

Estimation of Technical Losses in the Nigerian 330KV Transmission Network

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Abstract: In this study, the estimation of technical power losses associated with the Nigerian 330KV transmission network was carried out. In order to estimate the peak power losses, the 330 KV network was simulated in the computer using the Newton Raphson method in the Power World Simulator (PWS) software environment. The annual technical energy losses in the network was calculated based on the Load Factor (LF) and Loss Load Factor (LLF) from hourly readings and empirical formulae. The annual energy loss for 2005 was computed to be 337.5 GWH amounting to over two billion, six hundred Naira.

Key words: PHCN, power losses, load factor, loss load factor, power world simulator, transmission, power flow analysis

INTRODUCTION

The electrical utility is probably the largest and most complex industry in the world. The electrical engineer who works in this industry will encounter challenging problems in designing future power systems to deliver increasing amounts of electrical energy in a safe, clean and economical manner (Glover and Sharma, 2002). Electric energy purchases are 3% of the US Gross Domestic Product (GDP) and are increasing faster than the US rate of economic growth. The more power flows through the network, the more voltage drop becomes more excessive and power quality decline. In addition, large real power causes more energy ($\int I^2 R dt$) losses unnecessarily, when power is distributed to end users. The relationship between the input power, output power and the associated losses in a Power System is highlighted in Fig. 1.

The efficiency of the power system can be written as

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} = 1 - \frac{P_{loss}}{P_{out} + P_{loss}} = \frac{P_{out}}{P_{out} + P_{loss}} \quad (1)$$

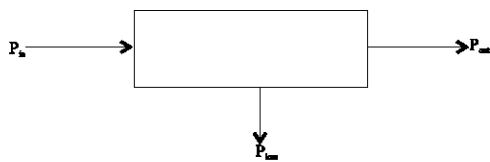


Fig. 1: Relationship between input and output power with associated losses in a power system

Countries such as China that have attached importance to loss minimization to enhance efficiency have about 13% T and D losses with India having about 22% (Pabla, 2003). The main reason attributed to low losses in China is installation of generating stations near load centres such as numerous mini/micro-hydro plants, nuclear plants, etc. The losses in other countries like Pakistan, Thailand, Philippines, Korea, Taiwan U.S.A. Japan are 28, 18, 18, 12.5, 9, 8 and 7%, respectively (1994) (Pabla, 2003). In Nigeria, losses in transmission and distribution lines are peaked at 44.5% of 'sent out' generation (NEPA, 2004). Based on the Power Holding Company of Nigeria (PHCN) annual reports for the 2004 and 2005, the transmission line losses alone were estimated at 9.2% of this value while the remaining was due to distribution network comprising technical and non technical losses. The objective of this study therefore, is to estimate the technical losses in the Nigerian 330 KV transmission network and proffer recommendations to reduce the losses and enhance the efficiency of the network.

MATERIALS AND METHODS

The procedure adopted for this study involved:

- Review of power losses and an overview of the Nigeria Power System with emphasis on generation and 330kV transmission network. These include the schematic diagrams of the entire network, line impedances and the associated lengths.

- Data gathering based on PHCN Logbooks, Reports, Visitation to transmission stations, line survey and interaction with PHCN staff.
- Presentation of data using reliable assessment tools such as Microsoft Access, by generating ‘Queries’ to obtain the minimum, maximum and average values for the various stations/lines with a view to get the voltage profiles of the various lines.
- Simulation of the network using Power World Simulator software (Version 8.0) to ascertain the various flow configurations and determine areas on the network with high or low bus voltage values based on $\pm 5\%$ of nominal value with a view to ascertain areas where compensatory work is required
- Contingency analysis of the network to study the effects of line failures/components on the system and make appropriate recommendations.

TECHNICAL AND NON-TECHNICAL LOSSES

The technical and non-technical losses of electricity transmission and distribution have increased considerably over the years and negatively influenced not just the electricity sector, but also the economy. Technical losses mean losses that happen because of the physical nature of the equipment and infrastructure of the power systems, i.e., iron losses, I²R losses (copper loss) in the conductor cables, transformers, switches and generators. Non-Technical Losses (NTL) are caused by actions external to the power system, or are caused by loads and conditions that the technical loss computation failed to take into account. Losses represent a considerable operating cost estimated to add 6-8 % to the cost of electricity and some 25% to the cost of delivery (Davidson *et al.*, 2002). The accurate

estimation of electrical losses will enable the power supply authority to determine with greater accuracy the operating cost for maintaining supply to consumers. This in turn will enable a more accurate estimate of the systems life time over the expected life of the installation.

