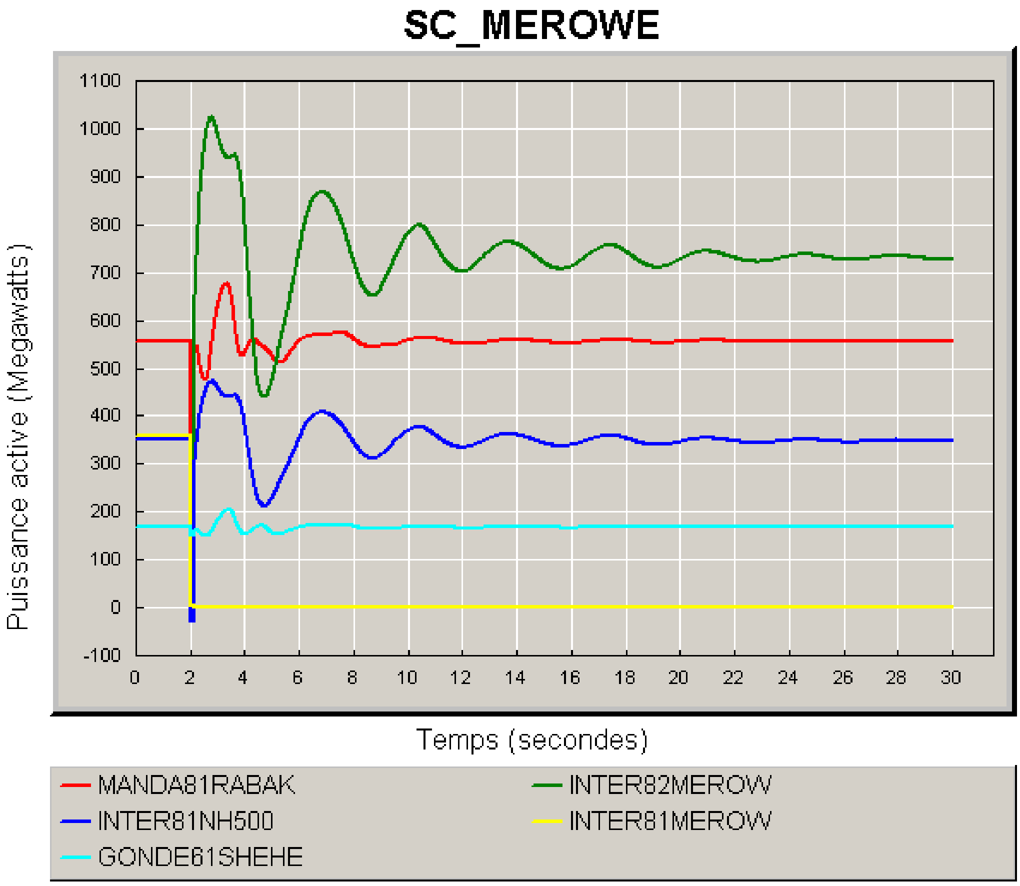


2.4 SHORT-CIRCUIT AT MEROWE ON MEROWE - INTERMEDIATE SUBSTATION

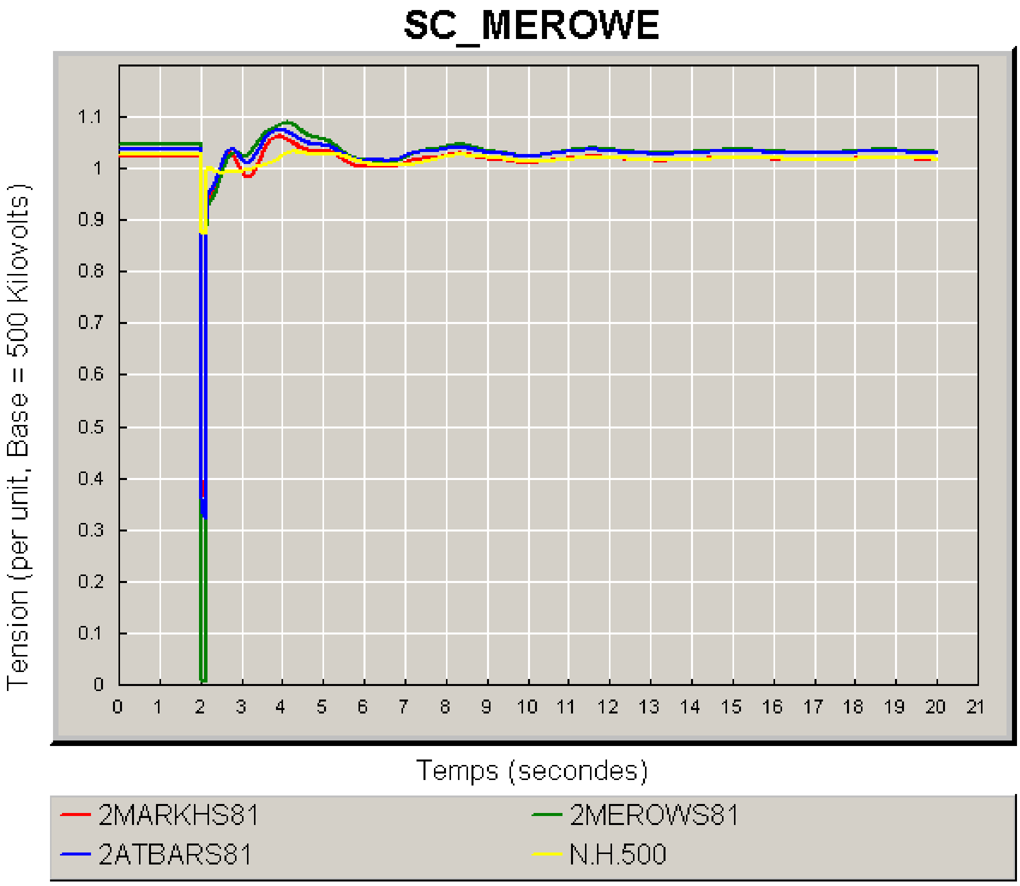
2.4.1 GENERATORS FREQUENCY VARIATION



2.4.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION

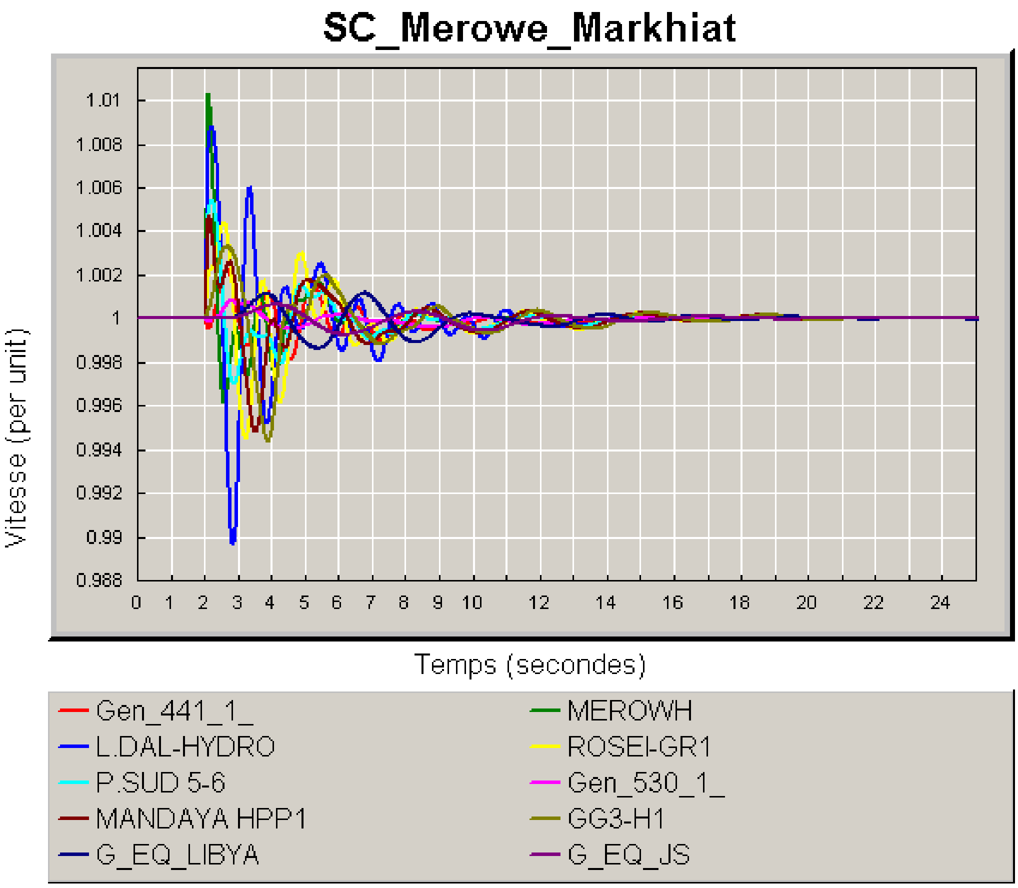


2.4.3 VOLTAGE VARIATION ON THE 500 KV

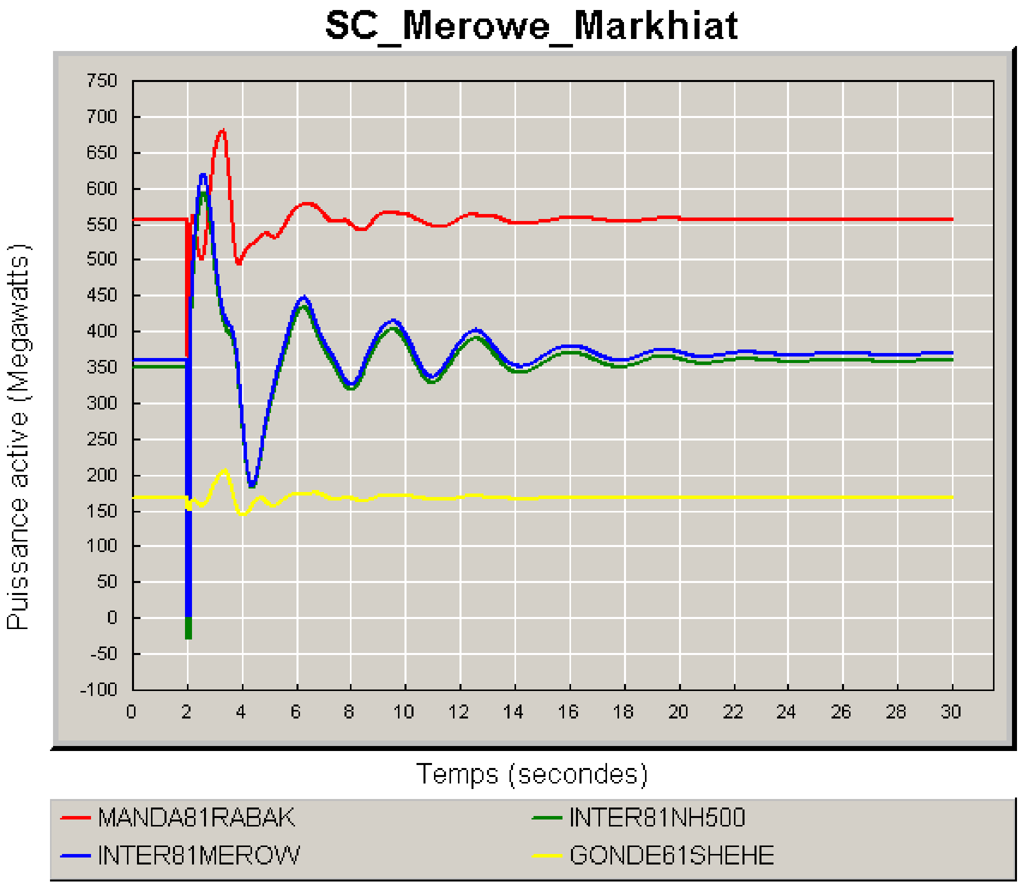


2.5 SHORT-CIRCUIT AT MEROWE ON MEROWE - MARKHIAT

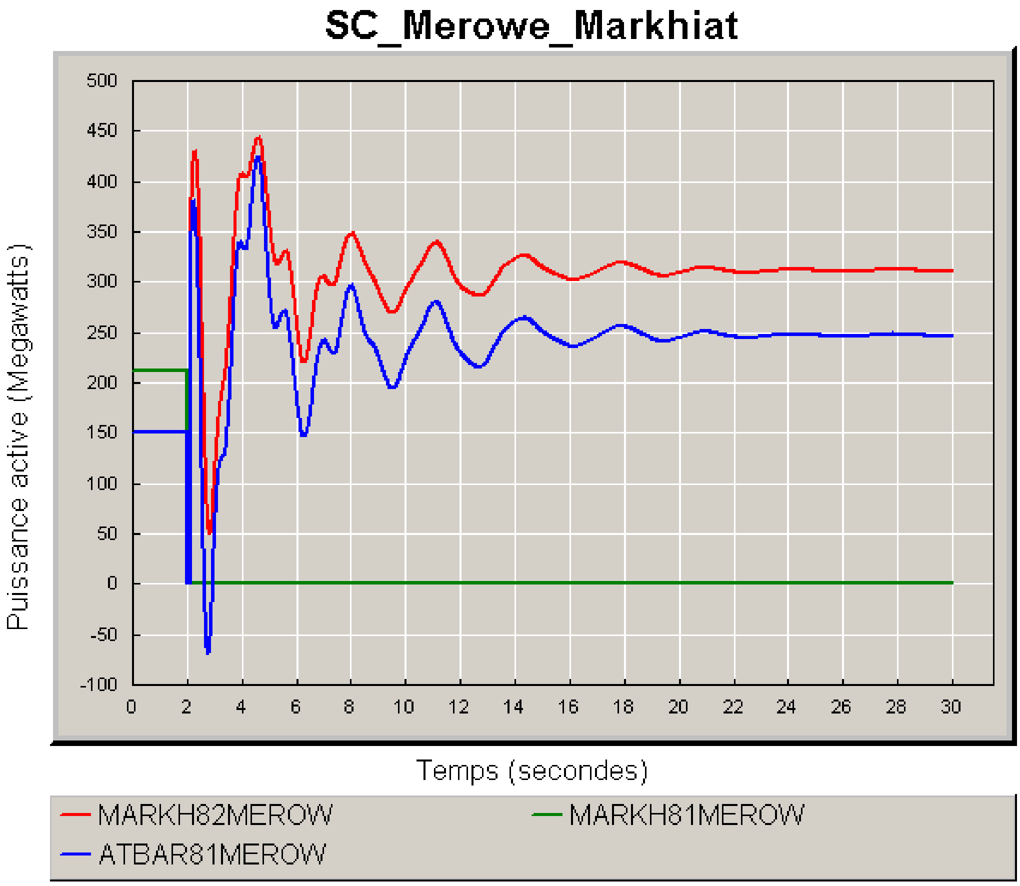
2.5.1 GENERATORS FREQUENCY VARIATION



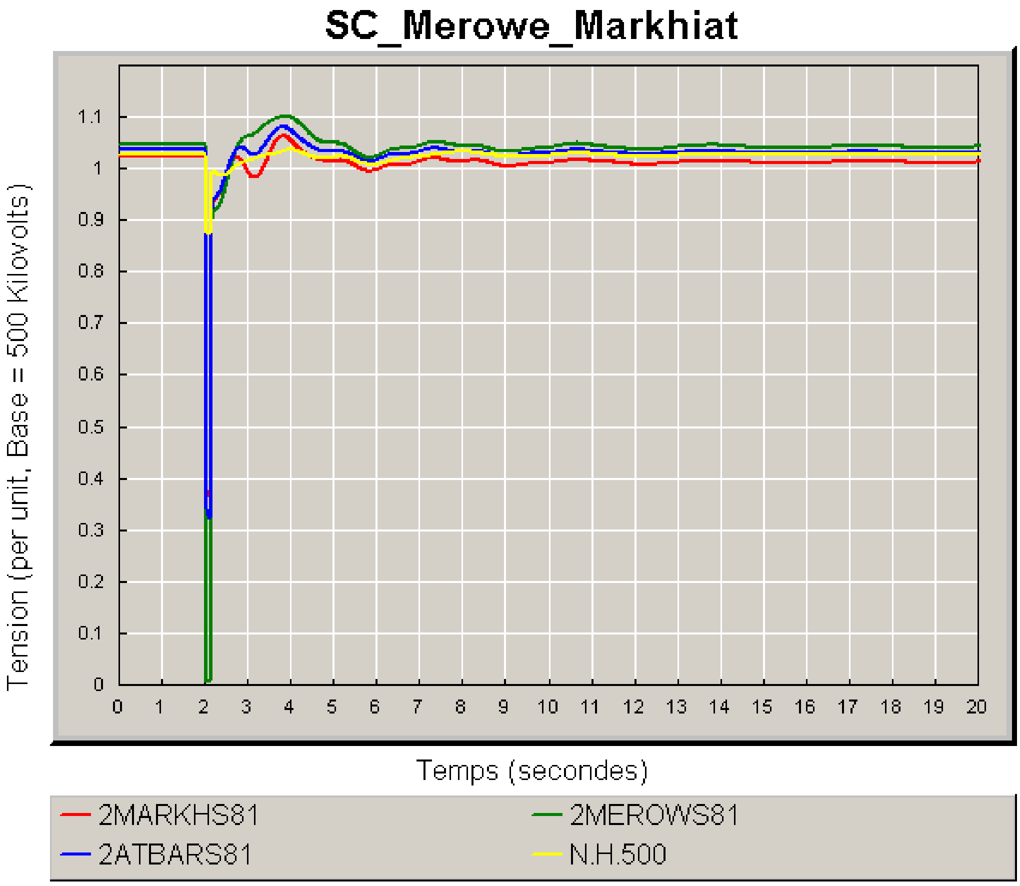
2.5.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



2.5.3 POWER FLOW VARIATION ON MEROWE - MARKHIAT AND MEROWE - ATBARA

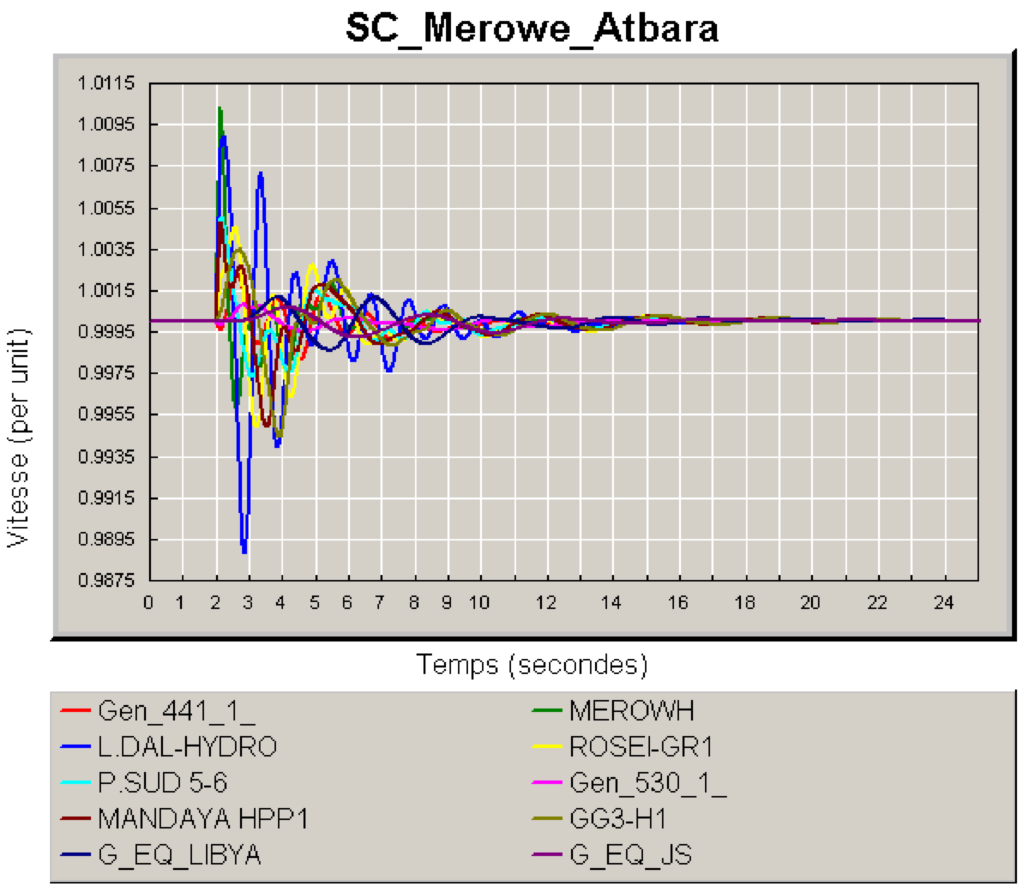


2.5.4 VOLTAGE VARIATION ON THE 500 KV

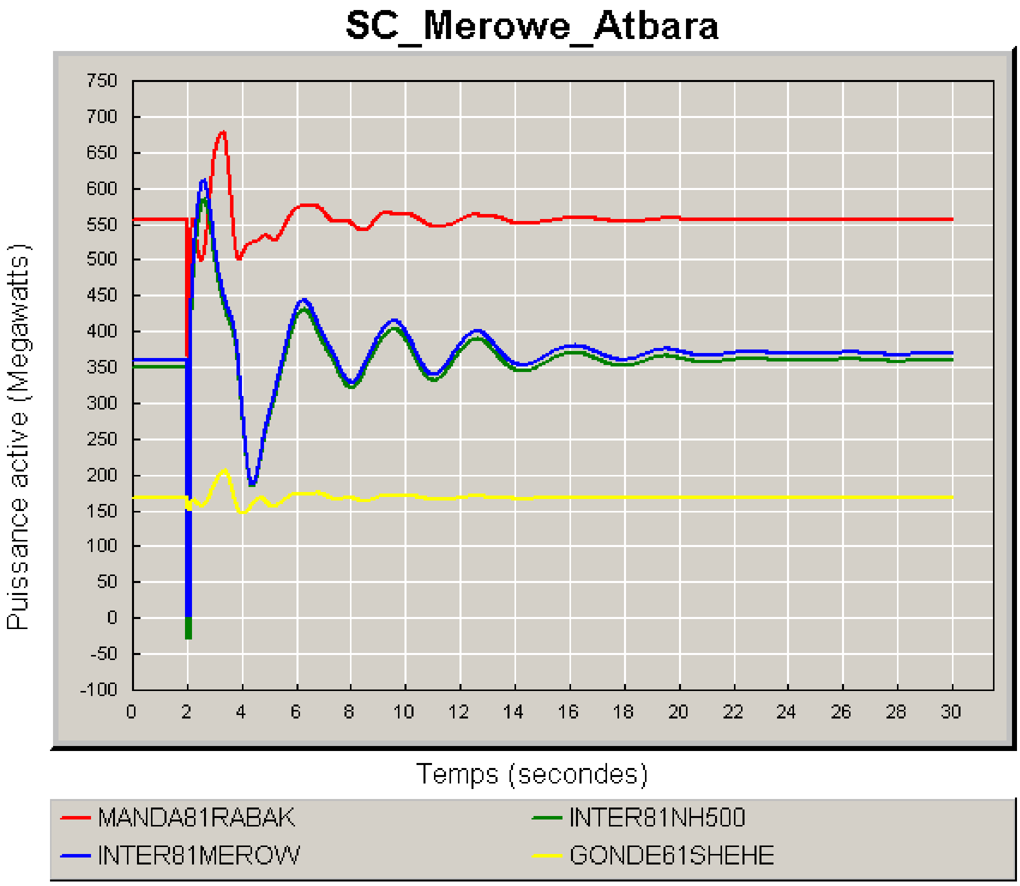


2.6 SHORT-CIRCUIT AT MEROWE ON MEROWE - ATBARA

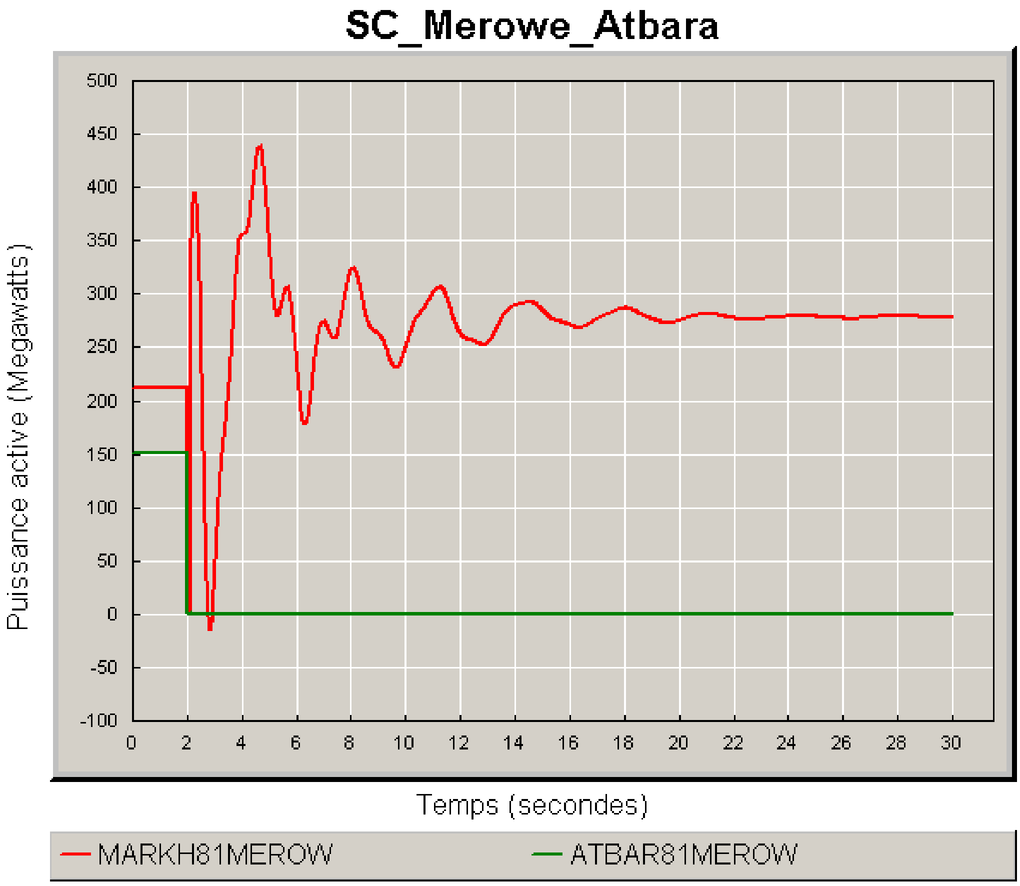
2.6.1 GENERATORS FREQUENCY VARIATION



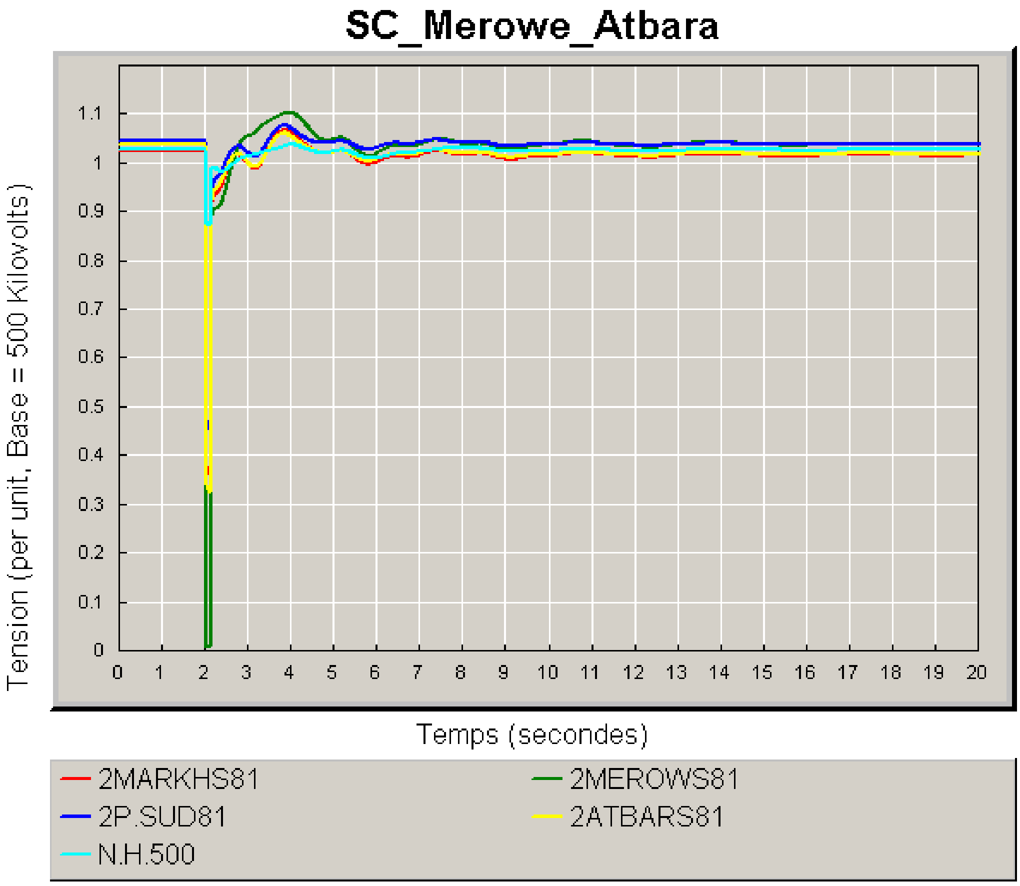
2.6.2 Power flow variation on ENTRO interconnection



