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# Assessment Of Existing Electrical Power Distribution Network At Normal Operating Mode (Acase Study Of Abuja)

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***ABSTRACT:*** *The research work evaluates the performance of power distribution network of Abuja, Nigeria;this was aimed at estimating the quality of operations of the existing network. Abuja being a Federal capital territory with a thick population, electricity supply to this area requires the provision of useful information for system development and planning of daily operations. Data was collected on the studiednetwork which includes ratings of network elements, and daily records of per-hour load readings for 365 days. The time series load records were used to determine expected daily load curves and maximum for Abuja district 132 kV and 33 kV feeders using a statistical-heuristic algorithm that dampens the inconsistencies in records due to load shedding.Normal mode variables were computed using method of sequential approximation, comprising sequential power flow and node voltage equations. Programming codes for this method were written in MathCAD Software for quick computation. The results obtained include voltage and power flow profiles in the network, and network efficiency.Reliability indices were also computed for Abuja district PDN in order to characterize or define its reliability with respect to standards. The results obtained was analysedand showed that many feeders in Abuja distribution network are overloaded. Also, the voltages at the receiving end of most of the nodes are below the acceptable value hence the performances of the feeders were inadequate by voltage requirement. Consequently, Abuja Power Distribution Network is currently inadequate to distribute the demand power without load shedding. This research has provided quantitative analysis essential to the operation and development of the 132 kV and 33 kV network.*

***KEYWORDS****-Distribution, Feeder, Normal mode, Network efficiency*

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## I. INTRODUCTION

Transmission lines supply distribution substations equipped with transformers stepped the high voltages down to lower levels. The transmission of large quantities of power over long distances is more economical at higher voltages. Power transmission at high voltage can be accomplished with lower currents, which lower the $I^2R$ losses and consequently reduce the voltage drop (Fink, 1985).The transmission system voltage is stepped-down to lower levels by distribution substation transformers. These feed the primary distribution networks and serve a large number of primary load canters.Their role and performance can be analysed in terms of different criteria; such as power flow, efficiency, qualityreliability, flexibility, andcomplexity (Wadhwa, 2005).Electrical energy is generated at the power stations (hydro-electric, thermal or nuclear) which are usually situated far away from the load centres. Hence an extensive network of conductors between the power stations and the consumers is required. The network of conductors is divided into two main components namely: the transmission system and the distribution system. The generation, transmission and distribution system of electrical power is called the electrical power supply system. The block diagram of a typical electrical supply system is shown in the figure below.

