ENTRO

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Analysis of the network expansion plan In the year 2015/2016

VOL 3.3 - SUDAN

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with participation of:

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

FINAL REPORT

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PHYSICAL UNITS AND CONVERSION FACTORS

bbl	barrel (1t = 7.3 bbl)
cal	calorie (1 cal = 4.1868 J)
Gcal	Giga calorie
GWh	Gigawatt-hour
h	hour
km	kilometer
km^2	square kilometer
kW	kilo Watt
kWh	kilo Watt hour (1 kWh = 3.6 MJ)
MBtu	Million British Thermal Units (= 1 055 MJ = 252 kCal)
	One cubic foot of natural gas produces approximately 1,000 BTU
MJ	Million Joule (= $0{,}948.10^{-3}$ Mbtu = 238.8 kCal)
MW	Mega Watt
m	meter
m^3/d	cubic meter per day
mm	millimeter
mm^3	million cubic meter
Nm^3	Normal cubic meter, i.e. measured under normal conditions, i.e. 0°C and 1013 mbar
	(1 Nm^3 = 1.057 m^3 measured under standard conditions, i.e. 15°C and 1013 mbar)
t	ton
Toe	tons of oil equivalent
Tcf	ton cubic feet
°C	Degrees Celsius

General Conversion Factors for Energy

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3412	1

ABBREVIATIONS AND ACRONYMS

ADB	African Development Bank
ADF	African Development Fund
CC	Combined Cycle
CCGT	Combined Cycle Gas Turbine
CIDA	Canadian International Development Agency
CT	Combustion Turbine
DANIDA	Danish Development Assistance
DFID	Department for International Development (UK)
DIDC	Department for International Development Cooperation (GoF)
DSA	Daily Subsistence Allowance
EEHC	Egyptian Electricity Holding Company
EEPCO	Ethiopian Electric Power Corporation
EHV	Extra High Voltage
EHVAC	Extra High Voltage Alternating Current
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EN	Eastern Nile
ENCOM	Eastern Nile Council of Ministers
ENSAP	Eastern Nile Subsidiary Action Program
ENSAPT	Eastern Nile Subsidiary Action Program Team
ENTRO	Eastern Nile Technical Regional Office
ENTRO PCU	Eastern Nile Technical Regional Office Power Coordination Unit
FIRR	Financial Internal Rate of Return
GEP	Generation Expansion Plan
GTZ	German Technical Co-operation
HPP	Hydro Power Plant
HFO	Heavy fuel oil
HV	High Voltage
HVDC	High Voltage Direct Current
ICCON	International Consortium for Cooperation on the Nile
ICS	Interconnected System
IDEN	Integrated Development of the Eastern Nile
IDO	Industrial Diesel Oil
IMF	International Monetary Fund
JICA	Japanese International Co-operation Agency
JMP	Joint Multipurpose Project
LNG	Liquefied Natural Gas
LOLP	Loss of Load Probability

LPG	Liquefied Petroleum Gas
LRFO	Light Residuel Fuel Oil
MENA	Middle East, North Africa Countries
MIWR	Ministry of Irrigation & Water Resources (Sudan)
MWR	Ministry of Water Resources (Ethiopia)
MWRI	Ministry of Water Resources and Irrigation (Egypt)
MSD	Medium Speed Diesel (TPP)
NBI	Nile Basin Initiative
NEC	National Electricity Corporation (Sudan)
NECC	National Electricity Control Centre (Egypt)
NELCOM	Nile Equatorial Lake Council of Ministers
NELSAP	Nile Equatorial Lake Subsidiary Action Program
NG	Natural Gas
NGO	Non Governmental Organization
NORAD	Norwegian Aid Development
NPV	Net Present Value
O&M	Operations and Maintenance
OCGT	Open Cycle Gas Turbine
OPEC	Organization of the Petroleum Exporting Countries
PBP	Pay Back Period
PHRD	Policy & Human Resource Development Fund
PIU	Project Implementation Unit
PRSP	Poverty Reduction Strategy Paper
RCC	Regional Electricity Control Centre (Egypt)
RE	Rural Electrification
SAPP	Southern Africa Power Pool
SIDA	Swedish International Development Agency
SSD	Slow speed diesel (TPP)
STPP	Steam Turbine Power Plant
STS	Senior Technical Specialist
TAF	Technical Assistant Fund
TPP	Thermal Power Plant
UA	Unit of Account
UNDP	United Nations Development Program
WB	World Bank

LIST OF TABLES

1. PRESENTATION

The purpose of this analysis was to assess the master plan proposed by NEC that is described in the report "Long Term Power System Planning Study" realised by PB Power and dated from the fifth of November 2006.

The behaviour of the Sudan power system was examined for the year 2015/2016 to analyse in steady state the situation with the 220 kV interconnection with Ethiopia planned for the year 2009 and without interconnection with Egypt, and to point out the possible weak points of the transmission system. Several load flow calculations were performed in normal and in contingency situations for the annual peak.

2. HYPOTHESES

All data used in the simulations came from the report "Long Term Power System Planning Study".

2.1 LOAD DEMAND

The moderate scenario was selected; the corresponding annual energy is 39 328 GWh.

The simulations were performed for the annual peak that appears in October. The total expected load in 2015/2016 is 6 446 MW and 2 924 MVAr. The corresponding power factor is equal to 0.9. This figure includes the transmission losses.

The sharing of the peak demand between the different substations was deduced from the load flow results attached to the Long Term Power System Planning Study.

The total load of Khartoum and Gazeerah area represented about 50 % of the total demand.

2.2 GENERATION

On the basis of meeting the demand corresponding to the moderate scenario, the following new generating plants were implemented on the system:

Commissioning Year	New power plants	Number of units	Total installed capacity (MW)
2008	Khartoum N ST	2 x 100	200
	Merowe HPP	2 x 125	250
2009	Port Sudan ST	3 x 135	405
	Kosti ST	2 x 125	250
	El Bagair ST	2 x 135	270
	Al Fula OCGT	1 x 61	61
	LSD	7 x 40	280
	Merowe HPP	8 x 125	1 000
2010	Kosti St	2 x 125	250
	Garri III ST	3 x 135	405
	El Bagair ST	2 x 135	270
	Al Fula ST	2 x 135	270
	S. Darfur D	1 x 50	50
2011	Garri III ST	1 x 135	135
	Port Sudan Coal ST	2 x 150	300
	Sennar Ext HPP	1 x 50	50
	Rumela HPP	1 x 30	30
2012	N. Darfur D	1 x 28	28
	Port Sudan Coal ST	1 x 400	400
	Roseires High HPP	136	136
2013	Shereiq	315	315
2014	W. Darfur D	1 x 31	31
	Al Fula CCGT	1 x 214	214
2015	Port Sudan Coal ST	1 x 400	400
	Low Dal HPP	340	340
2016	Kajbar	300	300
Total			6 640

Table 2.2-1 - New generating units

ST: steam; D: diesel; LSD: low speed diesel; CCGT: combined cycle gaz turbine; OCGT: open cycle gaz turbine

2.3 TRANSMISSION SYSTEM

2.3.1 TRANSMISSION LINE

The transmission system corresponds to the master plan network. It included all the transmission expansion projects up to the year 2015/2016.

The new lines used to develop the 220 kV system after the year 2009, have the following characteristics: bundle conductors, cross section: 2 x 240 mm² - ACSR

The 500 kV system is built using single circuit lines equipped with quad conductors, cross section 4 x 280 mm² - ACSR. It includes the new lines commissioned after 2007:

- Two lines Atbara - Kabashi
- Two lines Atbara - Port Sudan
- Two lines Hasaheisa - Kabashi
- One line Fula - Rabak
- One line Fula - Nyala

To realise the simulations, only the 500 kV and the 220 kV networks have been represented.

2.3.2 TRANSFORMERS

The Khartoum and Gazeerah areas are supplied by three 500/220 kV substations: Markhiat equipped with five 300 MVA transformers, Kabashi equipped with two 300 MWA transformers, Hasaheisa equipped with three 300 MVA transformers.

The 500 kV system is split in two parts, the main part in the north – east connecting Khartoum to Merowe and Port Sudan, the second part in the south west connecting Rabak to Fula and Nyala.

The 500 kV is interconnected to the 220 kV system by the 500/220 kV substations of:

- Port Sudan, equipped with three 300 MVA autotransformers;
- Atbara, equipped with two 300 MVA autotransformers;
- Merowe, equipped with two 150 MVA autotransformers;
- Nyala, equipped with three 150 MVA autotransformers;
- Fula, equipped with two 300 MVA autotransformers;
- Rabak, equipped with two 300 MVA autotransformers.

2.3.3 REACTIVE COMPENSATIONS

Shunt reactors:

To control the voltage profile of the 500 kV and 220 kV systems, shunt reactors have been connected on the bus bars and at the end of the lines.

The total of reactors amounts to 2 776 MVAr:

- 2 496 MVAr equipped the 500 kV lines
- 125 MVAr equipped the 500 kV bus bar
- 155 MVAr equipped the 220 kV bus bar

Shunt Capacitors:

To improve the power factor of the system, a total amount of 910 MVAr shunt capacitors have been installed on the 220 kV system.

2.3.4 INTERNATIONAL INTERCONNECTIONS

The interconnection between Ethiopia and Sudan, planned in year 2009, has been taken into account: The Sudan system is connected to the Ethiopian system with a 230 kV double circuit line. For the present study, Option C has been retained. It consists in a link between Gonder and Gedaref passing through Shehedi substation. The total length of the line is about 321 km, 171 km in Ethiopia and 150 km in Sudan. Compensation reactors have been installed to keep acceptable voltage profile (4 x 15 MVAr).