2.6.3 POWER FLOW VARIATION ON MEROWE - MARKHIAT AND MEROWE - ATBARA

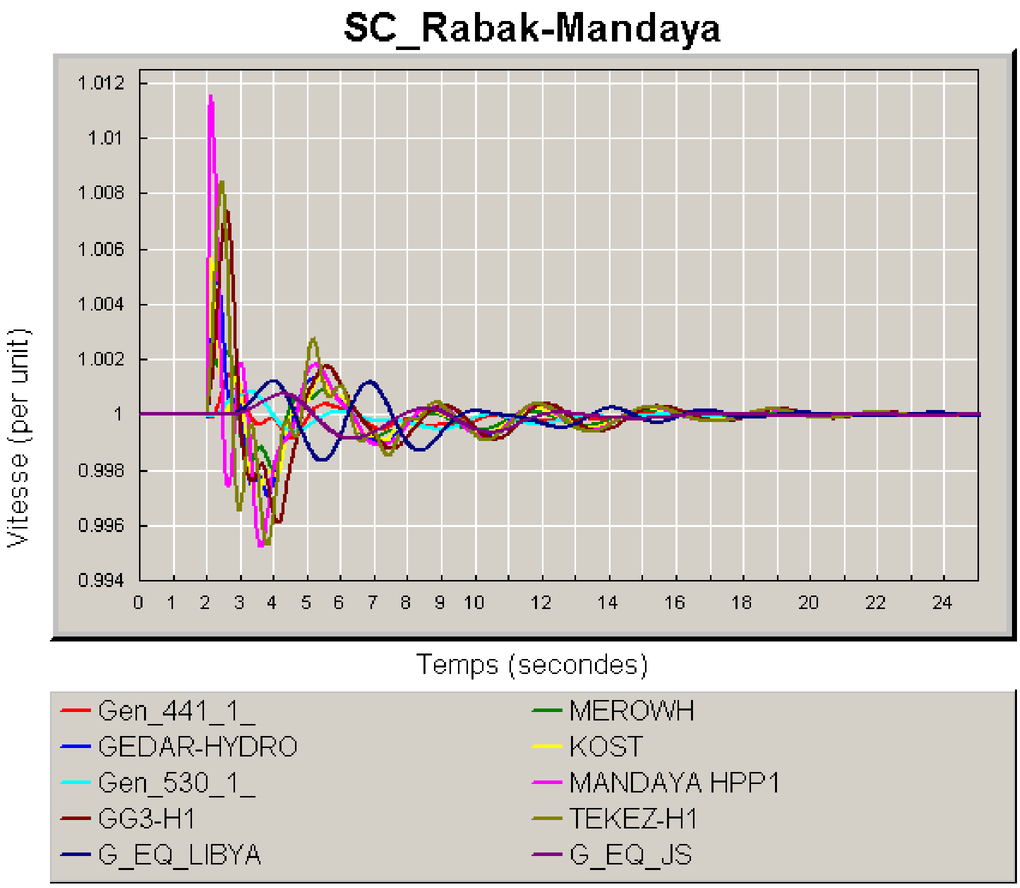


2.6.4 VOLTAGE VARIATION ON THE 500 KV

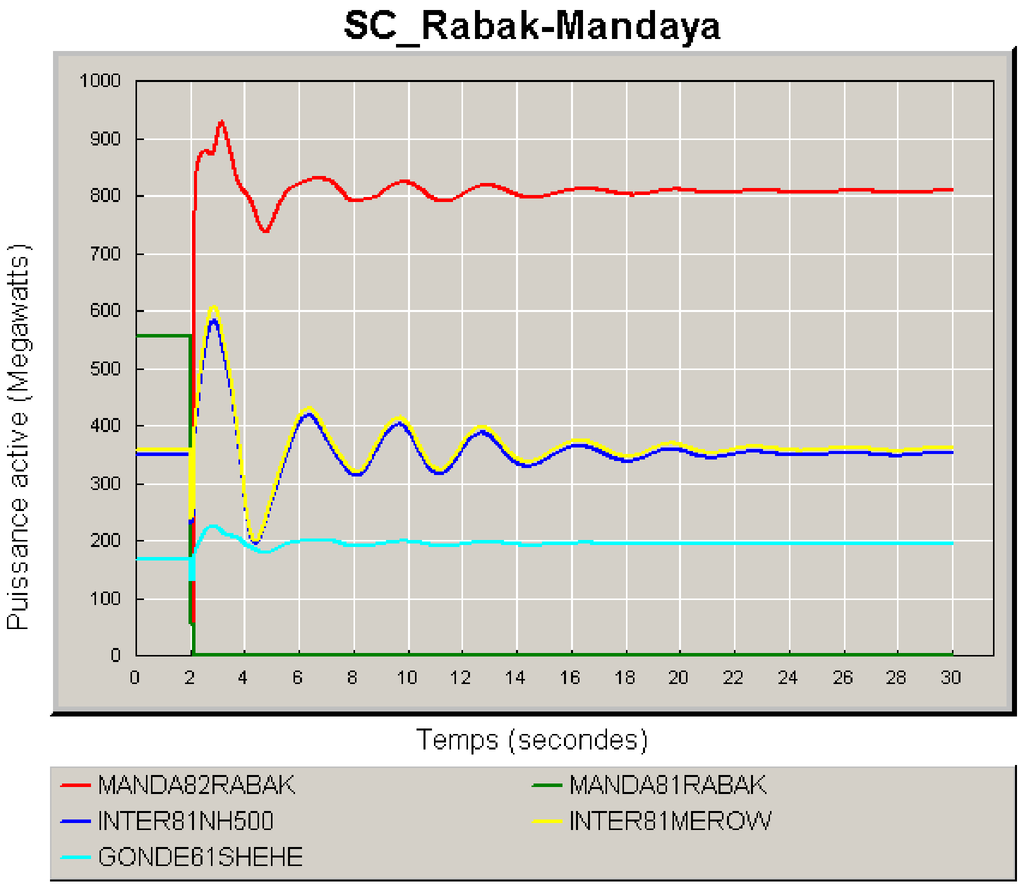


2.7 SHORT-CIRCUIT AT RABAK ON RABAK - MANDAYA

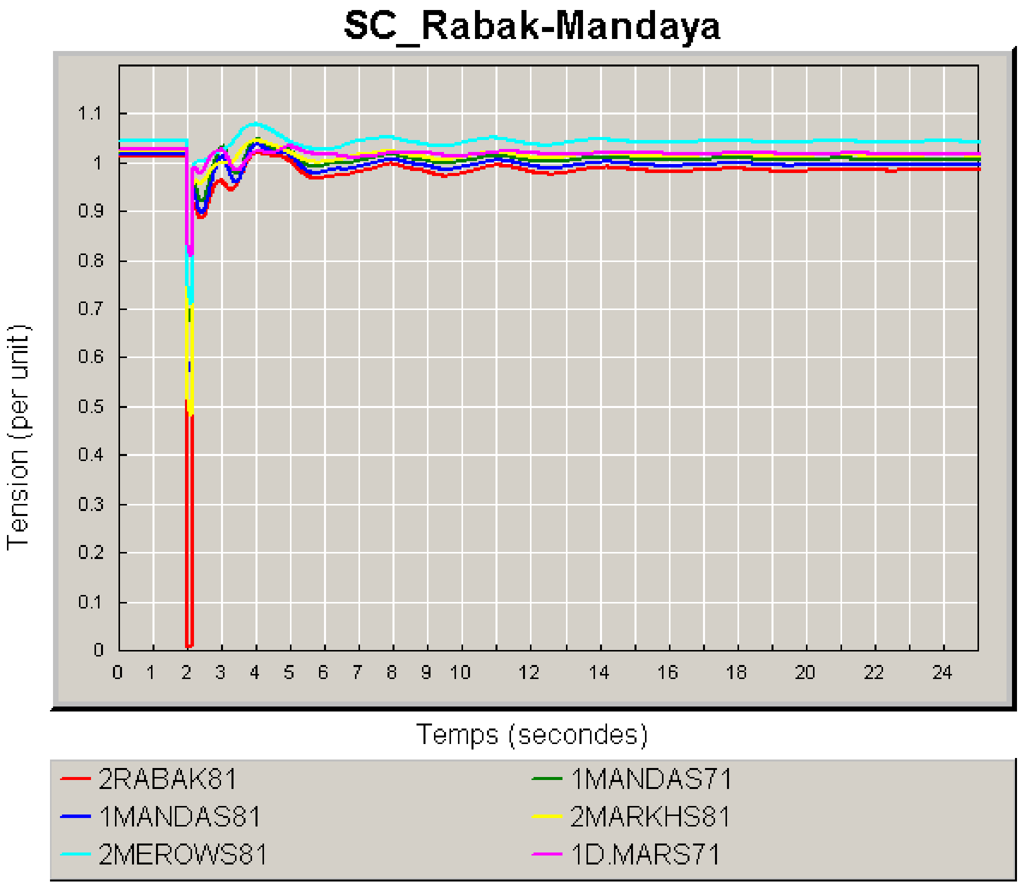
2.7.1 GENERATORS FREQUENCY VARIATION



2.7.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION

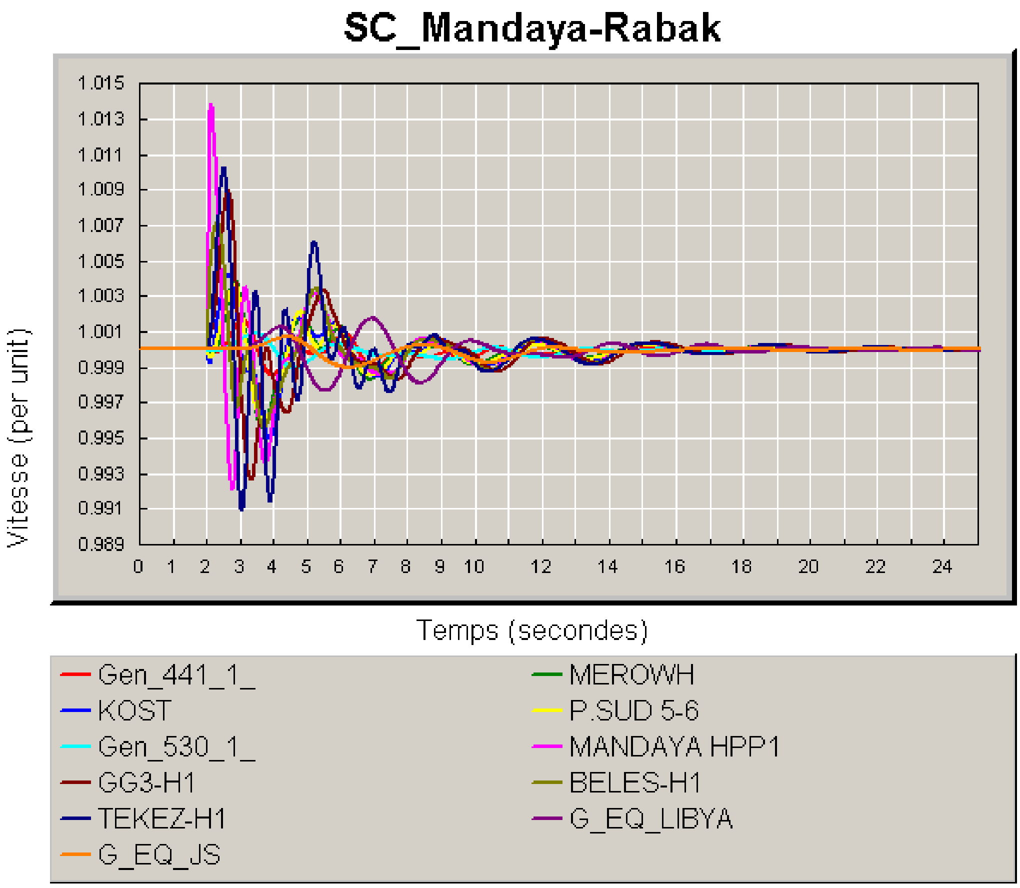


2.7.3 VOLTAGE VARIATION ON THE 500 KV

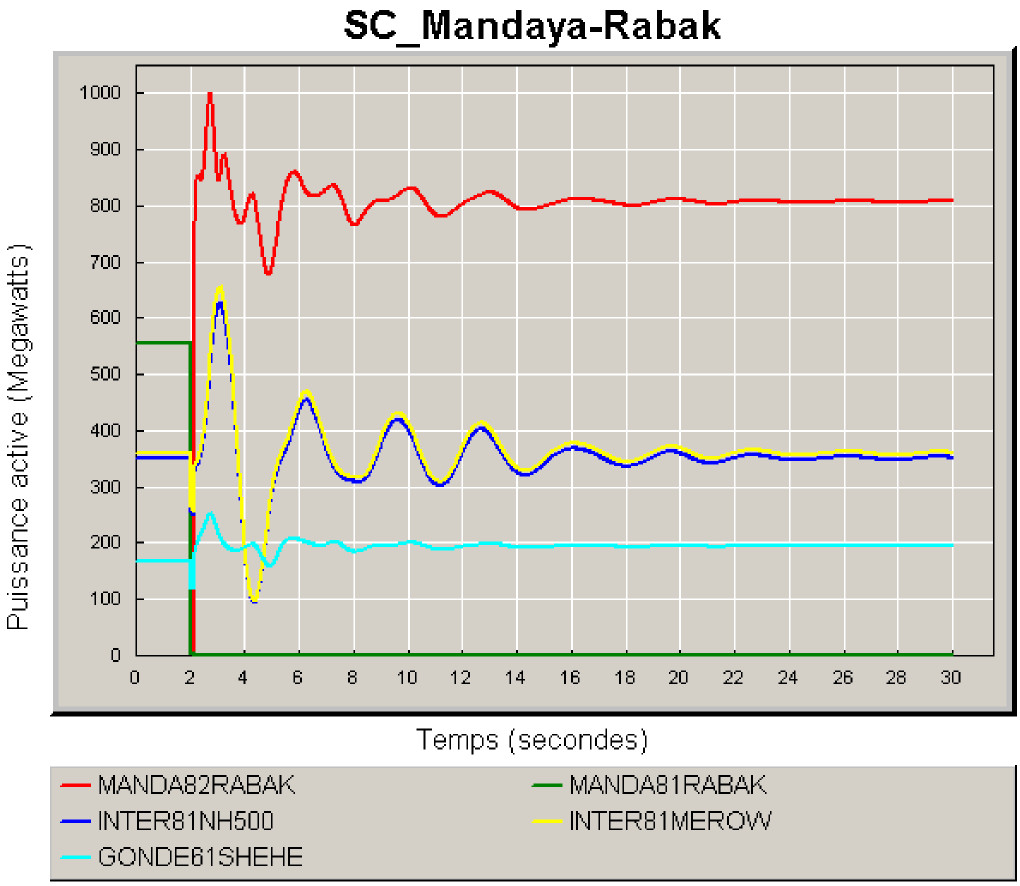


2.8 SHORT-CIRCUIT AT MANDAYA ON MANDAYA - RABAK

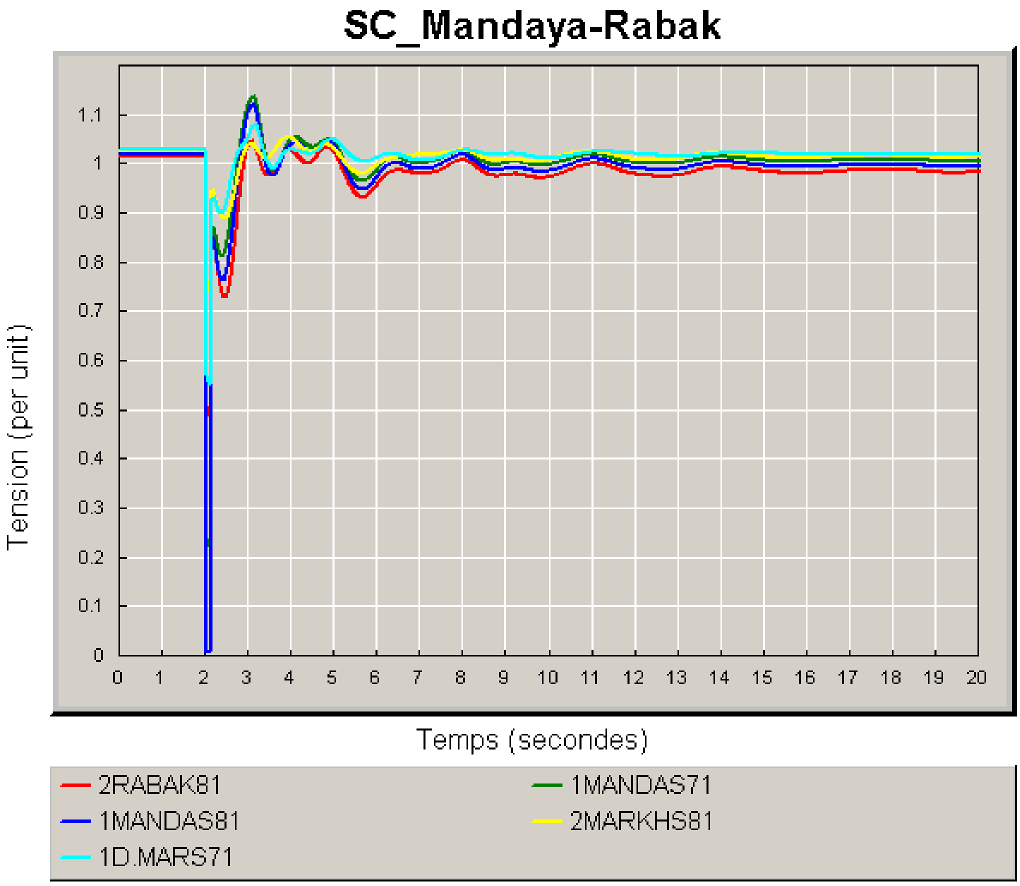
2.8.1 GENERATORS FREQUENCY VARIATION



2.8.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



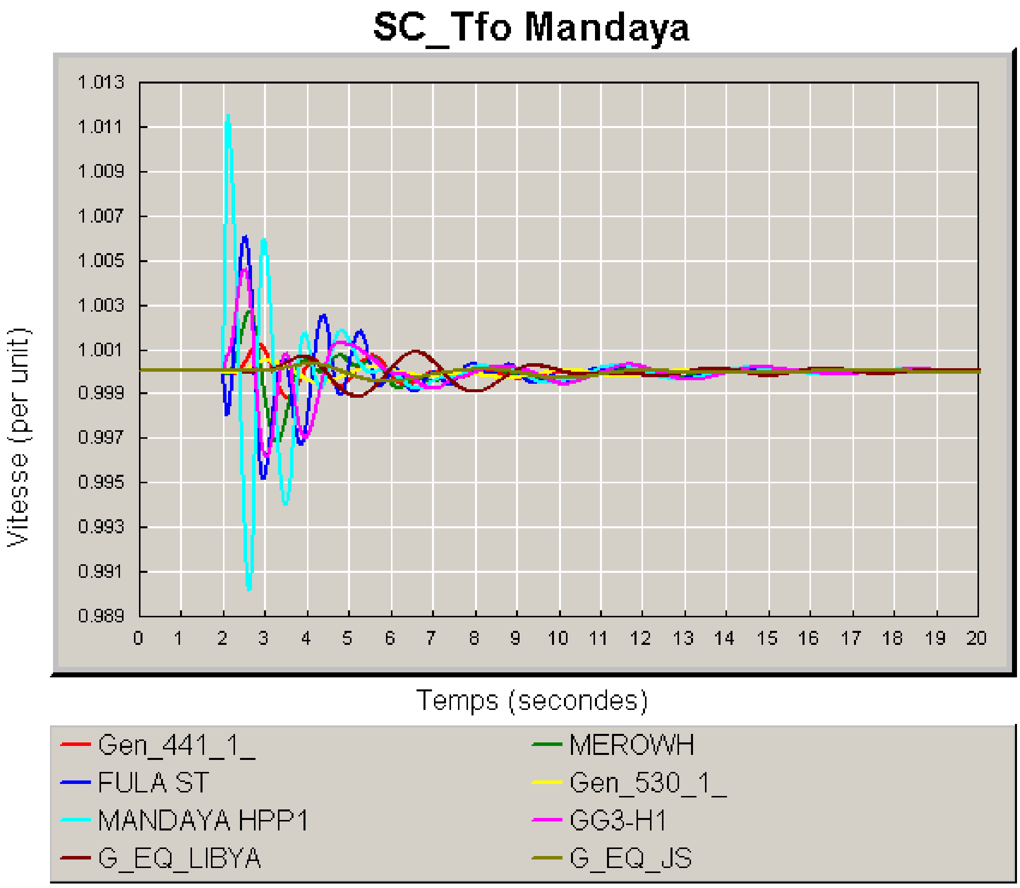
2.8.3 VOLTAGE VARIATION ON THE 500 KV



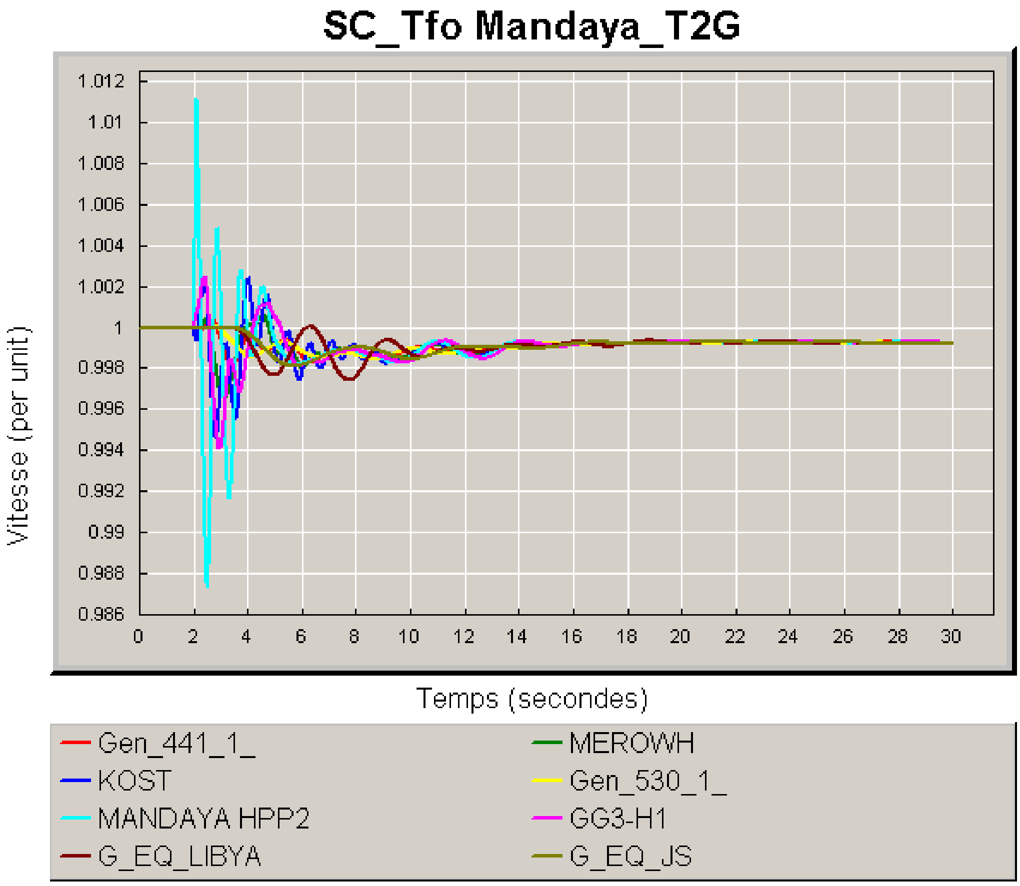
2.9 TRIPPING OF ONE OF THE THREE 400/500 KV TRANSFORMERS AT MANDAYA

2.9.1 GENERATORS FREQUENCY VARIATION

2.9.1.1 Without tripping 2 Mandaya units

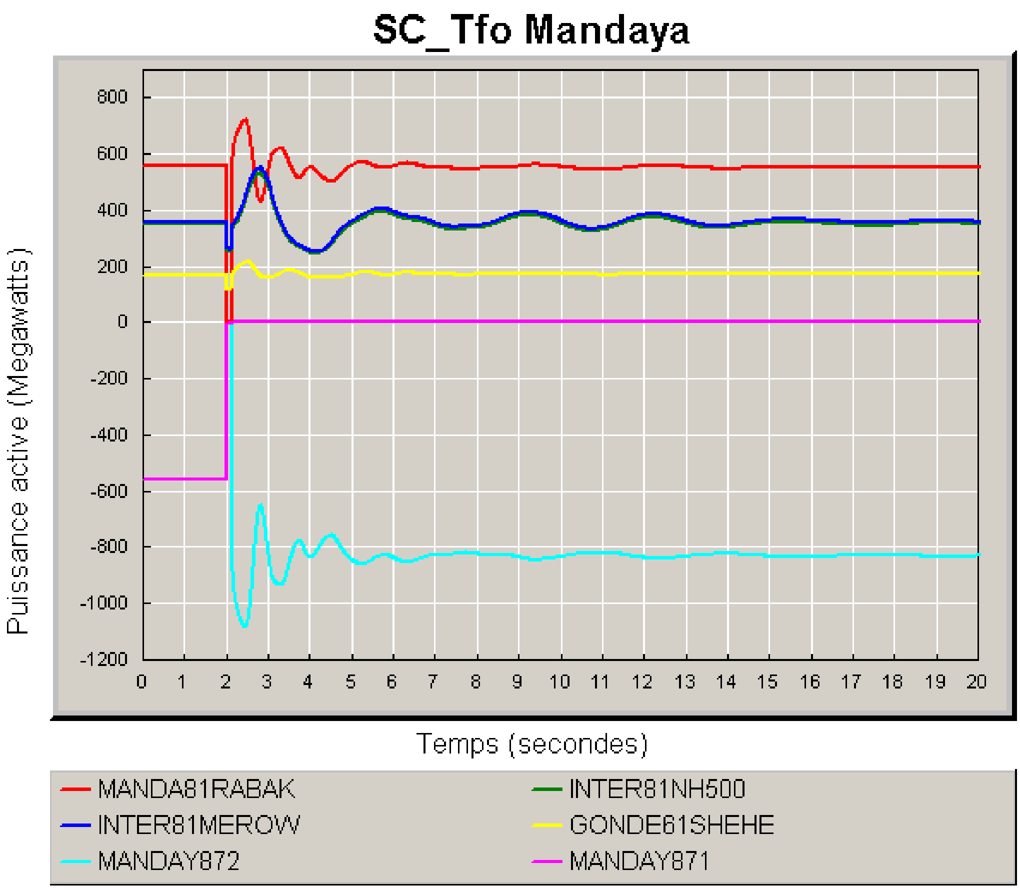


2.9.1.2 With the tripping of 2 Mandaya units

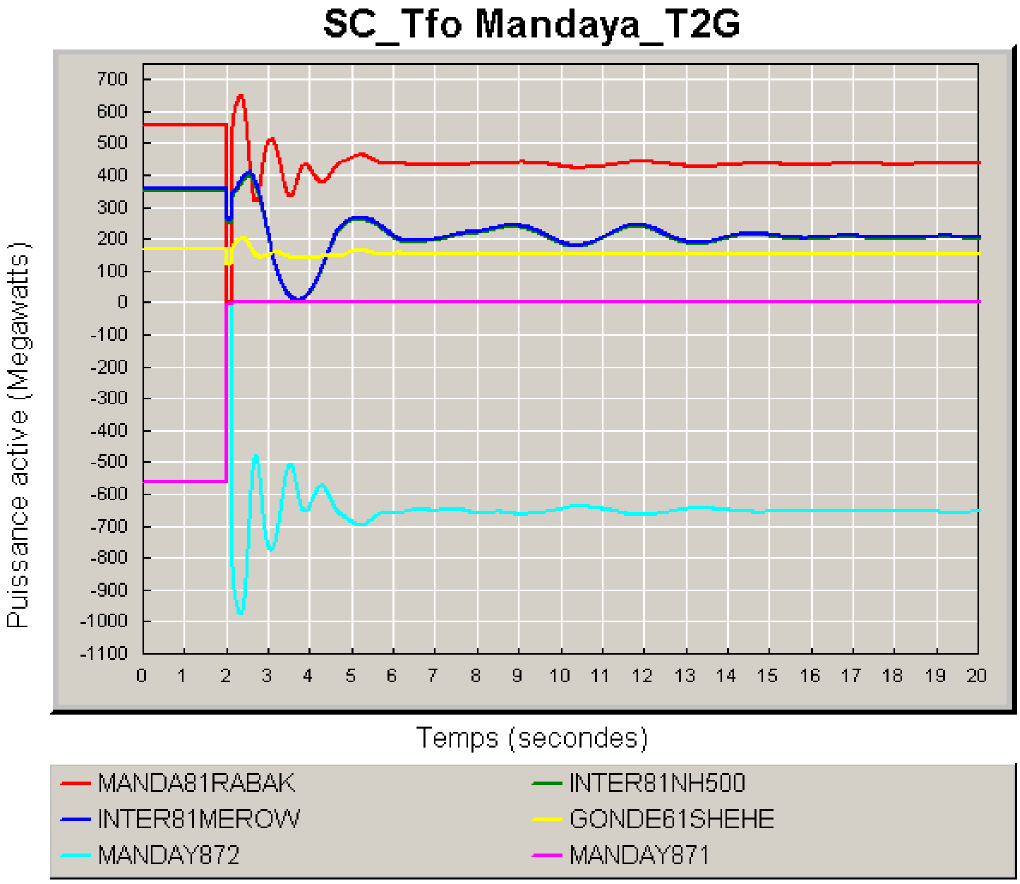


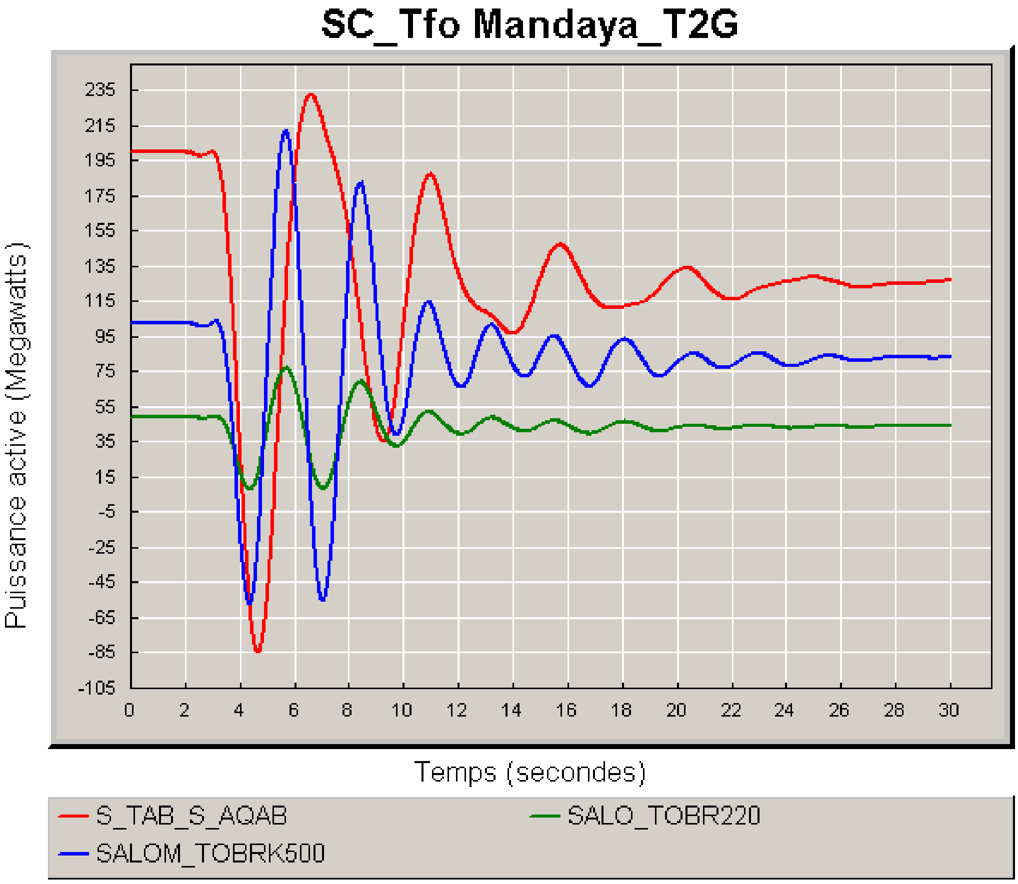
2.9.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION

2.9.2.1 Without tripping 2 Mandaya units



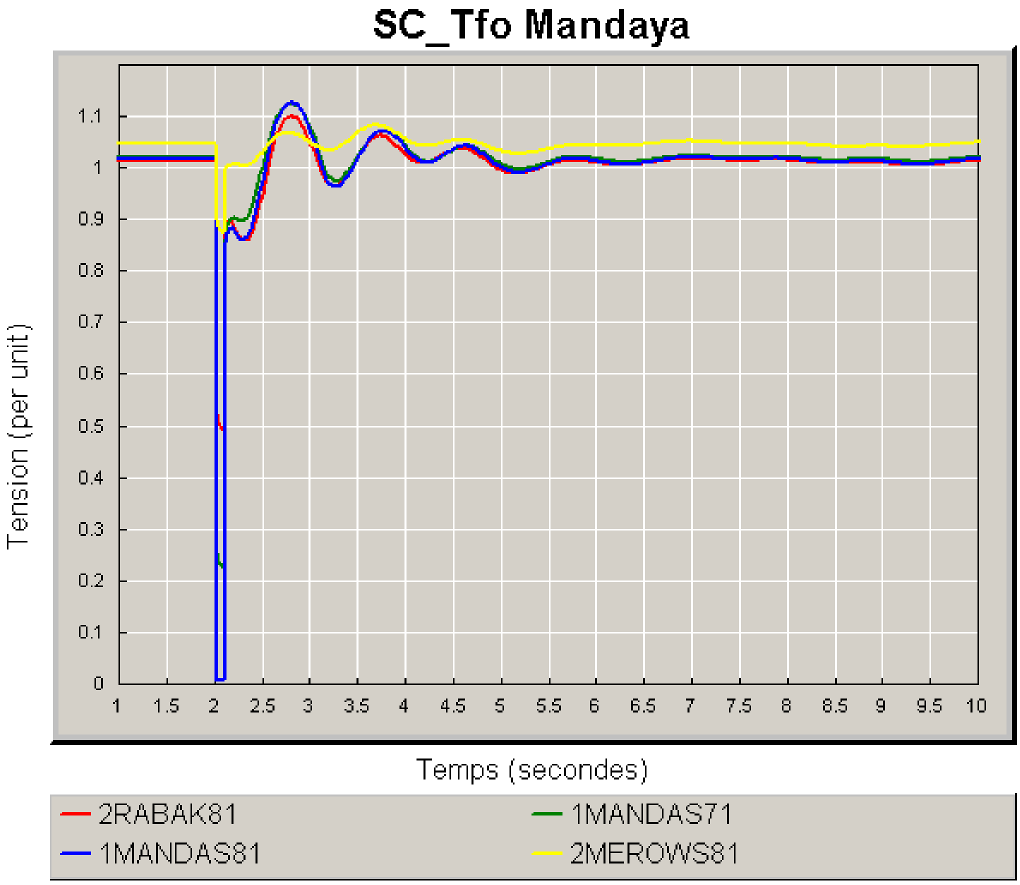
2.9.2.2 With the tripping of 2 Mandaya units



