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POWER SYSTEM CHARACTERISATION OF THE NIGERIAN SHIRORO COMPLEX

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ABSTRACT

The paper presents power system analysis of the Shiroro Complex using ERACS power system analysis software. The study was carried out under different loading and generation conditions, modeling philosophy, power flows and fault level. In all cases, the result obtained demonstrates the need for additional power generation facility and means of voltage compensation at receiving ends. For operational convenience and efficiency, this paper proposed regionalization in transmission and analysed one of the regions in Nigeria as a case study. This is to position the region as a suitable candidate for application of FACTS devices.

SIGNIFICANCE: The paper has provided the Power system analysis of a Power Holdings Company of Nigeria region which is needed for network upgrade, control and decentralisation. Decentralised structure and regionalized operation is necessary for full benefit of privatised Power Industry.

KEYWORDS*:* Shiroro Complex, Maximum Demand, Minimum Generation, Power Flow Analysis, Voltage Profile, Fault Level.

1.0 INTRODUCTION

The Electricity Industry is undergoing significant and irreversible change worldwide. This is reshaping the industry that has been remarkably stable for a long time and characterised by vertically integrated structure. In radial networks such as the structure of Power Holding Company of Nigeria (PHCN) owned grid, losses are expectedly high [Haruna, 2002]. Transmission losses alone represents up to 5-15% of the total generation capacity. [PHCN, 2006 and ERACS, 2004]. Several other factors have motivated the global changes occurring in the electric power industry such as energy trading, pricing and economics of power production, economic dispatch, power delivery and management [PHCN, 2006, and Haruna and Nafisatu, 2003].

Deregulation and unbundling of the hitherto vertically integrated Nigerian electricity supply industry calls for improved efficiency and competitiveness in energy management systems. This in turn gives rise to the need for introducing innovative technologies in power generation and transmission. The Nigerian power grid comprises 330kV and 132kV transmission systems which may be divided into two parts – a Southern part and a Northern part. The southern part of the grid is highly concentrated and interconnected and is primarily fed from a number of thermal power stations. The Northern part of the gird is spread over a wide geographical area and is characterized by radial transmission lines fed from three hydro generating stations with additional power serviced from the southern thermal power stations when hydrogenation is low.

The fact that a single company operates the power grid means that competitiveness may be undermined. However, the optimized use of the transmission system investments is important considering needs such as: supporting needed industrial development, job creation, and efficient utilization of scarce resources. As already mentioned FACTS (flexible AC transmission systems) control is a technology that responds to these needs. It significantly alters the way transmission systems are developed and controlled apart from improving asset utilization, system flexibility, and system performance [Haruna and Nafisatu, 2003]. In this respect, network studies are crucial for implementation of FACTS controllers with regard to determination of requirements such as type of controller, appropriate rating and location, and cost. ERACS software [ERACS, 2004] is used to carefully study and characterize a part of the Northern Nigeria grid network – the Shiroro

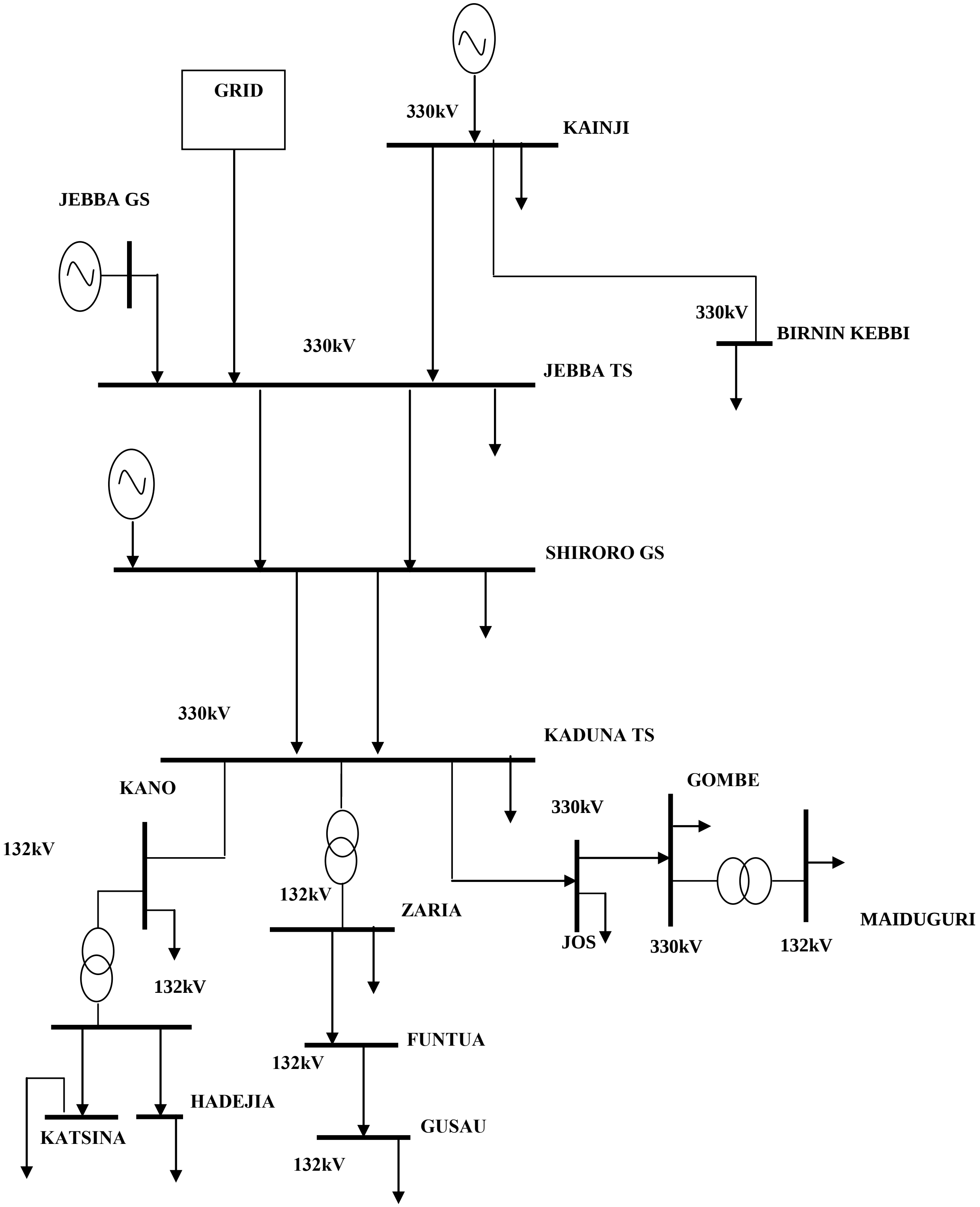

Fig. 1: One-line diagram of Shiroro Complex

Complex- considered being a candidate for future deployment of FACTS controllers. A description and ERACs modeling of the Shiroro complex is presented along with power flow case studies under selected contingencies.