For the analysis of the transmission system, it has been assumed that Sudan imported 100 MW from Ethiopia.

3. ANALYSIS OF THE TRANSMISSION SYSTEM, YEAR 2015/2016

Recall: The simulations were performed at the annual peak, which reaches 6 446 MW. Moreover, Sudan imported 100 MW from Ethiopia.

The detailed results of the simulations are presented in appendix M6 Vol3-3 attached at the report.

3.1 UNIT COMMITMENT

All the Hydro Power Plants were in operation. They generated 2 524 MW.

For the Thermal Power Plants, only the steam and the Combined Cycle Gaz Turbine units were in operation. They generated 3 822 MW.

The Diesel and Open Cycle Gaz Turbine units were out of operation.

The generation of each unit is displayed on the following table:

Unit commitment – SUDAN peak 2015/2016

HPP				
Plant	Net capacity (MW)	Generation (MW)	N° units	Tot al
MEROWE	125	119	10	1190
ROSEIRES	40	38	3	114
ROSEIRES2	40	38	4	152
ROSEIRES-H	135	125	1	125
J.AULIA	29	28	1	28
SENNAR	7.5	7	2	14
SENNAR EX	12.5	10	4	40
GIRBA	18	16	1	16
GEDAREF	30	25	1	25
L.DAL	340	280	1	280
KARMA	300	250	1	250
SHEREK	315	290	1	290
				2524
TPP				
Plant	Net capacity (MW)	Generation (MW)	N° units	Tot al
KHARTOUM N	60	51	2	102
KHART S5 S6	100	95	2	190
GARRI GT (CCGT)	38	26	2	52
GARRI STEAM (CCGT)	34	29	1	29
GARRI STEAM 3	129	120	4	480
P.SUD STEAM 2 3 4	129	120	3	360
P.SUD ST 5-6	143	136	2	272
P.SUD ST 1-5	380	361	2	722
KOSTI 1 2 3 4	119	113	4	452
BAGER 1 2 3 4	128	121	4	484
FULA 1 2 3 4	128	121	4	484
FULA GT (CCGT)	70	65	2	130
FULA STEAM (CCGT)	70	65	1	65
U.RUW DIESEL	26	0	1	0
ZALINGEI	26	0	1	0
GARRI STEAM 4	47.5	0	2	0
GARRI DIESEL	39	0	3	0
EL FASHER DIESEL	26	0	1	0
EID.BAB GT	60	0	1	0
KILO X	29	0	2	0
NYALA DIESEL	26	0	2	0
OBEID DIESEL	39	0	4	0
				3822
			Sub total	**6346**
Ethiopia import				**100**
			Total	**6446**

Table 3.1-1 - Unit commitment

3.2 ANALYSIS OF THE 500 AND 220 KV NETWORKS

3.2.1 NORMAL SITUATION

The whole transmission system was in operation. Sudan imported 100 MW from Ethiopia. The behaviour of the system was not satisfactory.

The 300 MVA 500/220 kV transformers of Hasaheisa substation were slightly overloaded by about 3 %.

The flows through each transformer reached 310 MVA (P = 289 MW; Q = 112 MVAr). The 500/220 kV transformations of Nyala and Merowe were heavy loaded, respectively 92 % and 71 % of their nominal rating. At Merowe substation, the power flowed from the 220 kV system to the 500 kV system due to the generation of Low Dal and Kajbar HPP. (total generated power=530 MW). The load of Northern State (Merowe and Dongola areas) reached 304 MW.

The flows through the most loaded 500/220 kV transformers are displayed on the following table:

Transformers	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Loading (%)	Tap position (%)
H.HEIY863	300	288.72	111.71	309.58	103.2	92.56
H.HEIY862	300	288.72	111.71	309.58	103.2	92.56
H.HEIY861	300	288.72	111.71	309.58	103.2	92.56
NYALAY863	150	136.25	24.26	138.4	92.3	96.25
NYALAY862	150	136.25	24.26	138.4	92.3	96.25
NYALAY861	150	136.25	24.26	138.4	92.3	96.25
MARKHY862	1200	825.81	231.05	857.53	71.5	96.28
MARKHY861	300	206.45	57.76	214.38	71.5	96.28
MEROWY862	150	-105.22	-14.42	106.2	70.8	103.75
MEROWY861	150	-105.22	-14.42	106.2	70.8	103.75

Table 3.2-1 - Loading of transformers

The flows over the 500 kV circuits were far below their thermal rating.

The most loaded 500 kV circuits were the two lines Markhiat-Merowe that were 29 % loaded.

The most loaded 220 kV circuits were the three circuits Bager - Giad, that were 89 % loaded and 82 % loaded, the two circuits Gamoea - Markhiat, that were 57.4 % loaded, the three lines Hasaheisa - Meringan, that were 56% loaded, and the three circuits Eid.B.- KiloX, that were 51.5 % loaded.

The loading of the other 220 kV lines was below 50 %.

The flows over the 500 kV and 220 kV lines are displayed on the Appendix M6 Vol3-3 §1.

The voltage profile was satisfactory, it was between 105.2 % and 99.7 % on the 500 kV system and between 105.5 % and 96.2 % on the 220 kV system.

The highest voltages on the 500 kV system appeared at Rabak, Fula and Merowe (respectively 526 kV, 525 kV and 524.5 kV), and the highest voltages on the 220 kV system appeared at Debeta, Abu Zaba and Roseires (respectively 232 kV, 231.9 kV and 230.6 kV).

On the 230 kV system, the lowest voltages appeared at Geneina (211.7 kV) and at Managil (213.9 kV).

The tap positions of the 500/220 kV transformers were below the nominal ratio in order to improve the 220 kV voltage profile, except in Merowe due to the generation of Merowe HPP.

The voltage profile is displayed on Appendix M6 Vol3-3 §1.

The generators operated within their reactive limits.

The active and reactive outputs of generators are displayed on Appendix M6 V3-3. §1

The total active losses amounted to 240 MW that represents about 3.8% of the total demand.

The losses of the interconnection between Ethiopia and Sudan reached 1.2 MW (1 % of the total exchange)

Conclusion:

The transmission system proposed in the report “Long Term Power System Planning Study” did not satisfy the planning criteria adopted by NEC: “No overload of any equipment in normal conditions”. Indeed, the three 500/220 kV transformers of Hasaheisa substation are overloaded by 3 %.

To satisfy the planning criteria, it is proposed to add a fourth 500/220 kV transformer at Hasaheisa for the year 2015/2016. The analysis of the transmission system in N-1 situation will be performed taking into account this reinforcement.

3.2.2 ANALYSIS OF CRITICAL N-1 SITUATIONS

The simulations were performed with a fourth 300 MVA 500/220 kV transformer at Hasaheisa substation.

The results are displayed in the Appendix M6 Vol3-3 §2.

3.2.2.1 Analysis of the 500/220 kV transformation

The tripping of one transformer was simulated for each 500/220 kV substation.

The number of 500/220 kV transformers proposed in the NEC Master Plan (November 2006) was sufficient to supply the demand in normal situation and N-1 situation except for Hasaheisa, Merowe and Nyala substations.

To satisfy the N-1 criterion, the system proposed in NEC Master Plan should be reinforced as follows:

- Hasaheisa substation: a fifth 500/220 kV transformer or a new 500/220 kV substation at Meringan connected to Hasaheisa with a 500 kV single circuit line, equipped with one 300 MVA 500/220 kV transformer.

- Merowe substation: a third 150 MVA transformer.
- Nyala substation: a fourth 150 MVA transformer and to secure Nyala substation in N-1 situation, a second 500 kV circuit between Fula and Nyala.

3.2.2.2 Analysis of the 500 kV lines

The tripping one by one of all 500 kV lines was simulated.

The main 500 kV transmission system connecting Merowe HPP to Khartoum area and Port Sudan TPP satisfies the N-1 criterion. Whatever the tripped line, the behaviour of the system was satisfactory: no overload appeared on the system and the voltage profile was kept within the limits.

On the contrary, in Darfur area, the transmission system proposed for the year 2015/2016 in the report "Long Term Power System Planning Study" does not satisfy the N-1 criterion:

- The tripping of the 500 kV line Fula - Nyala induced the collapse of the 220 kV under laying system.
- The tripping of one of the three 500/220 kV transformer of Nyala induced the overloading of the two remaining transformers.

The reinforcement suggested in the previous paragraph: a fourth 150 MVA transformer at Nyala and a second 500 kV circuit between Fula and Nyala will be taken into account in the following steps of the study.

3.2.2.3 Analysis of the 220 kV lines

The tripping one by one of the most loaded 220 kV lines was simulated.

In N-1 situation, the behaviour of the whole 220 kV system was satisfactory except between Bager TPP and Giad substation. Indeed, following the tripping of one of the three circuits, the two remaining circuits were overloaded by 35 %. These circuits allowed to evacuate the generation of Bager HPP connected on the 220 kV system and a part of the generation of Garri and Khartoum TPP.

To eliminate this constraint, it is possible to operate Bager with two separate bus bars, the first connected to Giad and the second connected to Kilo X.

3.3 SHORT-CIRCUIT CALCULATIONS

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

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

The short-circuit power of the Sudanese system was not very high; it did not exceed 10 000 MVA. The highest values reached about 9 600 MVA at Merowe 500 kV and about 8 050 MVA at Eid Babiker 220 kV.