The control of AC power in real time is very necessary since power flow is a function of the transmission line impedance, magnitude of the sending and receiving end voltages and the phase angle between these voltages. As the power transfer grows, the power system becomes increasingly more complex to operate and the system can become insecure when large power flows through with inadequate control and inability to utilize the full potential of transmission interconnections.

OVERVIEW OF NIGERIA POWER SYSTEM

The power stations in Nigeria are mainly hydro and thermal plants. Power Holding Company of Nigeria (PHCN) generating plants sum up to 6200MW out of which 1920 MW is hydro and 4280 MW thermal – mainly gas fired (Onohaebi, 2006). The Nigerian Electricity Network comprises 11,000 km Transmission lines (330 and 132 kV), 24000 km of Sub-transmission line (33 kV), 19000 km of distribution line (11 kV) and 22,500 Substations. (Sadoh, 2005). A critical study of the National Grid revealed the presence of only one major loop system involving Benin-Ikeja West-Ayede-Oshogbo and Benin. Loops system provide alternative routes for power flow. The absence of loops accounts mainly for the weak and unreliable power system in the country. The single line diagram of the existing 330kV Nigerian transmission network is shown in Fig. 2.

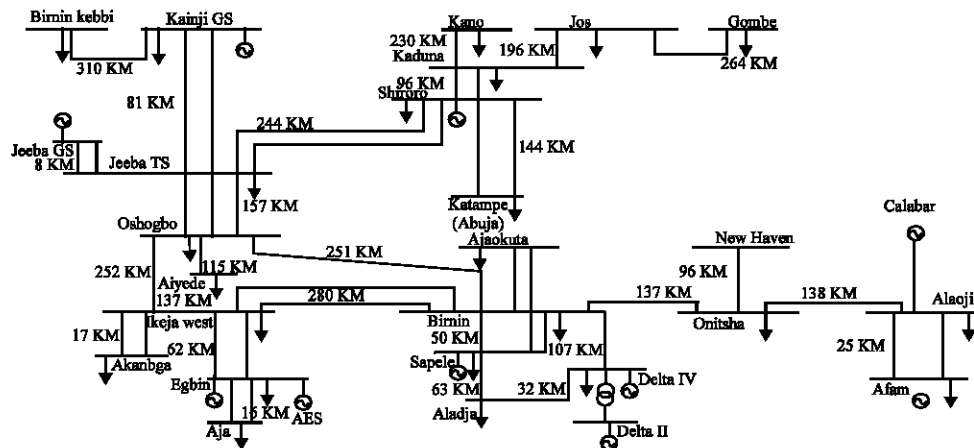


Fig. 2: Existing 330kV Nigerian transmission network

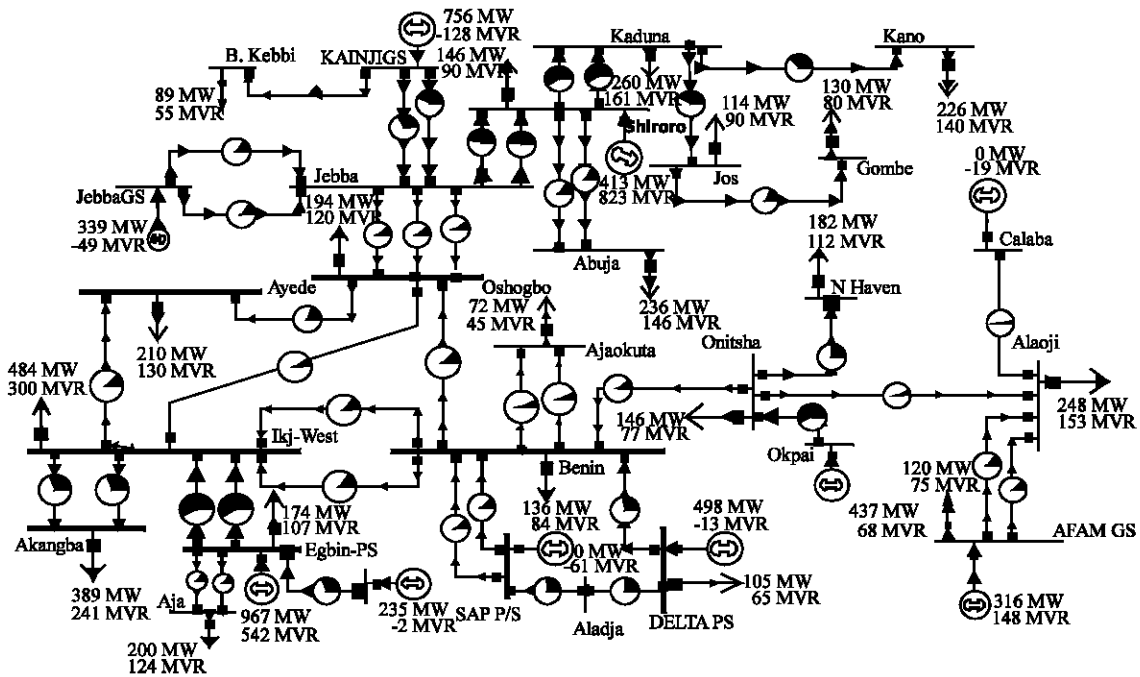


Fig. 3: Existing 330 kV transmission network (Simulated in the run mode)