The Shiroro Complex is a region of the national grid that transmits power at 330kV and 132kV in Nigeria. Distribution to major industrial and commercial consumers is at 33 and 11kV with 0.415kV as the terminal domestic consumer voltage. The region covers the major northern Nigeria cities of Kaduna, Zaria, Kano, Jos, Yola and Maiduguri. Funtua, Gusau, Katsina, Dutse, Azare, Bauchi, Gombe, Jebba towns and surrounding villages are within the region. The major sources of electricity are three hydro generating stations located at Kainji, Jebba and Shiroro with supplementary grid infeed from the southern part of Nigeria via Oshogbo, the National control centre. The single-line diagram of the Shiroro complex (SC) network is shown in figure 1. The emergency diesel generating plants in Abuja which now provide over 40% of the city demand are not considered in this network model as these plants are normally isolated from the grid during operation. Although, Abuja and Akwanga are part of this region, the 330kV line feeding them is modeled as a load at the Shiroro 330kV bus. This will not however affect the total load of the SC since the load used in the model is based on the transformer loading at Shiroro 330/132kV substation. The overall maximum system load for the SC is assumed to be 1500MW. This is considered representative of "unsuppressed" peak demand at the time of this study. The load under minimum demand conditions has been assumed to be 60% of maximum demand. The overall load at minimum demand is therefore 900MW. This figure is based on data for off-peak demand documented in recent PHCN operational reports [PHCN, 2006].

2.0 TRANSMISSION CIRCUITS DATA

Details of the 330kV circuits are given in Table 1. The 330kV circuits use twin 'Bison' (350mm2 ACSR) conductors in either single- or double- circuit configuration with a maximum continuous thermal capacity of approximately 777MVA. However, under typical environmental conditions in Nigeria the capacity of each 350mm2 conductor is approximately 680A. The positive-sequence impedance data assumed for 330kV transmission circuits is summarized in Table 2.

Table 1: Shiroro Complex 330kV Circuit Data

From	To	No. of Circuits	Construction	Length (km)
Kainji	Jebba	2	SC 2 x Bison	81
Jebba	Jebba Power Station	2	DC 2 x Bison	8
Jebba	Shiroro	2	SC 2 x Bison	244
Shiroro	Kaduna	2	SC 2 x Bison	96
Kaduna	Kano	1	SC 2 x Bison	230
Kaduna	Jos	1	SC 2 x Bison	196
Jos	Gombe	1	SC 2 x Bison	264

Table 2: Positive-sequence impedance data for 330kVcircuits

Construction	R_1 (Ω /km)	X_1 (Ω /km)	B_1 (μs/km)
SC 2 x Bison	0.0390	0.3310	3.490
DC 2 x Bison	0.0394	0.3030	3.812

2.1 Generation Data

Details of available generation plant within Shiroro complex are shown in Table 3. All units are hydro prime movers and so table 3 indicates rated power, (MVA) rated voltage (kV), maximum power output (Pmax) and reactive power limits Qmax and Qmin for each unit. Total active power generated at the three stations assuming full capacity utilization units is 1838MW.

Table 3: Installed generation plants on Shiroro Complex

Station	Unit	MVA	kV	Pmax (MW)	Qmax (Mvar)	Qmin (Mvar)
Jebba	1– 6	104	16	93 x 6	47.4	-30
			Sub-total	**558**		
Kainji	5– 6	125	16	120x2	37.5	-30
				240		
Kainji	8– 10	85	16	80 x 3	25	-30
				240		
Kainji	11–12	115	16	100x2	35.9	-30
				200		
			Sub-total	**680**		
Shiroro	1 – 4	177	16	150x4	79	-30
			Sub-total	**600**		
GRAND TOTAL			**1838**			

2.2 Load

The real and reactive system loads for substations under maximum and minimum demand conditions are shown in Table 4. The overall maximum system load for the complex is assumed to be 1500MW. The loads for Maiduguri, Yola and Potiskum are added on the 330kV bus in Gombe. Similarly, Katsina, Hadejia and Azare loads are added on 330kV bus in Kano.

Table 4: System Load Data

Substation	XT Loading (MW)	Maximum Demand		Minimum Demand	
		(MW)	(MVAR)	(MW)	(MVAR)
Jebba	20	30	10	10	5
Kaduna Main	270	370	210	210	70
Kumbotso	200	305	180	200	95
Shiroro	250	350	230	200	60
Gombe	180	290	180	180	50
Jos	100	155	90	100	40
Maiduguri	-	-	-	-	
Yola	-	-	-	-	
TOTAL	**1020**	**1500**		**900**	

3.0 DATA ANALYSIS

3.1 Power Flow Analysis

The main aim of a modern electrical power system is to satisfy continuously the electrical power contracted by all customers. This is a problem of great engineering complexity where the following operational policies must be implemented:

(i) Bus voltage magnitudes and system frequency must be kept within statutory limits ($\pm 2.5\%$ specified by IEC and $\pm 5\%$ in Nigeria

(ii) The alternating current (AC) voltage and current waveforms must remain largely sinusoidal (i.e minimal harmonic distortion);

(iii) Transmission lines must be operated well below their thermal and stability limits; and

(iv) Short-term interruptions must be kept to a minimum.

Moreover, because of the very competitive nature expected in a deregulated electricity supply industry, transmission cost must be kept as low as possible. To a large extent, several of these key issues in power system operation may be assessed quite effectively through power flow and derived studies [Erique et al, 2004, Young and Allan, 1999, Stott, 1974, Kersting and Philips, 1987]. The main objective of power flow studies is to determine the steady-state operating condition of the electrical power network. The steady-state may be determined by finding out, for given set of loading conditions, the flow of active and reactive power throughout the network and the voltage magnitudes and phase angles at all buses of the network. Expansion, planning, and daily operation of power systems rely on extensive power flow studies [Shirmohammadi et al, 1988, Baran and Wu, 1989, Luo and Semlyen, 1990, and Chiang, 1991]. The information conveyed by such studies indicates whether or not the nodal voltage magnitudes, as well as active and reactive power flows in transmission lines and transformers, are within prescribed operating limits. If voltage magnitudes are outside bounds in one or more points of the network, then appropriate action is taken in order to regulate such voltage magnitudes. Similarly, if the study predicts that the power flow in a given transmission line is beyond the power carrying capacity of the line, and then control action is taken. The economic design of power systems is therefore critically dependent on being able to predict the system behaviour under both normal and abnormal operating conditions.