The highest values are displayed on the following table:

Bus	Un (kV)	Tri phase		Mono phase	
		kA	MVA	kA	MVA
2MEROWS81	500	10.11	8 755	11.08	9 597
2P.SUD81	500	9.88	8 557	10.27	8 895
2EID.BS61	220	21.13	8 049	19.93	7 593
2BAGER61	220	20.29	7 730	19.33	7 366
2KILOXS61	220	20.19	7 693	17.67	6 731
2GARRIS61	220	20.18	7 690	21.44	8 168
2F.ZON	220	19.82	7 553	18.97	7 228
2KABASS61	220	19.71	7 510	14.7	5 603

Table 3.3-1 - Short circuit

The results for all substations are displayed on the Appendix M6 Vol3-3 §3.

4. CONCLUSIONS

The behaviour of the transmission system planned for the year 2015/2016, which is described on the “Long Term Power System Planning Study”, was analysed. Sudan imported 100 MW from Ethiopia over the 220 kV double circuit line Gedaref – Gonder

Load Flow calculations were performed in normal and in N-1 situations for the peak demand.

In Normal situation, the behaviour of the transmission system was not totally satisfactory. Indeed, the three 300 MVA 500/220 kV transformers of Hasaheisa were slightly overloaded by 3 %. Therefore, a fourth 300 MVA 500/220 kV transformer was assumed to be installed at Hasaheisa to recover a satisfactory behaviour and to comply with planning criteria adopted by NEC.

In N-1 situations, several constraints appeared on the system:

- Overload of the 500/220 kV transformations of Hasaheisa, Merowe and Nyala.
- Collapse of the western part of the system (Darfur area) following the tripping of the 500 kV line Fula - Nyala.
- Overload of the two 220 kV circuits between Bager and Giad, following the tripping of the third circuit.

To overcome these constraints and recover a system that satisfies the N-1 criterion, the following reinforcements are proposed:

- A fifth 300 MVA 500/220 kV transformers at Hasaheisa.
- A third 150 MVA 500/220 kV transformer at Merowe.

- Operation of Bager 220 kV substation with two separate bus bars in N-1 situation.
- A fourth 150 MVA 500/220 kV transformer at Nyala and a second 500 kV line Fula - Nyala with the convenient shunt reactors.

The proposed reinforcements described above will be included in the Sudanese transmission system - proposed by NEC Master Plan - for the study of the interconnection between Ethiopia, Egypt and Sudan.

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APPENDIX

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1 LOAD FLOW RESULTS PEAK 2015/2016 - NORMAL SITUATION

1.1 POWER FLOW ON THE 400 KV AND 230 KV LINES

Hasaheisa substation is equipped with a fourth 300 MVA 500/220 kV transformer.

line	from bus	to bus	Un (kV)	P (MW)	Q (MVAr)	S (MVA)	I (kA)	Active losses (MW)	Reactive losses (MVAr)	Rating (kA)	Loading (%)
ATBAR81KABAS	2KABASS81	2ATBARS81	500	-473.7	-119.17	488.46	0.55	7	-252.08	2.13	25.8
ATBAR81MEROW	2MEROWS81	2ATBARS81	500	298.57	-99.58	314.74	0.35	1.91	-217.12	2.13	16.3
ATBAR81P.SUD	2P.SUD81	2ATBARS81	500	429.88	-245.67	495.12	0.55	8.53	-419	2.13	25.7
ATBAR82KABAS	2ATBARS81	2KABASS81	500	480.7	-132.91	498.73	0.55	7	-252.08	2.13	26
ATBAR82P.SUD	2P.SUD81	2ATBARS81	500	429.88	-245.67	495.12	0.55	8.53	-419	2.13	25.7
FULA81NYALA	2NYALA81	2FULA81	500	-409.22	-247.6	478.29	0.55	7.63	-355.63	2.13	26
FULA81RABAK	2FULA81	2RABAK81	500	-157.78	-309.26	347.19	0.38	1.49	-643.98	2.13	17.9
H.HEI81KABAS	2KABASS81	2H.HEI81	500	461.85	7.46	461.91	0.52	4.28	-148.28	2.13	24.4
H.HEI82KABAS	2KABASS81	2H.HEI81	500	461.85	7.46	461.91	0.52	4.28	-148.28	2.13	24.4
MARKH81KABAS	2MARKHS81	2KABASS81	500	67.75	-223.29	233.34	0.26	0.19	-39.06	2.13	12.4
MARKH81MEROW	2MEROWS81	2MARKHS81	500	548.84	-125.88	563.09	0.62	11.34	-287.72	2.13	29.1
MARKH82MEROW	2MEROWS81	2MARKHS81	500	548.84	-125.88	563.09	0.62	11.34	-287.72	2.13	29.1
A.HAM61SHERE	2SHERES61	2A.HAM	220	7.52	-18.43	19.91	0.05	0.02	-21.93	0.97	5.2
A.HAM62SHERE	2SHERES61	2A.HAM	220	7.52	-18.43	19.91	0.05	0.02	-21.93	0.97	5.2
A.ZAB61DEBET	2DEBETS61	2A.ZABS61	220	7.18	-7.52	10.4	0.03	0	-14.32	0.97	2.7
A.ZAB61FULA	2A.ZABS61	2FULAS61	220	-10.33	-1.2	10.4	0.03	0.04	-25.49	0.97	2.7
A.ZAB62DEBET	2DEBETS61	2A.ZABS61	220	7.18	-7.52	10.4	0.03	0	-14.32	0.97	2.7
A.ZAB62FULA	2A.ZABS61	2FULAS61	220	-10.33	-1.2	10.4	0.03	0.04	-25.49	0.97	2.7
ALGHO61BARBA	2ALGHOS61	2BARBAS61	220	-74.5	-35	82.31	0.22	0.23	-4	0.97	22.2
ALGHO62BARBA	2ALGHOS61	2BARBAS61	220	-74.5	-35	82.31	0.22	0.23	-4	0.97	22.2
AROMA61KASSA	2KASSAS61	2AROMA	220	32.09	2.7	32.2	0.08	0.09	-12.3	0.97	8.4
ATBAR61BARBA	2ATBAS61	2BARBAS61	220	14.42	45.44	47.67	0.12	0.13	-6.81	0.97	12.6
ATBAR61P.SOU	2P.SOUDS61	2ATBAS61	220	79.73	-51.48	94.9	0.24	3.69	-77.9	0.97	24.7
ATBAR61SHEND	2ATBAS61	2SHENDIS61	220	74.92	-34.19	82.35	0.21	1.11	-24.11	0.97	21.8
ATBAR62BARBA	2ATBAS61	2BARBAS61	220	14.42	45.44	47.67	0.12	0.13	-6.81	0.97	12.6
ATBAR62P.SUD	2ATBAS61	2P.SOUDS61	220	-76.04	-26.43	80.5	0.21	3.69	-77.9	0.97	21.3
ATBAR62SHEND	2ATBAS61	2SHENDIS61	220	74.92	-34.19	82.35	0.21	1.11	-24.11	0.97	21.8
BAGER61GIAD	2BAGER61	2GIADS61	220	219.74	-36.87	222.81	0.58	1.66	5.72	0.67	85.7
BAGER62GIAD	2GIADS61	2BAGER61	220	-218.07	42.59	222.19	0.58	1.66	5.72	0.67	85.4
BAGER63GIAD	2BAGER61	2GIADS61	220	289.67	-58.35	295.49	0.76	2.58	7.12	0.97	78.7
BAGER63KILOX	2KILOXS61	2BAGER61	220	140.95	-69.81	157.29	0.41	0.73	-1.18	0.97	42.1
BARBA61SHERE	2BARBAS61	2SHERES61	220	-134.93	-13.76	135.63	0.35	2.08	-7.99	0.97	36.3
BARBA62SHERE	2BARBAS61	2SHERES61	220	-134.93	-13.76	135.63	0.35	2.08	-7.99	0.97	36.3
DEBBA61DONGO	2DEBBAS61	2DONGOS61	220	-48.59	10.95	49.81	0.13	0.75	-34.92	0.97	12.9
DEBBA61M.TOW	2DEBBAS61	2M.TOWS61	220	43.59	-13.45	45.62	0.11	0.36	-30.56	0.97	11.8
DEBBA62DONGO	2DONGOS61	2DEBBAS61	220	49.34	-45.87	67.37	0.17	0.75	-34.92	0.97	17.7
DEBBA62M.TOW	2DEBBAS61	2M.TOWS61	220	43.59	-13.45	45.62	0.11	0.36	-30.56	0.97	11.8
DEBET61OBEID	2OBEIDS61	2DEBETS61	220	7.21	-25.99	26.97	0.07	0.04	-18.47	0.97	7
DEBET62OBEID	2OBEIDS61	2DEBETS61	220	7.21	-25.99	26.97	0.07	0.04	-18.47	0.97	7