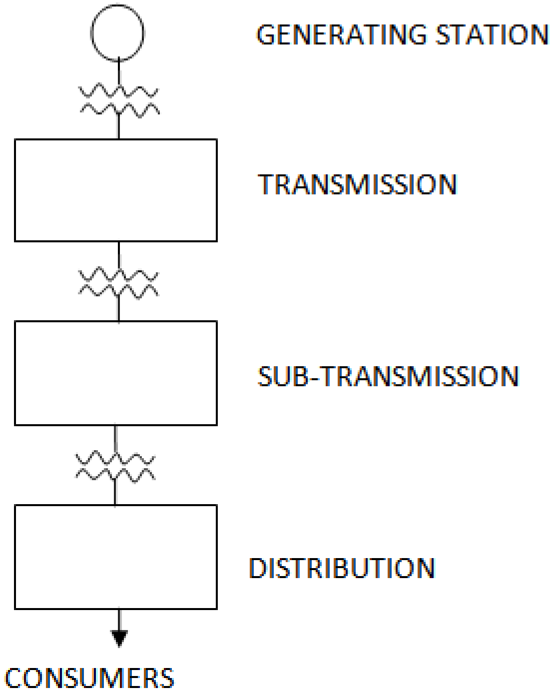


**Fig. 1.1:** Power generation, transfer and consumption sequence

The transmission system is to deliver bulk power from power stations to the load centres and large industrial consumers beyond the economical service range of the regular primary distribution lines whereas distribution system is to deliver power from power stations or substations to the various consumers. Electrical power can be transmitted and distributed by alternating current (ac) or direct current (dc), three-phase ac system is universally adopted for the transmission of large amount of power and three-phase plus neutral ac system is usually adopted for distribution of electrical power (Gupta, 2005).Generation voltages are 3.3, 6.6, 11, 16 or 33 kV; most usual values adopted in practice are 11 and 16kV. The transmission system may be further divided into primary and secondary (or sub) transmission. Similarly the distribution system may be divided into primary and secondary distribution. The primary transmission voltages are 110, 132, 220 330 or 400 kV depending upon the distance, the amount of power to be transmitted and the system stability (Gupta, 2005), In Nigeria, transmission voltage is either 330kV or 132kV. Secondary transmission voltage is normally 33kV. The voltages for primary distributions are 11kV and 33kV, depending upon the requirements of the bulk consumers and for secondary distribution usable voltage is 415/240V. Power distribution networks depend on geography, technological epoch, economic policy and international relations. They serve large numbers of consumers, their role and performance may be analysed in terms of different criteria, such as deliverability, cost, accessibility, reliability and complexity, to name some. For economic and political reasons, contemporary transmission networks are large and complex, spanning great distances and conveying power from many generators to many metropolitan areas located far away(Wadhwa, 2005).

## II. ABUJA POWER DISTRIBUTION SYSTEM

Electricity development in Nigeria started towards the end of the 19th century when the first generating power plant was installed in the city of Lagos in 1898 by the then colonial government. In 1950, the then colonial Government passed the ECN ordinance No. 15 of 1950, that brought under one umbrella the entire electricity department and all the undertakings controlled by the Native and Municipal Authority under the Works Department.The Niger Dam Authority was established by an act of Parliament in 1962 and charged with the responsibility of construction and maintenance of dams and others works in River Niger and other places (Power Holding Company of Nigeria PLC, 2005).In the early 1960s the Niger Dam Authorities (NDA) and Electricity Corporation amalgamated to form the Electricity Corporation of Nigeria (ECN). The ECN and the Niger Dam Authority (NDA) were merged to become the National Electric Power Authority (NEPA) with effect from the 1st of April 1972 to streamline their services for efficiency. The statutory function of the Authority is to generate, transmit and distribute electricity to all parts of the country. What is currently referred to as the Power Holding Company of Nigeria was formally known as National Electric Power Authority (www.wikipedia).The power system in Abuja presently consists of the grid 330KV for power transmission, regional network, local network and the consumers of electric power supply. Apo transmission substation (Apo T.S.) was installed and commissioned in 1981. The total installed capacity then was 90MVA and the station was fed through 150mm$^2$ ACSR (Aluminium Conductor Steel Reinforced)conductors. The 132kV double circuit overhead line from hydro-generation station at Shirroro was enrooted via Minna, Suleja to Apo substation in Abuja. The total route length was approximately 174km. At commissioning, six 33kV feeders and ten 11kV feeders were radiated from the transmission substation. In 1993, 132kV line was extended to Keffi in Nasarawa State from this same substation. In 1994, as the load increased, additional 45MVA was installed and commissioned at Apo T.S.In order to minimize losses, transmission voltage level to the Federal Capital Territory was raised to 330kV in 2005, from Shirroro generating station. This was accompanied with the installation of 2x150MVA 330/132kV transmission substation at Katampe. In the same substation is an installation of 2x60MVA 132/33kV transformers, where five 33kV feeders were raised to feed different places.The 132kV transmission was extended to Central Area with the capacity of 2x60MVA 132/33kV transformer. Underground cables are rarely used because of its cost, but due to limited space availability the power to Central Area was transported through underground cable with indoor switchgears arrangement.