Power flow studies (PFS) carried out and presented considered three different operating scenarios indicated in Table 5. The estimation and justification for values selected for maximum and minimum load demands were detailed in section 2. ERACS power flow calculation procedure is illustrated in fig. 2. The network connection and the results are presented in the succeeding sections.

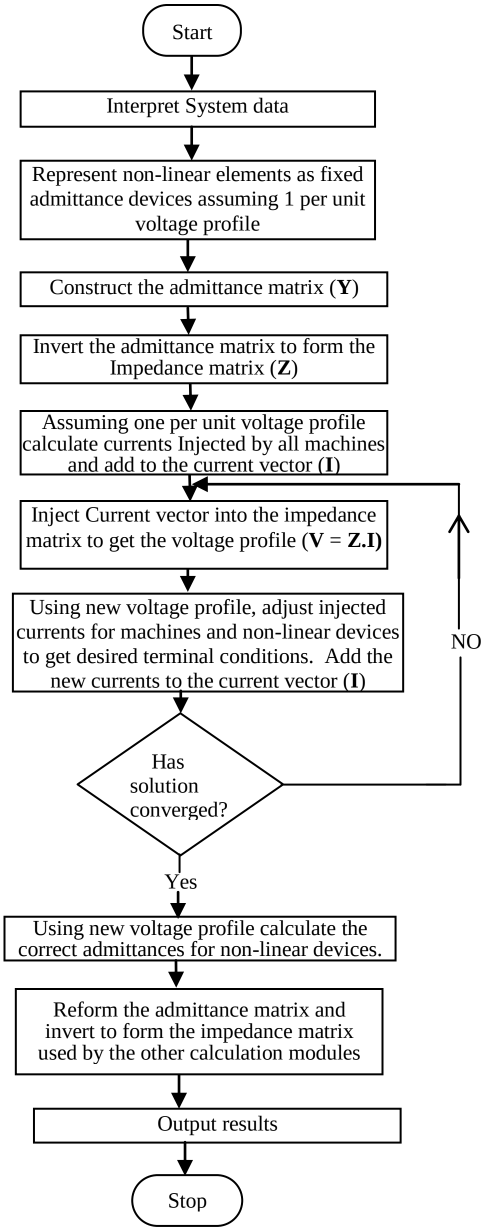

Fig 2: Power flow calculation procedure

Table 5: Power Flow case studies

PFS 1	Maximum demand (1500MW) and normal generation pattern
PFS 2	Maximum demand (1500MW) and minimum generation pattern
PFS 3	Minimum demand (900MW) and normal generation pattern

3.1.1 PFS 1 – Maximum Demand and normal generation pattern

The peak system load used for the study is 1500MW. The system loading is as provided in Table 4. Installed generation capacity is as given in table 3. Although, these records indicate a maximum demand of 1020MW, this has been scaled to 1500MW because this is considered more representative of the "unsuppressed" maximum demand at the time of undertaking the study. It has been assumed that all units temporarily out of service are available but with minimum spinning reserve. The result obtained is shown in fig 3. With exceptions of low voltages at the Kano 330kV bus (0.879pu) and Gombe 330kV bus (0.988pu) system voltage regulation is within acceptable limits. At Kano 330kV bus, 75MVAr shunt reactor can be switched in to control voltage under minimum demand conditions but there is no shunt capacitor to provide voltage support at maximum demand.

3.1.2 PFS 2 - Maximum demand and Minimum generation

This case was intended to represent the worst case combination of load level and generation dispatch with minimal power supplement from the South due to low generation at Egbin. The network configuration, load distribution and reactive compensation status are the same as for study case PFS 1.

The main features of the dispatch are the significantly reduced generation at the Shiroro complex and reduced power contribution from the South as a result of low generation at Egbin power station. If a total of 918.63MW is generated at Kainji and Jebba with no output from Shiroro generators, minimum of 581.37MW is expected from the south, else, load shedding and or outages are necessary to maintain system stability within the region. The results are shown in figure 4. This scenario is considered representative of the system operating conditions that are likely to exist during periods of reduced gas supply (pressure) when the output of Egbin power station is limited and the generation at hydro stations in the Shiroro Complex is also low.

3.1.3 PFS 3 - Minimum demand and normal generation pattern

This is an off-peak period with generation at about 82% of the maximum or 1510MW and 18% spinning reserve or 328MW of the total available generation in the complex of 1838MW. The power flow results for this operating scenario are summarized in figure 5, voltage regulation is within acceptable limits and all equipment is within rated thermal capability. Additional shunt reactors were assumed in Kaduna, Kano, and Gombe 330kV busbars as well as the 132kV buses in these locations and Maiduguri before convergence was achieved and to limit voltage rise in Kaduna and Shiroro.

Despite light system loading in this situation the voltage levels at Kano and Gombe 132kV were still less than 132kV as shown in figure 5. Maiduguri, Katsina and Hadejia have even lower voltages of 116, 117.0kV respectively instead of 132kV. The results of these scenarios and other relevant detail generated by the power analysis are presented in Tables 7 to 14. Graphical presentations are given where appropriate. Table 6 provides station busbar identification.

3.2 Voltage Profile

Table 7 indicates that there are slight increases above the 330kV nominal voltage at some buses, while there are significant voltage drops at Kano and Gombe under minimal loading but normal generation. This is graphically shown in fig.6. The percentage voltage drops or increases are within 0.385 to 2.9%. The voltage rise under this condition was controlled by assumption of reactors at the respective buses, even where none was physically available at a substation.

3.3 Cables and Transformer Loading

The overall result for transformers and cables loading indicate sufficient capacity for available power to be evacuated as far as transmission is concerned. However, due to underutilization of generating resources and inadequate spinning reserve, the transmission facility is being constantly underloaded. These are analysed in Table 9 and 10. Graphical representation for transformers and cable loading are illustrated in Figs 8 and 9 respectively.