line	from bus	to bus	Un (kV)	P (MW)	Q (MVAr)	S (MVA)	I (kA)	Active losses (MW)	Reactive losses (MVAr)	Rating (kA)	Loading (%)
DONGO61KARMA	2DONGOS61	2KARMAS61	220	-142.34	2.37	142.36	0.36	1.39	-4.68	0.97	37.5
DONGO62KARMA	2KARMAS61	2DONGOS61	220	143.73	-7.05	143.9	0.37	1.39	-4.68	0.97	37.6
E.DAE61NYALA	2E.DAE61	2NYALA61	220	89.81	-12.46	90.67	0.23	1.86	-29.56	0.97	23.5
E.DAE62NYALA	2E.DAE61	2NYALA61	220	89.81	-12.46	90.67	0.23	1.86	-29.56	0.97	23.5
E.DAEI61FULA	2FULAS61	2E.DAE61	220	103.36	-39.69	110.72	0.28	3.54	-40.4	0.97	28.5
E.DAEI62FULA	2FULAS61	2E.DAE61	220	103.36	-39.69	110.72	0.28	3.54	-40.4	0.97	28.5
E.RAH61OBEID	2OBEIDS61	2E.RAHS61	220	-38.21	11.49	39.9	0.1	0.04	-4.16	0.97	10.3
E.RAH61U.RAW	2U.RAWS61	2E.RAHS61	220	38.46	-31.97	50.02	0.13	0.21	-16.33	0.97	13
E.RAH62OBEID	2OBEIDS61	2E.RAHS61	220	-38.21	11.49	39.9	0.1	0.04	-4.16	0.97	10.3
E.RAH62U.RAW	2U.RAWS61	2E.RAHS61	220	38.46	-31.97	50.02	0.13	0.21	-16.33	0.97	13
EID.B61GARRI	2EID.BS61	2GARRIS61	220	-140.59	-13.7	141.25	0.37	1.61	-5.07	0.97	37.7
EID.B61KABAS	2KABASS61	2EID.BS61	220	138.49	7.4	138.68	0.36	0.77	-2.63	0.97	36.8
EID.B61KILOX	2KILOXS61	2EID.BS61	220	-180.91	27	182.92	0.48	0.64	0.04	0.97	48.9
EID.B62GARRI	2EID.BS61	2GARRIS61	220	-140.59	-13.7	141.25	0.37	1.61	-5.07	0.97	37.7
EID.B62KABAS	2KABASS61	2EID.BS61	220	138.49	7.4	138.68	0.36	0.77	-2.63	0.97	36.8
EID.B62KILOX	2KILOXS61	2EID.BS61	220	-180.91	27	182.92	0.48	0.64	0.04	0.97	48.9
EID.B63KILOX	2KILOXS61	2EID.BS61	220	-180.91	27	182.92	0.48	0.64	0.04	0.97	48.9
ETHIO-SUDAN	2GEDARS61	1SHEHE61	220	-49.57	-13.62	51.41	0.13	0.58	-36.18	0.97	13.4
F.ZON61GARRI	2GARRIS61	2F.ZON	220	135.84	28.79	138.86	0.36	0.13	-0.47	0.97	36.5
F.ZON61KABAS	2F.ZON	2KABASS61	220	141.08	9.19	141.38	0.36	0.69	-2.28	0.97	37.3
F.ZON61SHEND	2SHENDIS61	2F.ZON	220	53.3	-19.58	56.78	0.15	0.44	-22.02	0.97	14.9
F.ZON62GARRI	2F.ZON	2GARRIS61	220	-135.71	-29.26	138.83	0.36	0.13	-0.47	0.97	36.6
F.ZON62KABAS	2F.ZON	2KABASS61	220	141.08	9.19	141.38	0.36	0.69	-2.28	0.97	37.3
F.ZON62SHEND	2SHENDIS61	2F.ZON	220	53.3	-19.58	56.78	0.15	0.44	-22.02	0.97	14.9
FASHE61NYALA	2NYALA61	2FASHE61	220	35.29	-20.25	40.69	0.1	0.27	-31.6	0.97	10.8
FASHE62NYALA	2NYALA61	2FASHE61	220	35.29	-20.25	40.69	0.1	0.27	-31.6	0.97	10.8
GAMOE61J.AUL	2GAMOES61	2J.AULS61	220	117.2	-4.87	117.3	0.3	0.7	-4.55	0.97	31.2
GAMOE61MARKH	2MARKHS61	2GAMOES61	220	203.83	36.84	207.13	0.53	2.13	1.7	0.97	54.1
GAMOE62J.AUL	2GAMOES61	2J.AULS61	220	117.2	-4.87	117.3	0.3	0.7	-4.55	0.97	31.2
GAMOE62MARKH	2MARKHS61	2GAMOES61	220	203.83	36.84	207.13	0.53	2.13	1.7	0.97	54.1
GEDAR61GIRBA	2GEDARS61	2GIRBAS61	220	88.88	-32.8	94.74	0.24	1.48	-23.32	0.97	24.6
GEDAR61HAWAT	2HAWATS61	2GEDARS61	220	107.69	-39.37	114.66	0.29	1.77	-15.45	0.97	30
GEDAR62GIRBA	2GEDARS61	2GIRBAS61	220	88.88	-32.8	94.74	0.24	1.48	-23.32	0.97	24.6
GEDAR62HAWAT	2HAWATS61	2GEDARS61	220	107.69	-39.37	114.66	0.29	1.77	-15.45	0.97	30
GENEI61ZALIN	2ZALIN61	2GENEI61	220	130.07	7.64	130.29	0.34	2.91	-9.7	0.97	35.4
GETEI61MASHK	2GETEIS61	2MASHKS61	220	124.36	-21.98	126.29	0.33	1.29	-6.26	0.97	33.8
GETEIS62MASH	2GETEIS61	2MASHKS61	220	124.36	-21.98	126.29	0.33	1.29	-6.26	0.97	33.8
GIAD61H.HEI	2GIADS61	2H.HEIS61	220	76.49	-42.65	87.58	0.23	1.09	-8.6	0.67	33.7
GIAD61J.AUL	2J.AULS61	2GIADS61	220	-158.42	10.44	158.76	0.41	1.24	-1.72	0.97	42.5
GIAD62H.HEI	2GIADS61	2H.HEIS61	220	76.49	-42.65	87.58	0.23	1.09	-8.6	0.67	33.7
GIAD62J.AUL	2J.AULS61	2GIADS61	220	-158.42	10.44	158.76	0.41	1.24	-1.72	0.97	42.5
GIAD63H.HEI	2GIADS61	2H.HEIS61	220	99.85	-60.62	116.81	0.3	1.68	-13.21	0.97	31.1
GIRBA61HALFA	2GIRBAS61	2HALFAS61	220	11.51	-6.89	13.41	0.03	0.01	-12.39	0.97	3.5
GIRBA61KASSA	2GIRBAS61	2KASSAS61	220	57.35	-8.57	57.99	0.15	0.28	-12.84	0.97	15.1
GIRBA61SHOWA	2SHOWAS61	2GIRBAS61	220	-20	-10	22.36	0.06	0.04	-14.8	0.97	5.8
GIRBA62HALFA	2GIRBAS61	2HALFAS61	220	11.51	-6.89	13.41	0.03	0.01	-12.39	0.97	3.5

line	from bus	to bus	Un (kV)	P (MW)	Q (MVAr)	S (MVA)	I (kA)	Active losses (MW)	Reactive losses (MVAr)	Rating (kA)	Loading (%)
GIRBA62KASSA	2GIRBAS61	2KASSAS61	220	57.35	-8.57	57.99	0.15	0.28	-12.84	0.97	15.1
H.HEI61MERIN	2H.HEIS61	2MERINS61	220	153.23	22.61	154.89	0.39	1.95	2.49	0.67	58.4
H.HEI62MERIN	2H.HEIS61	2MERINS61	220	153.23	22.61	154.89	0.39	1.95	2.49	0.67	58.4
H.HEI63MERIN	2H.HEIS61	2MERINS61	220	204.16	22.98	205.45	0.52	3.03	2.24	0.97	53.7
HAWAT61SINGE	2HAWATS61	2SINGERS61	220	-134.21	34.87	138.66	0.35	2.33	-8.44	0.97	36.2
HAWAT62SINGE	2HAWATS61	2SINGERS61	220	-134.21	34.87	138.66	0.35	2.33	-8.44	0.97	36.2
J.AUL61GETEI	2J.AULS61	2GETEIS61	220	125.24	-26.09	127.93	0.33	0.88	-4.1	0.97	34.2
J.AUL62GETEI	2J.AULS61	2GETEIS61	220	125.24	-26.09	127.93	0.33	0.88	-4.1	0.97	34.2
KARMA61L.DAL	2L.DAL61	2KARMAS61	220	127.51	-15.6	128.47	0.32	2.06	-12.17	0.97	33.2
KARMA61MEROW	2MEROWS61	2KARMAS61	220	-72.9	-14.17	74.26	0.19	2.38	-56.92	0.97	19.5
KARMA62L.DAL	2L.DAL61	2KARMAS61	220	127.51	-15.6	128.47	0.32	2.06	-12.17	0.97	33.2
KARMA62MEROW	2MEROWS61	2KARMAS61	220	-72.9	-14.17	74.26	0.19	2.38	-56.92	0.97	19.5
KILOX61BAGER	2KILOXS61	2BAGER61	220	107.89	-49.1	118.54	0.31	0.47	-0.58	0.67	45.8
KILOX62BAGER	2KILOXS61	2BAGER61	220	107.89	-49.1	118.54	0.31	0.47	-0.58	0.67	45.8
L.DAL61W.HAL	2W.HALS61	2L.DAL61	220	-24.03	-21.74	32.41	0.08	0.13	-37.03	0.97	8.4
M.TOW61MEROW	2MEROWS61	2M.TOWS61	220	-32.67	-19.24	37.92	0.1	0.06	-7.13	0.97	9.9
M.TOW62MEROW	2M.TOWS61	2MEROWS61	220	32.73	12.11	34.9	0.09	0.06	-7.13	0.97	9.1
MAHAD61MARKH	2MAHADS61	2MARKHS61	220	-135.11	-10.33	135.5	0.35	0.34	-1.44	0.97	35.5
MAHAD62MARKH	2MAHADS61	2MARKHS61	220	-135.11	-10.33	135.5	0.35	0.34	-1.44	0.97	35.5
MAHAD63MARKH	2MAHADS61	2MARKHS61	220	-135.11	-10.33	135.5	0.35	0.34	-1.44	0.97	35.5
MANAG61MERIN	2MANAGS61	2MERINS61	220	-111.14	-65.42	128.97	0.35	1.5	-5.97	0.97	35.7
MARSH61MANAG	2MASHKS61	2MANAGS61	220	95.21	18.22	96.94	0.25	1.35	-13.36	0.97	26.1
MASHK61RABAK	2MASHKS61	2RABAKS61	220	9.47	-55.83	56.63	0.15	0.31	-20.85	0.97	15.2
MASHK62RABA	2MASHKS61	2RABAKS61	220	9.47	-55.83	56.63	0.15	0.31	-20.85	0.97	15.2
MERIN61SENNA	2MERINS61	2SENNAS61	220	63.93	-19.83	66.94	0.17	0.55	-8.86	0.67	25.8
MERIN62SENNA	2MERINS61	2SENNAS61	220	63.93	-19.83	66.94	0.17	0.55	-8.86	0.67	25.8
P.SUT61P.SUD	2P.SUT61	2P.SOUDS61	220	179.44	-5.11	179.51	0.45	0.21	-0.13	0.97	46.7
P.SUT61SUAK	2SUAKI61	2P.SUT61	220	-114	-54	126.14	0.33	1.5	-8.13	0.97	33.9
P.SUT62P.SUD	2P.SUT61	2P.SOUDS61	220	179.44	-5.11	179.51	0.45	0.21	-0.13	0.97	46.7
RABAK61RANK	2RABAKS61	2RANKS61	220	-19.41	-23.17	30.22	0.08	0.07	-22.8	0.97	7.9
RABAK61U.RAW	2U.RAWS61	2RABAKS61	220	-91.97	6.97	92.23	0.23	2.7	-35.55	0.97	24
RABAK62RANK	2RABAKS61	2RANKS61	220	-19.41	-23.17	30.22	0.08	0.07	-22.8	0.97	7.9
RABAK62U.RAW	2U.RAWS61	2RABAKS61	220	-91.97	6.97	92.23	0.23	2.7	-35.55	0.97	24
RANK61ROSEI	2RANKS61	2ROSEIS61	220	-38.98	-9.37	40.09	0.1	0.32	-33.2	0.97	10.4
RANK62ROSEI	2RANKS61	2ROSEIS61	220	-38.98	-9.37	40.09	0.1	0.32	-33.2	0.97	10.4
ROSEI61SINGE	2SINGERS61	2ROSEIS61	220	-116.66	4.6	116.75	0.3	2.96	-5.5	0.67	44.3
ROSEI62SINGE	2SINGERS61	2ROSEIS61	220	-116.66	4.6	116.75	0.3	2.96	-5.5	0.67	44.3
SENNA61SINGE	2SENNAS61	2SINGERS61	220	49.3	-34.97	60.44	0.16	0.42	-9.76	0.67	23.3
SENNA62SINGE	2SENNAS61	2SINGERS61	220	49.3	-34.97	60.44	0.16	0.42	-9.76	0.67	23.3
SUD-ETHI2	2GEDARS61	1SHEHE61	220	-49.57	-13.62	51.41	0.13	0.58	-36.18	0.97	13.4
ZALIN61NYALA	2NYALA61	2ZALIN61	220	113.15	-14.76	114.1	0.29	3.08	-22.29	0.97	30.3
ZALIN62NYALA	2NYALA61	2ZALIN61	220	113.15	-14.76	114.1	0.29	3.08	-22.29	0.97	30.3