## 2.1: Map of Abuja Electricity Network

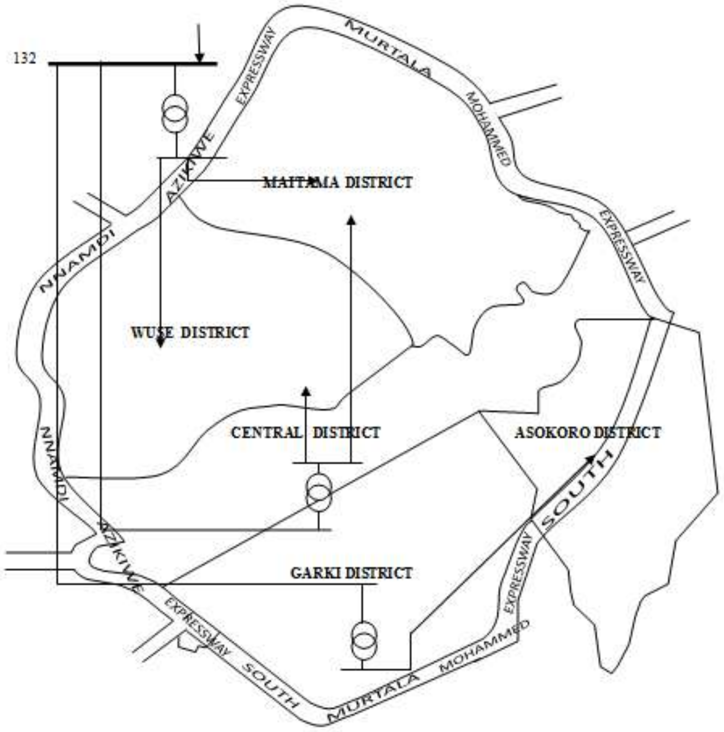


**Fig 2.1 Administrative Map of Abuja Showing Electricity Network**

## 2.2 Determination Of Daily Load Curves Of Abuja 132 Kv And 33 Kv Feeders

Primary data were collected at the transmission substations within Abuja to perform load analysis. In PHCN, log sheets are used by system operators to record the amount of power on each feeder. These readings are recorded hourly on daily basis in every substation. The concept of daily load dynamics comprises the determination of the variation of average or hourly power demand on a given feeder, evaluated for every hour in a 24 hour domain. These dynamics is useful for daily load management in a distribution system. Active load demands recording were done manually by the system operators. However, portable data logging meters or portable data loggers are designed to accomplish this task by recording readings at a set interval but it is not put to use. The data needed for this research work were extracted from the daily log sheets. The manual nature in which the data were recorded made the copying process of the required load readings from the daily log sheet into the electronic spread sheet highly tasking. Load shedding factor, rampant in the Nigerian power system had to be considered in arriving at estimates by using a simple statistical-heuristic model formulated by the research adviser as in equation (3.7) to (3.11). Data of outages arising from load shedding, system collapse, and hourly load reading on each feeder were from the primary data. The sending end active power and voltages were obtained from Katampe, Central Area and Apo 132/33 kV transmission stations for a period of 365days. Also the lines and transformer parameters were obtained from these stations.

### 2.3 Data Computation

The information obtained was tabulated in the Microsoft office Excel spread sheet. The load demands recorded on each of the feeders were summed to obtain the total active load in a day per station. The daily loads were evaluated on monthly, quarterly and annually basis by simple Excel program. The results were analysed graphically on daily, monthly, quarterly and annual basis. In order to estimate daily power dynamics of the feeders, the statistical maximum of each hour over a period of 365 days was analysed.

The maximum active power P on each feeder was obtained using equation3.1 while the reactive power Q on each feeder was gotten using equations 3.2a and 3.2b.

$$P_{max\,(\varphi)} = MAXP_{t,d} \qquad (3.1)$$

$$P_{max\,(\varphi)} = cos\varphi . S_{max\,(t)} = 0.85 S_{max\,(t)} \qquad (3.2a)$$

$$Q_{max} = P_{max}\, tg\varphi \qquad (3.2b)$$

$$where\ d = [1,2, \ldots \ldots \ldots .365];\ t = [1{:}00, 2{:}00, \ldots \ldots ,24{:}00]$$

The line and transformer data obtained from the 132/33kV transmission substations were used to calculate the line and transformer parameters using equation 3.3-3.8 in MathCAD 7 Professional software;

$$X_T = \sqrt{Z_T^2 - R_T^2} \quad [ohms] \qquad (3.3)$$

Where $X_T$ is transformer reactance, $Z_T$ is transformer impedance, and $R_T$ is transformer resistance.

Where $Z_T$ is transformer impedance, $Z_{\%}$ is percentage impedance, $V_{nom}$ is nominal voltage, $I_{nom}$ is nominal current.

$$R_T = \frac{0.05 * V_{nom}^2}{S_{nom}} \quad [ohms] \qquad (3.5)$$

Where $R_T$ is transformer impedance, $V_{nom}$ is nominal voltage, $S_{nom}$ is nominal power.

$$- m) \qquad (3.6)$$

Where $R_l$ is the total line resistance, $r_o$ is per-km active resistances, $l$ is length of power line, $N$ is number of circuit.

$$= \frac{x_o * l}{N} \quad (Ohms - m) \qquad (3.7)$$

Where $X_l$ is the total line reactance, $x_o$ is per-km active reactances, $l$ is length of power line, $N$ is number of circuit.

$$Q_c = N * V_o^2 * b_o\ (MVar) \qquad (3.8)$$

Where $Q_c$ is reactive power due to line capacitance, $N$ is number of circuits, $V_o$ is nominal voltage, $b_o$ is per-km line susceptance.