Table 6: Station Busbar Identification

S/N	BUSBAR ID	STATION NAME	NOMINAL VOLTAGE kV
1	33 – 1	KAINJI GRID	330
2	33 – 2	JEBBA GS	330
3	33 – 3	JEBBA TS	330
4	33 – 4	SHIRORO TS	330
5	33 – 5	KADUNA TS	330
6	33 – 6	KANO TS	330
7	32 – 7	KANO DS	132
8	32 – 8	KADUNA TS2	132
9	32 – 9	ZARIA TS	132
10	33 – 10	JOS-GOMBE	330
11	32 – 7PQ	KANO-HADEJIA	132
12	32 – 7PQ	DAKATA-KATSINA	132
13	33 – 10PQ	GOMBE-MAIDUGURI	330/132
14	33 – 10PQ	GOMBE-YOLA	330/132

Table 7: Power flow Results for minimum demand on normal generation

Busbar ID	**pV (pu)**	**V(kV)**	**AV (deg)**	**DV (kV)**	**Hz**	**PL (MW)**	**QL (MW)**	**PG (MW)**	**QG (MVAr**
33-1	1	330	0	0	50	0.31	0.75	1354	5605
33-2	1.0784	332.39	0.7717	2.39	50	16.4	1.21	1287	136
33-3	1.121	334.35	0.7665	4.35	50	37.1	310.3	0	118
33-4	1.095	333.15	0	3.15	50	6.5	0	0	14.93
33-5	1.220	337.28	0.7665	7.28	50	22.3	0	0	5.078
33-6	0.939	310.16	0.8069	-19.84	50	18.2	0	0	0.074
32-7	0.879	116.14	1.3303	15.86	50	1.65	0.187	0	0
32-8	1.016	134.13	0.8068	2.13	50	0.9	0	0	0.055
33-9	0.988	130.51	1.0994	-1.49	50	0.133	0.06	0	179.0
33-10	0.912	301.18	1.2248	-28.82	50	11.95	0.15	0	0.634
32-7PQ	0.879	116.14	1.0994	-15.86	50	0.55	0.045	0	0.301
32-7PQ	0.880	117.10	0.7804	-14.90	50	1.01	0	0	0.512
33-10PQ	0.912	301.18	1.1967	-28.82	50	1.95	0.172	0	0.634
33-10PQ	0.912	301.18	0.7804	-28.82	50	1.95	0	0	0.634

P_G = Power generated in MW
P_L = Power losses in MW
Q_G = Reactive power generated in MVAr
Q_L = Reactive power loss in MVAr
pV = Busbar voltage in pu
V(kV) = Busbar voltage in kV

AV = Voltage angle in Degree
DV = Percentage voltage drop
Hz = Burbar frequency in Hz

Table 8: Fault Characteristic for Shiroro Complex

BUSBAR 1D	3XR	1F (MVA)	1I (kA)	Zp (pu)	AZp (deg)	Zn (pu)	AZn (deg)
33-1	14.665	101.517	5.328	0.932668	86.0992	0.908953	85.8478
33-2	11.354	3.205	0.561	1.683341	84.9666	1.514028	84.0594
33-3	10.686	3.206	0.561	1.696574	84.654	1.523071	83.8048
33-4	10.686	3.206	0.561	1.696574	84.654	1.523071	83.8048
33-5	6.096	3.171	0.555	1.805574	80.6839	1.64595	79.2446
33-6	7.555	18.941	26.351	6.103568	82.4597	5.930297	82.1142
32-7	6.087	3.172	0.555	1.80619	80.671	1.646532	79.2314
32-8	10.012	23.245	32.339	5.048246	84.2961	4.872214	84.0203
32-9	7.692	18.941	26.351	6.118212	82.5926	5.944349	82.2447
33-10	10.012	23.245	32.339	5.048246	84.2961	4.872214	84.0203
32-7pQ	8.281	3.194	0.559	1.731366	83.1145	1.564822	81.9893
32-7pQ	8.724	28.266	39.324	4.277709	83.4608	4.105779	83.0544
33-10pQ	8.281	3.194	0.559	1.731366	83.1145	1.564822	81.9893
33-10pQ	8.724	28.266	39.324	4.277709	83.4608	4.105779	83.0544

3 XR = Three phase reactance to resistance ratio
IF = Single phase to earth fault level (MVA)
1I = Single phase to earth fault current
Zp (pu) = Positive sequence driving point impedance (pu)
AZp (deg) = Positive sequence driving point impedance Angle (o)
Zn (pu) = negative sequence driving point impedance
AZn (deg) = negative sequence driving point impedance (o)

Table 9: Terminal Power Losses

Cable ID	Bus ID	LOSSES P (MW)	LOSSES Q (MVAr)	LOSSES S (MVA)	pf
DL-1	33-1	0.1583	0.66	1.3331	0.8689
DL-2	33-2	0.431	0.4842	1.0104	0.8777
DL-3	33-3	0.313	0.5079	0.8274	0.7894
DL-4	33-4	0.6825	0.3361	0.7608	0.8971
DL-5	33-5	0.8314	0.4502	0.9454	0.8794
DL-6	33-6	1.314	0.2631	0.6351	0.9102
DL-7	33-10	2.161	0.5079	0.8274	0.7894

Table 9b: Power Losses in Transformers

Transformer ID	1Bus	V (kV)	2V(kV)	AV (deg)	P (MW)	Q (MVAr)
T1A-SH	33-1	330	132	0.76646	0.696577	0.653304
2T2-JB	33-2	332.39	132.9	0.810837	0.780154	0.582708
T1B-SH	33-3	334.35	134.8	0.76646	0.696577	0.453304
T2A-KD	33-4	333.15	133.7	0.780437	0.762505	0.705033
T3-KD	33-5	337.28	134.8	0.000002	2.739909	1.138846
T1-KN	33-6	310.16	137.2	0.806866	1.250389	1.19139
T4-GB	33-10	301.18	116.8	0.780437	4.162851	3.105256
T3-GB	33-10	301.18	112.3	0.806821	6.200248	5.152481
T2-GB	33-10	301.18	110.1	0.810837	10.180154	9.082708

Table 10: Transformer Load

Transformer ID	Location	Wdg 1 (% Current Loading)	Wdg 2 (% Current Loading)
TIA-SH	Kainji	25.437052	25.437052
2T2-JB	Jebba	21.509264	21.509264
T1B-SH	Shiroro	20.313248	20.313248
T2A-KD	Kaduna	19.492893	19.492893
T3-KD	Kaduna	19.451431	19.451431
T1-KN	Kano	16.005217	16.005217
T4-GB	Gombe	16.005217	16.005217
T3-GB	Gombe	14.757242	14.757242
T2-GB	Gombe	14.757242	14.757242