Table 1.1-1 - Load flow results. N situation

1.2 FLOWS THROUGH THE 500/220 KV TRANSFORMERS

Hasaheisa substation is equipped with a fourth 300 MVA 500/220 kV transformer.

Transformers	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Loading (%)	Tap position (%)
NYALAY863	150	136.26	24.22	138.39	92.3	96.25
NYALAY862	150	136.26	24.22	138.39	92.3	96.25
NYALAY861	150	136.26	24.22	138.39	92.3	96.25
H.HEIY863	300	228.78	77.87	241.67	80.6	93.8
H.HEIY862	300	228.78	77.87	241.67	80.6	93.8
H.HEIY861	300	228.78	77.87	241.67	80.6	93.8
H.HEIY864	300	228.78	77.87	241.67	80.6	93.8
MEROWY862	150	-105.22	-14.01	106.15	70.8	103.75
MEROWY861	150	-105.22	-14.01	106.15	70.8	103.75
MARKHY862	1 200	805.8	229.69	837.9	69.8	96.28
MARKHY861	300	201.45	57.42	209.47	69.8	96.28
ATBARY862	300	88	39.77	96.57	32.2	100
ATBARY861	300	88	39.77	96.57	32.2	100
RABAKY862	300	-80.01	44.38	91.49	30.5	100
RABAKY861	300	-80.01	44.38	91.49	30.5	100
FULAY861	300	50.68	3.59	50.8	16.9	100
FULAY862	300	50.68	3.59	50.8	16.9	100
KABASY862	300	45.64	19.6	49.67	16.6	100
KABASY861	300	45.64	19.6	49.67	16.6	100
P.SUDY863	300	38.59	14.82	41.34	13.8	100
P.SUDY862	300	38.59	14.82	41.34	13.8	100
P.SUDY861	300	38.59	14.82	41.34	13.8	100

Table 1.2-1 - Flows through 500/220 kV transformers

1.3 500 KV AND 220 KV VOLTAGE PROFILE

Hasaheisa substation is equipped with a fourth 300 MVA 500/220 kV transformer.

Bus	Un (kV)	Usol (kV)	U p.u.
2ATBARS81	500	520.6	1.04
2FULA81	500	525.0	1.05
2H.HEI81	500	501.0	1.00
2KABASS81	500	513.8	1.03
2MARKHS81	500	509.8	1.02
2MEROWS81	500	525.1	1.05
2NYALA81	500	513.8	1.00
2P.SUD81	500	522.5	1.04
2RABAK81	500	526.3	1.05
2A.HAM	220	227.6	1.03
2A.ZABS61	220	231.9	1.05
2ALGHOS61	220	220.5	1.00
2AROMA	220	226.5	1.03
2ATBAS61	220	224.7	1.02
2BAGER61	220	223.2	1.01
2BARBAS61	220	222.2	1.01
2DEBBAS61	220	229.9	1.05
2DEBETS61	220	232.0	1.05
2DONGOS61	220	225.7	1.03
2E.DAE61	220	229.4	1.04
2E.RAHS61	220	230.2	1.05
2EID.BS61	220	222.3	1.01
2F.ZON	220	225.3	1.02
2FASHE61	220	223.3	1.02
2FULAS61	220	230.5	1.05
2GAMOES61	220	223.1	1.01
2GARRIS61	220	225.7	1.03
2GEDARS61	220	228.4	1.04
2GENEI61	220	211.8	0.96
2GETEIS61	220	221.7	1.01
2GIADS61	220	223.1	1.01
2GIRBAS61	220	228.7	1.04
2H.HEIS61	220	227.4	1.03
2HALFAS61	220	228.6	1.04
2HAWATS61	220	227.2	1.03
2J.AULS61	220	221.9	1.01
2KABASS61	220	223.9	1.02
2KARMAS61	220	227.6	1.03
2KASSAS61	220	227.8	1.04
2KILOXS61	220	222.0	1.01
2L.DAL61	220	230.0	1.05
2M.TOWS61	220	227.6	1.03
2MAHADS61	220	226.5	1.03

Bus	Un (kV)	Usol (kV)	U p.u.
2MANAGS61	220	214.6	0.98
2MANAGS61	220	214.6	0.98
2MANAGS61	220	214.6	0.98
2MARKHS61	220	227.3	1.03
2MASHKS61	220	221.0	1.00
2MERINS61	220	222.5	1.01
2MEROWS61	220	226.6	1.03
2NYALA61	220	227.7	1.02
2OBEIDS61	220	230.4	1.05
2P.SOUDS61	220	228.0	1.04
2P.SUT61	220	228.2	1.04
2RABAKS61	220	227.4	1.03
2RANKS61	220	229.7	1.04
2ROSEIS61	220	230.0	1.05
2SENNAS61	220	223.0	1.01
2SHENDIS61	220	225.8	1.03
2SHERES61	220	226.7	1.03
2SHOWAS61	220	228.0	1.04
2SINGERS61	220	226.1	1.03
2SUAKI61	220	220.9	1.00
2U.RAWS61	220	228.6	1.04
2W.HALS61	220	228.0	1.04
2ZALIN61	220	218.7	0.99

Table 1.3-1 - Voltage profile

1.4 GENERATION

Hasaheisa substation is equipped with a fourth 300 MVA 500/220 kV transformer.