Table 1: Bus information for voltages, loading and losses for the existing condition of 330kV Nigeria transmission network

Number	name	Area	kV level	Load MW	Load MVR	Gen MW	GenMVR	Volt	Angle shunt
1	Oshogbo		1	330	194	120	0	0 0.99	-6.8
2	Benin		1	330	136	84	0	0 1.00	-3.3
3	Ikj-West		1	330	484	300	0	0 0.96	-6.9
4	Ayede		1	330	210	130	0	0 0.96	-9.0
6	Onitsha		1	330	146	77	0	0 0.98	-2.0
7	Akangba		1	330	389	241	0	0 0.96	-7.5
10	Egbin-PS		1	330	174	107	967	542 1.00	-2.9
11	DELTA PS		1	330	105	65	498	-13 1.00	0.5
17	SAP P/S		1	330	0	0	0	-61 1.00	-2.5
18	Aja		1	330	200	124	0	0 0.99	-3.4
19	Ajaokuta		1	330	72	45	0	0 1.01	-4.5
20	N Haven		1	330	182	112	0	0 0.96	-5.1
21	Alaoji		1	330	248	153	0	0 0.96	-5.2
22	AFAM GS		1	330	120	75	316	148 1.00	-1.3
23	Jebba		1	330	0	0	0	0 1.00	-4.7
24	JebbaGS		1	330	0	0	339	-49 1.00	-4.5
25	KAINJIGS		1	330	0	0	756	-128 1.00	0.0
26	B Kebbi		1	330	89	55	0	0 0.98	-4.9
27	Shiroro		1	330	146	90	413	823 1.00	-21.2
28	Kaduna		1	330	260	161	0	0 0.90	-27.7
29	Kano		1	330	226	140	0	0 0.75	-40.4
30	Jos		1	330	114	90	0	0 0.76	-39.4
31	Gombe		1	330	130	80	0	0 0.66	-50.8
32	Abuja		1	330	236	146	0	0 0.97	-24.1
33	AES		1	330	0	0	235	-2 1.00	-2.9
34	Okpai		1	330	0	0	437	68 1.00	2.3
35	Calaba		1	330	0	0	0	-19 1.00	-5.2
36	Aladja		1	330	0	0	0	0 1.00	-1.6

Number of buses 28, Total load 3861.0 MW 2395.0 MVAR, Total generation 3961.5 MW 1309.4 MVAR, Losses 100.5 MW-1085.6 MVAR Unserved load 0.0 MW, Interchange error 0.00, Bus information

POWER FLOW ANALYSIS OF THE EXISTING 330KV TRANSMISSION NETWORK

The 330kV network was analysed using the Power Word Simulator in Matlab Environment.