Table 11: Power Flow Analysis for Transformer and Cables

Cable Loading				
Cable ID	**Busbar @ End 1**	**End 1 (% Current Loading)**	**Busbar @ End 2**	**End 2 (% Current Loading)**
DL-1	33-1	24.6977	32-8	24.7123
DL-2	33-2	18.7191	32-9	18.7844
DL-3	33-3	17.5404	32-10	17.5907
DL-4	33-4	14.164	33-2	14.1706
DL-5	33-5	11.8294	33-4	11.8232
DL-6	33-6	11.7186	33-5	11.7054
D-10	32-7	11.7186	33-6	11.7054

4.0 RESULTS

4.1 Fault Level

Tables 12 and 13 contain details of results obtained for single and three-phase fault levels, respectively.
In most cases, the reacted capacity utilized is less than 90% for the 132kV lines; while the installed capacity has adequate fault MVA ratings for both single and three-phase faults. The result for 330kV system however, indicates the need for upgrade of protection devices and circuit breaker because of significant full capacity utilization. The graphical representations are in fig 10 and 11 for both Single and Three Phase Fault levels respectively.

Table 12: Single Phase Fault

Single Phase Fault Table			
Busbar ID	**Specified Rating (kA)**	**Calculated Fault Level (kA)**	**Rating Capacity Used (%)**
33-1	62.60	62.60	100
33-2	62.60	62.60	100
33-3	62.60	62.60	100
33-4	62.60	62.60	100
33-5	62.60	62.60	100
33-6	62.60	62.60	100
32-10	62.60	62.60	100
32-10	62.60	60.62	100
32-7	18.37	62.60	33.00
33-10	34.99	0.561	1.60
32-8	34.99	0.561	1.60
32-9	34.99	0.561	1.60
32-7PQ	34.99	1.434	4.10
32-7PQ	34.99	0.559	1.60

32-7PQ	34.99	0.555	1.59
32-7PQ	34.99	0.555	1.59
33-10	34.99	0.555	1.59
32-7PQ	34.99	0.555	1.59
32-7PQ	18.37	0	0.00

Table 13: Three Phase Fault Level

Three Phase Fault Table

Busbar ID	Specified Rating(kA)	Calculated Fault Level (kA)	Rating Capacity Used (%)
33-1	43.13	43.13	100
33-2	43.13	43.13	100
33-3	43.13	43.13	100
33-4	43.13	43.13	100
33-5	43.13	43.13	100
33-6	43.13	43.13	100
33-10	17.50	10.00	57.10
33-10	43.13	43.13	100
32-7	43.13	43.13	100
33-10	13.12	4.54	34.60
32-8	26.24	14.67	55.90
32-9	26.24	14.67	55.90
32-7PQ	26.24	20.99	80.00
32-7PQ	26.24	14.43	55.00
32-7PQ	26.24	13.50	51.46
32-7PQ	26.24	13.50	51.46
33-10	26.24	13.50	51.46
32-7PQ	26.24	13.50	51.46
32-7PQ	13.12	0	0.00

Table 14: Three Phase Fault Level

Three Phase Fault Table			
Busbar ID	**Specified Rating(kA)**	**Calculated Fault Level (kA)**	**Rating Capacity Used (%)**
33-1	43.13	43.13	100
33-2	43.13	43.13	100
33-3	43.13	43.13	100
33-4	43.13	43.13	100
33-5	43.13	43.13	100
33-6	43.13	43.13	100
33-10	17.50	10.00	57.10
33-10	43.13	43.13	100
32-7	43.13	43.13	100
33-10	13.12	4.54	34.60
32-8	26.24	14.67	55.90
32-9	26.24	14.67	55.90
32-7PQ	26.24	20.99	80.00
32-7PQ	26.24	14.43	55.00
32-7PQ	26.24	13.50	51.46
32-7PQ	26.24	13.50	51.46
33-10	26.24	13.50	51.46
32-7PQ	26.24	13.50	51.46
32-7PQ	13.12	0	0.00

5.0 CONCLUSION

The paper has presented power system analysis of the Shiroro Complex ranging from modeling philosophy, power flow and fault levels. It is highlighted that economic design of power systems is dependent on accurate prediction of system behaviour under different operating conditions. For this reason, three different operating scenarios which are representative of existing condition in the SC were analyzed. Maximum demand and normal generating condition considered full capacity utilization of generating resources of the complex which remain inadequate. Power supplement from the south which is the only alternative now is not always available or adequate due to shortages of gas supply at the southern thermal stations. Even light load condition considered under minimum demand and assumption of normal generation indicated the need for improved voltage regulation and compensation. The lower than nominal voltages at the far receiving ends of the radial - network are serious cause for concern due to adverse effects on industrial and domestic loads with both economic and social consequences.

Efficient and flexible compensation technology is needed to permit not only voltage compensation device installation at different locations but also provide for alternative small generating options to be connected to the network at any location and at varying voltage levels. Of course, synchronizing different sources of power require not only voltage magnitude but voltage phase angle and sequence matching as well. Satisfying these requirements simultaneously require the installation of flexible alternating current transmission system (FACTS) controllers and their accurate location within the network.

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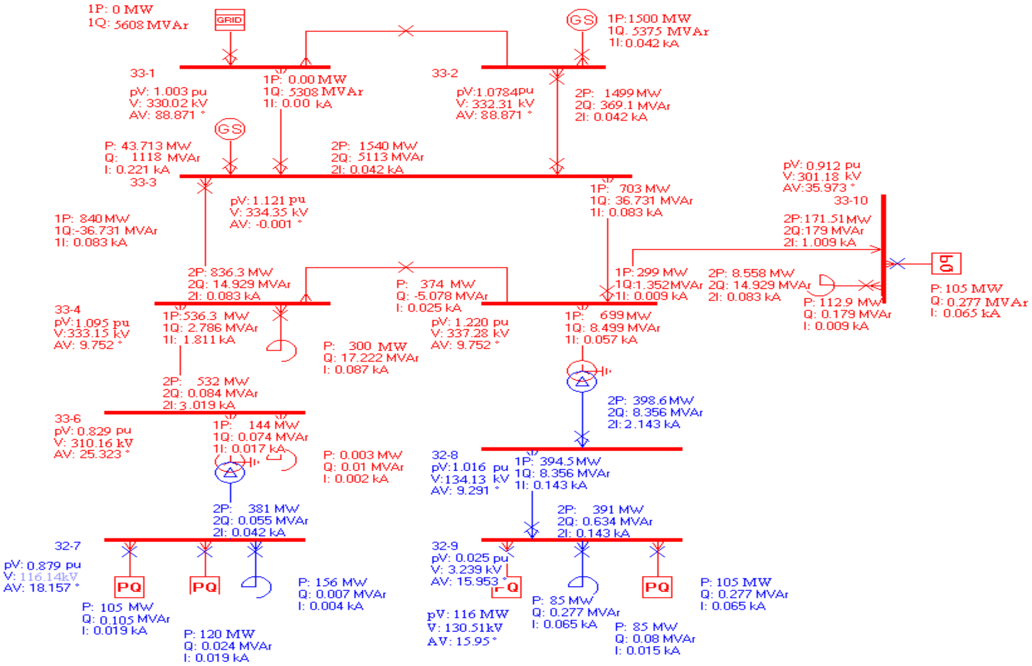