Generators	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Qmax (MVAr)	Qmin (MVAr)	Q/Qlim
BAGER STEAM	600	484	142.22	504.46	260	-156	54.7
KHARTOUM S	150	102	16.04	103.25	66	-40	24.3
KHART S5-6	222	190	25.96	191.77	96	-60	27.0
FULA STEAM	150	121	-12.23	121.62	65	-39	31.4
FULA GT	160	138	-0.39	138	70	-42	0.9
FULA ST	80	70	-0.2	70	35	-21	1.0
FULA234	450	363	68.47	369.4	195	-117	35.1
GARRI 3 STEA	600	480	92.57	488.84	260	-156	35.6
GARRI GT	95	52	27.25	58.71	56	-24	48.7
GARRI STEAM	45	26	12.62	28.9	27	-13	46.7
GEDAR-HYDRO	34	25	-8.5	26.41	-8.5	-8.5	100.0
GIRBA HYDRO	22.5	16	0.43	16.01	13.5	-8.1	3.2
J.AUL-HYDRO	40	28	4.22	28.32	24	-14.4	17.6
KARMA HYDRO	335	250	11.55	250.27	146	-87	7.9
L.DAL-HYDRO	380	280	-22.3	280.89	165	-100	22.3
MEROWH	1400	1190	21.84	1190.2	610	-370	3.6
P.SUD T1-5	900	708.29	46.09	709.79	392	-236	11.8
P.SUD 5-6	340	272	17.72	272.58	146	-88	12.1
P.SUDST2-3-4	450	360	33.02	361.51	195	-117	16.9
KOST	552	452	-22.43	452.56	240	-144	15.6
ROSEI-GR1	172	152	14.06	152.65	63.2	-38	22.2
ROSEI GR2	133.5	114	10.7	114.5	77.7	-46.8	13.8
ROSEIH-GR3	150	125	-24.14	127.31	65	-39	61.9
SENNAR-HYDRO	18.8	14	-1.77	14.11	11.2	-6.8	26.0
SENNAR-HYD2	56	40	-3.32	40.14	24	-14	23.7
SHEREK HYDRO	350	290	3.08	290.02	153	-90	2.0

Table 1.4-1 - Generation

2 LOAD FLOW RESULTS PEAK 2015/2016 - N-1 SITUATIONS

2.1 ANALYSIS OF THE 500/220 KV TRANSFORMATION

2.1.1 TRIPPING OF ONE OF THE THREE TRANSFORMERS AT NYALA

Following the tripping, the behaviour of the system was not satisfactory.

The two remaining Nyala transformers were overloaded by 34 %. The flow through each transformer reached 201 MVA (P=195 MW; Q=47 MVAr) that represents 94 % of the total initial flow.

The flows through all the transformers are displayed on the following table:

Transformers	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Loading (%)
NYALAY863	150	195.05	47.26	200.7	133.8
NYALAY862	150	195.05	47.26	200.7	133.8
H.HEIY863	300	228.99	77.86	241.86	80.6
H.HEIY862	300	228.99	77.86	241.86	80.6
H.HEIY861	300	228.99	77.86	241.86	80.6
H.HEIY864	300	228.99	77.86	241.86	80.6
MEROWY862	150	-105.22	-14.05	106.15	70.8
MEROWY861	150	-105.22	-14.05	106.15	70.8
MARKHY862	1 200	806.42	229.85	838.54	69.9
MARKHY861	300	201.61	57.46	209.64	69.9
ATBARY862	300	88.04	39.68	96.56	32.2
ATBARY861	300	88.04	39.68	96.56	32.2
RABAKY862	300	-79.92	43.23	90.87	30.3
RABAKY861	300	-79.92	43.23	90.87	30.3
FULAY861	300	60.11	-1.29	60.13	20
FULAY862	300	60.11	-1.29	60.13	20
KABASY862	300	45.82	19.36	49.74	16.6
KABASY861	300	45.82	19.36	49.74	16.6
P.SUDY863	300	38.71	14.77	41.43	13.8
P.SUDY862	300	38.71	14.77	41.43	13.8
P.SUDY861	300	38.71	14.77	41.43	13.8

Table 2.1-1 - Tripping of one Nyala transformer

The voltage profile was not significantly affected.

2.1.2 TRIPPING OF ONE OF THE FIVE MARKHIAT TRANSFORMERS

Following the tripping, the behaviour of the system was satisfactory.

The flows through the four remaining transformers were below their nominal rating; the flow reached 259 MVA in each remaining transformer at Markhiat that represents 99 % of the total initial flow.

The flows through all the transformers are displayed on the following table:

Transformers	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Active losses (MW)	Reactive losses (MVAr)	Loading (%)	Tap position (%)
NYALAY863	150	136.27	24.1	138.38	0.57	14.25	92.3	96.25
NYALAY862	150	136.27	24.1	138.38	0.57	14.25	92.3	96.25
NYALAY861	150	136.27	24.1	138.38	0.57	14.25	92.3	96.25
MARKHY862	1 200	983.27	327.21	1036.29	3.84	115.31	86.4	93.8
H.HEIY863	300	232.04	79.56	245.3	0.87	26.1	81.8	92.56
H.HEIY862	300	232.04	79.56	245.3	0.87	26.1	81.8	92.56
H.HEIY861	300	232.04	79.56	245.3	0.87	26.1	81.8	92.56
H.HEIY864	300	232.04	79.56	245.3	0.87	26.1	81.8	92.56
MEROWY862	150	-105.22	-14.94	106.27	0.35	8.86	70.8	103.75
MEROWY861	150	-105.22	-14.94	106.27	0.35	8.86	70.8	103.75

Table 2.1-2 - Tripping of one Markhiat transformer

The voltage profile was not significantly affected.

The flows over the transmission lines were not affected.

2.1.3 TRIPPING OF ONE OF THE TWO MEROWE TRANSFORMERS

Following the tripping of the transformer, the behaviour of the system was not acceptable. The remaining transformer was overloaded by 40 %. About 210 MVA flowed from the 220 kV to the 500 kV system that corresponds to the difference between the generation of Low Dal and Kajbar HPP (530 MW) and the local demand. (304 MW).

The flows through all the transformers are displayed on the following table:

Transformers	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Loading (%)	Tap position (%)
MEROWY862	150	-209.73	-11.94	210.06	140	105
NYALAY863	150	136.26	24.18	138.39	92.3	96.25
NYALAY862	150	136.26	24.18	138.39	92.3	96.25
NYALAY861	150	136.26	24.18	138.39	92.3	96.25
H.HEIY863	300	229.74	83.36	244.4	81.5	92.56
H.HEIY862	300	229.74	83.36	244.4	81.5	92.56
H.HEIY861	300	229.74	83.36	244.4	81.5	92.56
H.HEIY864	300	229.74	83.36	244.4	81.5	92.56
MARKHY862	1 200	803.3	221.96	833.4	69.4	96.28
MARKHY861	300	200.82	55.49	208.35	69.4	96.28
ATBARY862	300	87.97	38.2	95.9	32	100
ATBARY861	300	87.97	38.2	95.9	32	100
RABAKY862	300	-79.99	44.24	91.41	30.5	100
RABAKY861	300	-79.99	44.24	91.41	30.5	100
FULAY861	300	50.66	3.67	50.79	16.9	100
FULAY862	300	50.66	3.67	50.79	16.9	100
KABASY862	300	45.17	14.36	47.39	15.8	100
KABASY861	300	45.17	14.36	47.39	15.8	100
P.SUDY863	300	38.7	14.52	41.33	13.8	100
P.SUDY862	300	38.7	14.52	41.33	13.8	100
P.SUDY861	300	38.7	14.52	41.33	13.8	100

Table 2.1-3 - Tripping of one Merowe transformer

In low hydraulic period, the generation of Kajbar and Low Dal HPP would be close to 0 MW. Therefore, in N-1 situation, the remaining 150 MVA 500/220 kV transformer of Merowe could not supply the local demand.

Connecting Kajbar or Low Dal HPP on the 500 kV system would avoid to evacuate the extra generation through the 500/220 kV Merowe transformation and to overload the remaining transformer in N-1 situation. But the second constraint, supplying the local demand in case of low hydro generation would remain.

Therefore, to satisfy the N-1 criterion, the system should be reinforced with a third 150 MVA 500/220 kV transformer at Merowe.

2.1.4 TRIPPING OF ONE OF THE FOUR HASAHEISA TRANSFORMERS

2.1.4.1 With the El Bager plants generating their maximum output

The three remaining transformers at Hasaheisa were slightly overloaded by 2.6 %.

The total flow in the remaining transformers reached 924 MVA that represents 95 % of the initial flow.

Transformers	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Loading (%)	Tap position (%)
H.HEIY863	300	286.43	112.87	307.86	102.6	92.56
H.HEIY861	300	286.43	112.87	307.86	102.6	92.56
H.HEIY864	300	286.43	112.87	307.86	102.6	92.56
NYALAY863	150	136.25	24.29	138.4	92.3	96.25
NYALAY862	150	136.25	24.29	138.4	92.3	96.25
NYALAY861	150	136.25	24.29	138.4	92.3	96.25
MARKHY862	1 200	820.06	232.12	852.28	71	96.28
MARKHY861	300	205.02	58.03	213.07	71	96.28
MEROWY862	150	-105.22	-14.17	106.17	70.8	103.75
MEROWY861	150	-105.22	-14.17	106.17	70.8	103.75
ATBARY862	300	89.48	39.41	97.77	32.6	100
ATBARY861	300	89.48	39.41	97.77	32.6	100
RABAKY862	300	-80.04	44.64	91.64	30.5	100
RABAKY861	300	-80.04	44.64	91.64	30.5	100
KABASY862	300	52.59	17.84	55.53	18.5	100
KABASY861	300	52.59	17.84	55.53	18.5	100
FULAY861	300	50.71	3.44	50.83	16.9	100
FULAY862	300	50.71	3.44	50.83	16.9	100
P.SUDY863	300	37.56	15.06	40.47	13.5	100
P.SUDY862	300	37.56	15.06	40.47	13.5	100
P.SUDY861	300	37.56	15.06	40.47	13.5	100

Table 2.1-4 - Tripping of one Hasaheisa transformer

2.1.4.2 With one El Bager unit out of operation

The three remaining transformers at Hasaheisa were overloaded by 6.3%.

The flows over the transmission lines were not significantly affected.