The single line circuit diagram of the existing network was redrawn using the Edit Mode available in the Power World Simulator. The input data for the power flow analysis include the generator's output power, maximum and minimum reactive power limits of the generator, MW

Table 1: Continued

Transmission line information								
From	To	ID	MVA %	Loaded	Loss-MW	Loss-MVR	Amps	Tap
1	2	1	94.9	12.5	0.59	-89.56	167.7	
3	1	1	7.2	10.2	0.10	-92.33	140.2	
4	1	1	150.3	19.8	0.85	-34.07	275.2	
23	1	1	79.3	10.4	0.35	-56.14	138.7	
23	1	2	79.3	10.4	0.35	-56.14	138.7	
23	1	3	79.3	10.4	0.35	-56.14	138.7	
3	2	1	112.9	14.9	0.77	-106.32	205.0	
3	2	2	112.9	14.9	0.77	-106.32	205.0	
2	6	3	73.7	9.7	0.28	-2.73	128.7	
2	11	1	203.5	26.8	1.62	-27.22	355.4	
2	17	1	94.7	12.5	0.17	-19.54	165.4	
2	17	2	94.7	12.5	0.17	-19.54	165.4	
2	19	1	63.2	8.3	0.11	-74.36	110.4	
19	2	2	42.5	5.6	0.11	-74.36	73.7	
4	3	1	101.9	13.4	0.51	-44.21	186.6	
3	7	1	230.4	30.3	0.34	2.42	418.2	
3	7	2	230.4	30.3	0.34	2.42	418.2	
3	10	1	435.3	57.3	4.49	9.76	790.2	
10	3	2	447.1	58.8	4.49	32.06	782.3	
6	20	1	189.8	25.0	1.34	-22.69	338.7	
6	21	1	54.7	7.2	0.16	-46.31	97.7	
6	34	1	436.7	57.5	3.95	12.05	779.3	
10	18	1	113.2	14.9	0.13	-9.18	198.1	
10	18	2	113.2	14.9	0.13	-9.18	198.1	
10	33	1	235.0	30.9	0.00	0.01	411.2	
36	11	1	188.5	24.8	0.81	-17.80	329.5	
36	17	1	188.5	24.8	0.38	-8.55	329.5	
20	21	1	42.1	4.2	0.02	-48.16	77.0	
21	22	1	104.4	13.7	1.02	-2.09	189.4	
21	22	2	104.4	13.7	1.02	-2.09	189.4	
35	21	1	19.3	2.5	0.00	-53.05	33.8	
24	23	1	171.2	17.1	0.09	-2.66	299.6	
24	23	2	171.2	17.1	0.09	-2.66	299.6	
25	23	1	335.9	33.6	3.35	-3.30	587.7	
25	23	2	335.9	44.2	3.35	-3.30	587.7	
27	23	1	373.9	49.2	12.77	16.20	654.1	
27	23	2	373.9	49.2	12.77	16.20	654.1	
26	25	1	104.6	13.8	0.91	-98.39	186.1	
28	27	1	451.9	59.5	8.21	37.43	875.1	
28	27	2	451.9	59.5	8.21	37.43	875.1	
27	32	1	121.9	16.0	0.89	-45.95	213.3	
27	32	2	121.9	16.0	0.89	-45.95	213.3	
28	29	1	284.7	37.5	9.42	20.09	551.3	
28	30	1	313.6	41.3	9.45	28.68	607.3	
30	31	1	147.1	19.4	4.34	-20.09	338.3	

and MVAR peak loads, impedance of the lines, voltage and power ratings of the lines and transformer data. These were entered into the dialog box of PWS and simulated using the Newton Raphson iterative method available in the Run Mode as shown in Fig. 3 of the PWS. Figure 4(a-f) shows Bus view of power flow and bus voltages some major transmission stations. Table 1 shows the bus Information for voltages, loading and losses the existing condition 330 kV Nigeria Transmission Network.

CONTINGENCY ANALYSIS OF THE EXISTING 330KV NETWORK

The bulk power system is designed and operated to provide continuity of service in the case

of possible contingencies such as loss of generation unit, loss of transmission line, or failure of any single component of the system (IEEE, 1997) Preventive operating procedures means operating the system in such a way as to avoid severe interruptions as a result of certain component outages or failures (IEEE, 1997).