### 2.4 Evaluation of efficiency of the 132 and 33 kV networks of Abuja in terms of power and voltage transfer

The performance of the power flow analysis by successive approximation using the MathCAD 7 Professional software, the network parameters in respect of active resistances, reactance of the lines and transformers, susceptances of the lines, nominal voltage of the system, name and length of the line and percentage impedance of the transformers were collated from transmission substations. The line and transformer data obtained from the 132/33kV transmission substations were used to calculate the line and transformer parameters using equation 3.3-3.8 in MathCAD 7 Professional software;

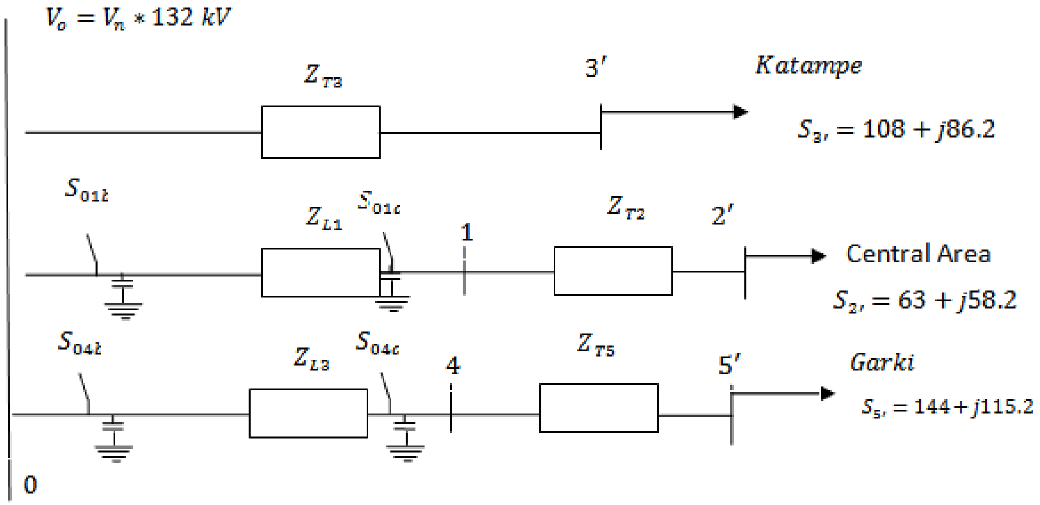


**Figure 2. 2** Equivalent circuit of Abuja 132/33kV Transmission network

The working mode parameters of the power system are:
1. The node voltages such as the sending end voltages and receiving end voltages ($V_S, V_R$)
2. Power flow: the sending end power and receiving end powers (P, Q and S)
3. Losses on the lines ($\Delta P_l,\ \Delta Q_l$)

The mode parameter calculation using the Successive Approximation Methods were run on MathCAD 7 Professional software for each bus using equations 2.9 to 2.12:
The receiving end voltages were determined using equation 3.9 since the send end voltage is known through the data received.

$$V_n = \sqrt{\left[V_{n+1} + \left(\frac{P_{n+1}r + Q_{n+1}x}{V_{n+1}}\right)\right]^2 + \left(\frac{P_{n+1}x - Q_{n+1}r}{V_{n+1}}\right)} \qquad (2.9)$$

Where $V_n$ is receiving end voltages, $V_{n+1}$ is sending end voltage, $P_{n+1}$ is sending end active power, $Q_{n+1}$ is sending end reactive power, $x$ is line reactance, $r$ is line resistance.