Transformers	Sn (MVA)	P (MW)	Q (MVAr)	S (MVA)	Loading (%)	Tap position (%)
H.HEIY863	300	296.12	118.32	318.88	106.3	90.08
H.HEIY861	300	296.12	118.32	318.88	106.3	90.08
H.HEIY864	300	296.12	118.32	318.88	106.3	90.08
NYALAY863	150	136.25	24.14	138.38	92.3	96.25
NYALAY862	150	136.25	24.14	138.38	92.3	96.25
NYALAY861	150	136.25	24.14	138.38	92.3	96.25
MARKHY862	1 200	854.19	248.44	889.59	74.1	93.8
MARKHY861	300	213.55	62.11	222.4	74.1	93.8
MEROWY862	150	-105.22	-16.5	106.5	71	103.75
MEROWY861	150	-105.22	-16.5	106.5	71	103.75
ATBARY862	300	92.63	32.46	98.16	32.7	100
ATBARY861	300	92.63	32.46	98.16	32.7	100
RABAKY862	300	-79.98	44.23	91.4	30.5	100
RABAKY861	300	-79.98	44.23	91.4	30.5	100
KABASY862	300	69.2	-5.01	69.38	23.1	100
KABASY861	300	69.2	-5.01	69.38	23.1	100
FULAY861	300	50.65	3.69	50.78	16.9	100
FULAY862	300	50.65	3.69	50.78	16.9	100
P.SUDY863	300	44.46	11.85	46.01	15.3	100
P.SUDY862	300	44.46	11.85	46.01	15.3	100
P.SUDY861	300	44.46	11.85	46.01	15.3	100

Table 2.1-5 - Tripping of one Hasaheisa transformer. One Bagger unit off

In normal situation, the three 500/220 kV transformers of Hasaheisa were overloaded by 3 %. This N-1 situation was worsened when one unit of Bager TPP is out of operation So it is necessary to install a fourth transformer at Hasaheisa to avoid any overload in normal condition.

Nevertheless, in N-1 situation the three remaining transformers at Hasaheisa were overloaded by 6 %, (one unit of Bager out of operation).

To satisfy the N-1 criterion, a fifth 500/220 kV transformer would be necessary.

Another solution could be to create a new 500/220 kV substation at Meringan connected to Hasaheisa with a 500 kV single circuit line.

This Meringan substation would be equipped with one 300 MVA 500/220 kV transformer. (the fifth transformer).

Simulations were carried out with this reinforcement. One unit of Bager being out of operation, the transformers of Hasaheisa and Meringan were respectively 68 % and 75 % loaded. In N-1 situation, they were respectively 82.4 % and 86.3 % loaded.

2.1.5 CONCLUSION

The number of 500/220 kV transformers proposed in the NEC Master Plan (November 2006) was sufficient to supply the demand in normal situation and N-1 situation except for Hasaheisa, Merowe and Nyala substations.

For the 500/220 kV Hasaheisa substation, a fourth transformer was necessary to avoid any overload in normal situation.

To satisfy the N-1 criterion, the system proposed in NEC Master Plan should be reinforced as follows:

- Hasaheisa substation: a fifth 500/220 kV transformer or a new 500/220 kV substation at Meringan connected to Hasaheisa with a 500 kV single circuit line, equipped with one 300 MVA 500/220 kV transformer.
- Merowe substation: a third 150 MVA transformer
- Nyala substation: a fourth 150 MVA transformer and to secure Nyala substation in N-1 situation, a second 500 kV circuit between Fula and Nyala.

2.2 ANALYSIS OF THE TRIPPING OF THE 500 KV LINES

Tripping of one of the two 500 kV lines Markhiat - Merowe

In normal situation, about 1 098 MW (29.1 % of rating) flowed over the two lines from Merowe to Markhiat.

Following the tripping, the behaviour of the transmission system was acceptable.

About 75.3 % of the initial flow was transferred on the second line that corresponded to 44% of its nominal rating.

Lines 500 kV

Line	from bus	to bus	P (MW)	Q (MVAr)	S (MVA)	I (kA)	Rating (kA)	Loading (%)
MARKH81MEROW	2MEROWS81	2MARKHS81	827.12	40.6	828.11	0.93	2.13	43.7
ATBAR81KABAS	2KABASS81	2ATBARS81	-594.82	-121.74	607.15	0.72	2.13	34
ATBAR82KABAS	2ATBARS81	2KABASS81	607.15	-48.36	609.08	0.7	2.13	33
ATBAR81MEROW	2MEROWS81	2ATBARS81	569	-19.99	569.35	0.64	2.13	30
MARKH81KABAS	2MARKHS81	2KABASS81	-201.53	-292.01	354.8	0.43	2.13	20.1

Table 2.2-1 - Tripping of one line Markhiat - Merowe

On the 500 kV system, the voltage profile was significantly affected. The voltages dropped at Markhiat from 510 kV to 478 kV (-6 %) and at Hasaheisa from 501 kV to 468.5 kV (-8 %).

Thanks to the transformer taps, the voltage profile on the 220 kV was not significantly affected.

Bus	Un (kV)	Usol (kV)	V p.u.
2MEROWS81	500	514.5	1.03
2ATBARS81	500	501.3	1.00
2KABASS81	500	484.5	0.97
2MARKHS81	500	478.1	0.96
2H.HEI81	500	468.5	0.94
2MARKHS61	220	227.4	1.03
2H.HEIS61	220	227.0	1.03
2KABASS61	220	219.2	1.00
2ATBAS61	220	218.8	0.99
2MANAGS61	220	214.1	0.97

Table 2.2-2 - Tripping of one line Markhiat - Merowe. Voltage profile

2.2.1.1 Tripping of one of the two 500 kV lines Atbara – Port Sudan

The total generation at Port Sudan amounted to 1185 MW.

In normal situation, about 860 MW (25.7 % of rating) flowed over the two lines from Port Sudan to Atbara and about 156 MW (25 % of rating) flowed over the two 220 kV circuits from Port Sudan to Atbara.

Following the tripping, the behaviour of the transmission system was satisfactory. 95.8 % of the initial flow was transferred on the second line that corresponded to 44.1 % of its nominal rating (824 MW).

The 220 kV double circuit line Atbara – Port Sudan was 35 % loaded.

The voltage profile was slightly affected.

The voltage at Atbara decreased from 521 kV to 507.2 kV and at Hasaheisa from 501 kV to 491 kV.

Thanks to tap changer of the 500/220 kV transformers, the voltage on the 220 kV network was not significantly affected: the voltage at Hasaheisa decreased from 227 kV to 226 kV.

2.2.1.2 Tripping of one of the two 500 kV lines Atbara - Kabashi

In normal situation, about 960 MW (26 % of its rating) flowed over the two lines from Atbara to Kabashi. About 150 MW flowed from Atbara to Shendi (22 % of its rating).

Following the tripping, the behaviour of the transmission system was satisfactory. 76.5 % of the initial flow was transferred on the second line that corresponded to 39.3 % of its nominal rating (735 MW). About 220 MW flowed on the 220 kV double circuit line Atbara – Shendi (32 % of its rating).

The voltage profiled was affected. The voltages at Kabashi dropped from 514 kV to 484 kV (-6 %) and at Hasaheisa from 501 kV to 469 kV (-6 %).

Thanks to tap changer of the 500/220 kV transformers, the voltage on the 220 kV network was not affected.

2.2.1.3 Tripping of one of the two 500 kV lines Hasaheisa - Kabashi

In normal situation, about 925 MW (24.4 % of its rating) flowed over the two 500 kV lines from Kabashi to Hasaheisa. On the 220 kV system, about 730 MW flowed from Bager to Giad (85 %) and about 250 MW flowed from Giad to Hasaheisa (33 % of its rating).

Following the tripping, the behaviour of the transmission system was acceptable. 84.5 % of the initial flow was transferred on the second line that corresponded to 45.3 % of its nominal rating (780 MW). About 810 MW flowed from Bager to Giad (94.7 % of its rating) and about 370 MW flowed Giad to Hasaheisa (46% of its rating).

The voltage profiled on the 500 kV network was significantly affected. The voltages at Hasaheisa dropped from 501 kV to 456 kV (-9 %)

The tap changers of the Hasaheisa transformers were at their lower limit; the voltage reached 222 kV at Hasaheisa and 210 kV at Managil.

2.2.1.4 Tripping of the 500 kV Fula – Rabak line

In normal situation, about 160 MW (18 % of its rating) flowed over the line from Rabak to Fula. About 180 MW flowed from Rabak to U. Ruwaba (85 %) on the 220 kV double circuit line.

Following the tripping, the behaviour of the transmission system was satisfactory.

The Fula TPP controlled the voltage profile on the 500 kV and 220 kV systems.

The flow over the double circuit line Rabak - U.Ruwaba reached about 350 MW (48.5 % of its rating).

The voltage profile was slightly affected, the following values were collected:

- Fula 500 kV: 515.4 kV (-2 %)
- Fula 220 kV: 227 kV (-1.5 %)
- Nyala 500 kV: 500.5 kV (-2.5 %)
- Nyala 220 kV: 227.7 kV (+0 %)
- Obeid 220 kV: 219.9 kV (-4.4 %)

2.2.1.5 Tripping of the 500 kV Fula – Nyala line

Nyala 500/220 kV substation was equipped with three 150 MVA 500/220 kV transformers.

The diesel units of South Darfur, North Darfur and West Darfur, whose total generation amounted about 100 MW, were not in operation.

In normal condition, about 410 MW flowed from Fula to Nyala over the 500 kV single circuit line, and about 210 MW over the 220 kV double circuit line Fula - Eid Daien. So the total transmitted power between Fula and Nyala was about 620 MW.

Following the tripping of the 500 kV line Fula - Nyala, the maximum transmissible power on the 220 kV system between Fula and Nyala is about 380 MW ($P_{max}=U^2/2X$), that is far below the transmitted power between the two substations. Therefore, the power system cannot operate properly, following the tripping of the 500 kV line a collapse appeared on the western area.