The North America Electric Reliability Council (NERC) guidelines recommend making it operational requirements that systems be able to handle any single contingency. The adoption of NERC guidelines has increased the operating security of interconnected systems and reduce the frequency with which major disturbance occurred. In the light of the above, the Nigerian 330 kV transmission network was subjected to single contingency analysis.

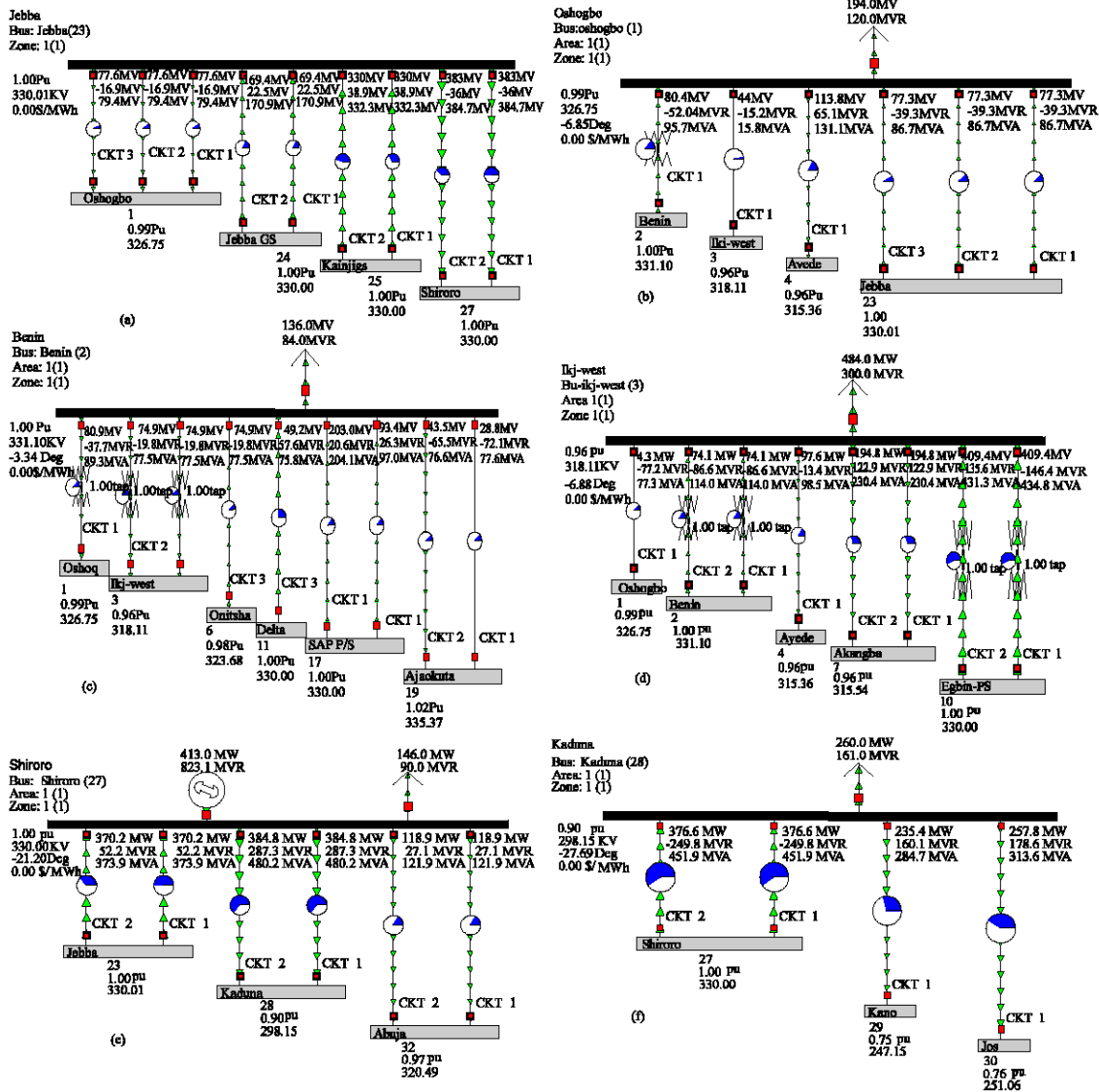


Fig. 4: Bus view of power flow and bus voltages at some major transmission station

The various contingencies involving the effect of loss of any single line on the network resulted in 45 different contingencies. The summary of the voltage tolerance violations is shown in Appendix 1.