Where $S_{n+1}$ is sending end apparent power, $Q_c$ is reactive power due to line capacitance.

$$S_n = S_{n+1} + \left[\frac{}{V^2}\right] R_n + j\left[\frac{}{V^2}\right] X_n (2.10b)$$

Where $S_{n+1}$ is sending end apparent power, $S_n$ is receiving end apparent power, $P_{n+1}$ is sending end active power, $Q_{n+1}$ is sending end reactive power, $V_0$ is nominal voltage, $R_n$ is line resistance, $X_n$ is line reactance.

whe ; the nominal voltage.

$$\Delta Q_l = \frac{P_l^2 + Q_l^2}{V_o^2}\ x\ \ MVar \qquad (2.12)$$

where$\Delta Q_l$ is reactive power losses in the line, $P_l$ is active power in the line, $Q_l$ is active power in the line,$V_o$ is the nominal voltage.

$$\Delta S_l = \Delta P_l + j\Delta Q_l \qquad (2.13)$$

where$\Delta S_l$ is apparent power losses in the line, $\Delta Q_l$ is reactive power losses in the line, $\Delta P_l$ is active power losses in the line.

With equations 2.9 to 2.10b, receiving-end voltage and power were calculated. This will give us fair idea of the expected power and voltage at the utilization point. The losses on the lines were calculated using equations 2.11 to 2.13

The transmission efficiency was also calculated with the equation (2.14)

$$Efficiency = \frac{Real\ power\ at\ the\ receiving\ end\ \ (P_R)}{Real\ power\ at\ the\ sending\ end\ \ (P_S)} \qquad (2.14)$$

The efficiency on the power transformer and the line were calculated and the result is presented in table 4.25, the calculation was made for 132 and 33 kV lines, the efficiency was calculated based on the receiving-end and sending-end power.

The voltage deviation of the line was calculated based on the receiving-end and sending-end voltage

$$\%\mathrm{V}_{\mathrm{deviation}} = \frac{\mathrm{V}_{(\mathrm{N})} - \mathrm{V}_{(\mathrm{A})}}{\mathrm{V}_{(\mathrm{A})\mathrm{l}}} \times 100 \qquad (2.15)$$

where$\mathrm{V}_{(\mathrm{N})}$ is nominal voltage at and $\mathrm{V}_{(\mathrm{A})}$ is actual voltage at full load.

Apparent power at the receiving ends of the transmission lines was expressed from equation 2.16

$$\mathrm{S}_{\mathrm{n}}(\mathrm{MVA}) = \sqrt{\mathrm{P}_{\mathrm{n}}^{2} + \mathrm{Q}_{\mathrm{n}}^{2}} (2.16)$$

Where $S_n$ is receiving end apparent power of the line, $P_n$ is receiving end active power of the line, $Q_n$is receiving end reactive power of the line.

The power factor (PF) of the receiving end apparent power was computed in equation 2.17

$$\mathrm{PF}_{\mathrm{n}} = \cos_{\mathrm{n}} = \frac{\mathrm{Re}\ (\mathrm{S}_{\mathrm{n}})}{|\mathrm{S}_{\mathrm{n}}|} \qquad (2.17)$$

Where $PF_n$ is power factor, $Re\ (S_n)$ is the active power, $|S_n|$ is the magnitude of the apparent power.

The calculations were made for 132kV katampe, central Area and Apo lines and transformers The same calculations were repeated for all the 33kV lines.

## III. RESULTS AND ANALYSIS

Using equations 2.1 and 2.2 estimates of active load for four quarters and the entire year were obtained. These estimates were graphed and shown in Figures 4.1 to 4.6 in actual units respectively. Analysis of these estimates shows the following:

(i) The daily maximum for 132 kV CA feeder was 89 MW at 0.85 p.f. and occurred at 11:00 am . The quarter based daily load graphs of CA are similar with the year based daily load graphs . This indicates that the estimated curve can be relied upon. The total installed capacity of transformers in Central Area substation is 120 MW; this is an indication that at maximum load, the loading of the station will be 74%.

(ii) The daily maximum for 33 kV CA feeder is 63.3 MW at 0.85 p.f. and occurs at 11:00 am The quarter based daily load graphs of CA are similar with the year based daily load graphs . This indicates that the estimated curve can be relied upon as well. In addition, the trend is similar to that of132kV except that the magnitude of the active power demand differs.

Figures 3.1, 3.2 and Table 3.1 present the morning and evening peak loads on 132 and 33 kV feeders for central area (CA); The graphs could be reprated for other areas in the same manner. It was observed that the summation of the total 33kV active power connected toApo and Katampe line is greater than 132kV active Power, the reason being the diversity in peak loads of 33kV feeders.