The generation of the diesel units in Darfur area would not be sufficient to avoid the collapse of the local system in N-1 situation.

2.2.2 CONCLUSION: BEHAVIOUR OF THE 500 KV TRANSMISSION SYSTEM IN N-1 SITUATION

The main 500 kV transmission system connecting Merowe HPP to Khartoum area and Port Sudan TPP satisfies the N-1 criterion. Whatever the tripped line, the behaviour of the system was satisfactory: no overload appeared on the system and the voltage profile was kept within the limits.

On the contrary, in Darfur area, the transmission system proposed for the year 2015/2016 in the report “Long Term Power System Planning Study” does not satisfy the N-1 criterion:

- The tripping of the 500 kV line Fula - Nyala induced the collapse of the 220 kV under laying system.
- The tripping of one of the three 500/220 kV transformer at Nyala induced the overloading of the two remaining transformers.

To overcome these constraints, a fourth 150 MVA transformer at Nyala and a second 500 kV circuit between Fula and Nyala are proposed to be installed.

The reinforcement suggested above will be taken into account in the following steps of the study.

2.3 ANALYSIS OF THE 220 KV LINES

In normal situation, the most loaded lines were the following:

Line	Un (kV)	P (MW)	Q (MVAr)	S (MVA)	I (kA)	Rating (kA)	Loading (%)
BAGER61GIAD	220	219.72	-37.08	222.83	0.58	0.67	85.7
BAGER62GIAD	220	218.06	-42.8	222.22	0.58	0.67	85.4
BAGER63GIAD	220	289.64	-58.62	295.51	0.76	0.97	78.6
H.HEI61MERIN	220	153.08	22.67	154.75	0.39	0.67	58.4
H.HEI62MERIN	220	153.08	22.67	154.75	0.39	0.67	58.4
GAMOE61MARKH	220	203.66	37	207	0.53	0.97	54.1
GAMOE62MARKH	220	203.66	37	207	0.53	0.97	54.1
H.HEI63MERIN	220	203.97	23.06	205.27	0.52	0.97	53.6
EID.B61KILOX	220	-180.89	27.04	182.9	0.48	0.97	48.9
EID.B63KILOX	220	-180.89	27.04	182.9	0.48	0.97	48.9
EID.B62KILOX	220	-180.89	27.04	182.9	0.48	0.97	48.9
P.SUT61P.SUD	220	181.33	-5.56	181.42	0.46	0.97	47.2
P.SUT62P.SUD	220	181.33	-5.56	181.42	0.46	0.97	47.2
KILOX61BAGER	220	107.88	-49.13	118.54	0.31	0.67	45.8
KILOX62BAGER	220	107.88	-49.13	118.54	0.31	0.67	45.8
KILOX63BAGER	220	107.88	-49.13	118.54	0.31	0.67	45.8

Table 2.3-1 - Flows over the 220 kV network. Normal situation

2.3.1 TRIPPING OF ONE OF THE THREE CIRCUITS BAGER – GIAD

In normal condition, a part of the power generated by Garri and Khartoum TPP flowed to Bager, Giad and Hasaheisa to supply the local demand. Consequently, the three circuits between Bager and Giad were heavy loaded due to this flow and the generation of Bager TPP.

Following the tripping of one of the three circuits, the behaviour of the system was not satisfactory.

Whatever the tripped circuit, the two remaining circuit were overloaded. In the worst situation - tripping of the single circuit line - the remaining double circuit line was overloading by 35 %. The voltage profile was not affected.

To eliminate this constraint, it is possible to interrupt the flow coming from Garri and Khartoum TPP by opening the link between Kilo X and Bager.

For example: by separating the bus bar at Bager in two nodes, the first connected to Kilo X and the second connected to Giad. Bager TPP would be connected on the second bus bar. With such operation scheme, the behaviour of the 220 kV system was satisfactory.

2.3.2 TRIPPING OF ONE OF THE THREE CIRCUITS HASAHEISA – MERINGAN

Following the tripping of the single circuit line, the behaviour of the system was satisfactory. The remaining double circuit line was 92.5 % loaded (246 MVA, 0.62 kA, over each circuit). The voltage profile was not significantly affected (Managil: -1 %)

2.3.3 TRIPPING OF ONE UNIT OF BAGER TPP

The behaviour of the system was satisfactory. The flow over the double circuit line Gamoeia - Markhiat increased by 24 MW to reach 432 MW. And the flow over the three circuits Eid Babiker - Kilo X increased by 50 MW to reach 594 MW.

2.3.4 TRIPPING OF ONE OF THE TWO CIRCUIT OF THE LINE GAMOEIA – MARKHIAT, ONE UNIT OF BAGER BEING OUT OF OPERATION.

The behaviour of the system was acceptable. The remaining circuit was 98 % loaded.

The voltage profile was slightly affected, the voltage slipped from 223 kV to 219 kV at Gamoeia.

2.3.5 TRIPPING OF ONE OF THE THREE CIRCUITS BETWEEN EID BABIKER AND KILO X, ONE UNIT OF BAGER BEING OUT OF OPERATION.

The behaviour of the system was satisfactory. The remaining circuits were 79 % loaded.

The voltage profile was not affected.

2.4 CONCLUSION

In N-1 situation, the behaviour of the whole 220 kV system was satisfactory except between Bager TPP and Giad substation. Indeed, following the tripping of one of the three circuits, the two remaining circuits were overloaded by 35 %. These circuits allowed to evacuate the generation of Bager HPP connected on the 220 kV system and a part of the generation of Garri and Khartoum TPP.

To eliminate this constraint, it is possible to operate Bager with two separate bus bars, the first connected to Giad and the second connected to Kilo X.

3 SHORT-CIRCUIT RESULTS PEAK 2015/2016

Bus	Un (kV)	Tri phase		Mono phase	
		kA	MVA	kA	MVA
2MEROWS81	500	10.11	8755	11.08	9597
2P.SUD81	500	9.88	8557	10.27	8895
2KABASS81	500	9.64	8351	4.31	3729
2ATBARS81	500	9.43	8162	5.29	4578
2MARKHS81	500	8.99	7787	4.33	3750
2H.HEI81	500	6.87	5947	2.69	2328
2FULA81	500	4.1	3550	4	3466
2RABAK81	500	3.4	2947	1	863
2NYALA81	500	1.91	1652	1.07	927
2EID.BS61	220	21.13	8049	19.93	7593
2BAGER61	220	20.29	7730	19.33	7366
2KILOXS61	220	20.19	7693	17.67	6731
2GARRIS61	220	20.18	7690	21.44	8168
2F.ZON	220	19.82	7553	18.97	7228
2KABASS61	220	19.71	7510	14.7	5603
2GIADS61	220	18.56	7073	12.92	4923
2J.AULS61	220	15.42	5875	8.89	3388
2H.HEIS61	220	14.62	5571	5.86	2234
2MARKHS61	220	14.5	5526	4.26	1625
2P.SUT61	220	13.5	5144	11.61	4422
2GAMOES61	220	13.15	5010	5.57	2121
2RABAKS61	220	12.79	4872	13.19	5024
2P.SOUDS61	220	12.69	4834	10.38	3954
2MAHADS61	220	12.46	4748	3.89	1484
2ATBAS61	220	12.08	4603	5.57	2120
2GETEIS61	220	11.41	4349	6.5	2477
2MERINS61	220	10.74	4092	5.15	1962
2MASHKS61	220	10.45	3982	6.26	2384
2BARBAS61	220	9.12	3475	5.35	2037
2MEROWS61	220	9.01	3432	2.53	964
2FULAS61	220	8.9	3392	10.6	4041
2SHENDIS61	220	8.46	3224	4.72	1797

Bus	Un (kV)	Tri phase		Mono phase	
		kA	MVA	kA	MVA
2ROSEIS61	220	7.72	2940	8.85	3370
2KARMAS61	220	7.34	2797	7.82	2980
2ALGHOS61	220	7.14	2722	4.06	1545
2M.TOWS61	220	7.08	2697	2.38	907
2RANKS61	220	7.05	2686	4.78	1820
2SENNAS61	220	6.97	2654	4.95	1886
2SHERES61	220	6.7	2554	7.18	2737
2SINGERS61	220	6.45	2456	4.27	1628
2MANAGS61	220	6.21	2366	3.23	1232
2L.DAL61	220	6.03	2299	6.95	2646
2DONGOS61	220	5.78	2201	4.39	1671
Z	220	5.35	2039	2.88	1097
2A.ZABS61	220	5.07	1932	3.42	1303
2HAWATS61	220	4.76	1813	3.67	1399
2DEBBAS61	220	4.7	1790	2.33	889
2DEBETS61	220	4.44	1693	2.78	1059
2U.RAWS61	220	4.39	1674	2.62	996
2OBEIDS61	220	4.16	1585	2.49	949
2E.RAHS61	220	4.16	1584	2.48	944
2GEDARS61	220	4.09	1557	4.99	1899
2SUAKI61	220	4.02	1532	2.33	889
2NYALA61	220	3.65	1391	1.12	426
2A.HAM	220	3.63	1383	2.59	985
2E.DAE61	220	3.5	1333	1.62	616
2GIRBAS61	220	2.53	965	2.24	855
2HALFAS61	220	2.15	818	1.71	652
2FASHE61	220	2.14	814	0.79	299
2KASSAS61	220	2.11	801	1.66	632
2ZALIN61	220	2.03	774	0.76	288
2SHOWAS61	220	1.77	674	1.28	489
2W.HALS61	220	1.69	645	1.02	389
2AROMA	220	1.61	613	1.13	428
2GENEI61	220	1.28	486	0.53	201

Table 3-1 - Flows over the 220 kV network. Normal situation