ESTIMATION OF ANNUAL ENERGY LOSS OF THE NETWORK

From the results obtained in the simulation of peak loads under peak generation for December 2005, the total energy loss was obtained as follows:

The daily load factor was calculated based on the hourly load readings as:

$$\text{Daily Load Factor (LF)} = \frac{\text{Average load in 24 h}}{\text{Maximum load in 24 h}}$$

The annual load factor defined as the ratio of annual load energy to the energy represented by the peak demand multiplied by 8,760 h was estimated from the average load by using typical daily and monthly peak-load variations. Thus, the annual load factor LF_A was obtained as

$$LF_A = LF_D \times R_{WM} \times R_{MA} \text{ (IEEE, 1997)}$$

Where

LF_A = Annual Load Factor

LF_D = Daily Load Factor

R_{WM} = Ratio of average daily peak load to monthly peak load

R_{MA} = Ratio of average monthly peak load to annual peak load

Appendix 1: Summary of voltage violations for the existing condition

Contingency records label	Skip	Processed	Solved	Violations	Max line %	Min volt	Max volt
L00001Oshogbo-00002BeninC1	No	Yes	Yes	5		0.66	
L00003Ikj-West-00001OshogboC1	No	Yes	Yes	6		0.66	
L00004Ayede-00001OshogboC1	No	Yes	Yes	6		0.66	
L00023Jebba-00001OshogboC1	No	Yes	Yes	5		0.66	
L00023Jebba-00001OshogboC2	No	Yes	Yes	5		0.66	
L00023Jebba-00001OshogboC3	No	Yes	Yes	5		0.66	
L00003Ikj-West-00002BeninC1	No	Yes	Yes	6		0.66	
L00003Ikj-West-00002BeninC2	No	Yes	Yes	6		0.66	
L00002Benin-00006OnitshaC3	No	Yes	Yes	5		0.66	
L00002Benin-00011DELTA PSC1	No	Yes	Yes	4		0.66	
L00002Benin-00017SAPP/SC1	No	Yes	Yes	4		0.66	
L00002Benin-00017SAPP/SC2	No	Yes	Yes	4		0.66	
L00002Benin-00019AjaokutaC1	No	Yes	Yes	4		0.66	
L00019Ajaokuta-00002BeninC2	No	Yes	Yes	4		0.66	
L00004Ayede-00003Ikj-WestC1	No	Yes	Yes	5		0.66	
L00003Ikj-West-00007AkangbaC1	No	Yes	Yes	5		0.66	
L00003Ikj-West-00007AkangbaC2	No	Yes	Yes	5		0.66	
L00003Ikj-West-00010Egbin-PSC1	No	Yes	Yes	8	117.3	0.66	
L00010Egbin-PS-00003Ikj-WestC2	No	Yes	Yes	8	116.4	0.66	
L00006Onitsha-00020NHavenC1	No	Yes	Yes	6		0.66	
L00006Onitsha-00021AlaojiC1	No	Yes	Yes	5		0.66	
L00006Onitsha-00034OkpaiC1	No	Yes	Yes	8		0.66	
L00010Egbin-PS-00018AjaC1	No	Yes	Yes	4		0.66	
L00010Egbin-PS-00018AjaC2	No	Yes	Yes	4		0.66	
L00010Egbin-PS-00033AESC1	No	Yes	Yes	4		0.66	
L00036Aladja-00011DELTA PSC1	No	Yes	Yes	4		0.66	
L00036Aladja-00017SAPP/SC1	No	Yes	Yes	4		0.66	
L00020NHaven-00021AlaojiC1	No	Yes	Yes	5		0.66	
L00021Alaoji-00022AFAMGSC1	No	Yes	Yes	6		0.66	
L00021Alaoji-00022AFAMGSC2	No	Yes	Yes	6		0.66	
L00035Calaba-00021AlaojiC1	No	Yes	Yes	4		0.66	
L00024JebbaGS-00023JebbaC1	No	Yes	Yes	4		0.66	
L00024JebbaGS-00023JebbaC2	No	Yes	Yes	4		0.66	
L00025KAINJIGS-00023JebbaC1	No	Yes	Yes	5	105.9	0.66	
L00025KAINJIGS-00023JebbaC2	No	Yes	Yes	4		0.66	
L00027Shiroro-00023JebbaC1	No	Yes	Yes	5	105.9	0.66	
L00027Shiroro-00023JebbaC2	No	Yes	Yes	5	105.9	0.66	
L00026BKebbi-00025KAINJIGSC1	No	Yes	Yes	4		0.66	
L00028Kaduna-00027ShiroroC1	No	Yes	No	Unsolved			
L00028Kaduna-00027ShiroroC2	No	Yes	no	Unsolved			
L00027Shiroro-00032AjujaC1	No	Yes	Yes	5	0.66		
L00027Shiroro-00032AjujaC2	No	Yes	Yes	5	0.66		
L00028Kaduna-00029KanoC1	No	Yes	Yes	2	0.775		
L00028Kaduna-00030JosC1	No	Yes	Yes	2	0.81		
L00030Jos-00031GombeC1	No	Yes	Yes	3	0.795		