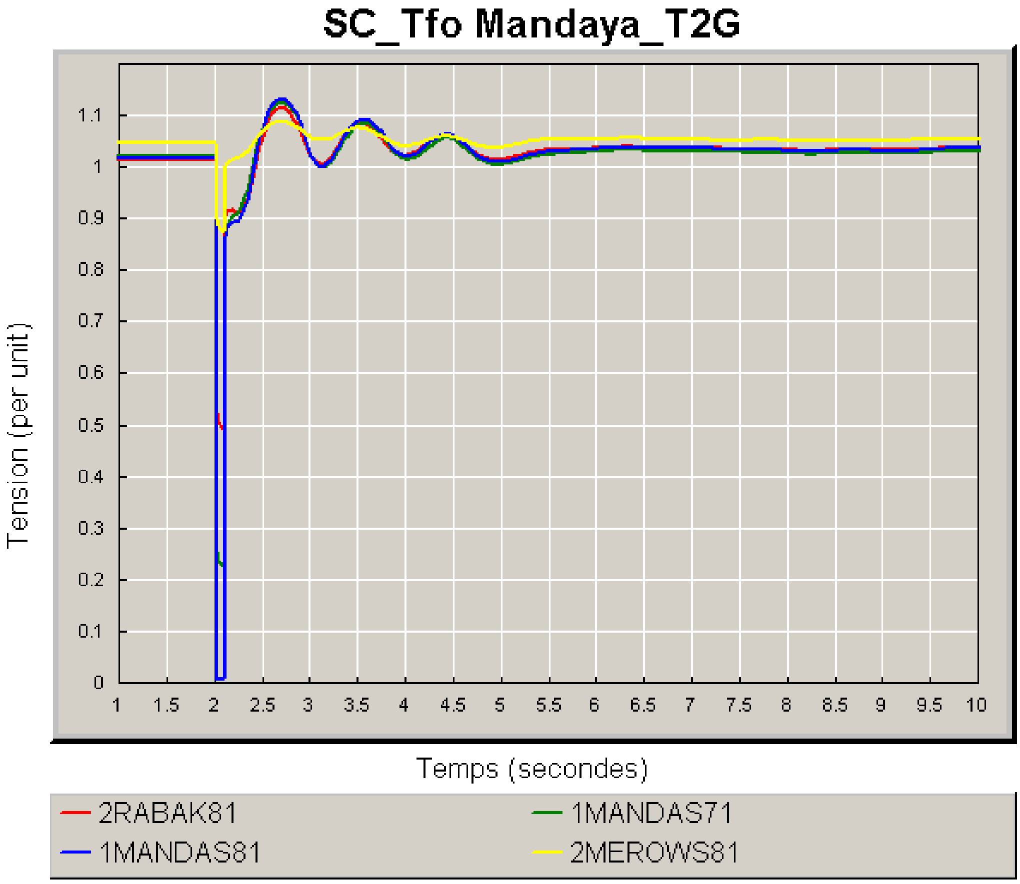

SC_Tfo Mandaya_T2G
Puissance active (Megawatts)
235
215
195
175
155
135
115
95
75
55
35
15
-5
-25
-45
-65
-85
-105
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Temps (secondes)
S_TAB_S_AQAB
SALO_TOBR220
SALOM_TOBRK500

2.9.3 VOLTAGE VARIATION ON THE 500 KV

2.9.3.1 Without tripping 2 Mandaya units



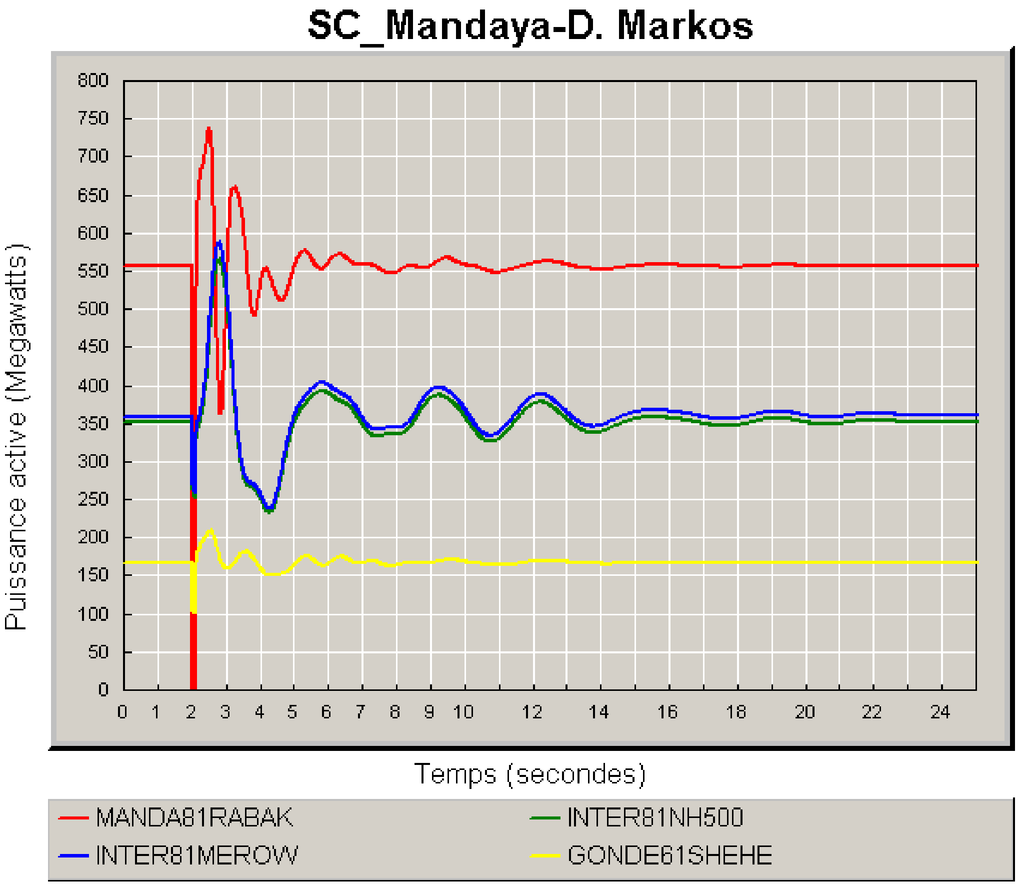
2.9.3.2 With the tripping of 2 Mandaya units



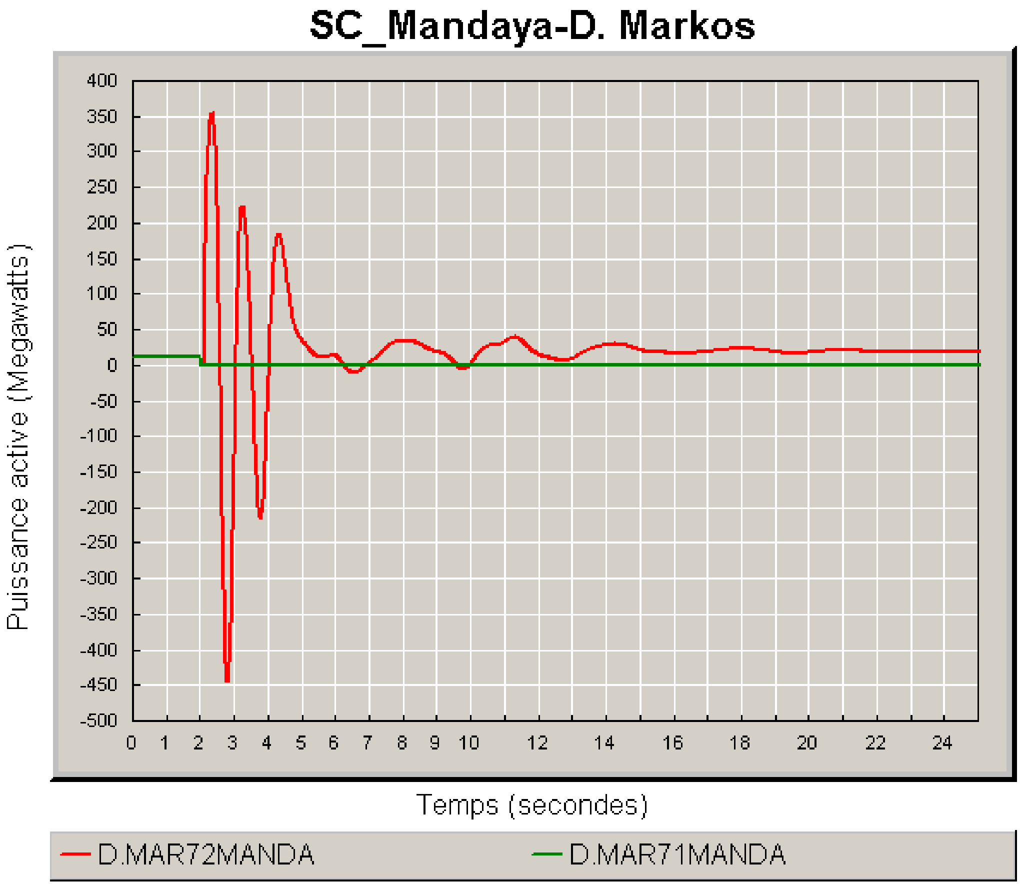
2.10 SHORT-CIRCUIT AT MANDAYA ON MANDAYA - DEBRE MARKOS

2.10.1 GENERATORS FREQUENCY VARIATION

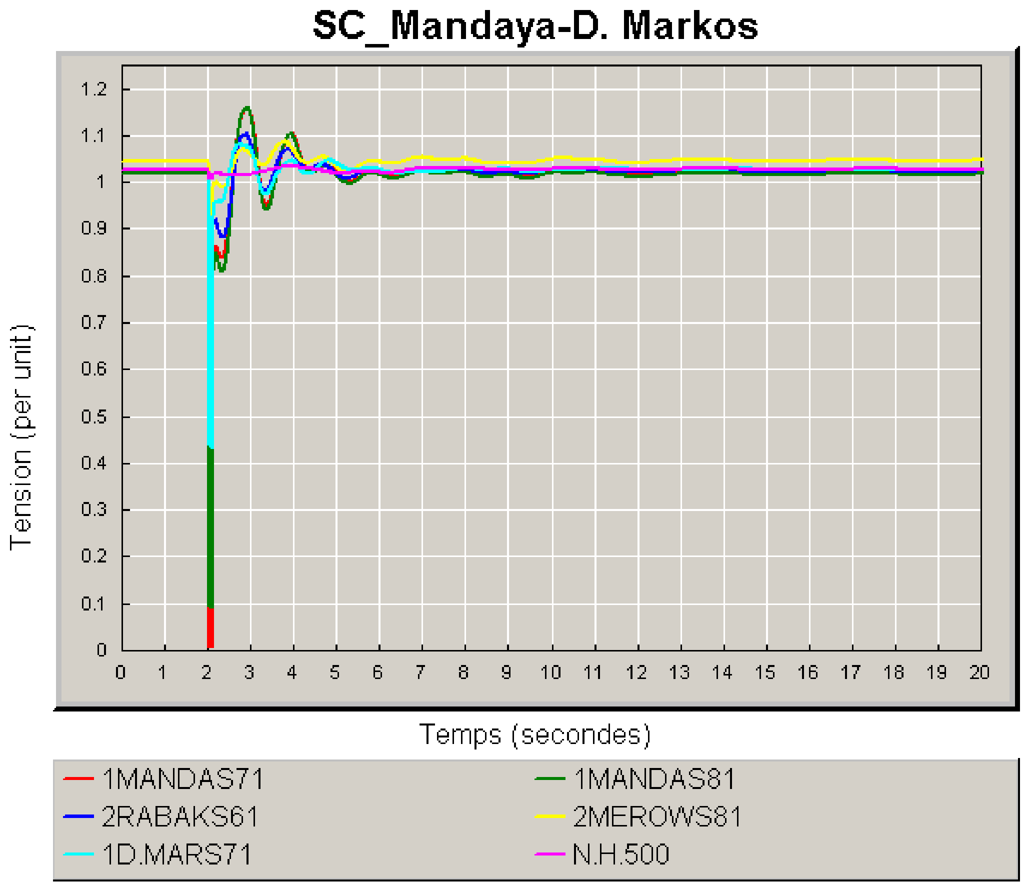
2.10.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



2.10.3 Power flow variation on the double circuit Mandaya - Debre Markos

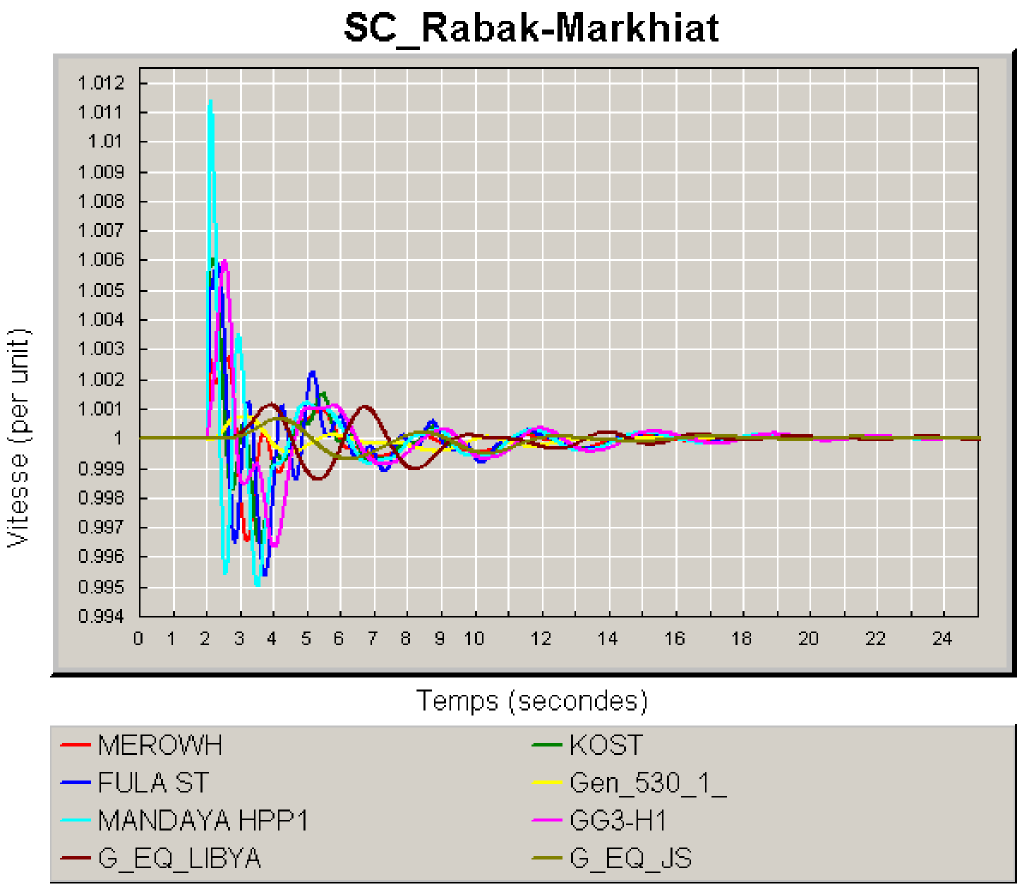


2.10.4 VOLTAGE VARIATION ON THE 500 KV

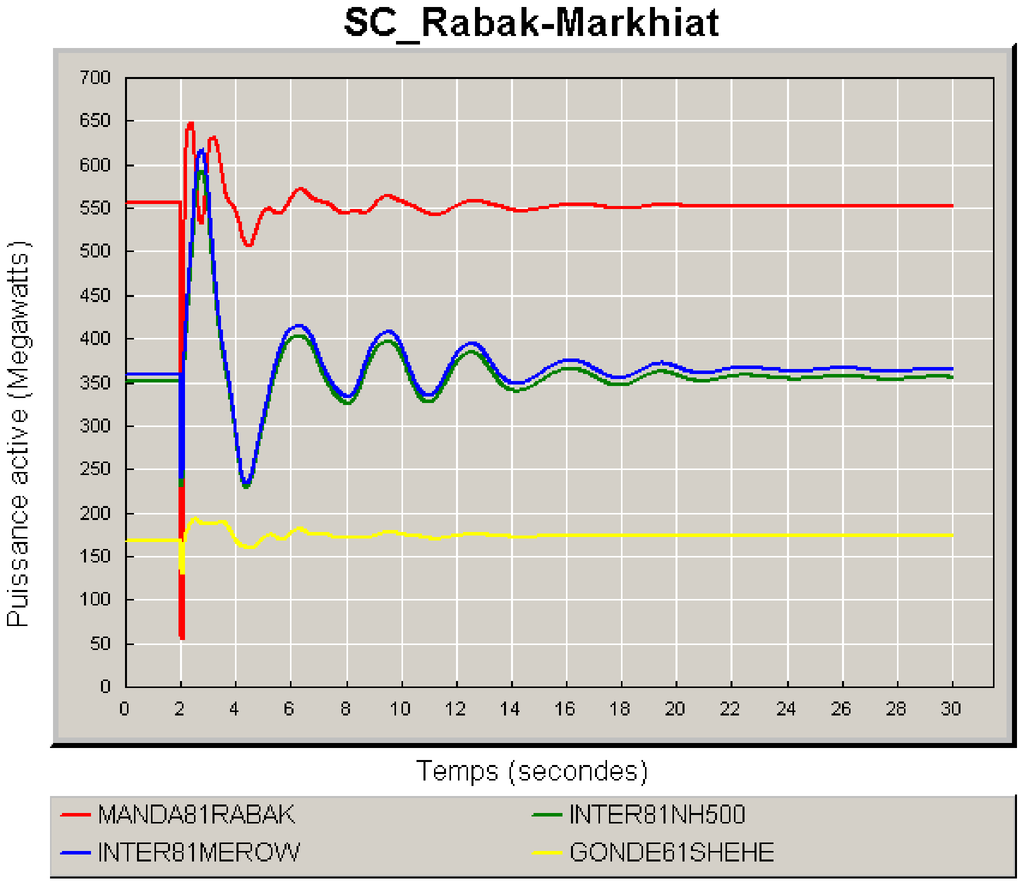


2.11 SHORT-CIRCUIT AT RABAK ON RABAK - MARKHIAT

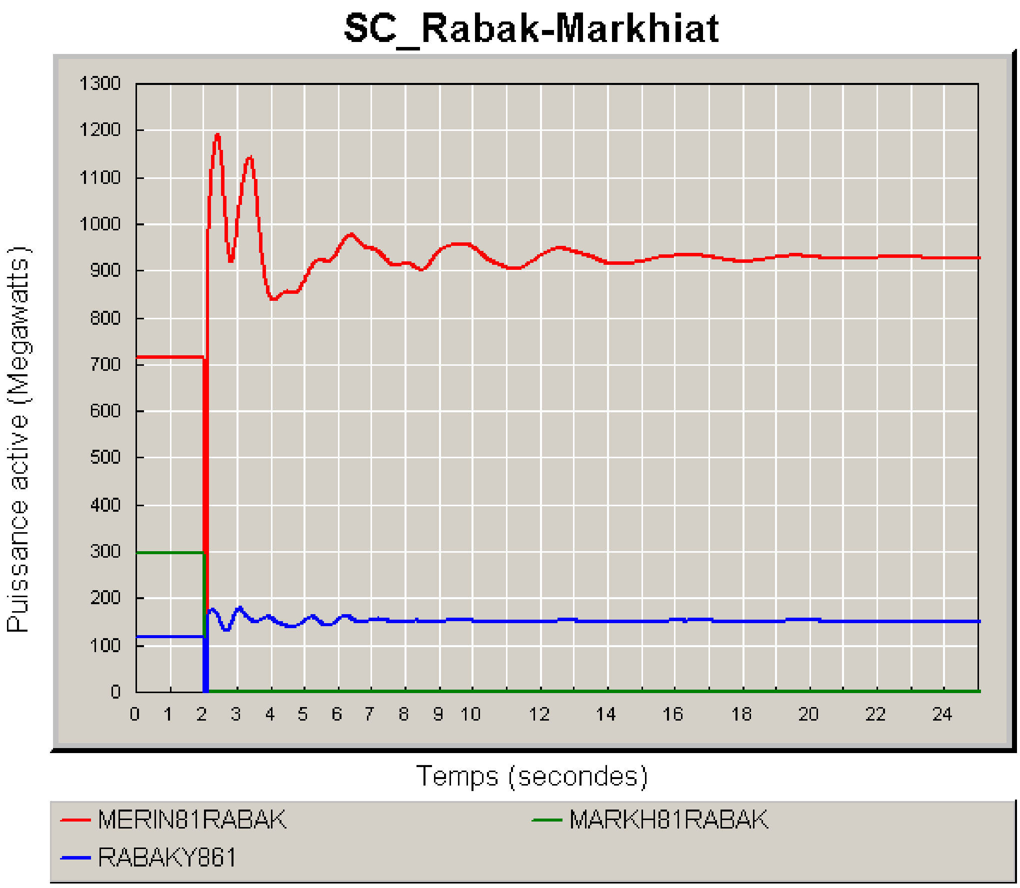
2.11.1 GENERATORS FREQUENCY VARIATION



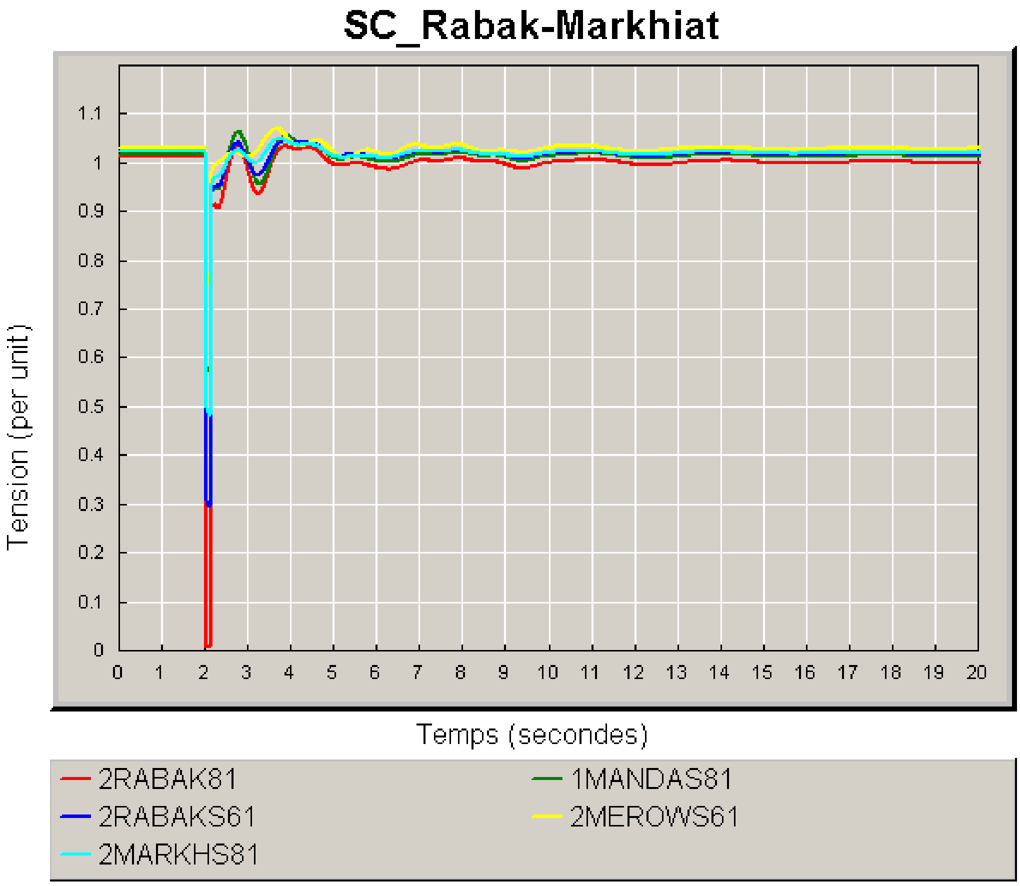
2.11.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



2.11.3 POWER FLOW VARIATION ON MARKHAIT - RABAK - MERINGAN AND THROUGH RABAK TRANSFORMERS

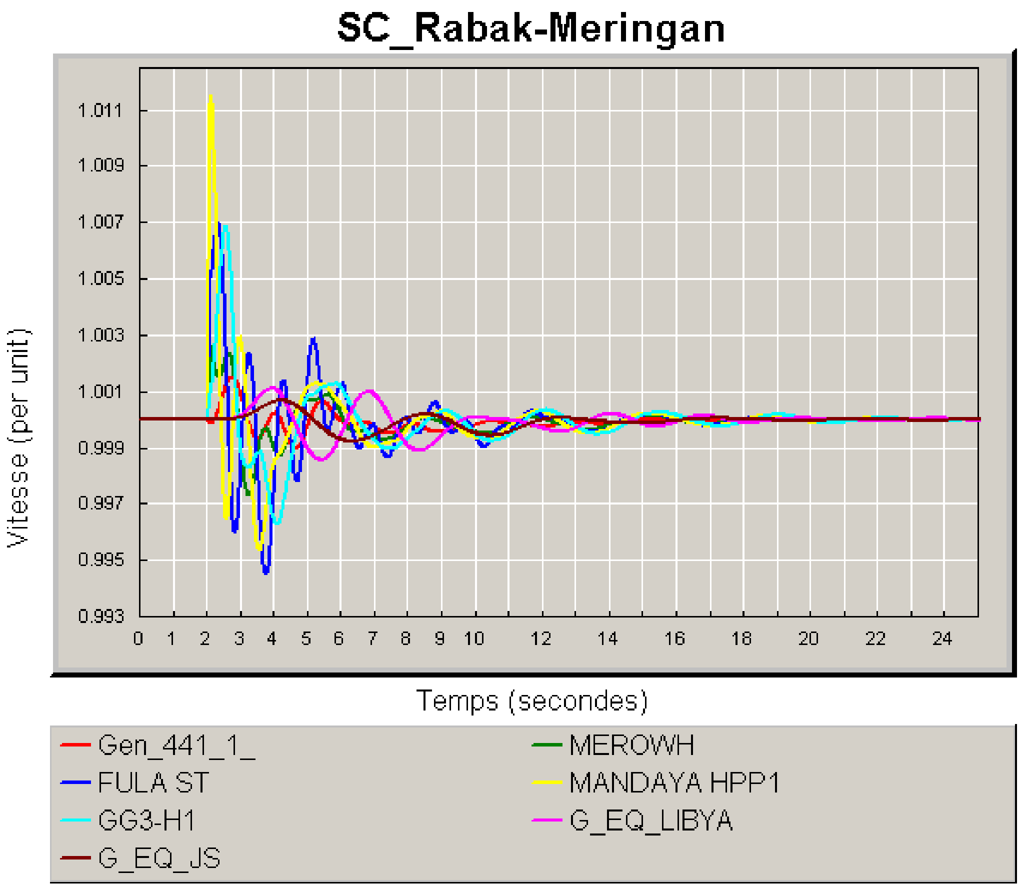


2.11.4 VOLTAGE VARIATION ON THE 500 KV

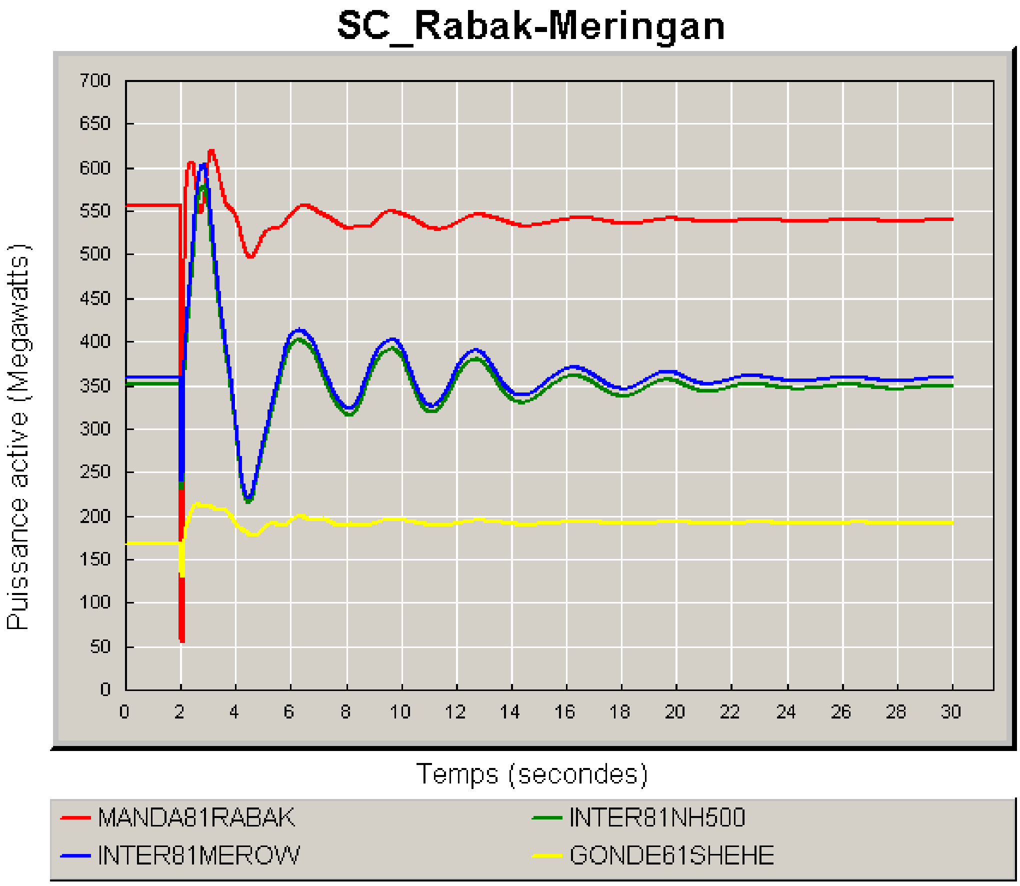


2.12 SHORT-CIRCUIT AT RABAK ON RABAK - MERINGAN

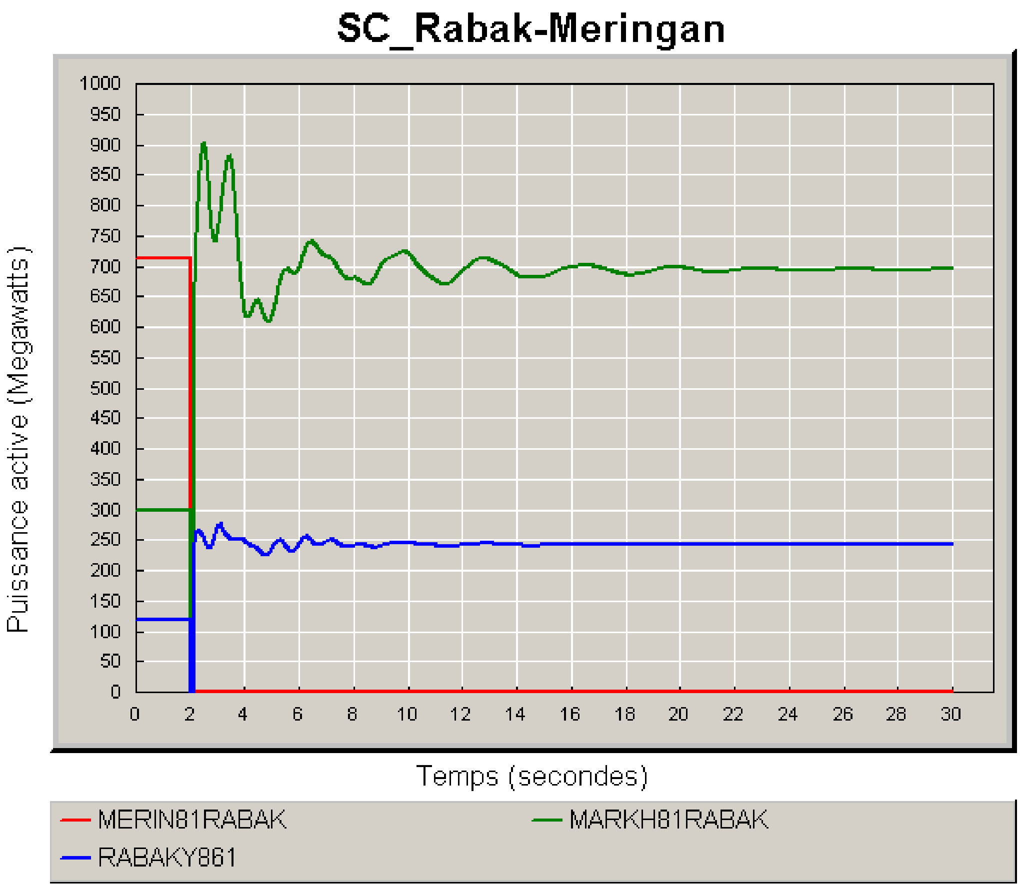
2.12.1 GENERATORS FREQUENCY VARIATION



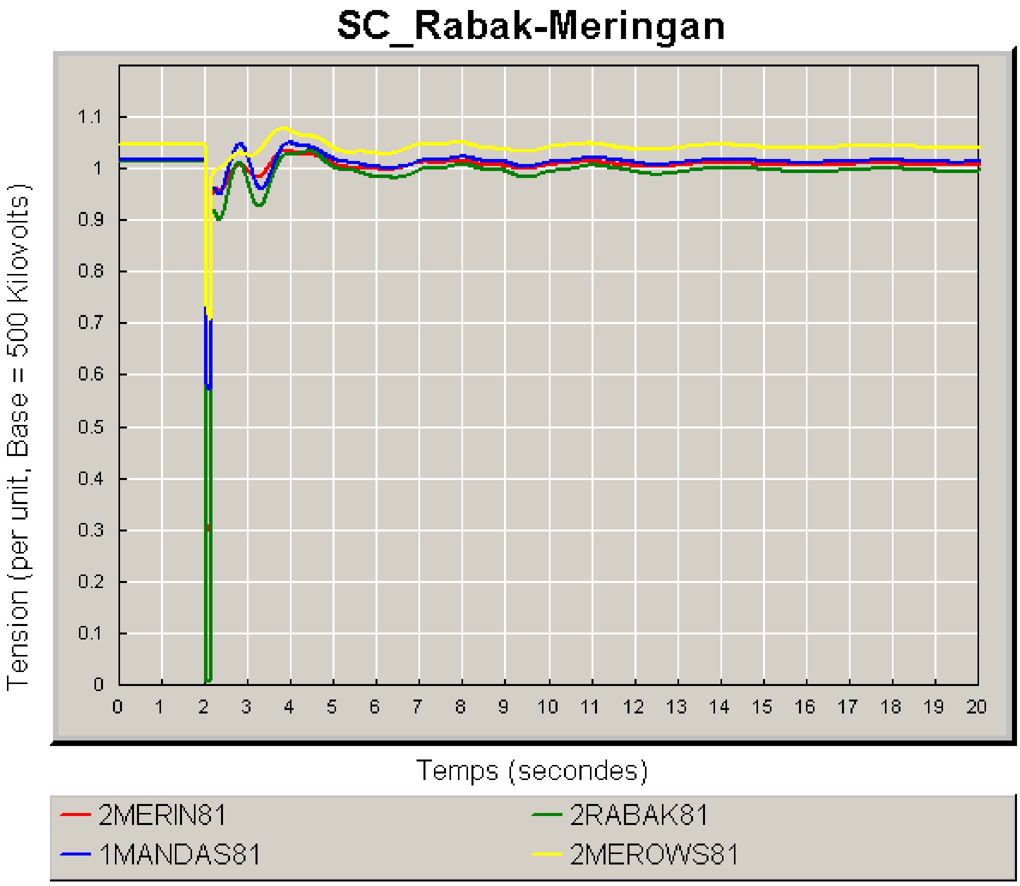
2.12.2 Power flow variation on ENTRO interconnection