Fig 3: Shiroro Complex Maximum Demand Normal Generation

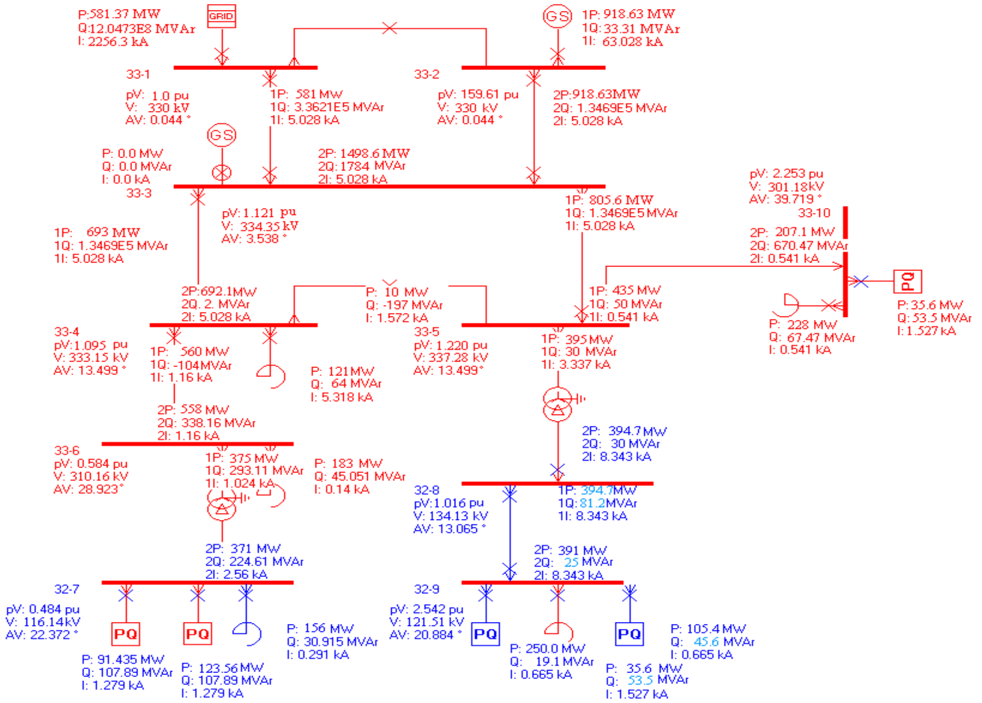

Fig 4: Shiroro Complex Maximum Demand Minimal Generation

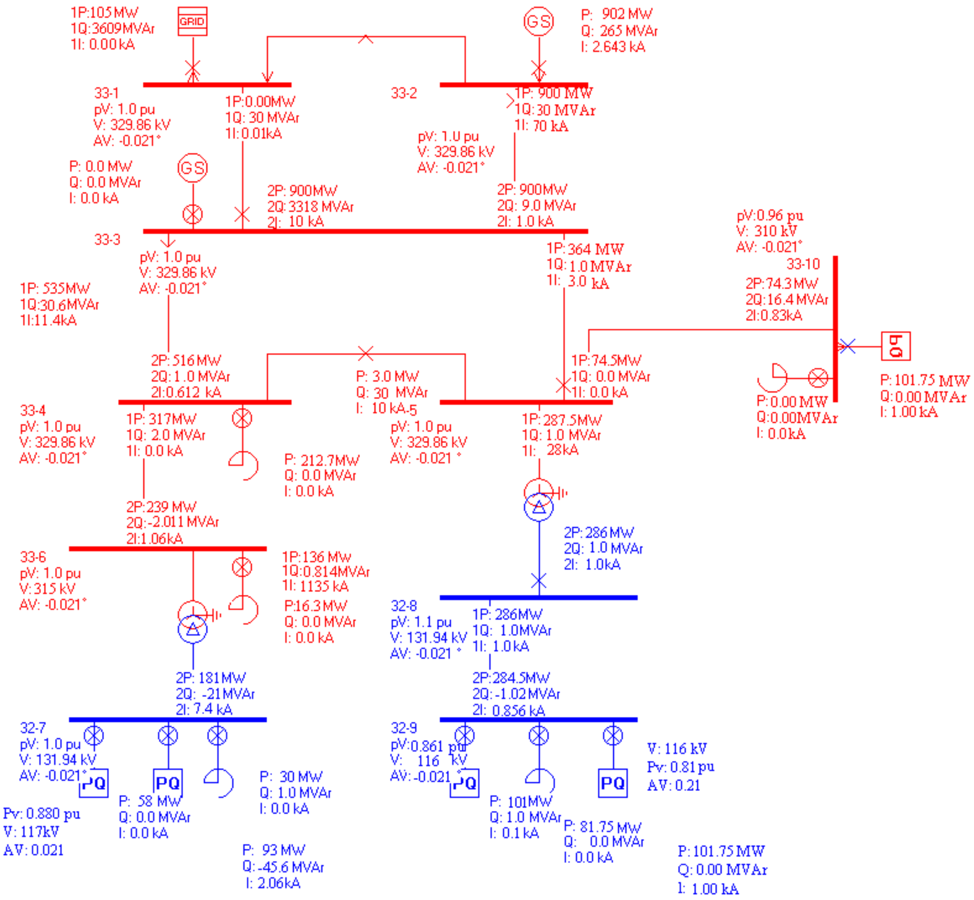

Fig. 5: Shiroro Complex Minimum Demand Normal Generation