Table 2: The Hourly loading for Ajaokuta bus

Time(Hours)	1	2	3	4	5	6	7	8	9	10	11	12
Load (MW)	30	25	27	27	27	32	38	33	31	25	23	25
Time(Hours)	13	14	15	16	17	18	19	20	21	22	23	24
Load (MW)	27	41	41	47	23	23	38	47	43	37	31	24

Using the Ajaokuta 330kV bus as a case study for a typical day in December 2005, the hourly loadings (MW) are shown Table 2 and plotted in Fig. 5.

From the hourly readings, peak load is 47 MW and off peak load is 23 MW.

$$\text{Daily Load Factor (LF)} = \frac{\text{Daily average load}}{\text{Maximum (peak) load}} = 0.681$$

The daily peak load for December 2005 at Ajaokuta bus is plotted in Fig. 6(a and b).

The average daily peak load for December 2005 is 51.9 with monthly peak load of 72MW

$$\text{Thus } LF_A = 51.9/72 = 0.721$$

$$\text{Average monthly peak load} = 857/12 = 71.417$$

$$Rma = 71.417/72 = 0.992$$

$$\text{Thus, Annual Load Factor} = 0.681 \times 0.721 \times 0.992 = 0.487$$

$$\text{Load Loss Factor (LLF)} = C(LF) + (1 - C)LF^2$$

Where C = 0.3 for transmission lines

$$= 0.3 \times 0.487 + 0.7 \times 0.487^2 = 0.383$$

$$\text{Annual MWH Loss} = \text{LLF} \times \text{Peak Loss in MW} \times 8,760$$