2.12.3 Power flow variation on Markhait - Rabak - Meringan and through Rabak transformers

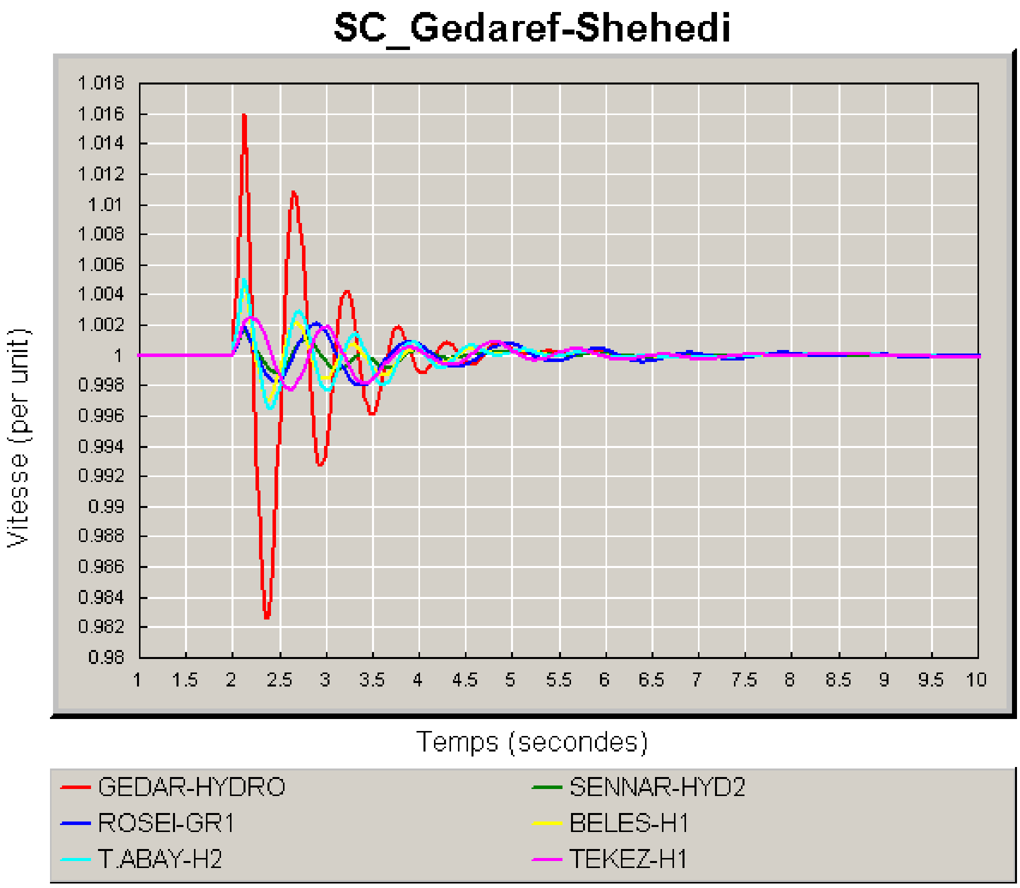


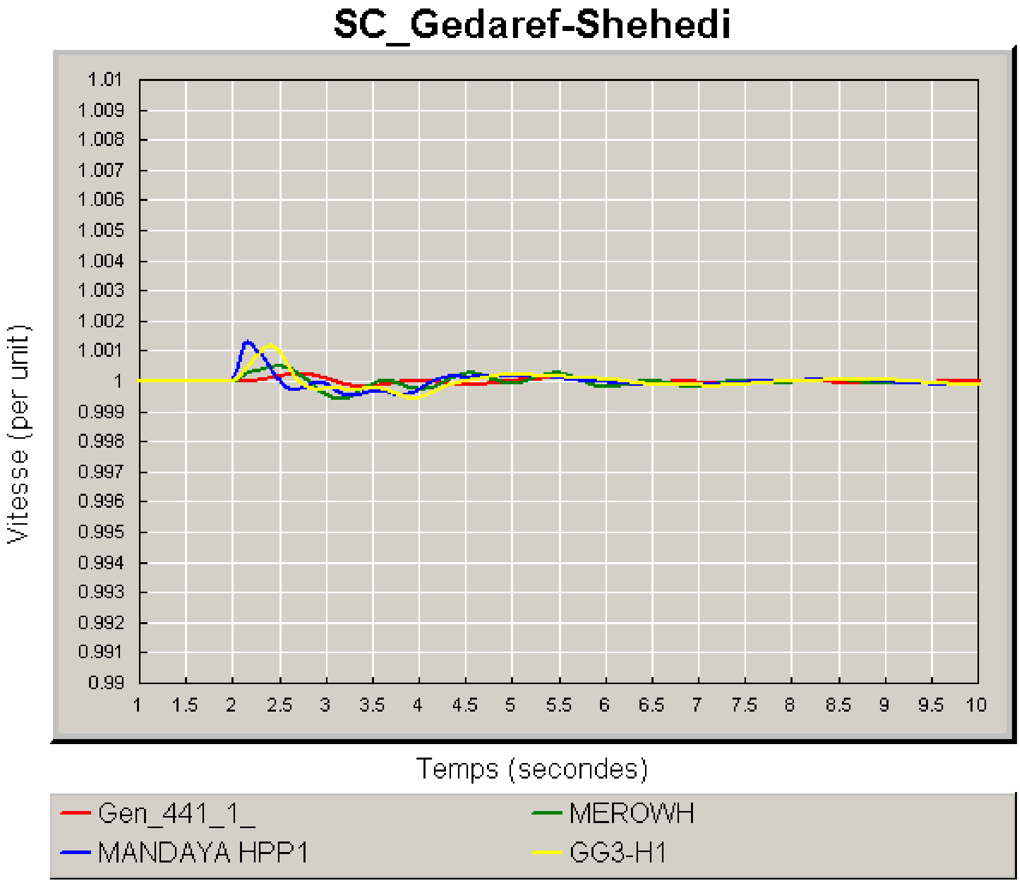
2.12.4 VOLTAGE VARIATION ON THE 500 KV



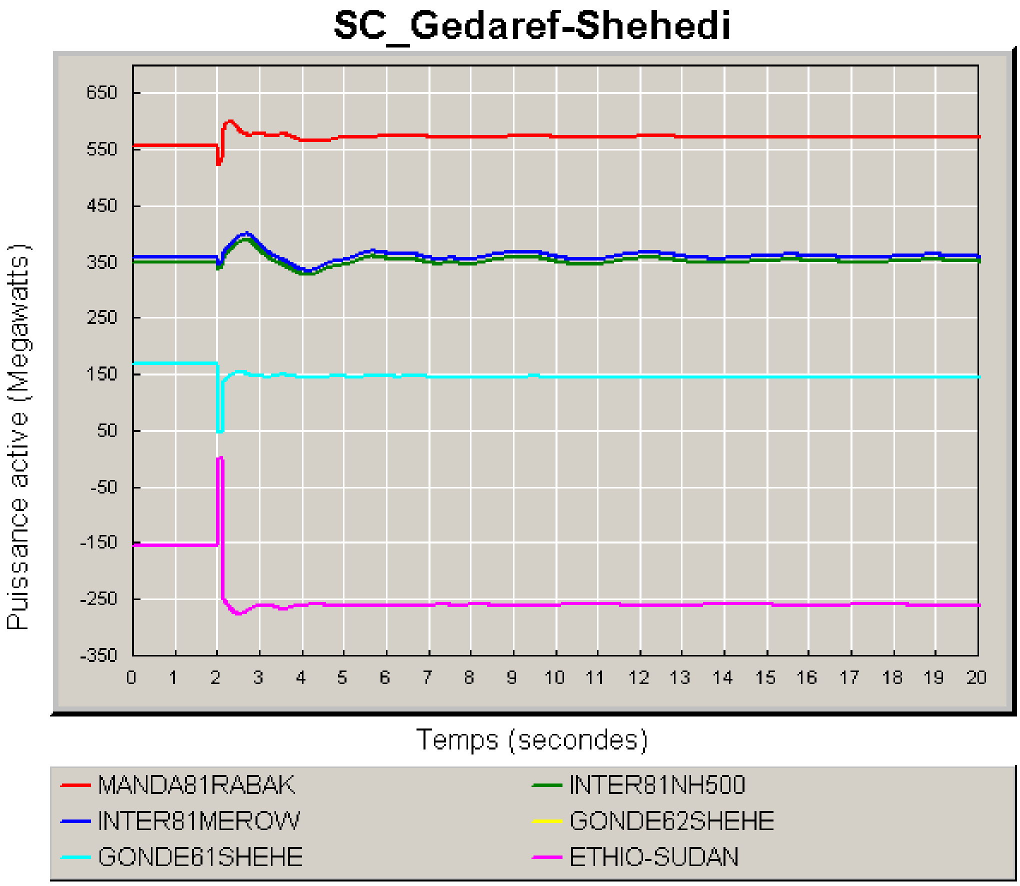
2.13 SHORT-CIRCUIT AT GEDAREF ON GEDAREF - SHEHEDI

2.13.1 GENERATORS FREQUENCY VARIATION

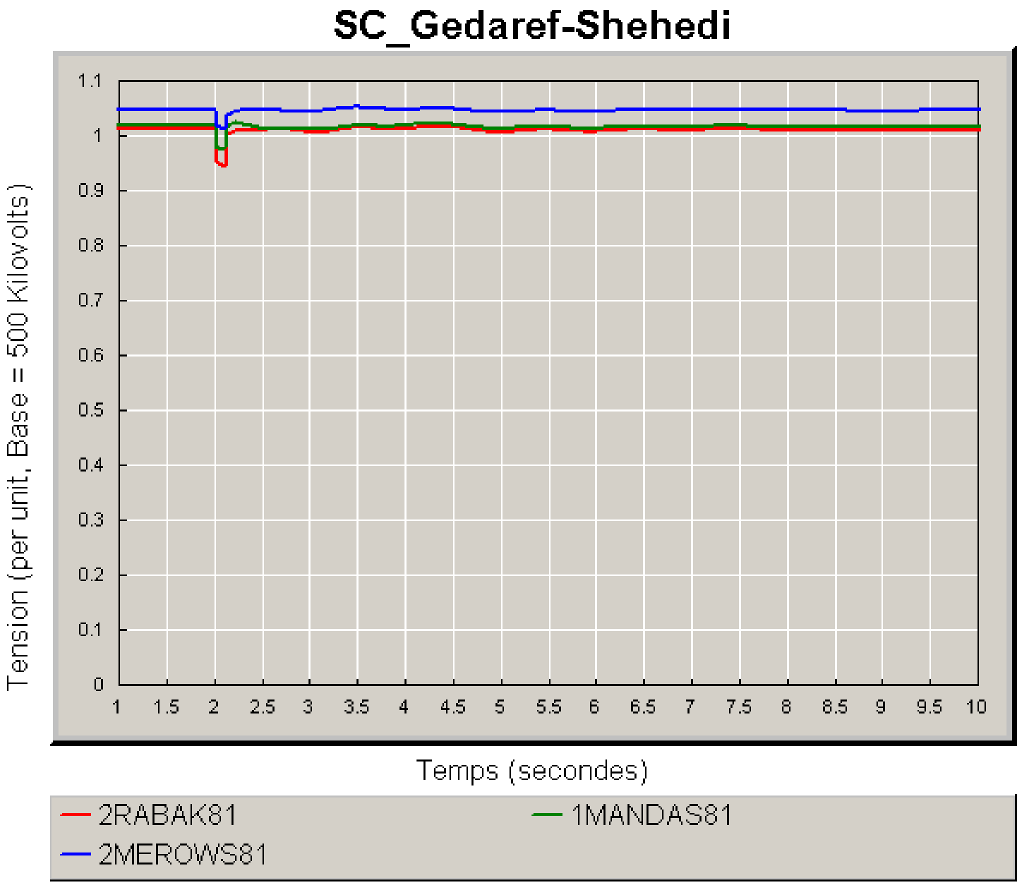



SC_Gedaref-Shehedi
Vitesse (per unit)
1.01
1.009
1.008
1.007
1.006
1.005
1.004
1.003
1.002
1.001
1
0.999
0.998
0.997
0.996
0.995
0.994
0.993
0.992
0.991
0.99
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
Temps (secondes)
Gen_441_1_
MEROWH
MANDAYA HPP1
GG3-H1

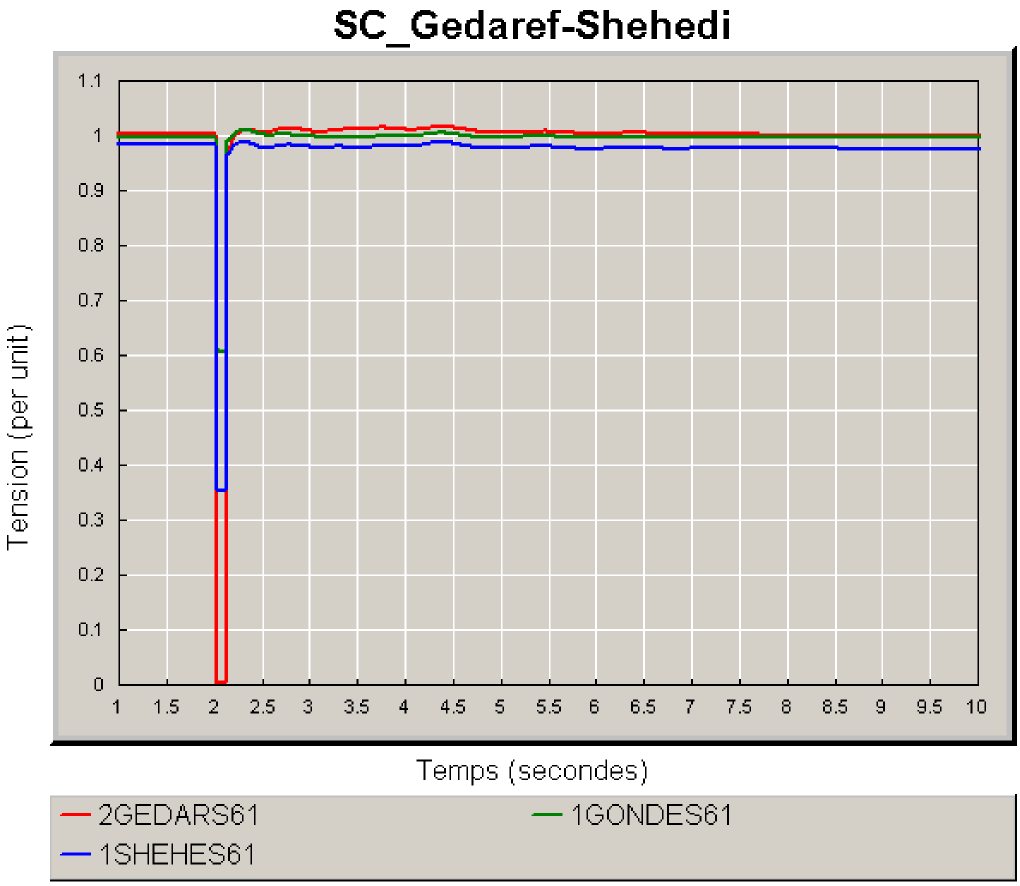
2.13.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



2.13.3 VOLTAGE VARIATION ON THE 500 KV

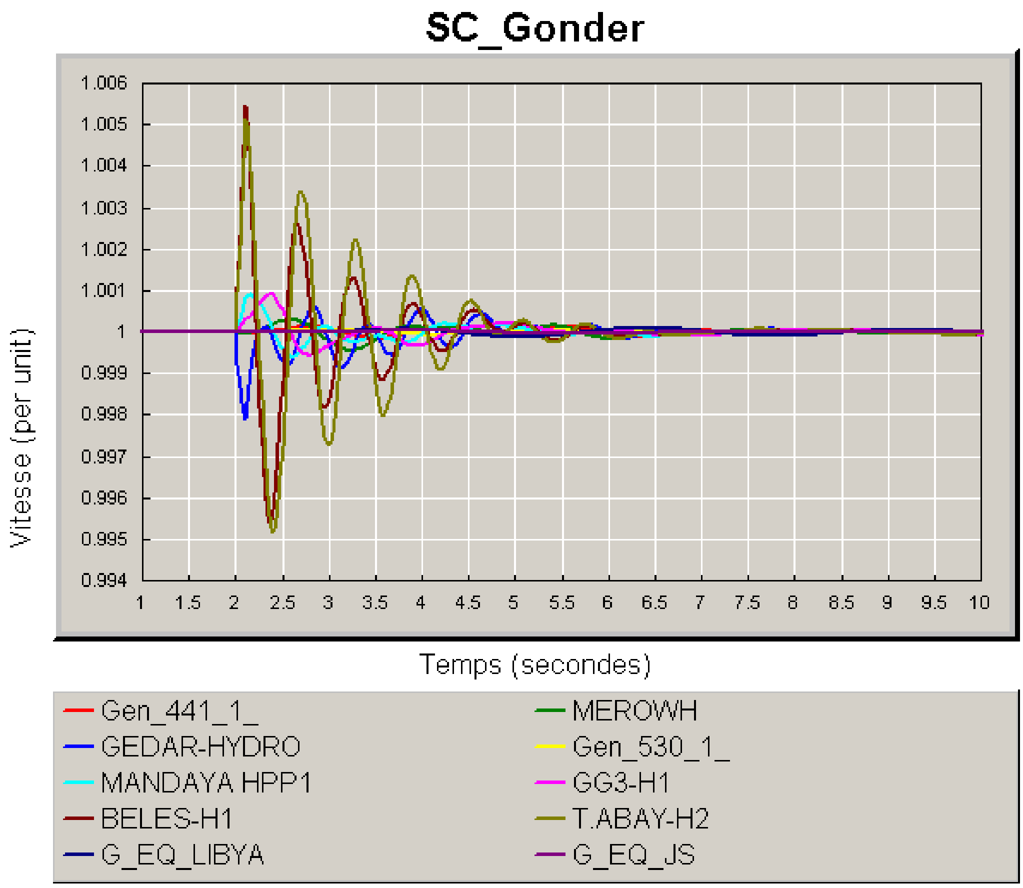


2.13.4 VOLTAGE VARIATION ON THE 220 KV

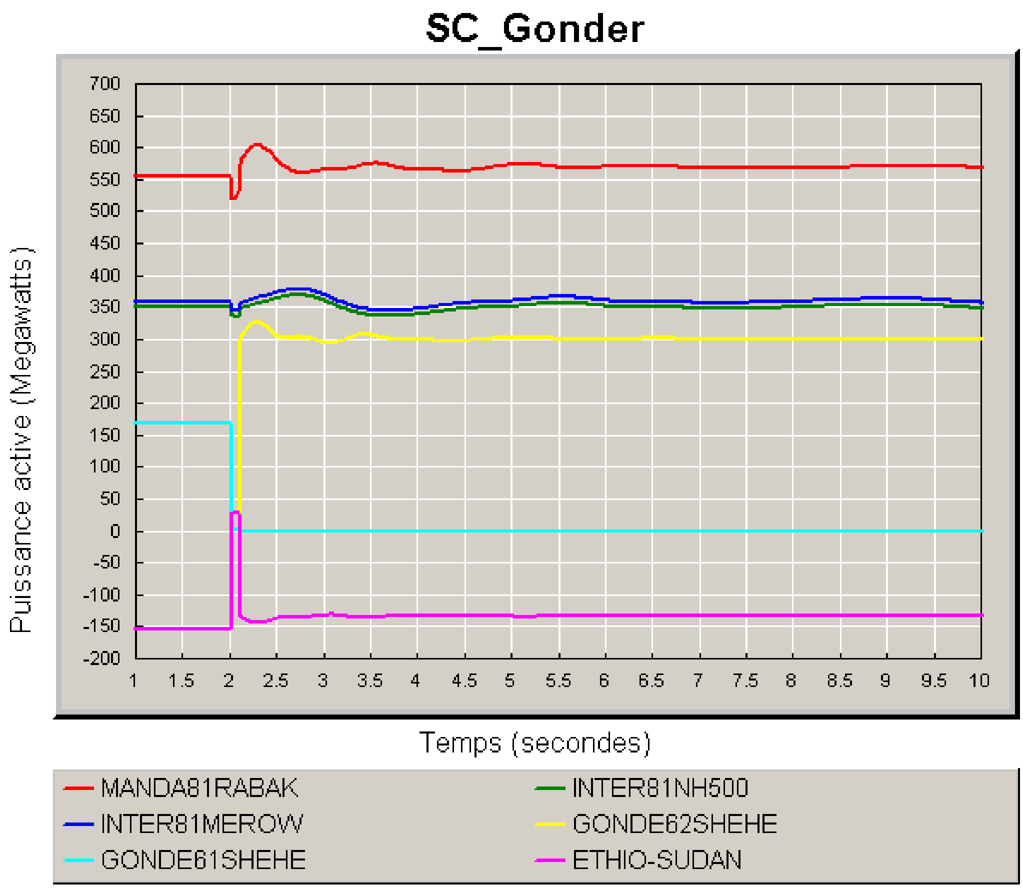


2.14 SHORT-CIRCUIT AT GONDER ON GONDER - SHEHEDI

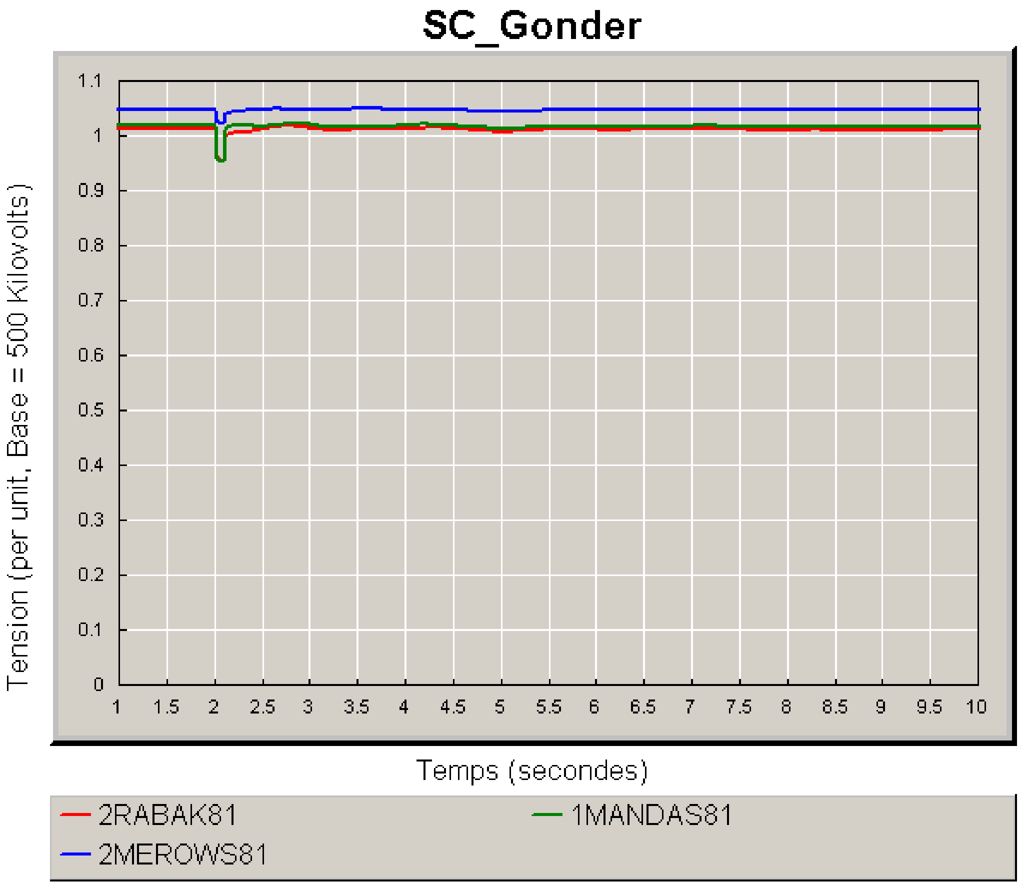
2.14.1 GENERATORS FREQUENCY VARIATION



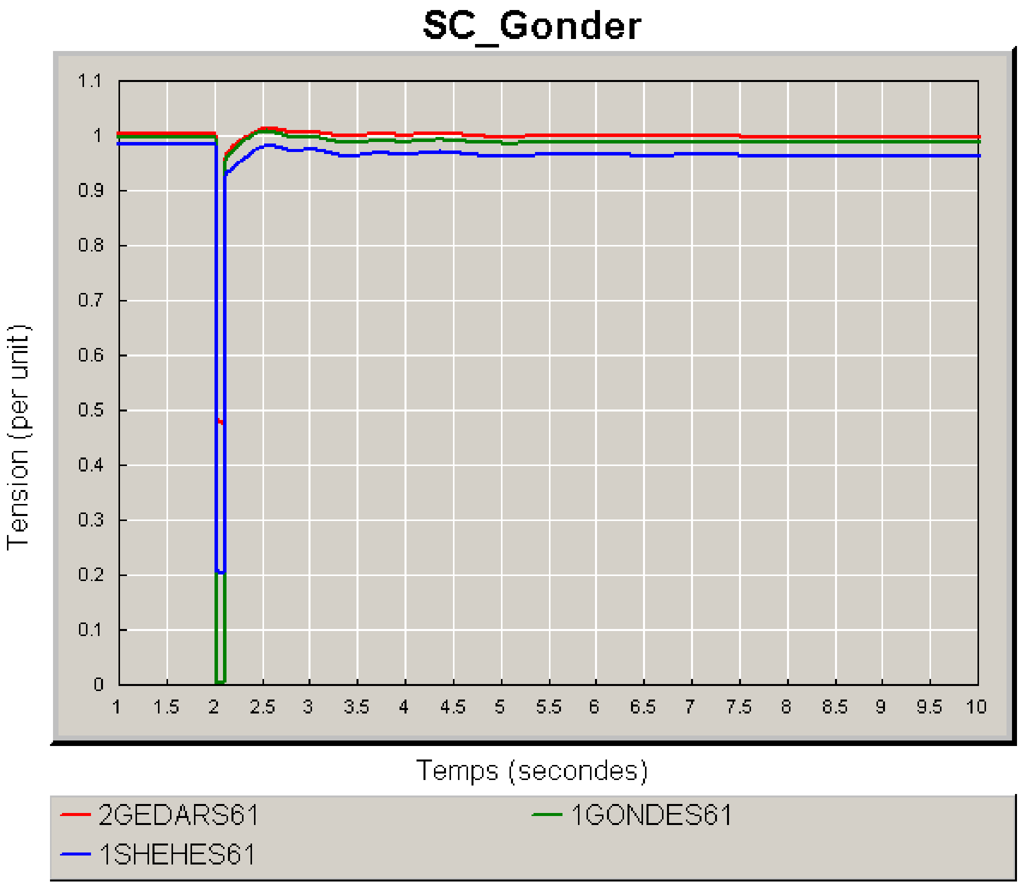
2.14.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