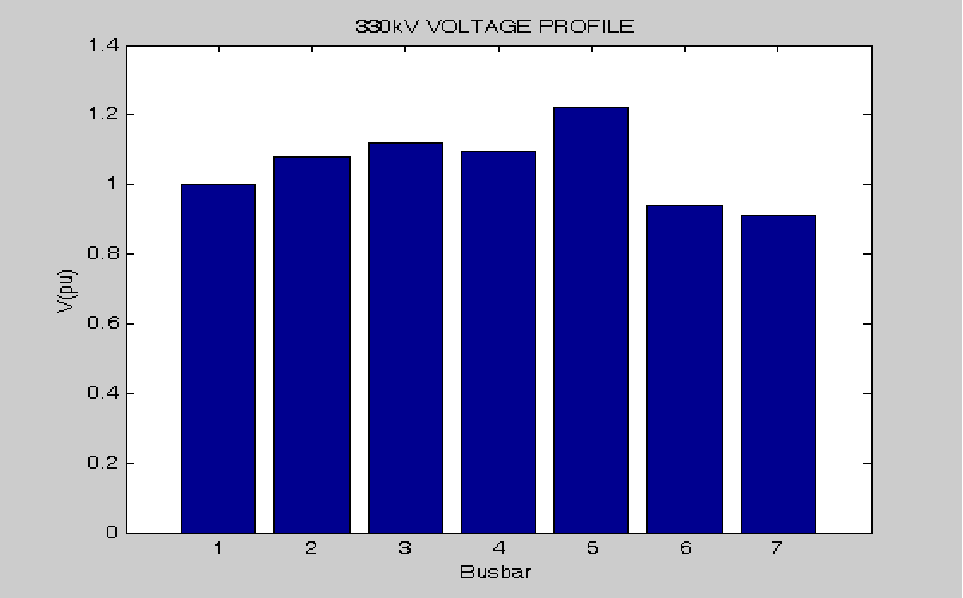

Fig 6: Voltage Profile for minimum demand normal generation at 330kV Busbars

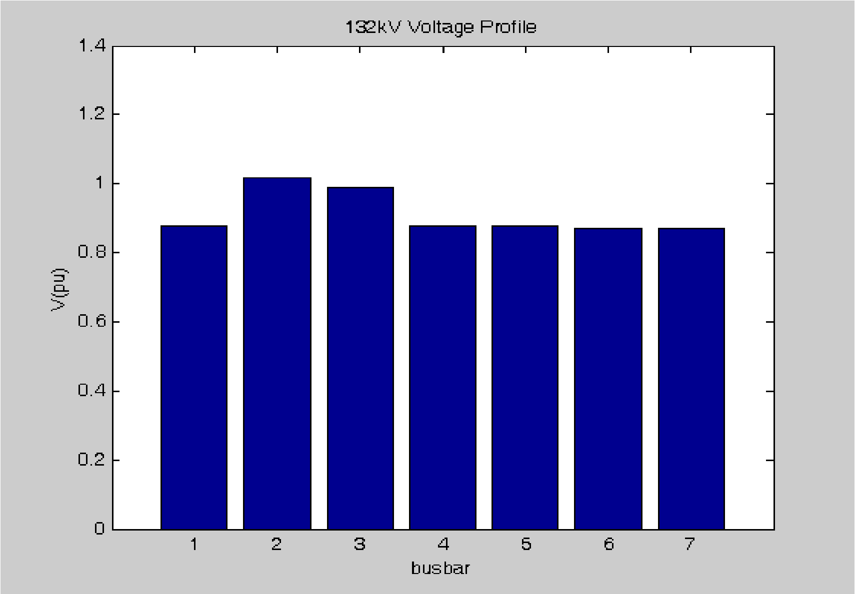

Fig 7: Voltage Profile at 132kV Busbars for minimum demand and normal generation