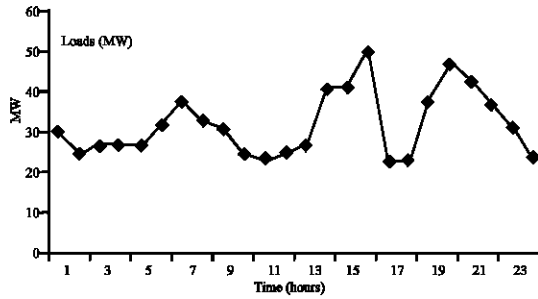


Fig. 5: Hourly load curve of power consumed at Ajaokuta bus

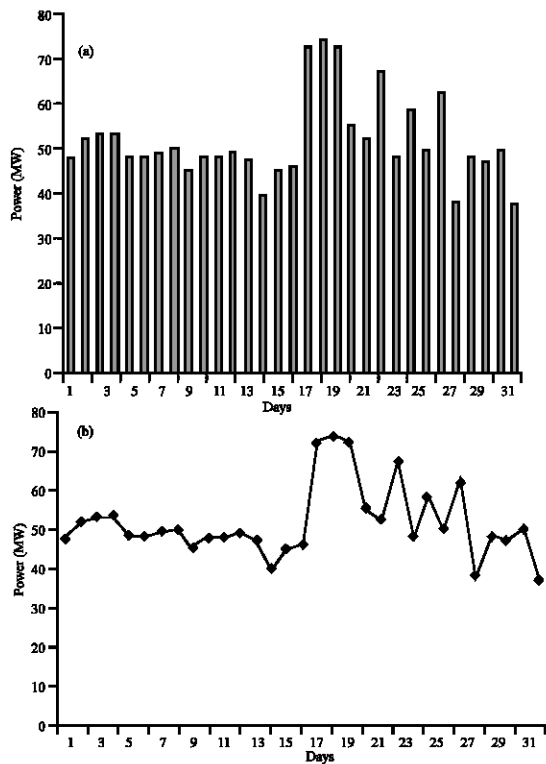


Fig. 6: Daily peak load of December 2005 is 51.9 with monthly peak load of 72MW

Using the peak power loss under maximum generation and peak loading, i.e. 100.6 MW we have,
 Total energy loss for 2005 as
 $= 0.383 \times 100.6 \times 8,760$
 $= 337,521 \text{ MWH}$

RESULTS

- The power flow analysis revealed that the existing condition of the Nigerian 330kV transmission is very unsatisfactory. The bus voltages at Kaduna, Kano, Jos and Gombe were found at the time of the

investigation to be (298kV, 0.903pu), (247kV, 0.75pu), (251kV, 0.76pu) and (217kV, 0.66pu). These voltages are ridiculously low for the system to perform efficiently.

- The contingency analysis carried out on the network to verify the effect of losing any line in the system also indicates a total of 208 violations. There is no line in the network that does not result in at least 2 violations. Increase or decrease in loading conditions further forces more buses to be out of tolerance.
- The power losses on some of the lines were high, with Shiroro-Jebba line recording the highest value of 12.77MW, with percentage loading of only 50.8%.
- The real power losses in the network under the existing condition amounted to 100.6 MW. The energy loss for 2005 due to 330kV transmission lines alone was found to be 337.5 GWH amounting to over two billion, six hundred thousand naira.
- The contingency analysis under the existing condition revealed that Ikeja-Egbin line recorded MVA violation and was over loaded up to 118% when one of the circuits was opened. This could lead to steady state instability due to I^2R (heating) of the lines or on the protection system as a result of over current. This situation also forces the voltages as Ikeja West, Akangba and Ayede to be low, apart from those in Kaduna, Jos, Kano and Gombe.
- The only link between the Southern and Northern parts of the National Grid is between Oshogbo and Jebba. Thus, any major fault on this link can lead to failure or separation of the network.
- Low voltage at Ayede bus, Akangba, Onitsha, Alaoji, New Heaven, were also observed under certain contingencies with Ayede and Akangba featuring more prominently. This suggests the need to introduce additional lines on the network to improve the voltage profiles.

The implications of the above findings are that the existing Nigerian 330 kV network cannot cope with high loading conditions in case of faults arising from line failure. It also shows the vulnerability of the system to instability, failure, high voltage drops and power losses as well very low efficiency.

RECOMMENDATIONS

It is highly recommended, that a good study of this nature should form the background of whatever further investment are to made in the power sector. This will bring great improvement in voltage regulation, minimize power losses (and hence financial losses) and ensure system adequacy, reliability and efficiency.

- The addition of new lines to form more loops in the system will improve the National Grid and ensure the security and reliability of the system.
- The length of transmission lines should be made as short as possible by introducing more substations in the network. Voltage drops and power losses increase with increase in line length and loading and thus have corresponding effect on the system.
- The use of Flexible AC Transmission Systems (FACTS) devices such as STATCOM, UPFC, etc, in the network to improve the power quality should be properly harnessed. These have numerous advantages over the conventional compensating devices.
- A Sustainable Energy Sector Strategy (SESS) must be put in place that will provide maximum allowable total losses in electrical network especially in this era of deregulation.

CONCLUSION

The Nigerian 330 KV transmission network is associated with various problems. This study had focused on the technical losses estimation in the network. The system is characterized by high voltage drops and power losses associated with long and fragile radial network, making it vulnerable to failure and poor performance. The energy loss in the year for 2005 due to the 330 KV network is 337.5 GWH amounting to over 2.6 billion naira.

Recommendations are proffered to improve the network towards ensuring a reliable and efficient system and restore the confidence of the Nigeria citizens in the power sector.

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Evaluation and University Educational Use. They are also grateful to PHCN for providing relevant data necessary for the power flow study.

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