2.14.3 VOLTAGE VARIATION ON THE 500 KV

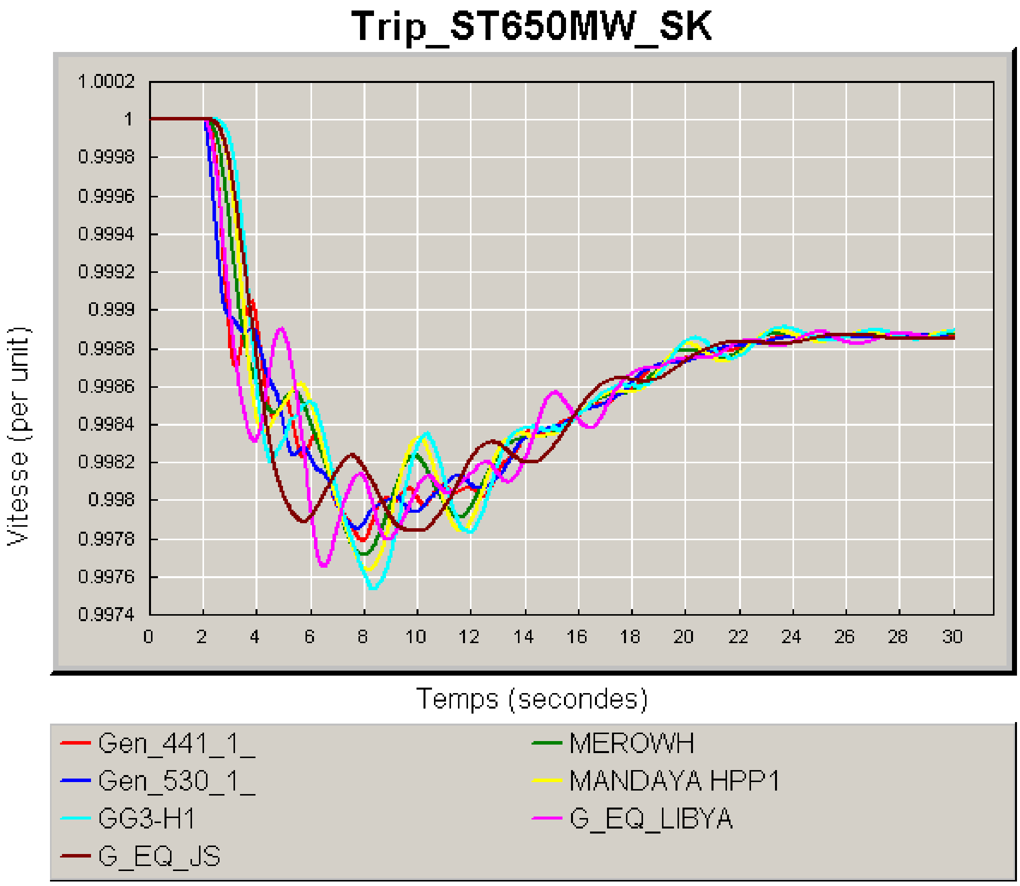


2.14.4 VOLTAGE VARIATION ON THE 220 KV

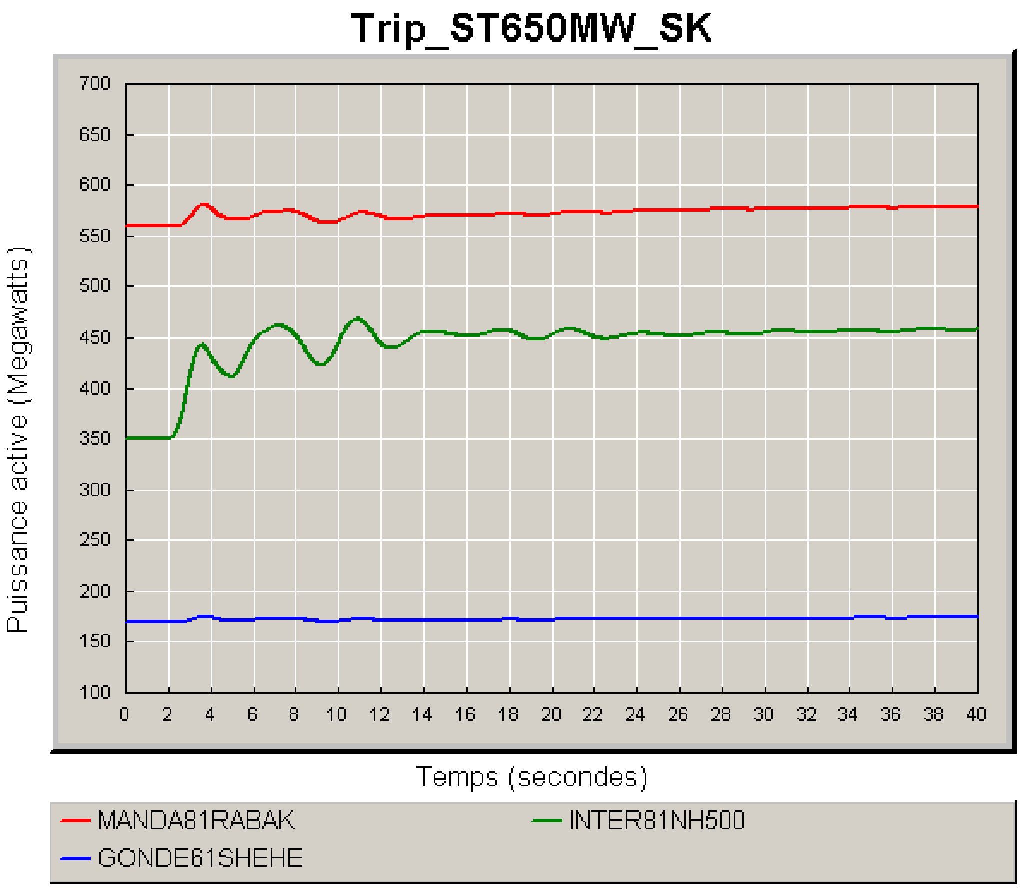


2.15 TRIPPING OF THE MAIN UNIT IN EGYPT : SIDI KRIR 650 MW STEAM TURBINE

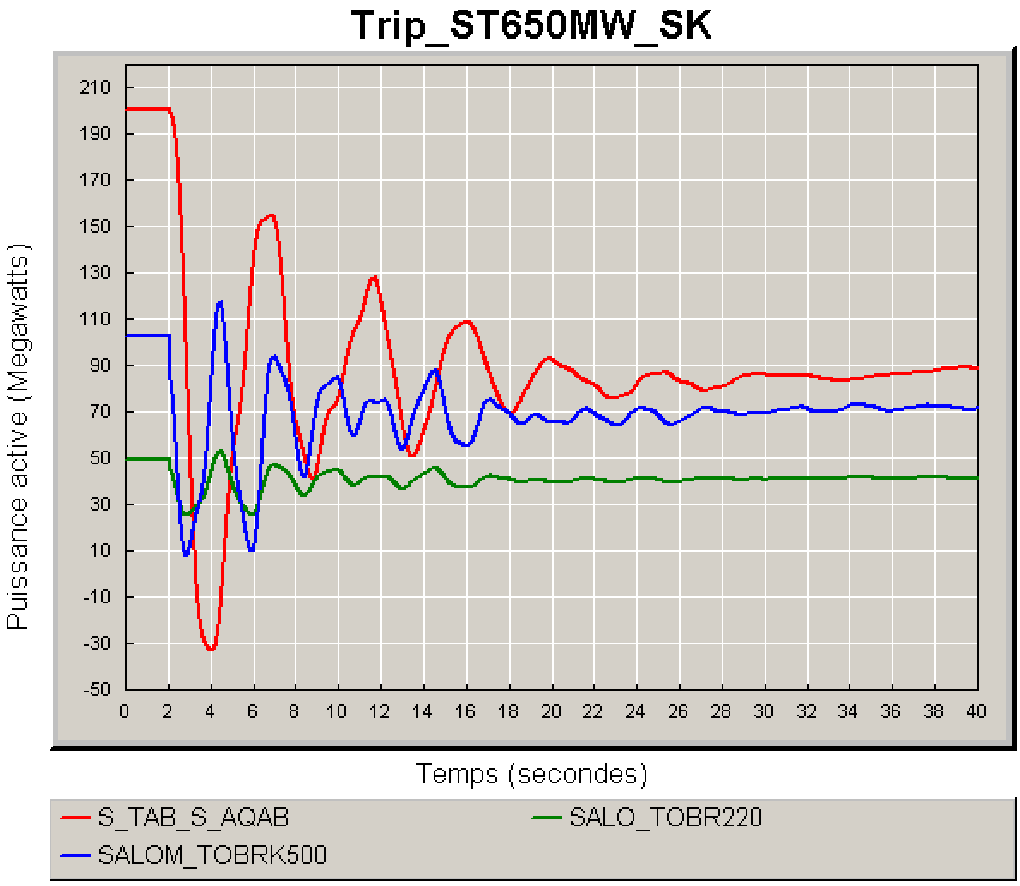
2.15.1 GENERATORS FREQUENCY VARIATION



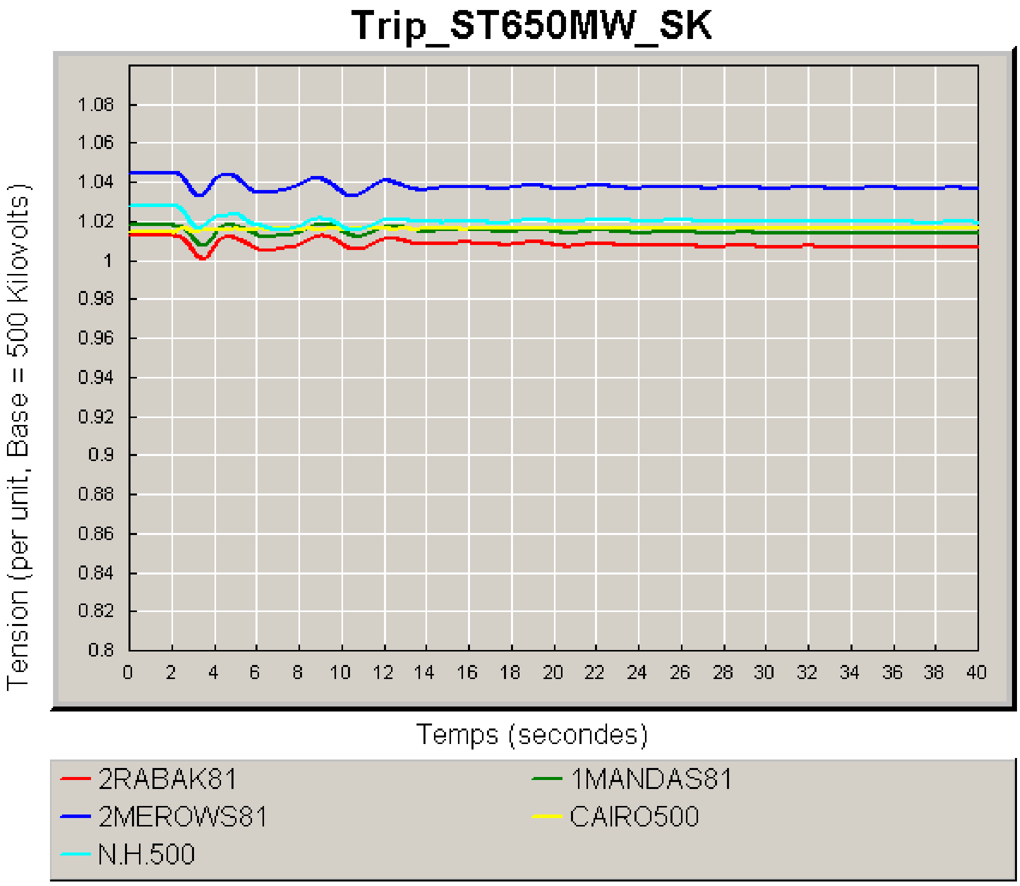
2.15.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



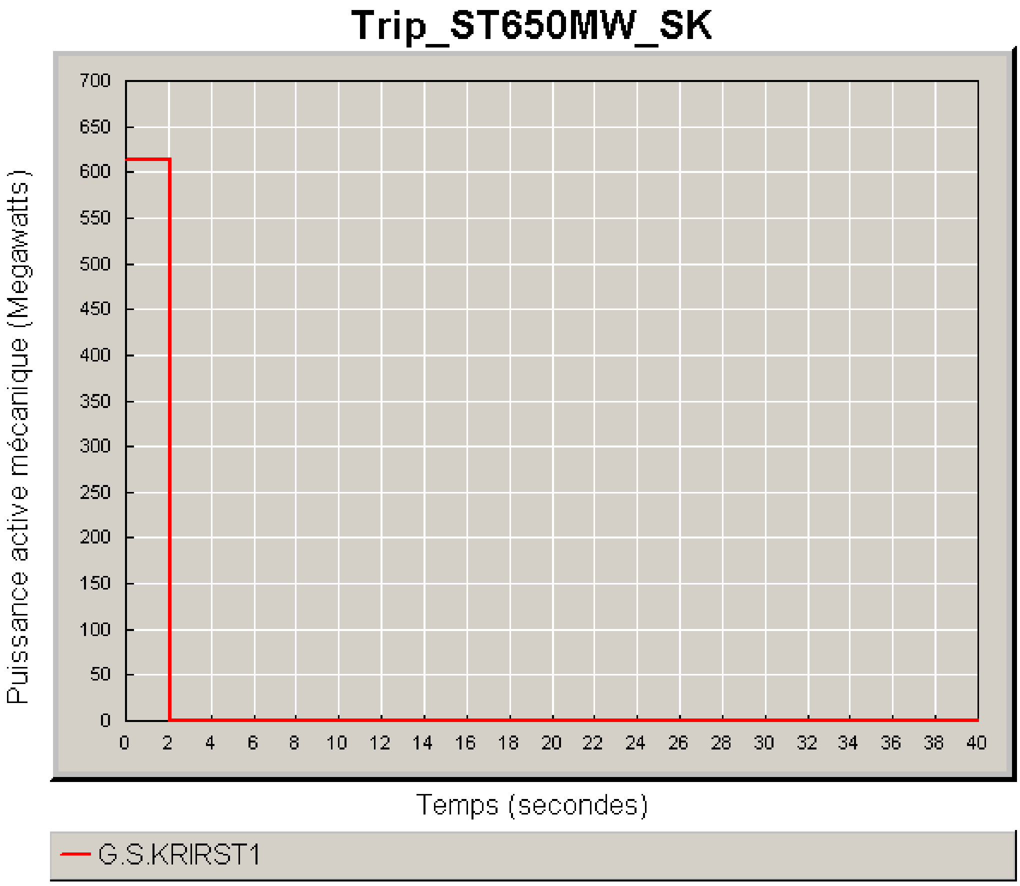
2.15.3 POWER FLOW VARIATION ON EGYPT - LIBYA AND EGYPT - JORDAN INTERCONNECTION



2.15.4 VOLTAGE VARIATION

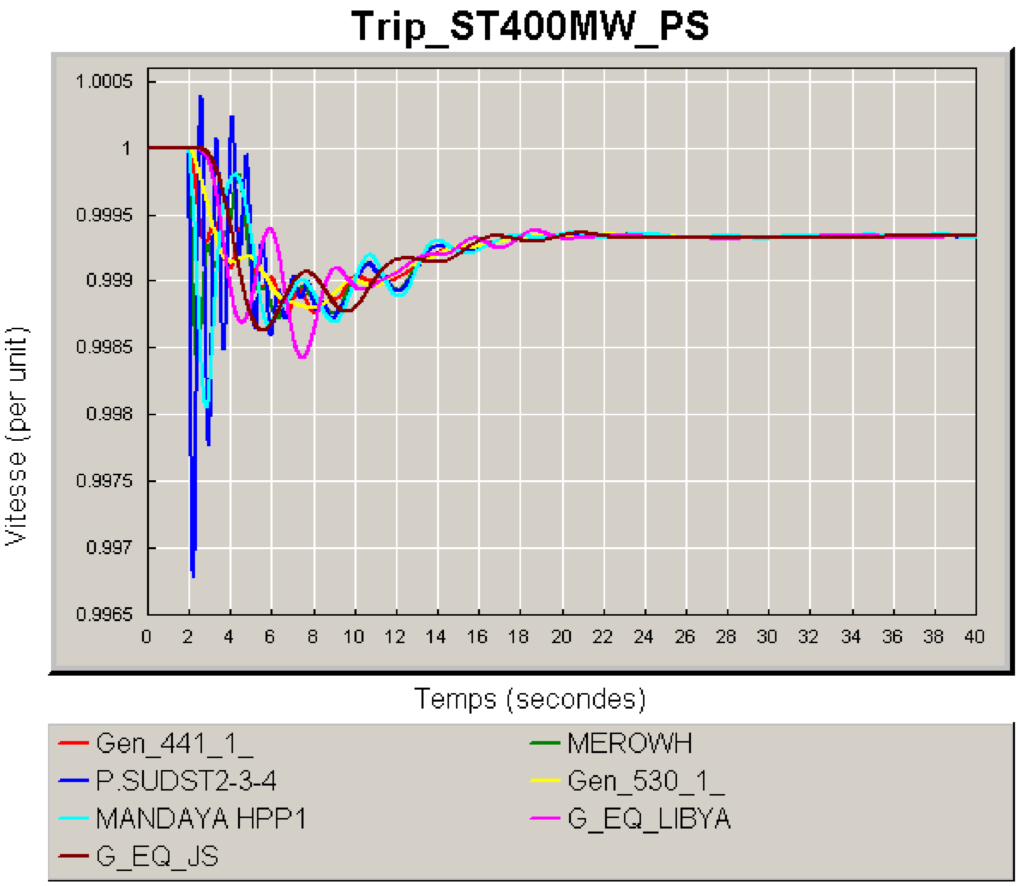


2.15.5 TRIPPING OF SIDI KRIR 650 MW STEAM TURBINE

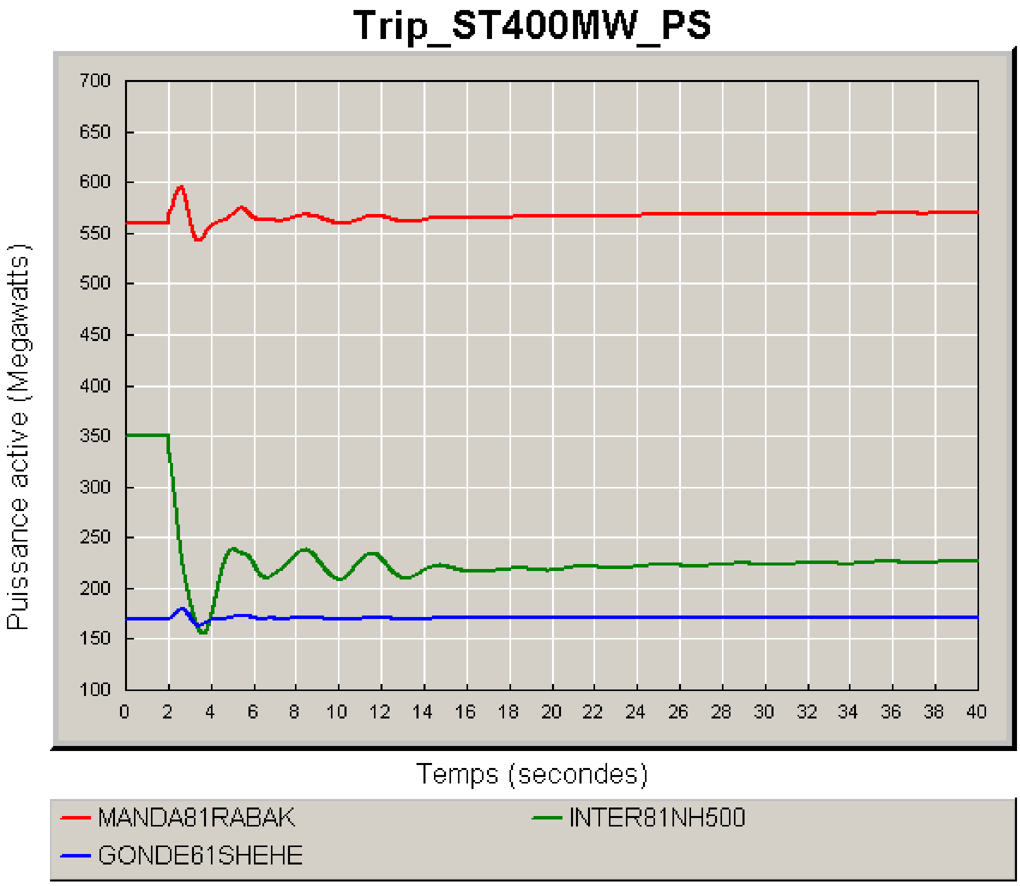


2.16 TRIPPING OF THE MAIN UNIT IN SUDAN : PORT SUDAN 400 MW STEAM TURBINE

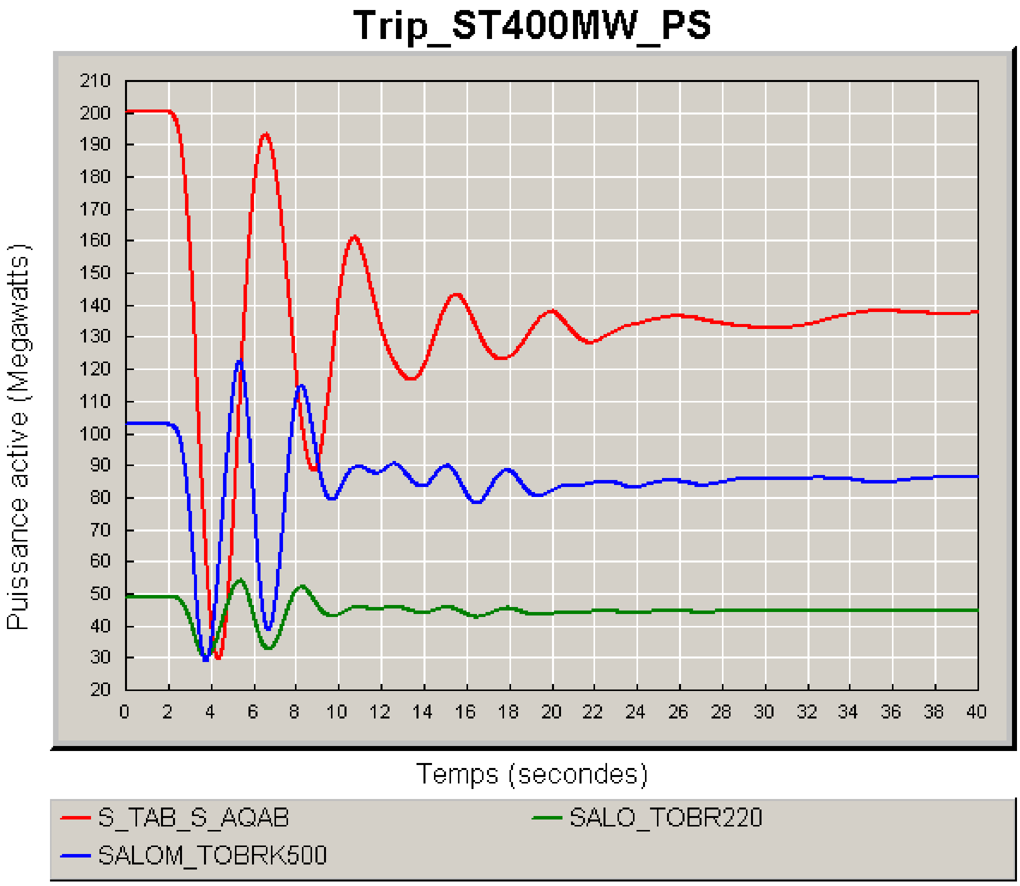
2.16.1 GENERATORS FREQUENCY VARIATION



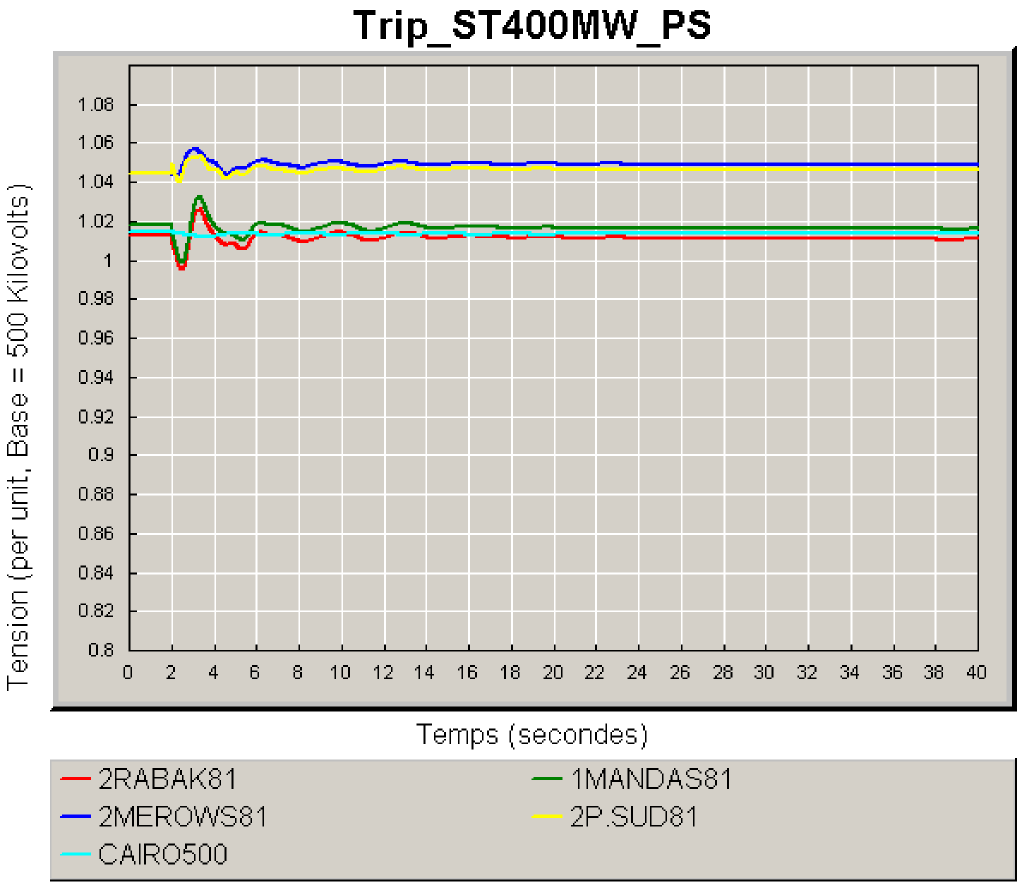
2.16.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



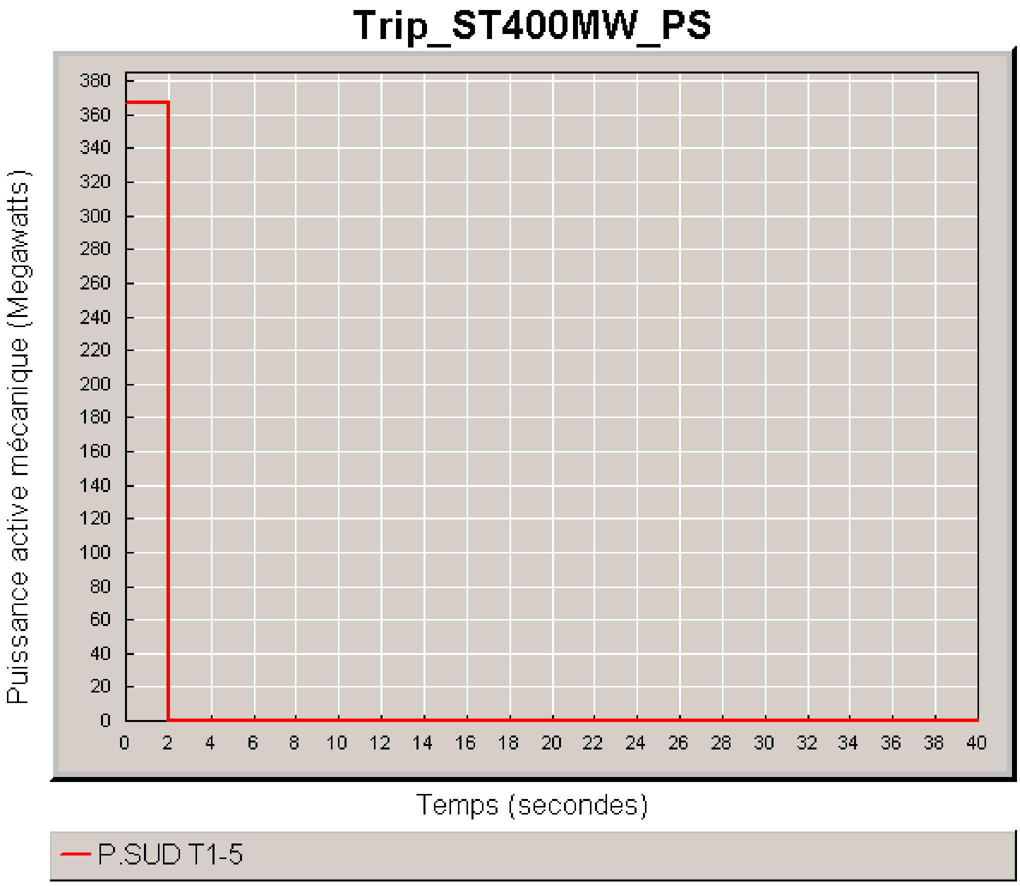
2.16.3 Power flow variation on Egypt - Libya and Egypt - Jordan interconnection