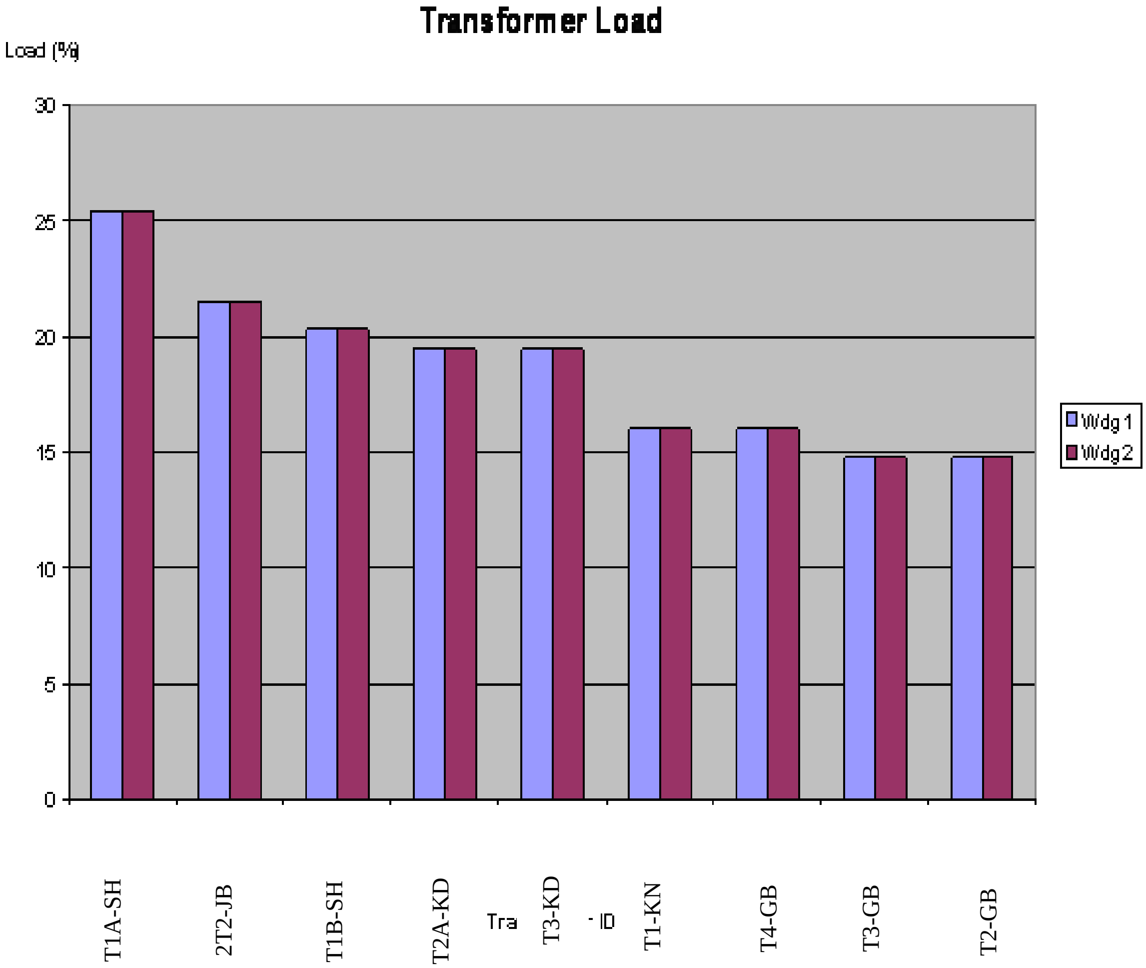

Fig 8: Transformer Load

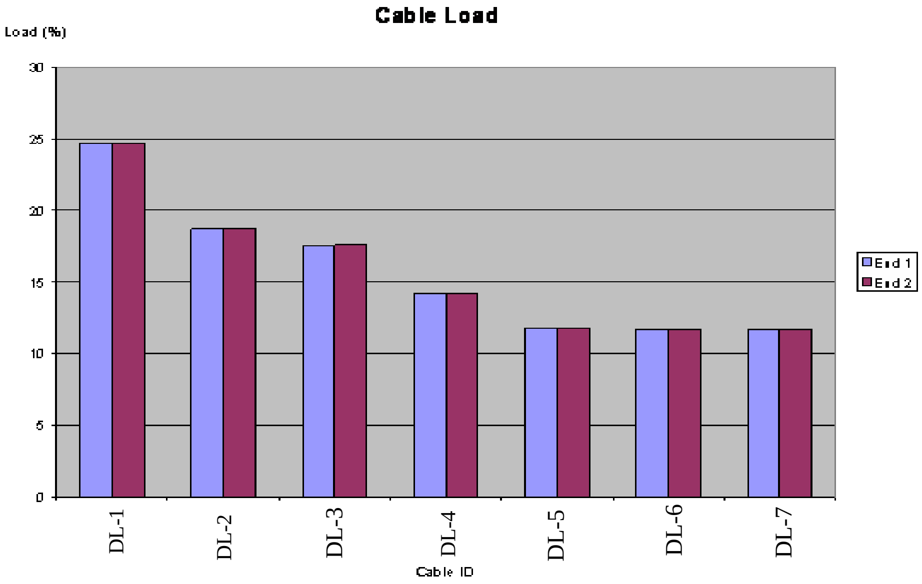

Fig. 9: Cable Load

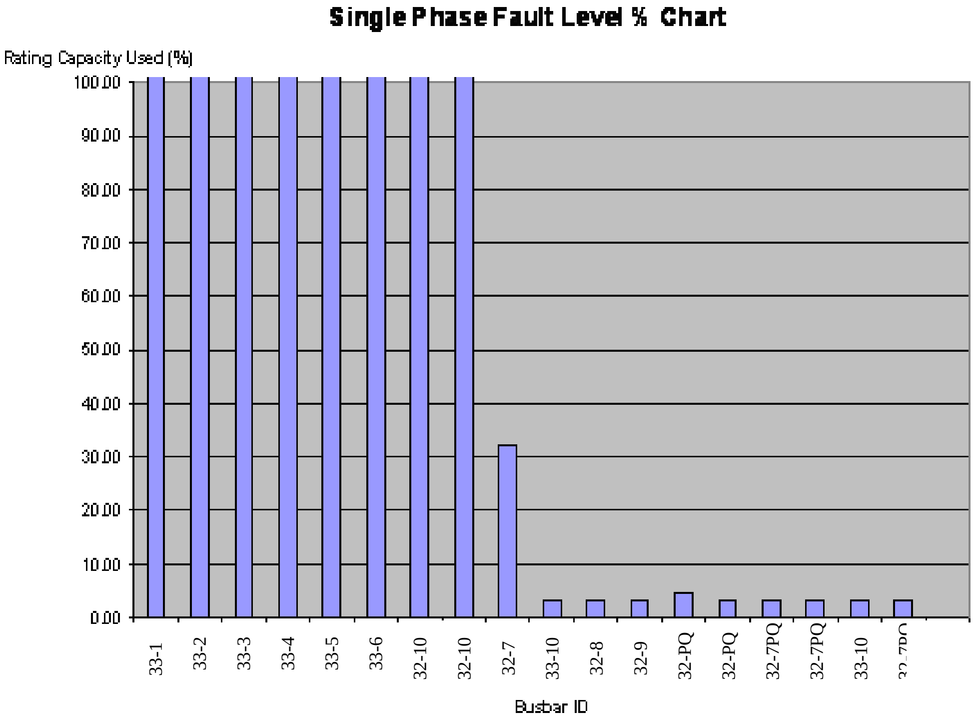

Fig 10: Single Phase Fault Level

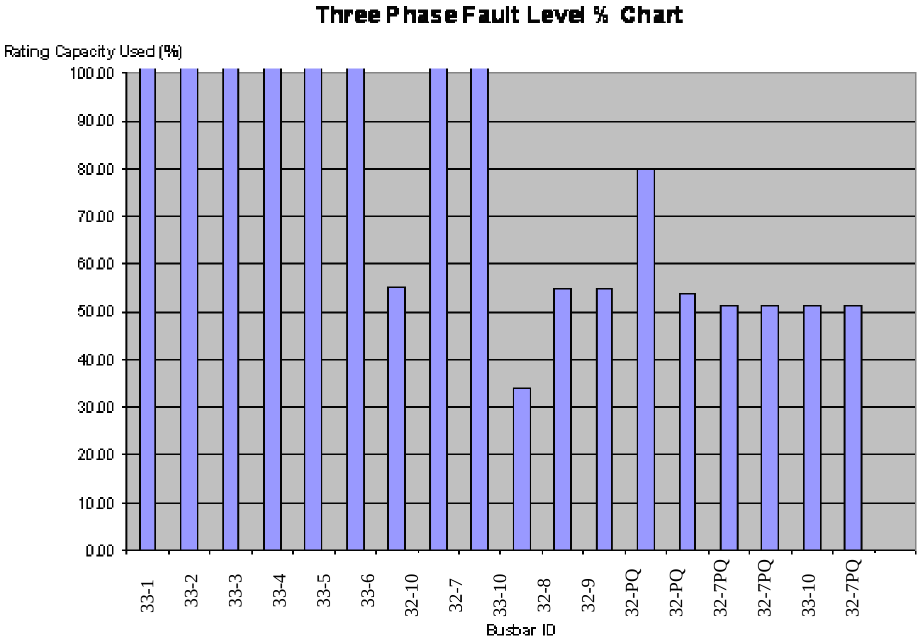

Fig 11: Three Phase Fault Level