2.16.4 VOLTAGE VARIATION

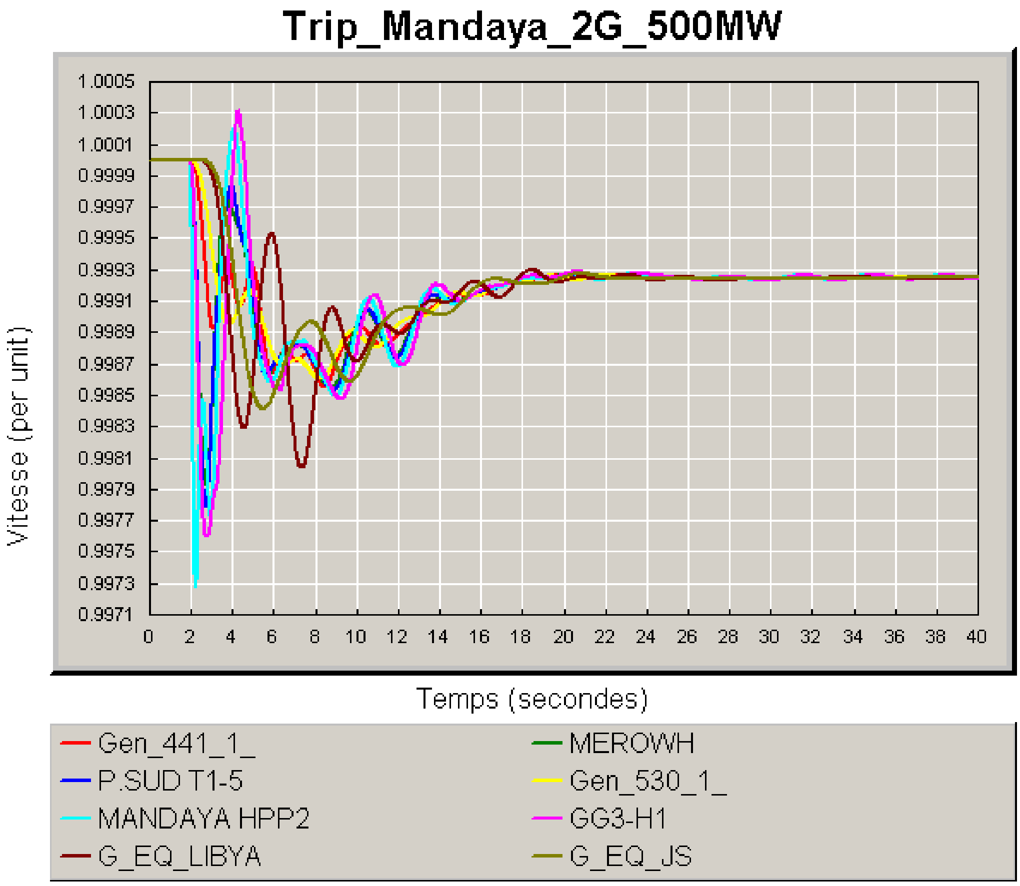


2.16.5 Tripping of Port-Sudan 400 MW Steam Unit

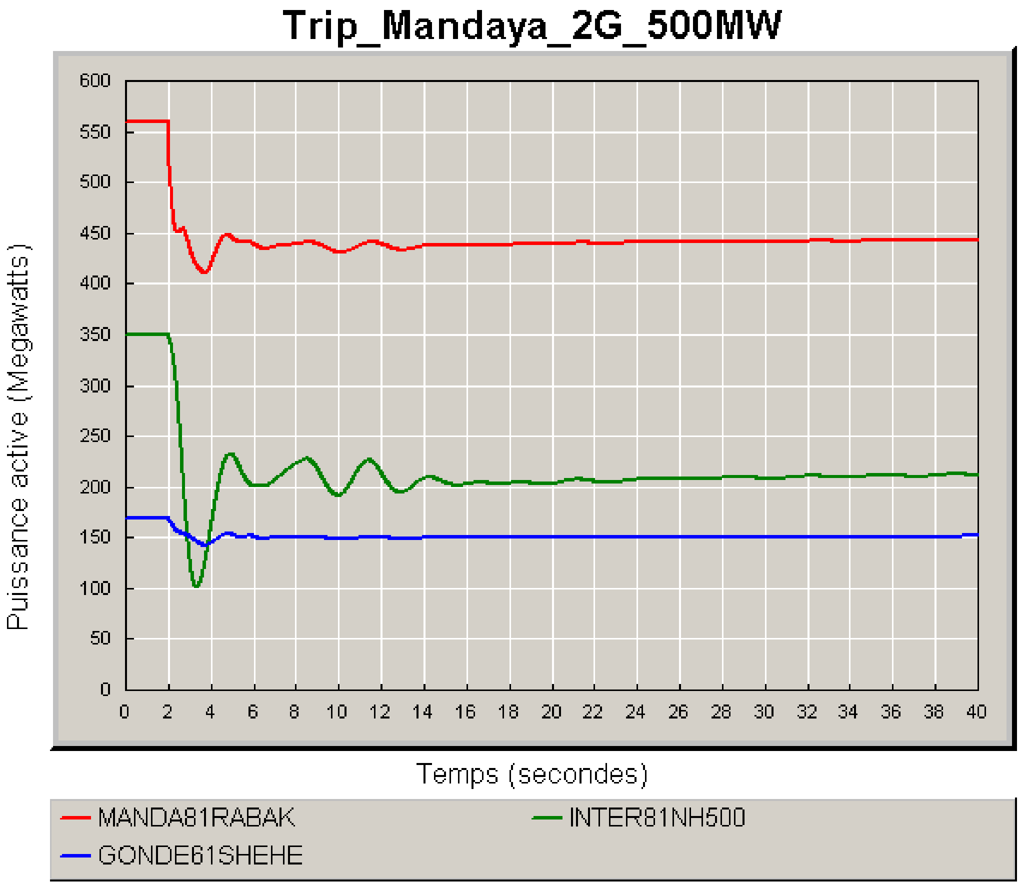


2.17 TRIPPING OF THE MAIN 2 UNITS IN ETHIOPIA : 2 UNITS OF 250 MW IN MANDAYA

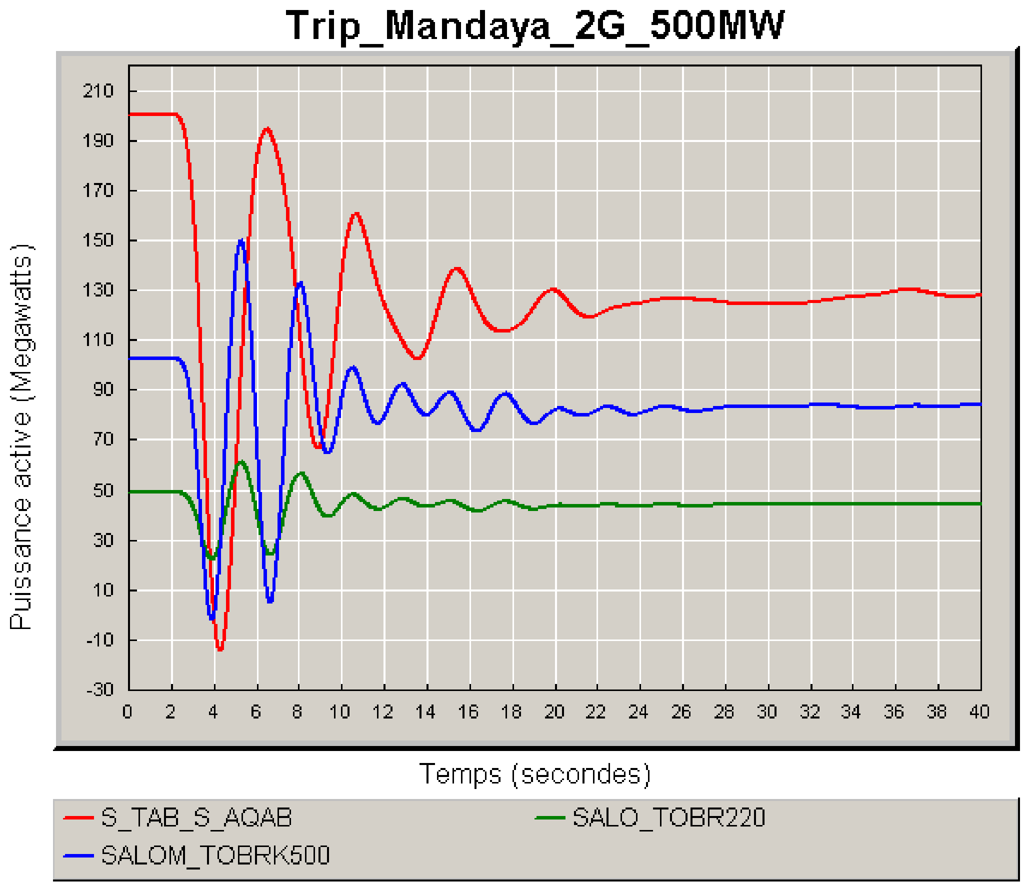
2.17.1 GENERATORS FREQUENCY VARIATION



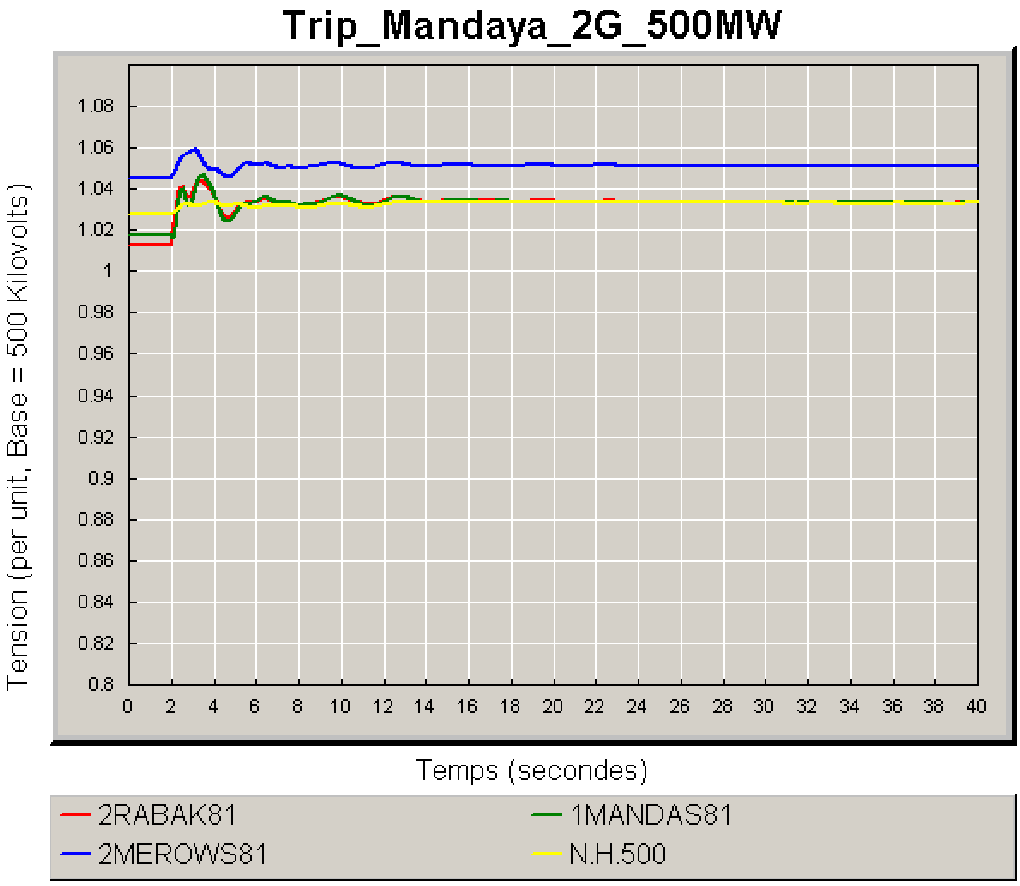
2.17.2 POWER FLOW VARIATION ON ENTRO INTERCONNECTION



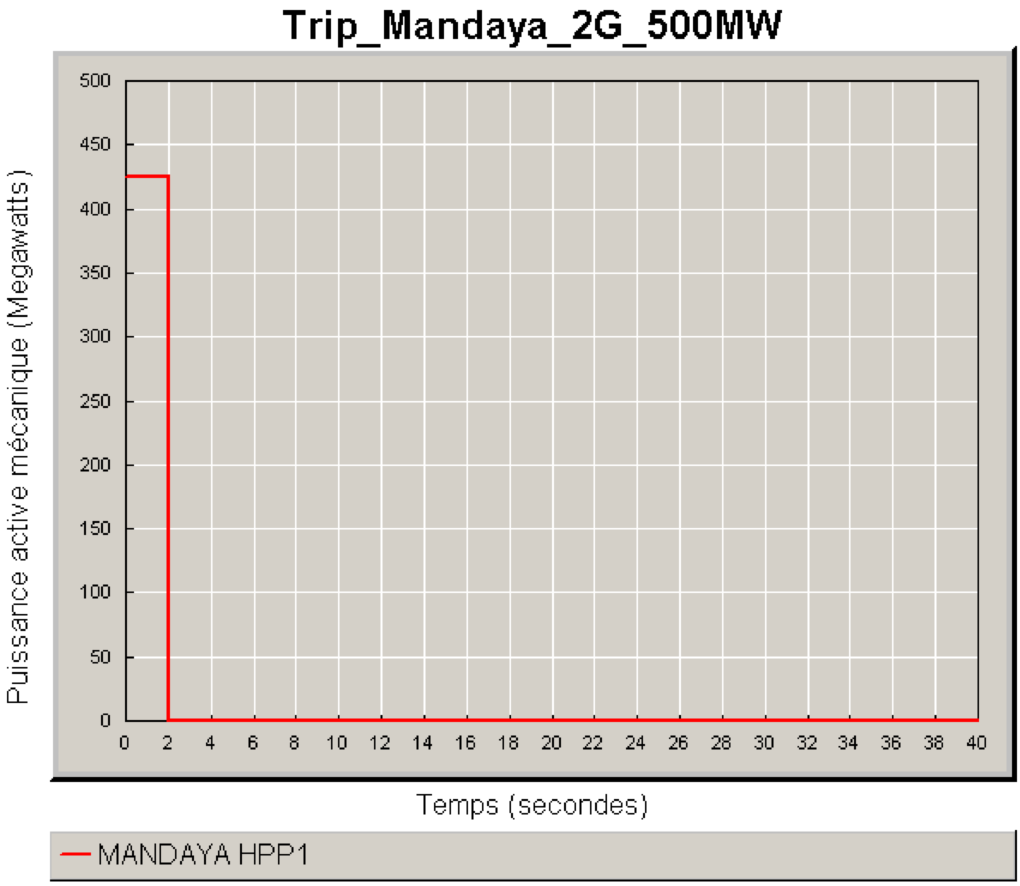
2.17.3 POWER FLOW VARIATION ON EGYPT - LIBYA AND EGYPT - JORDAN INTERCONNECTION



2.17.4 VOLTAGE VARIATION



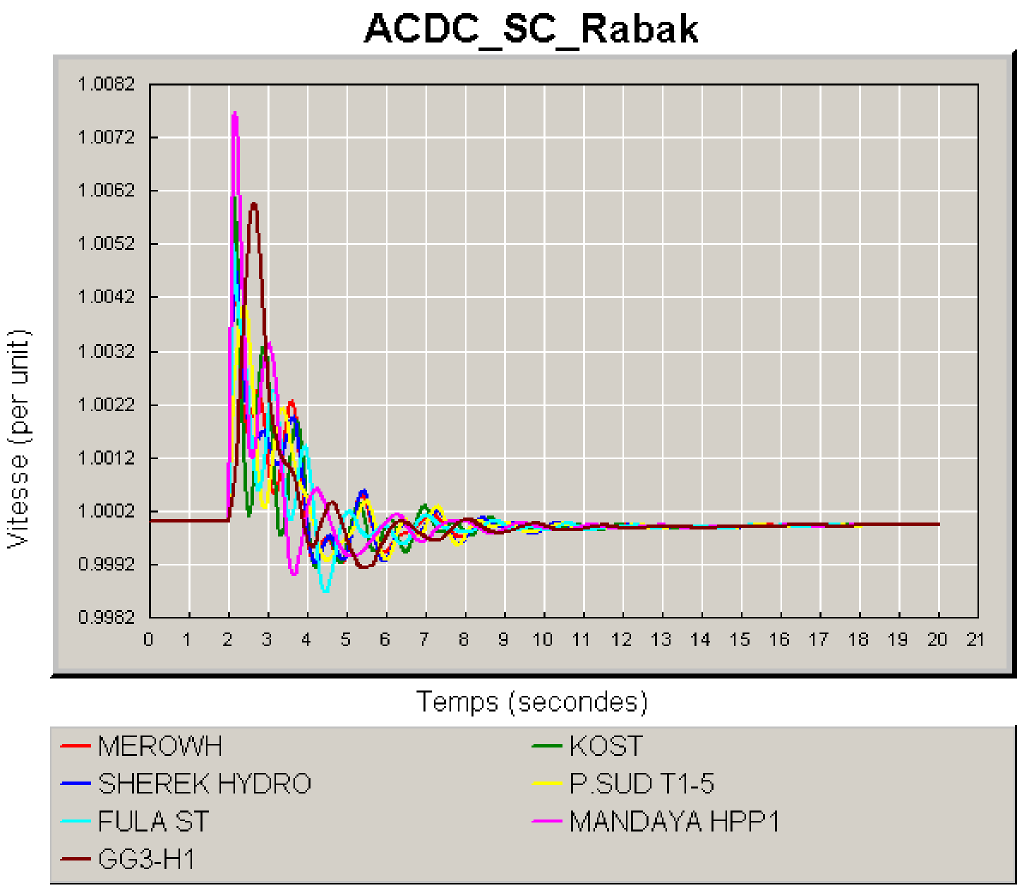
2.17.5 TRIPPING OF MANDAYA UNITS



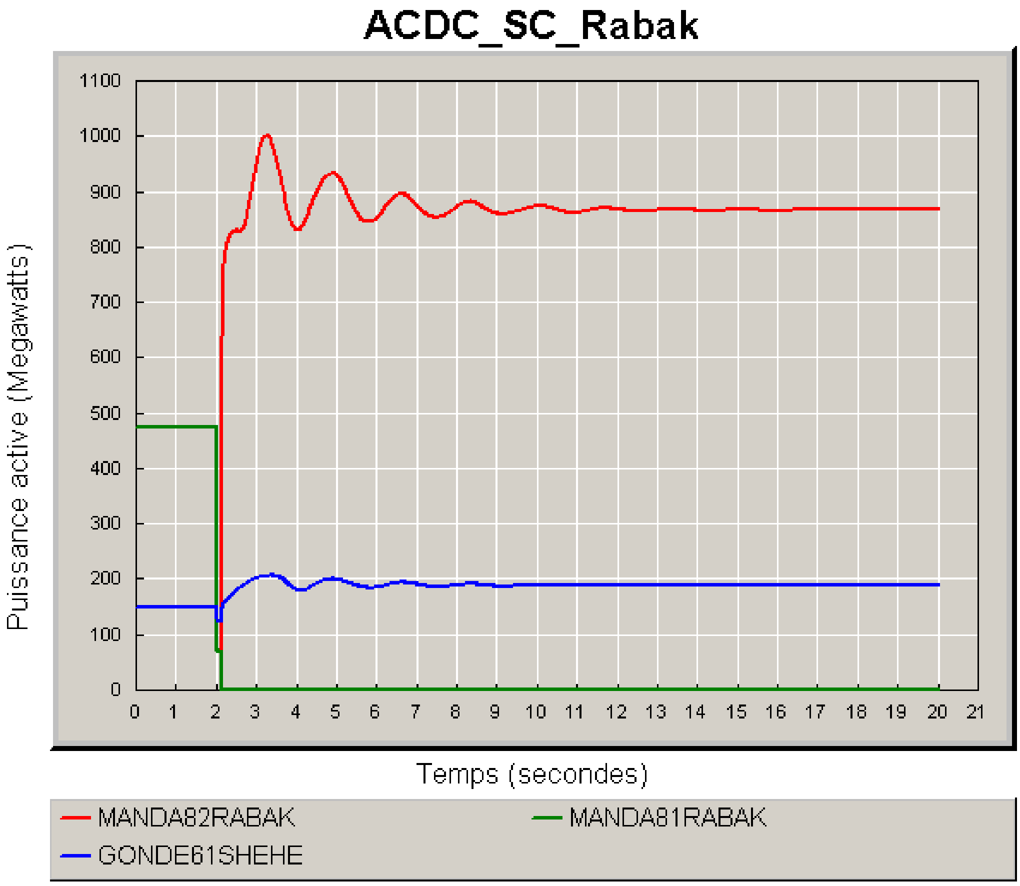
3 Mixt AC and DC option

3.1 SHORT-CIRCUIT AT RABAK ON MANDAYA - RABAK

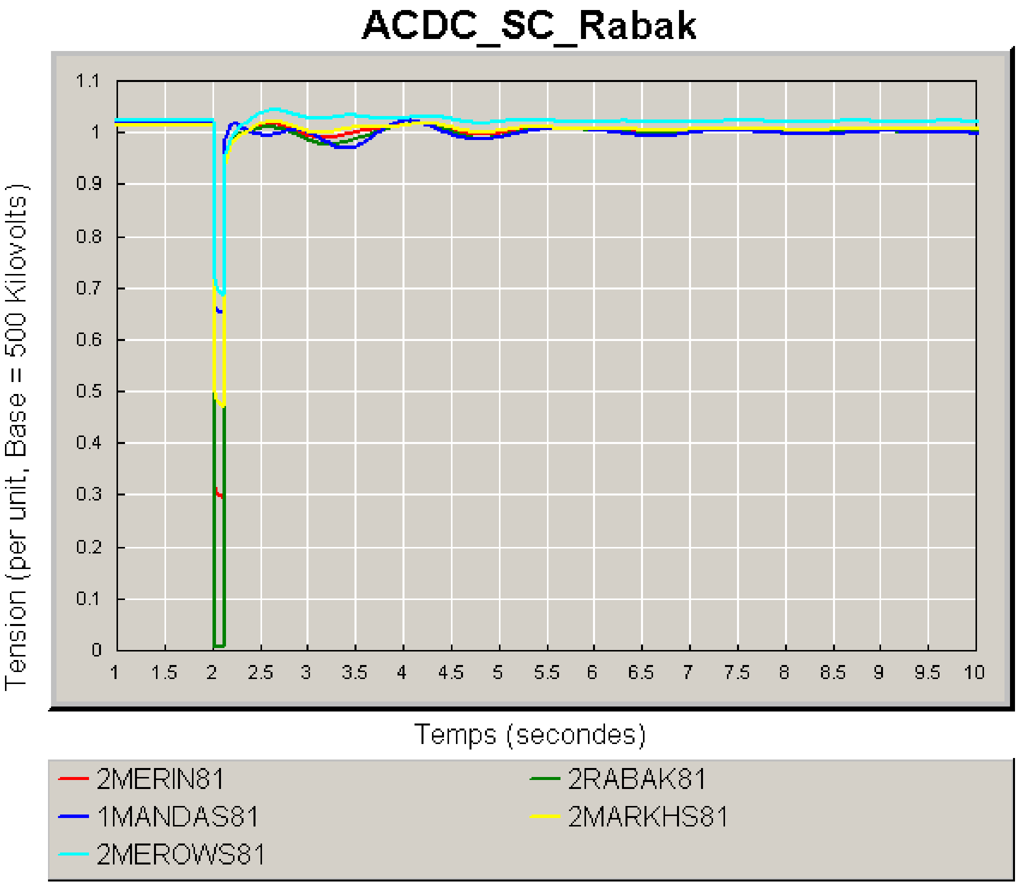
3.1.1 GENERATORS FREQUENCY VARIATION



3.1.2 POWER FLOW VARIATION ON THE INTERCONNECTION ETHIOPIA - SUDAN

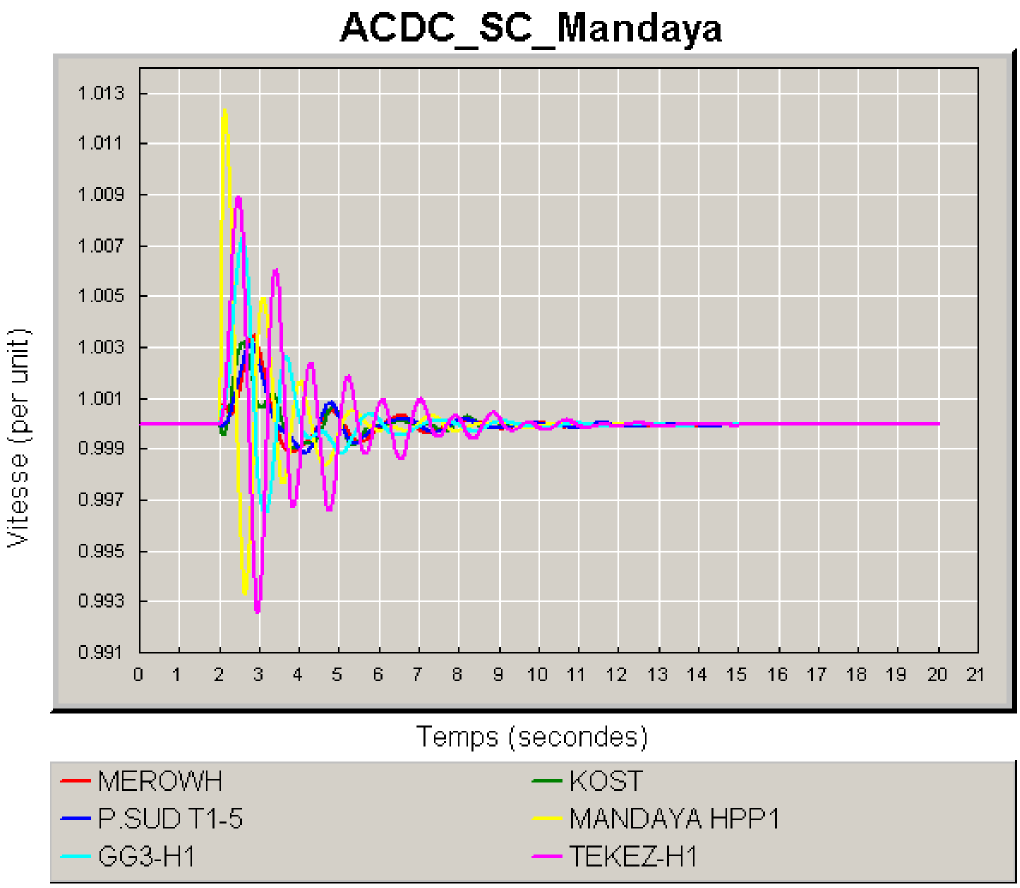


3.1.3 VOLTAGE VARIATION ON THE 500 KV

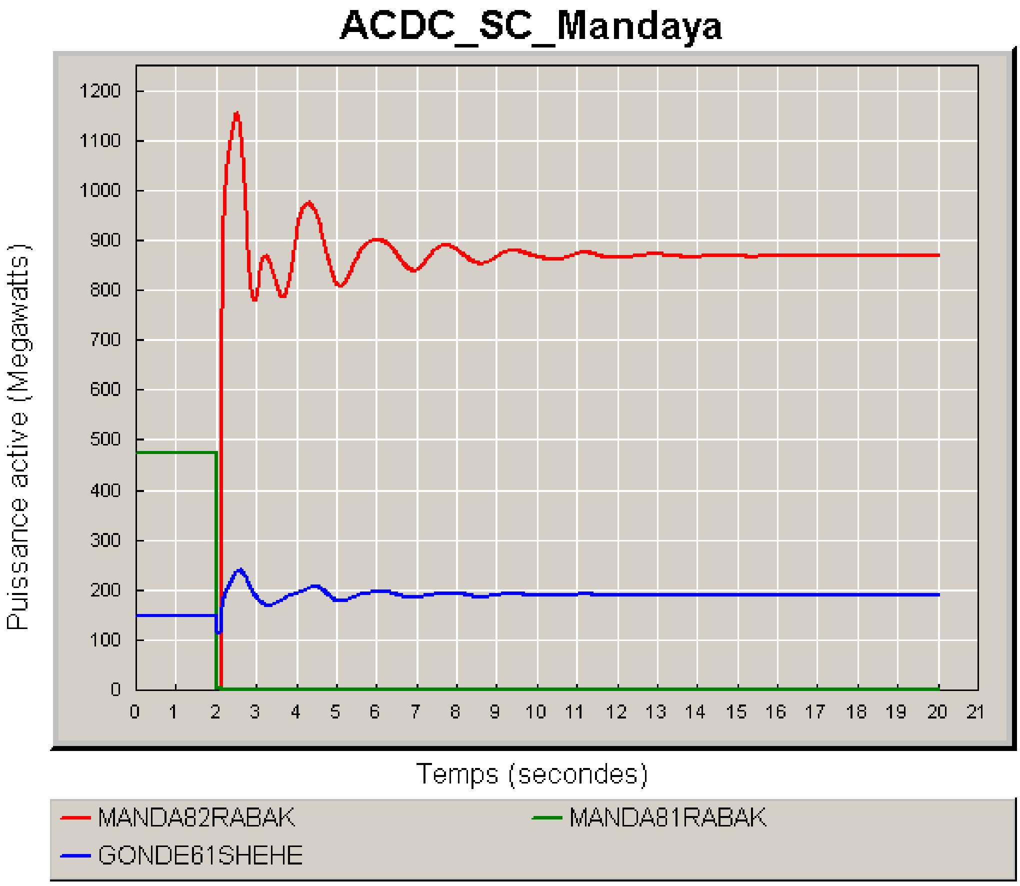


3.2 SHORT-CIRCUIT AT MANDAYA ON MANDAYA - RABAK

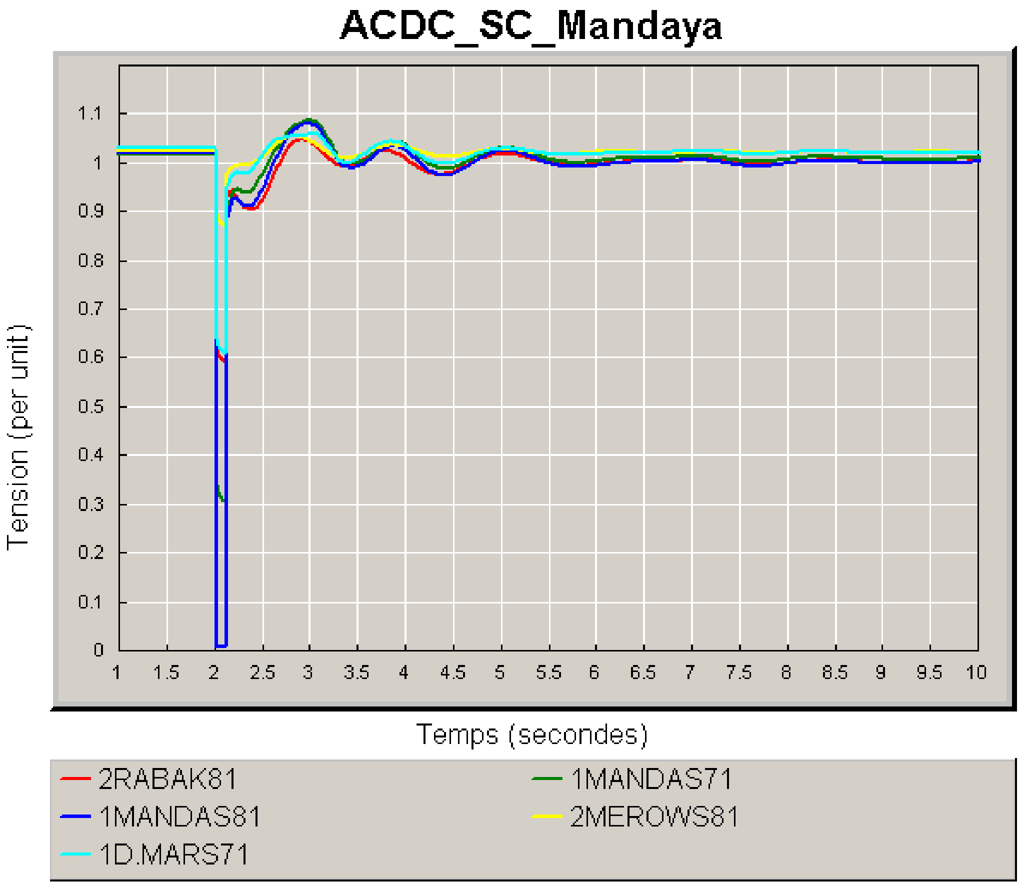
3.2.1 GENERATORS FREQUENCY VARIATION



3.2.2 POWER FLOW VARIATION ON THE INTERCONNECTION ETHIOPIA - SUDAN



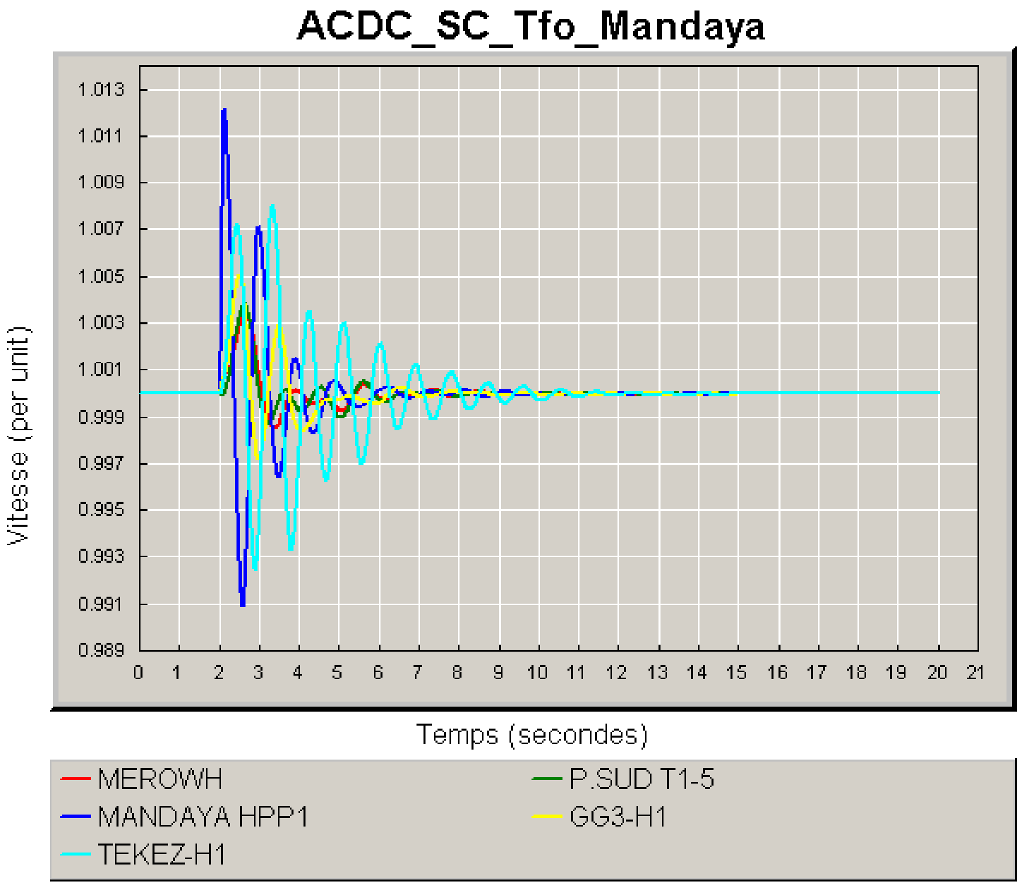
3.2.3 VOLTAGE VARIATION ON THE 500 KV



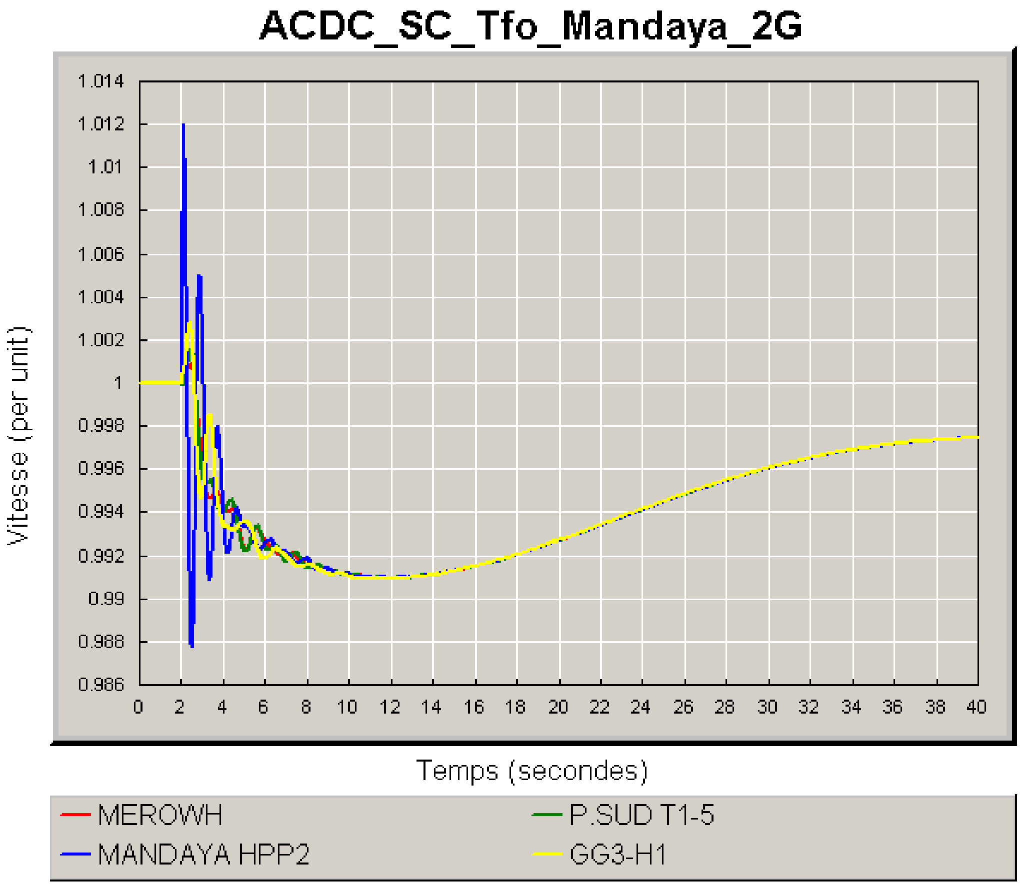
3.3 TRIPPING OF ONE OF THE TWO 400/500 KV TRANSFORMERS AT MANDAYA

3.3.1 GENERATORS FREQUENCY VARIATION

3.3.1.1 Without tripping 2 Mandaya units

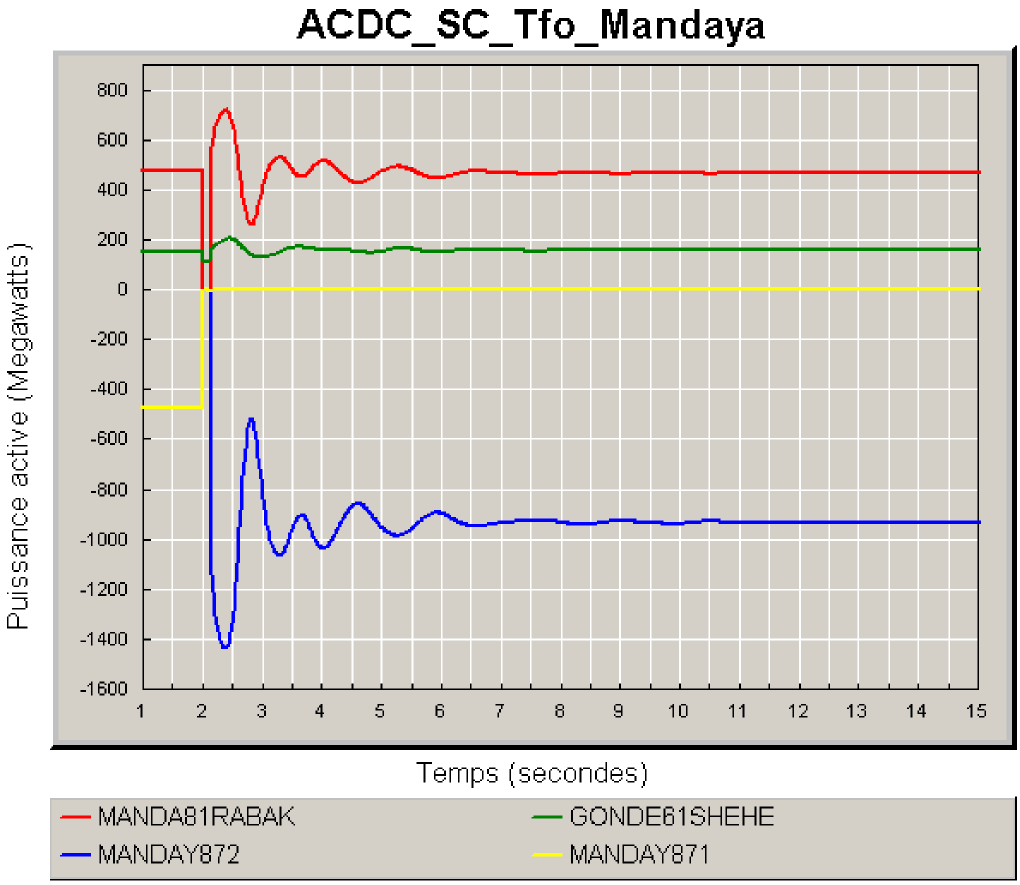


3.3.1.2 With the tripping of 2 Mandaya units

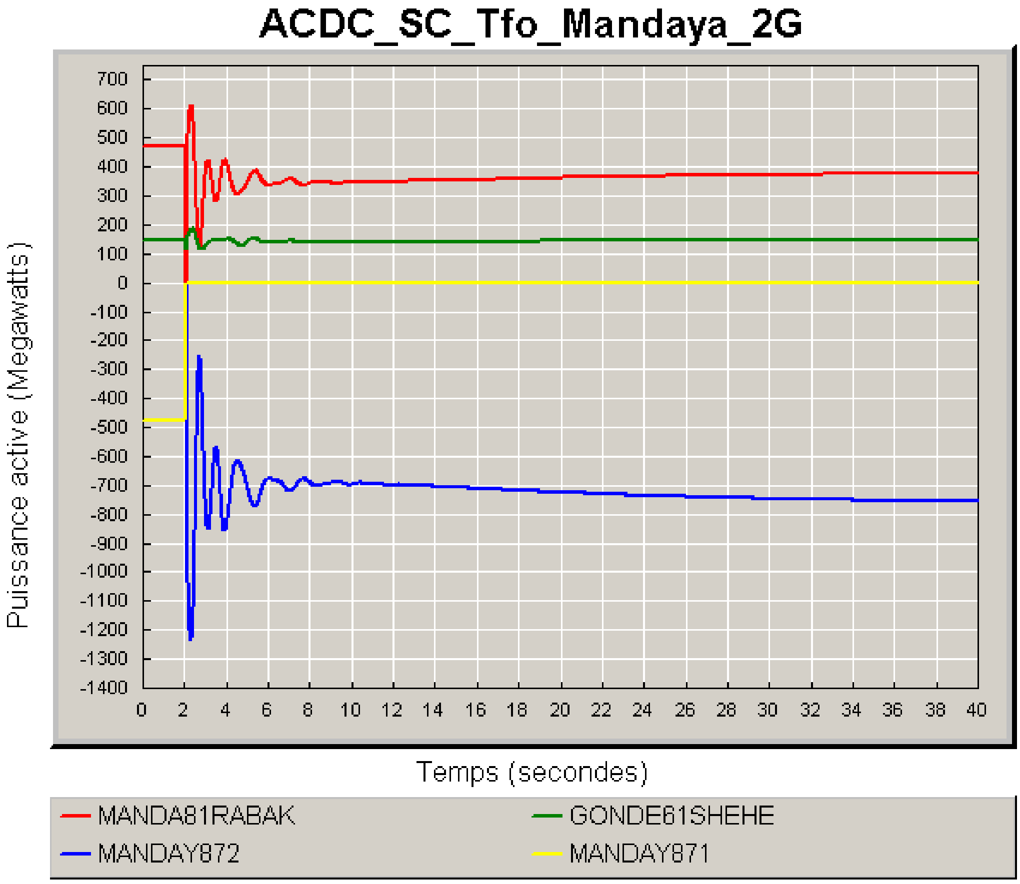


3.3.2 POWER FLOW VARIATION ON THE INTERCONNECTION ETHIOPIA - SUDAN

3.3.2.1 Without tripping Mandaya units

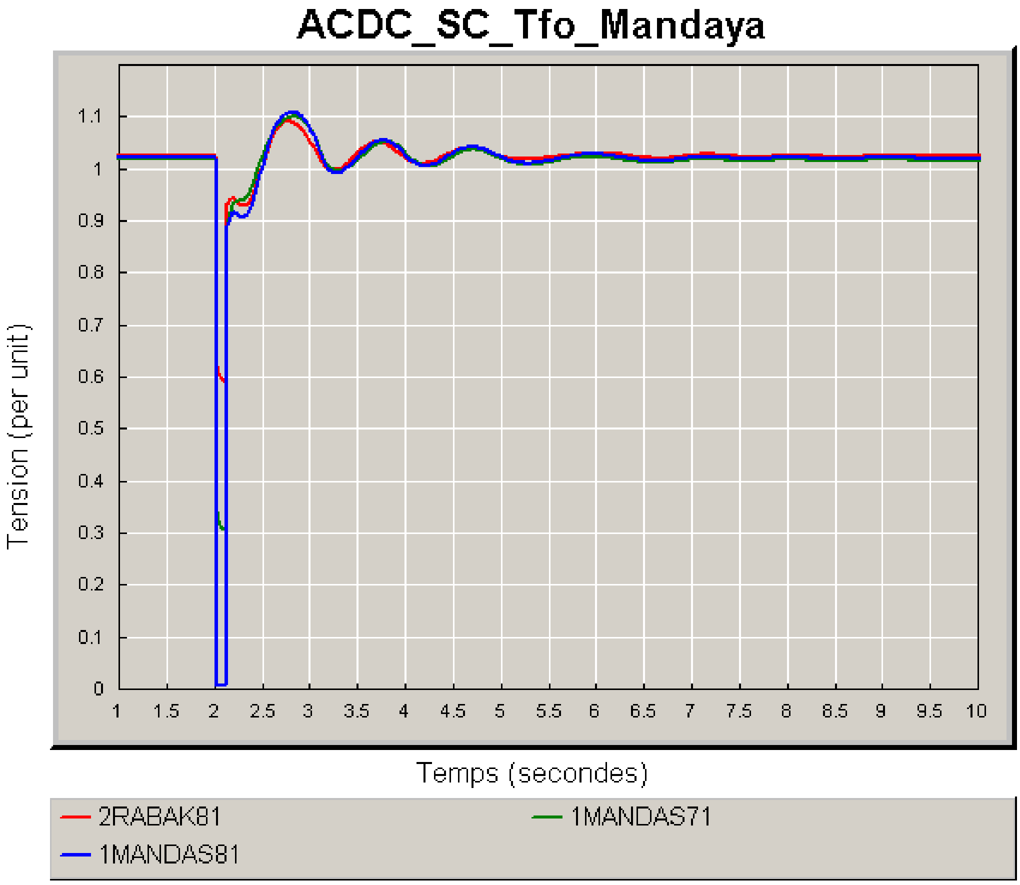


3.3.2.2 With the tripping of 2 Mandaya units



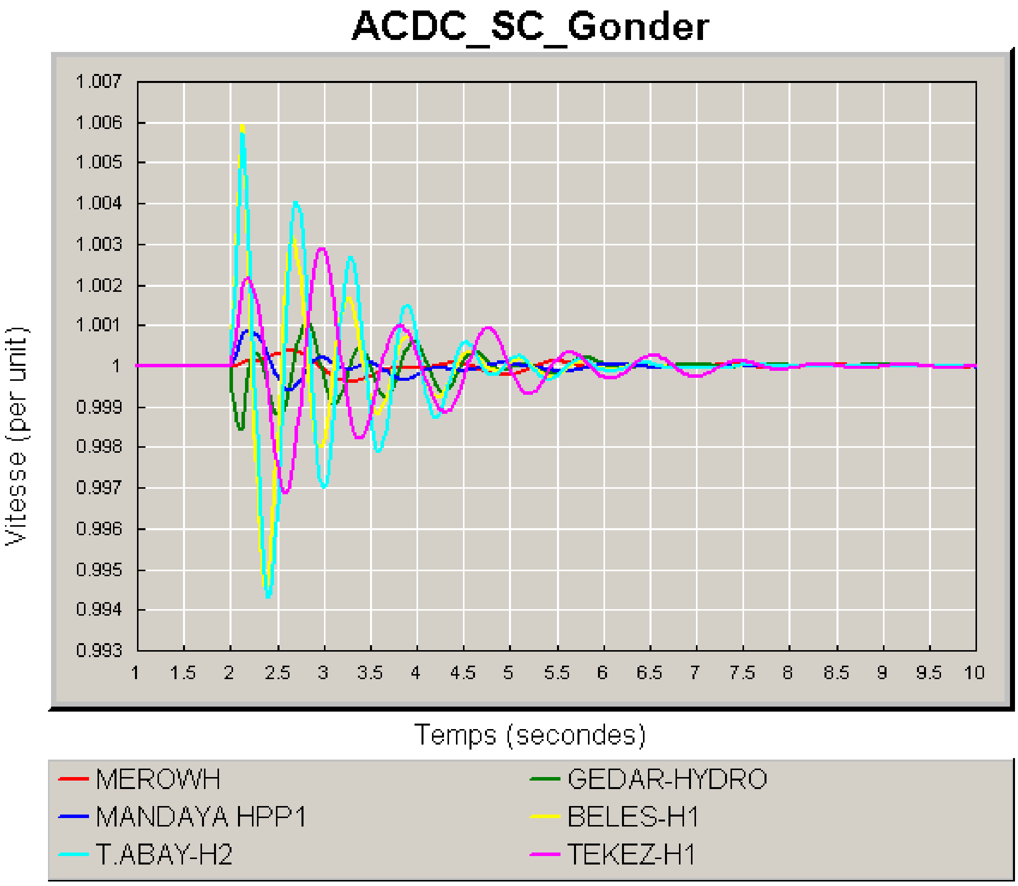
3.3.3 VOLTAGE VARIATION ON THE 500 KV

3.3.3.1 Without tripping 2 Mandaya units

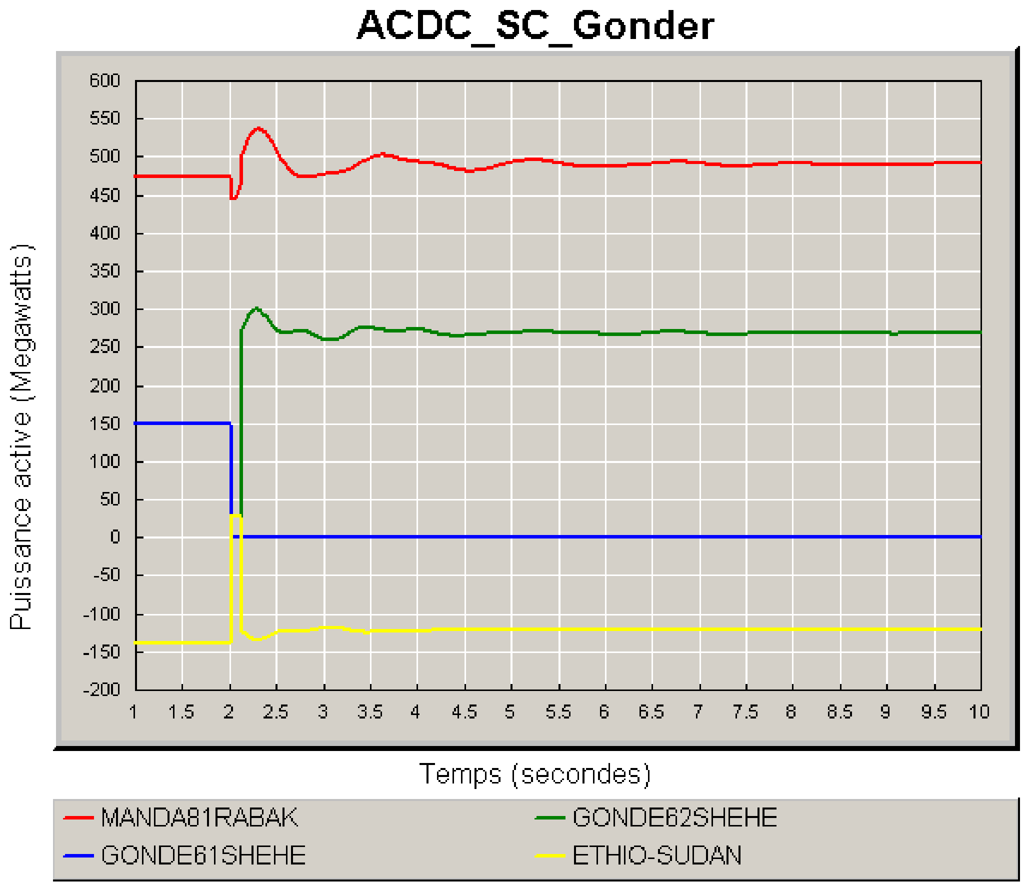


3.4 SHORT-CIRCUIT AT GONDER ON THE 220 KV INTERCONNECTION GONDER - GEDAREF

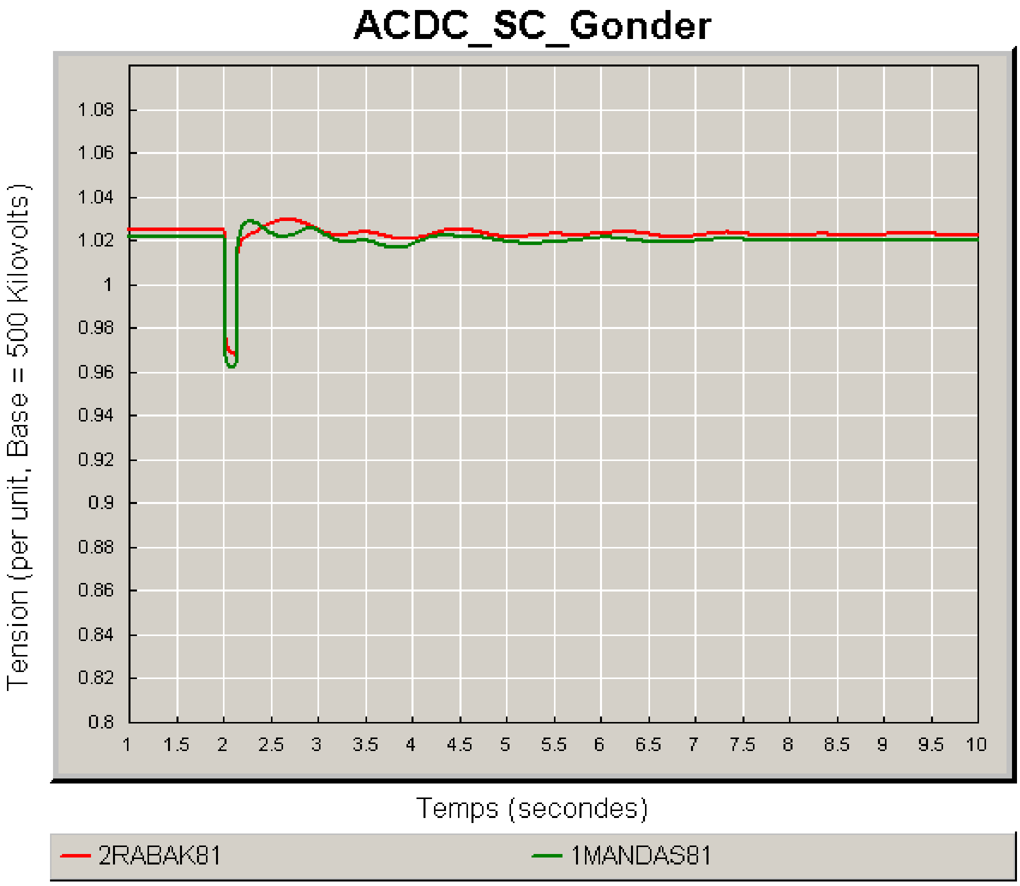
3.4.1 GENERATORS FREQUENCY VARIATION



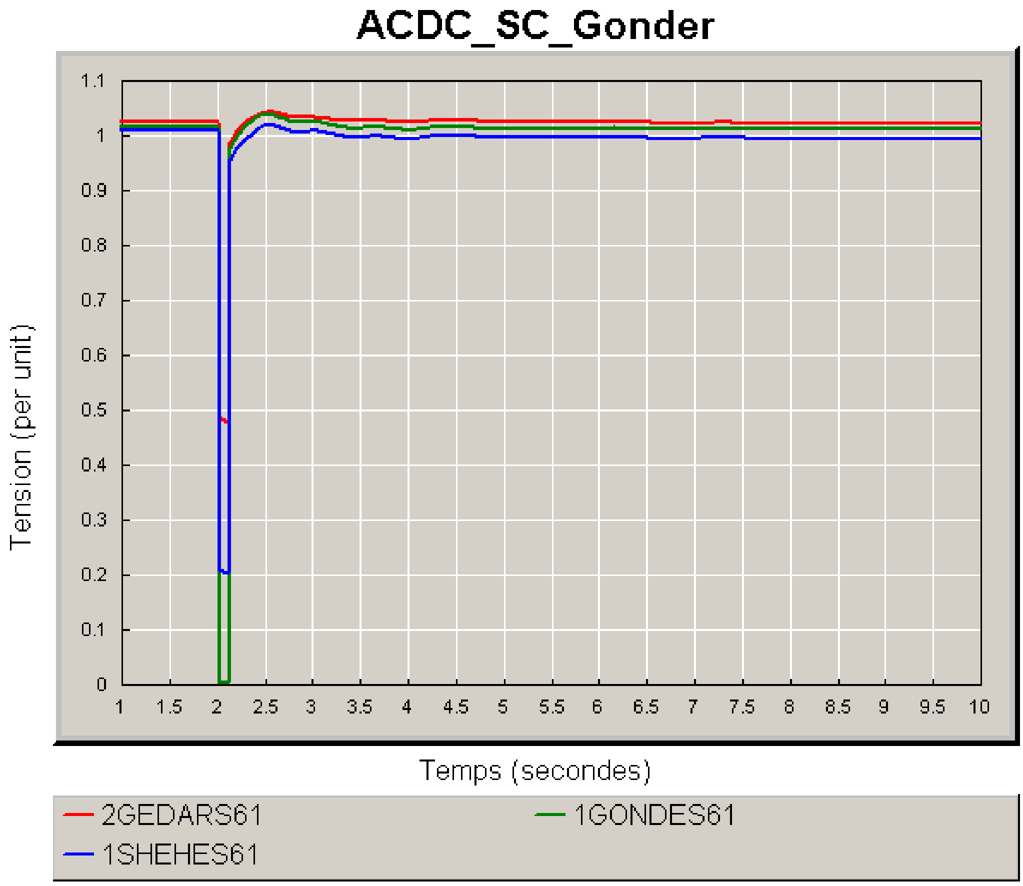
3.4.2 POWER FLOW VARIATION ON THE INTERCONNECTION ETHIOPIA - SUDAN



3.4.3 VOLTAGE VARIATION ON THE 500 KV

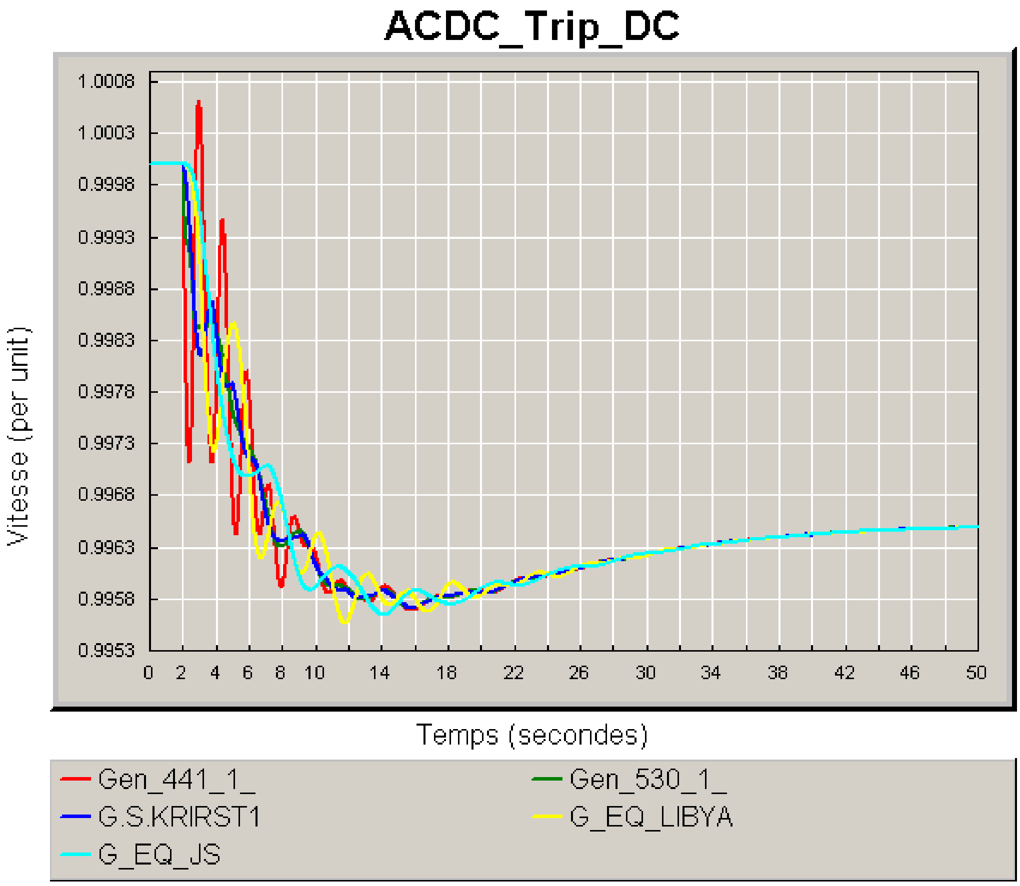


3.4.4 VOLTAGE VARIATION ON THE 220 KV

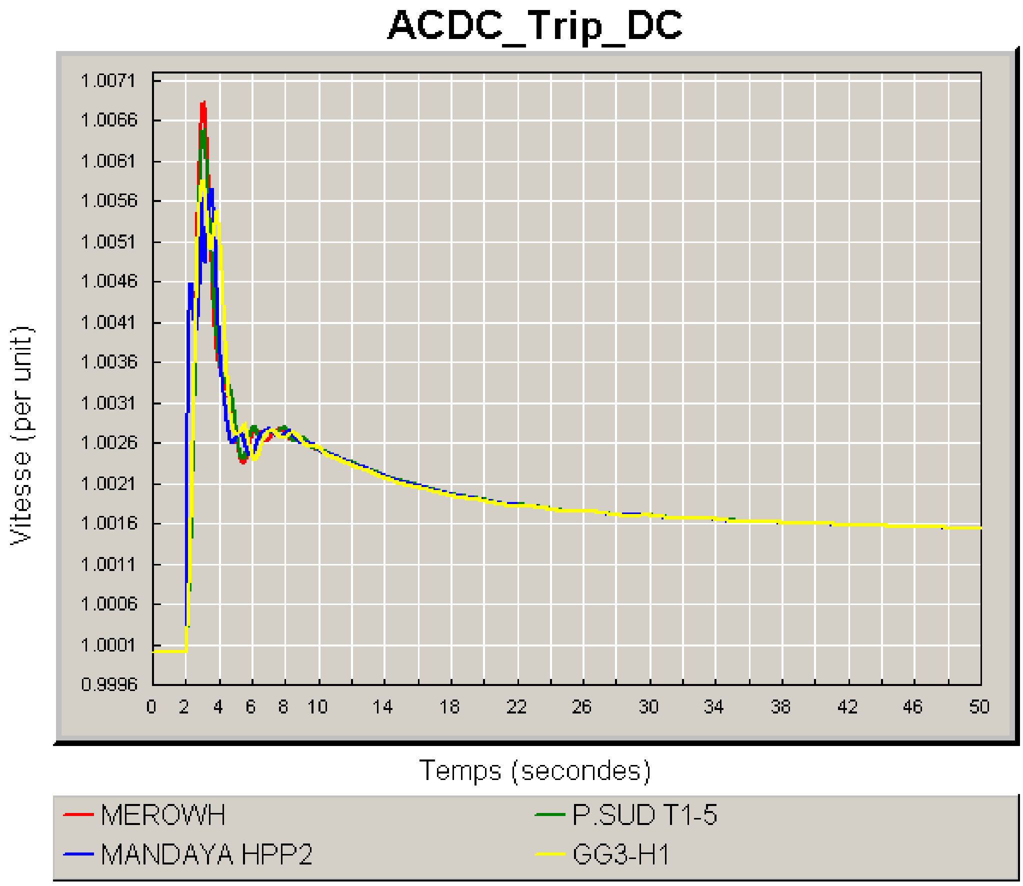


3.5 TRIPPING OF THE DC INTERCONNECTION BETWEEN ETHIOPIA AND EGYPT

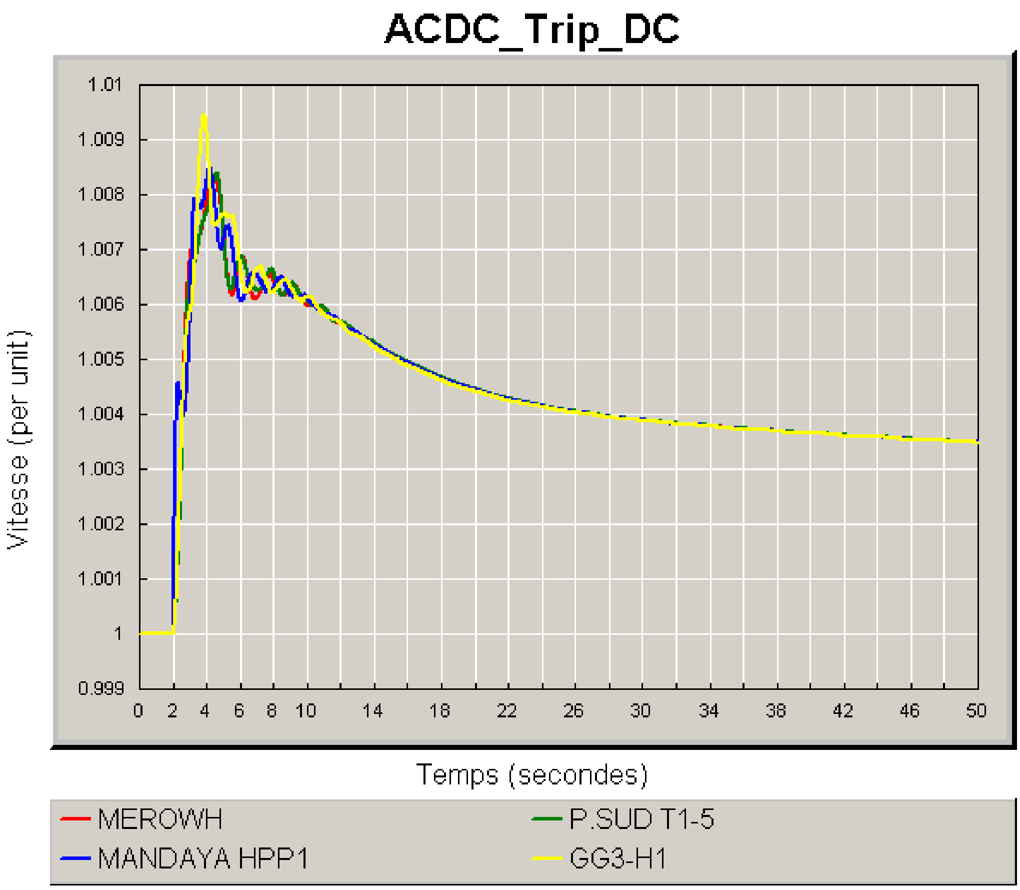
3.5.1 GENERATORS FREQUENCY VARIATION IN EGYPT, JORDAN, SYRIA AND LIBYA



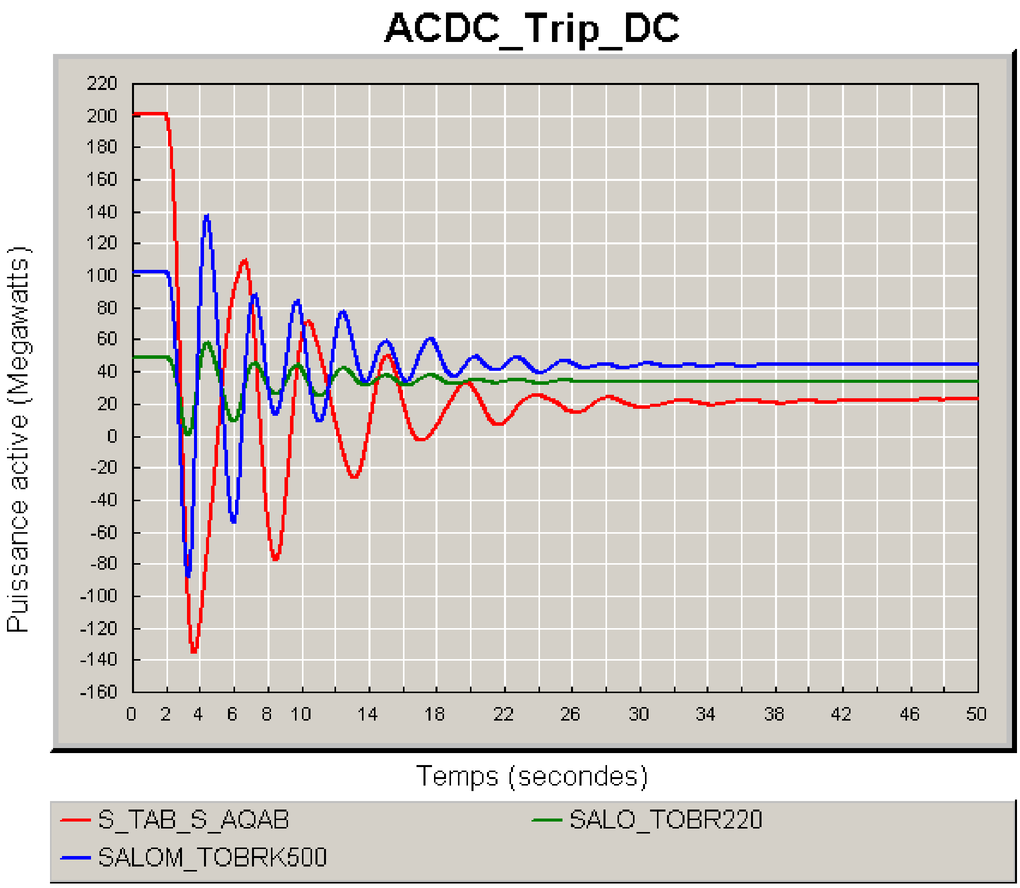
3.5.2 GENERATORS FREQUENCY VARIATION IN ETHIOPIA AND SUDAN



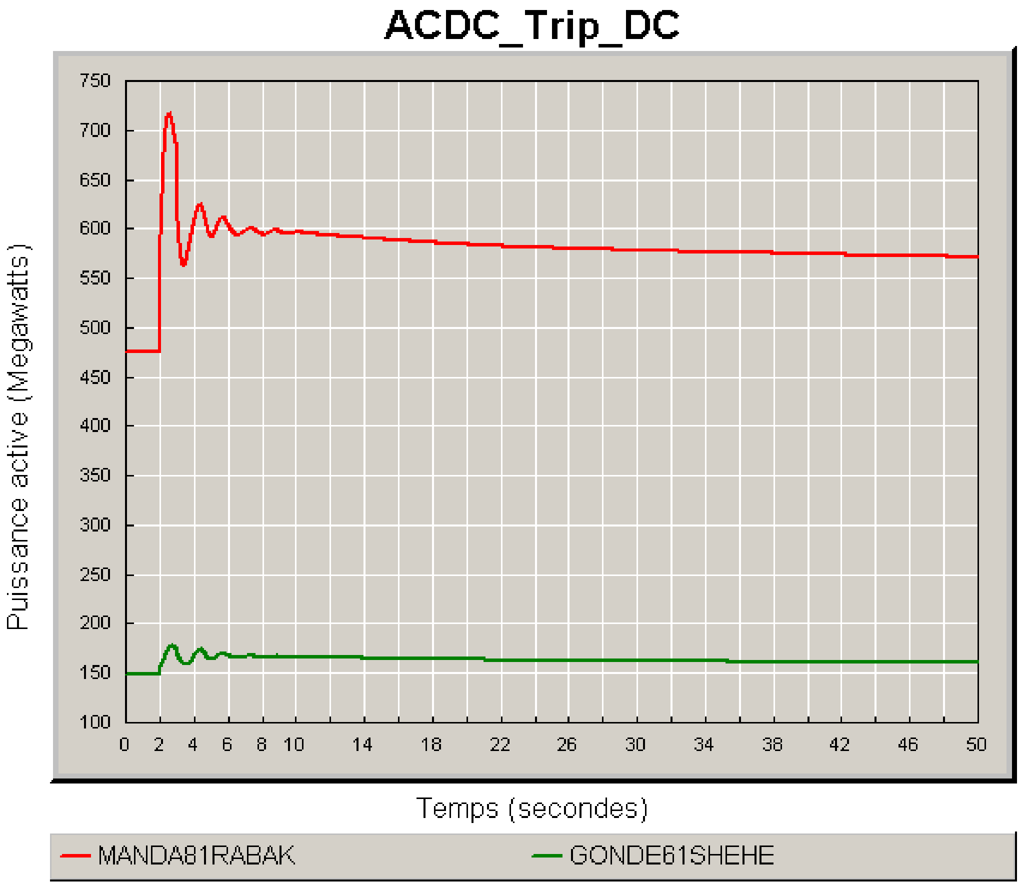
Without the tripping of the 2 units of Mandaya :


ACDC_Trip_DC
Vitesse (per unit)
1.01
1.009
1.008
1.007
1.006
1.005
1.004
1.003
1.002
1.001
1
0.999
0
2
4
6
8
10
14
18
22
26
30
34
38
42
46
50
Temps (secondes)
MEROWH
P.SUD T1-5
MANDAYA HPP1
GG3-H1

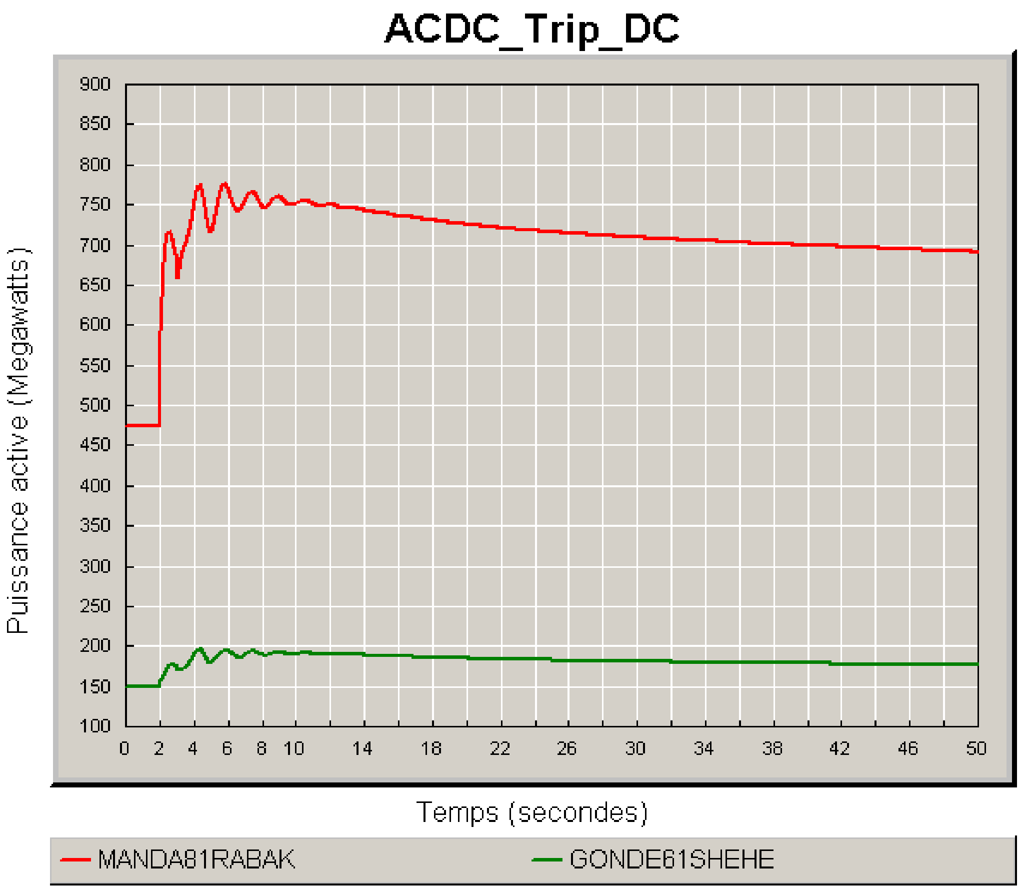
3.5.3 Power flow variation on the interconnection Egypt - Libya and Egypt - Jordan



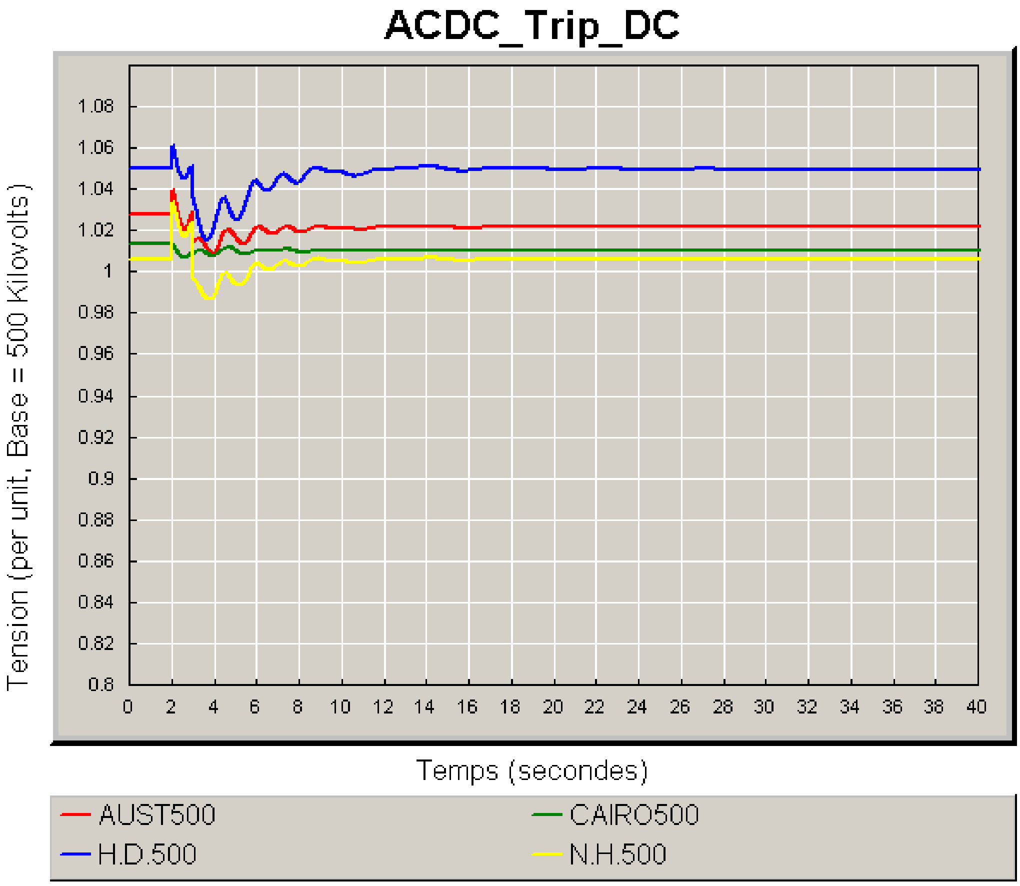
3.5.4 POWER FLOW VARIATION ON THE INTERCONNECTION ETHIOPIA - SUDAN



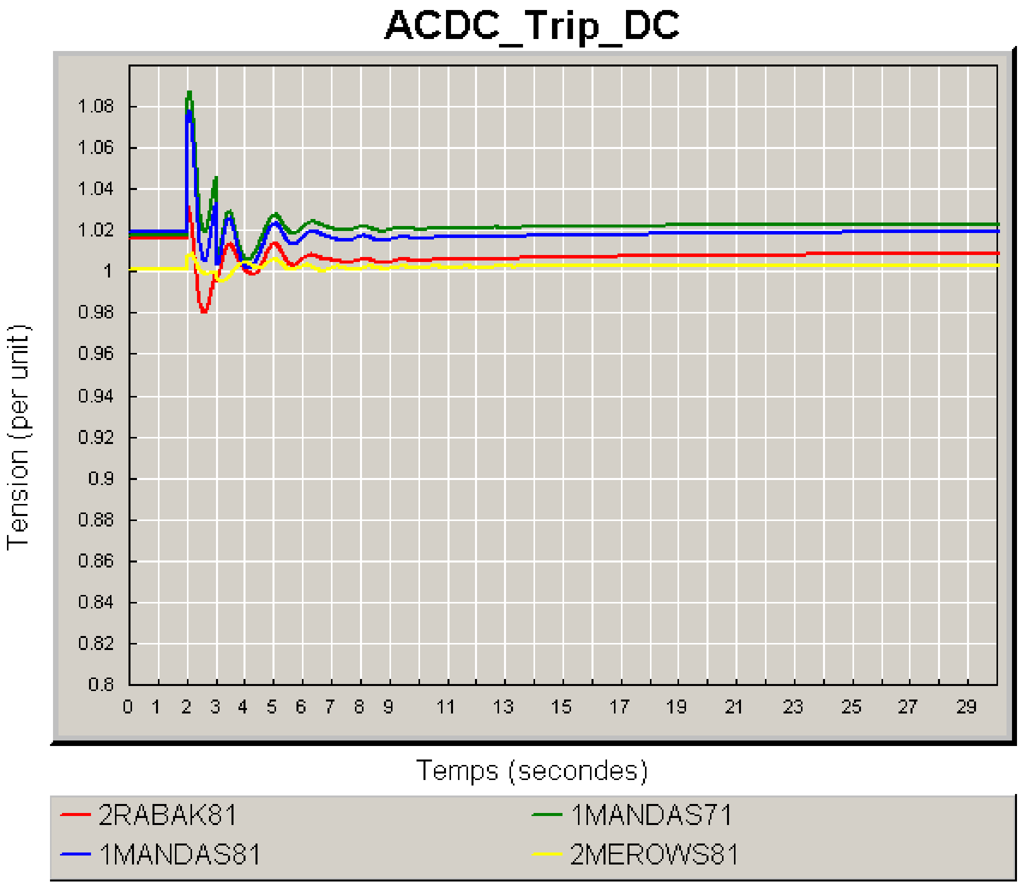
Without the tripping of the 2 units of Mandaya :



3.5.5 VOLTAGE VARIATION ON THE EGYTIAN 500 KV

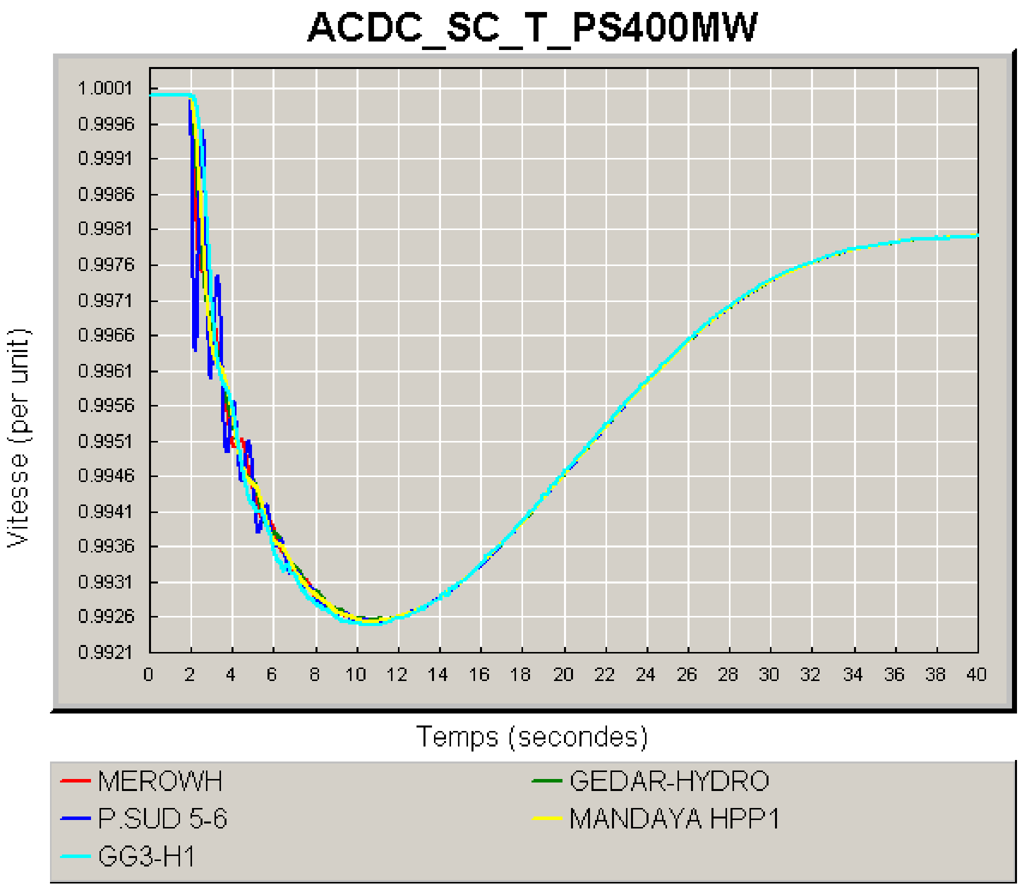


3.5.6 VOLTAGE VARIATION ON THE ETHIOPIAN AND SUDANESE SYSTEM

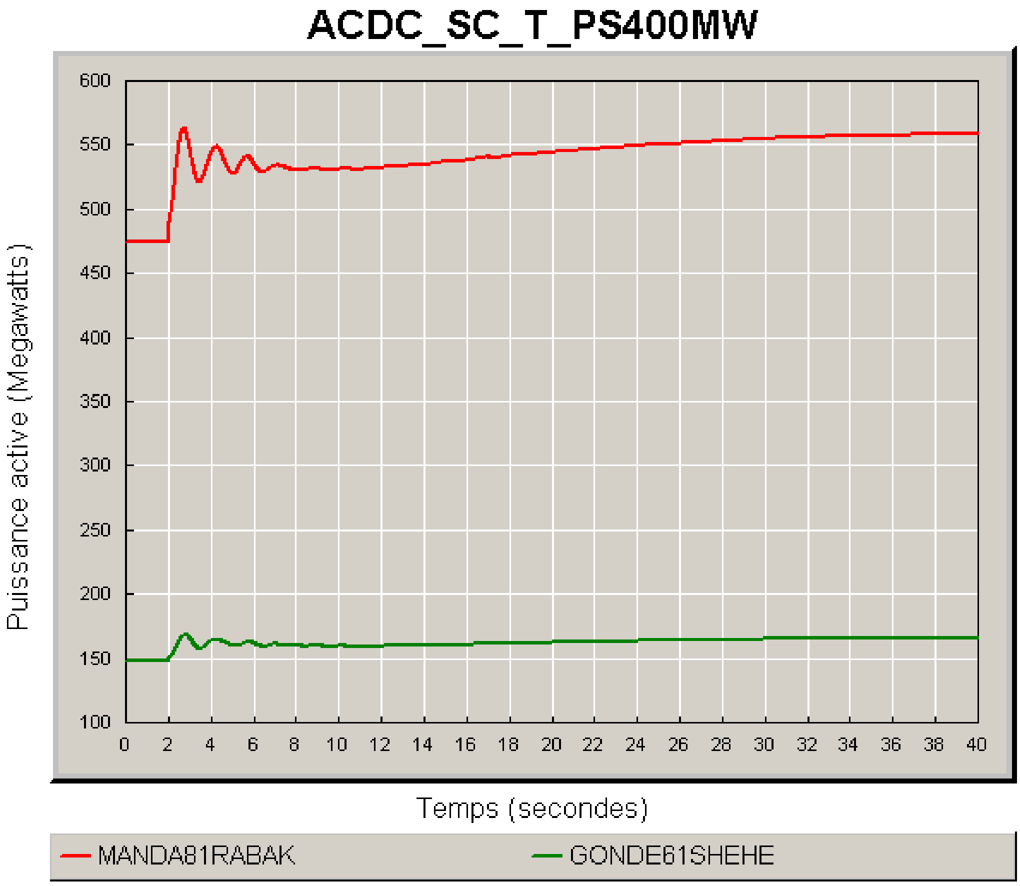


3.6 TRIPPING OF THE MAIN UNIT IN SUDAN

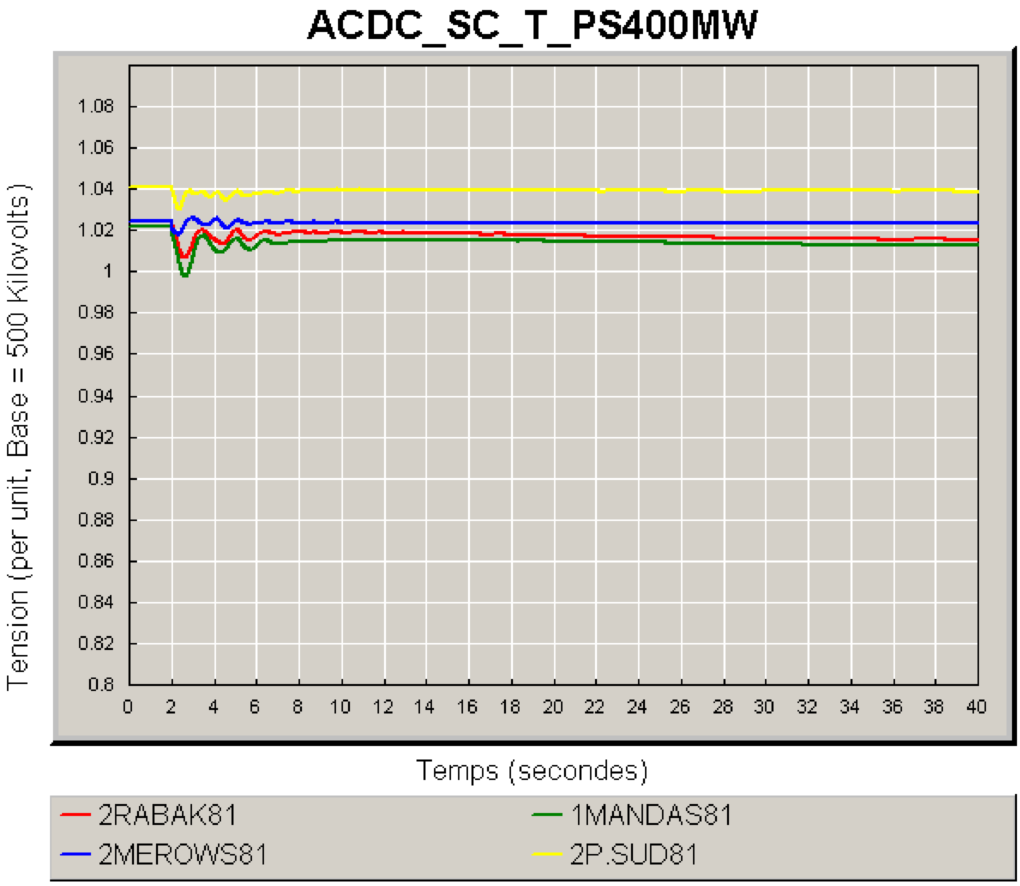
3.6.1 GENERATORS FREQUENCY VARIATION



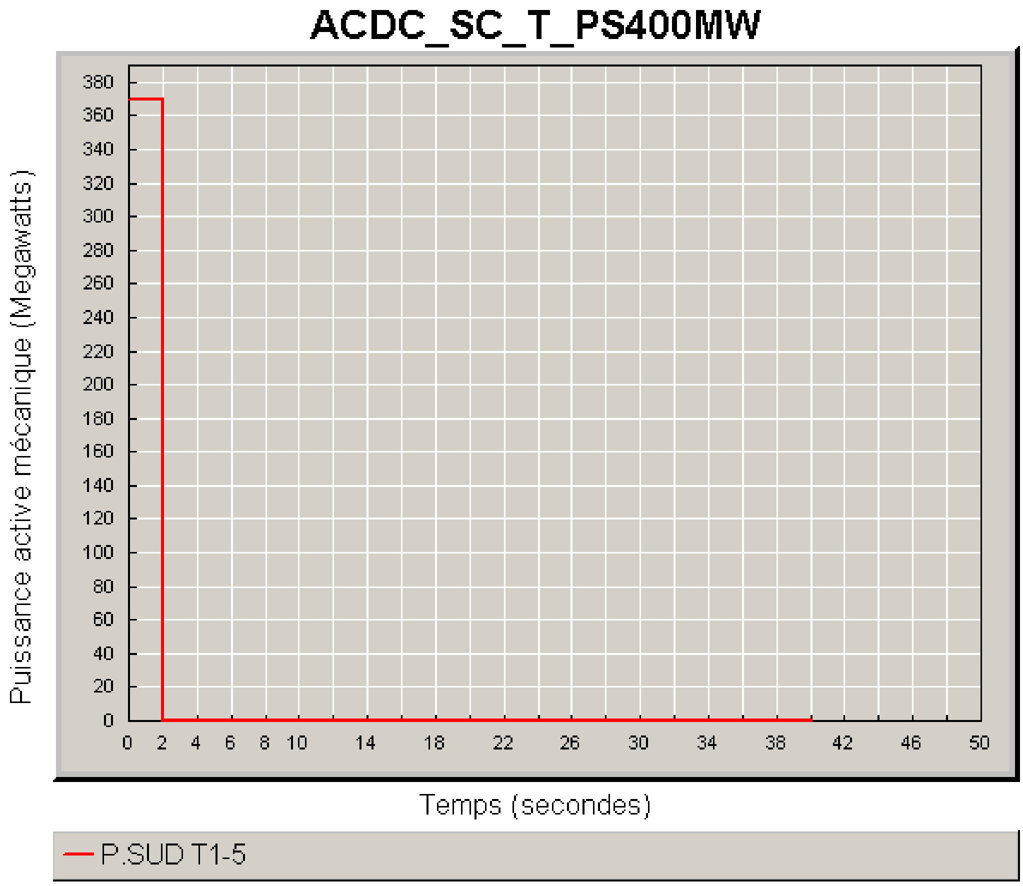
3.6.2 POWER FLOW VARIATION ON THE INTERCONNECTION ETHIOPIA - SUDAN



3.6.3 VOLTAGE VARIATION ON THE 500 KV

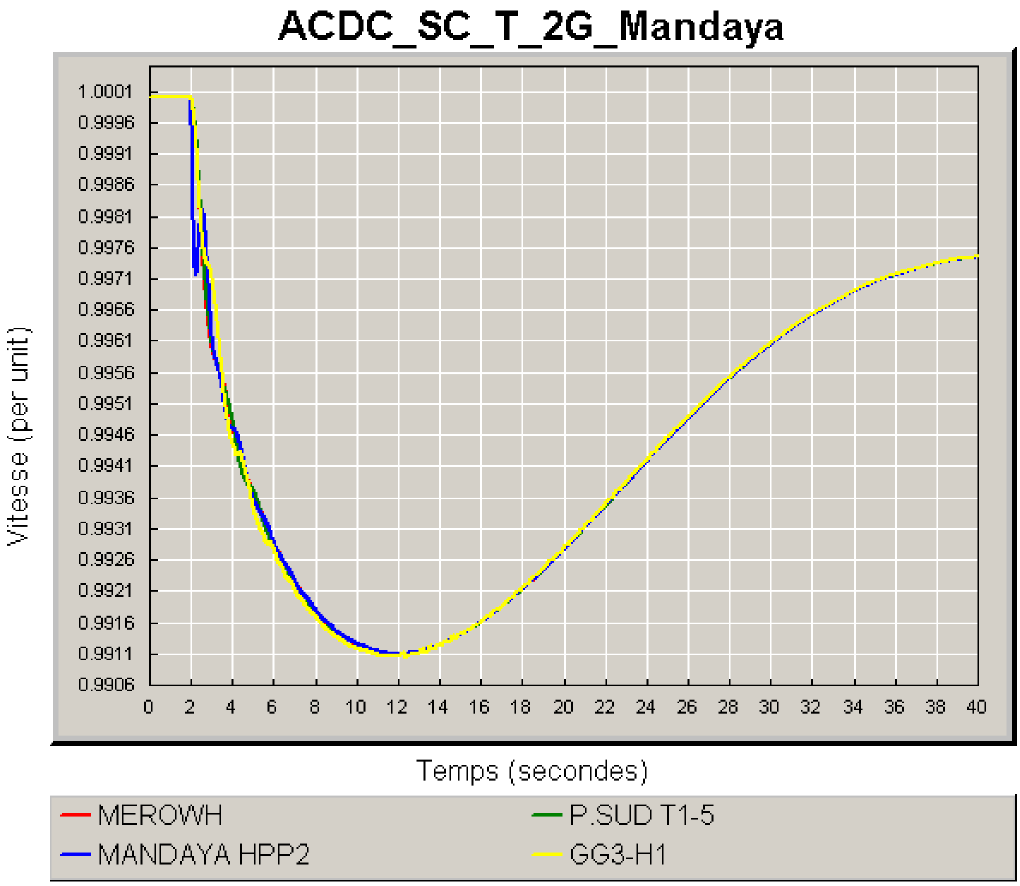


3.6.4 Tripping of Port Sudan 400 MW Steam Turbine

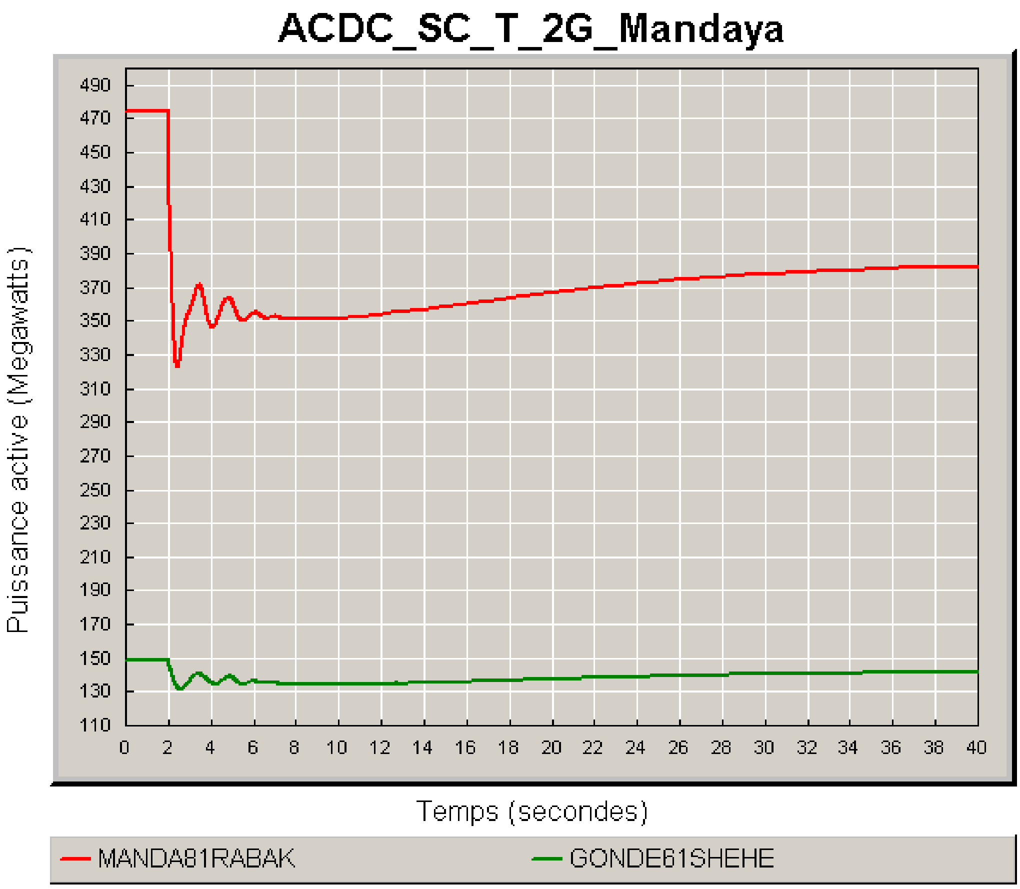


3.7 TRIPPING OF THE MAIN 2 UNITS IN ETHIOPIA : 2 UNITS OF 250 MW IN MANDAYA

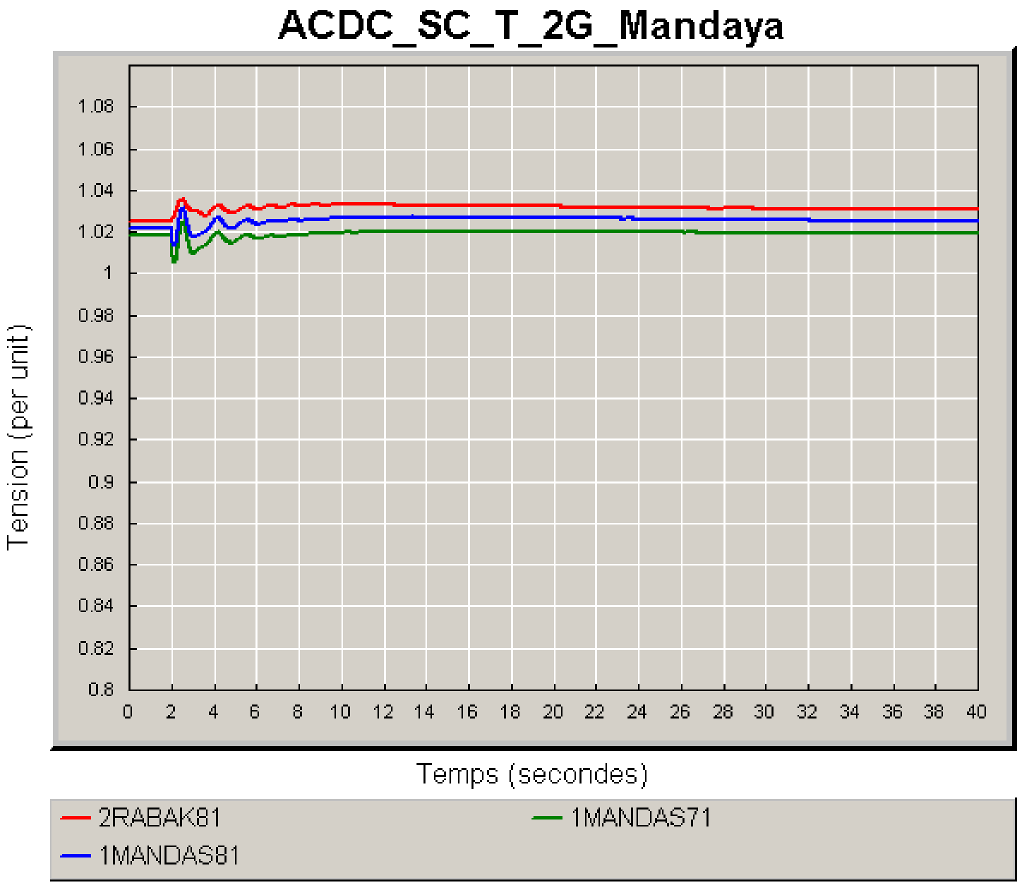
3.7.1 GENERATORS FREQUENCY VARIATION



3.7.2 POWER FLOW VARIATION ON THE INTERCONNECTION ETHIOPIA - SUDAN



3.7.3 VOLTAGE VARIATION ON THE 500 KV



3.7.4 TRIPPING OF TWO 250 MW UNITS OF MANDAYA