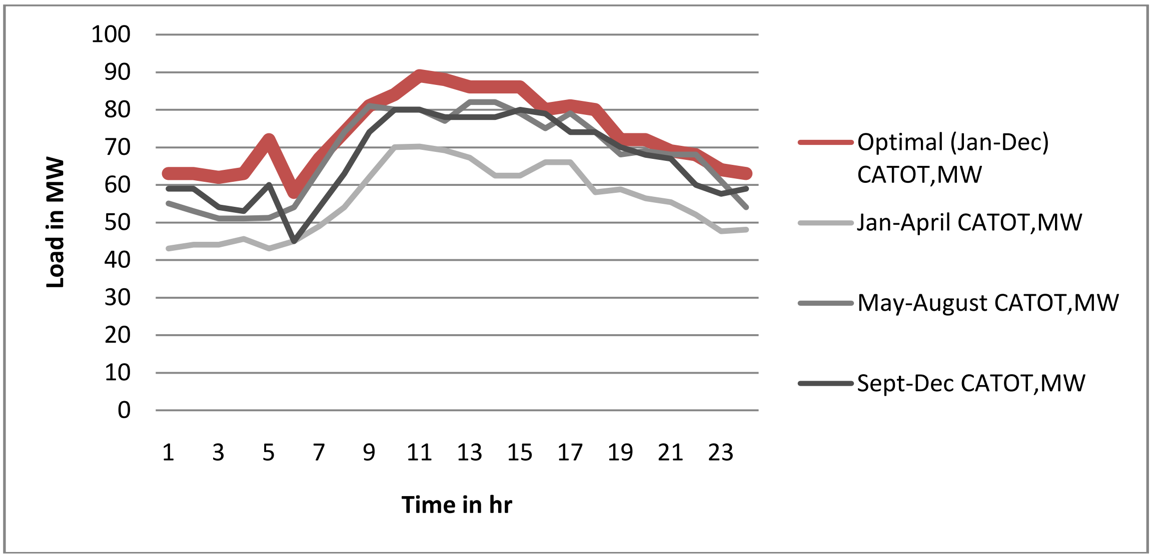


**Fig. 3.1** DAILY ACTIVE LOAD CURVE AT 132kV CENTRAL AREA FEEDER FOR 2009

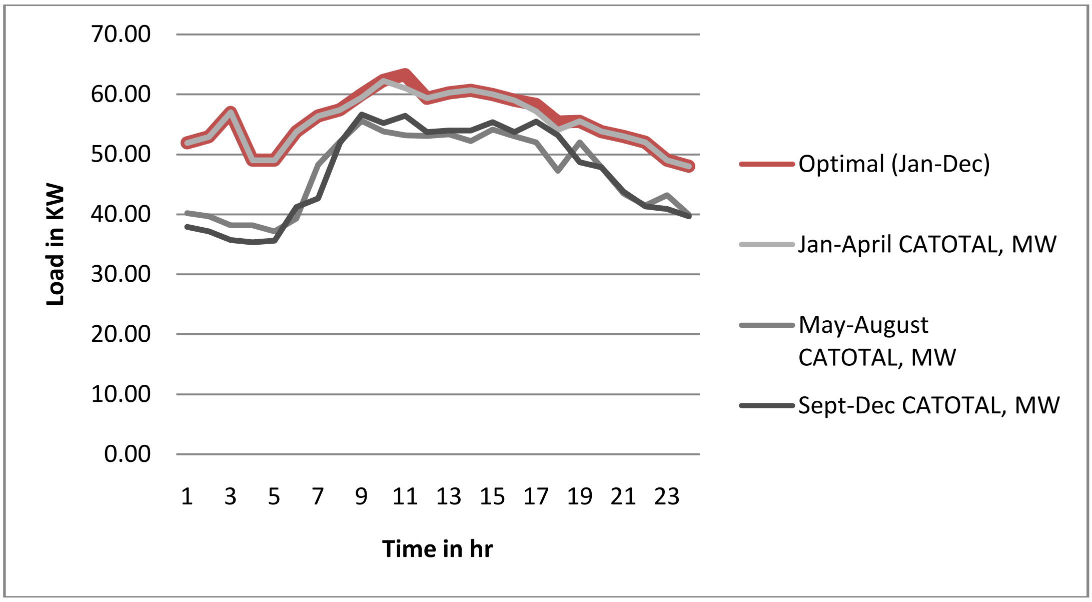


**Fig. 3.2** DAILY ACTIVE LOAD CURVE 33KV AT CENTRAL AREA FEEDER FOR 2009

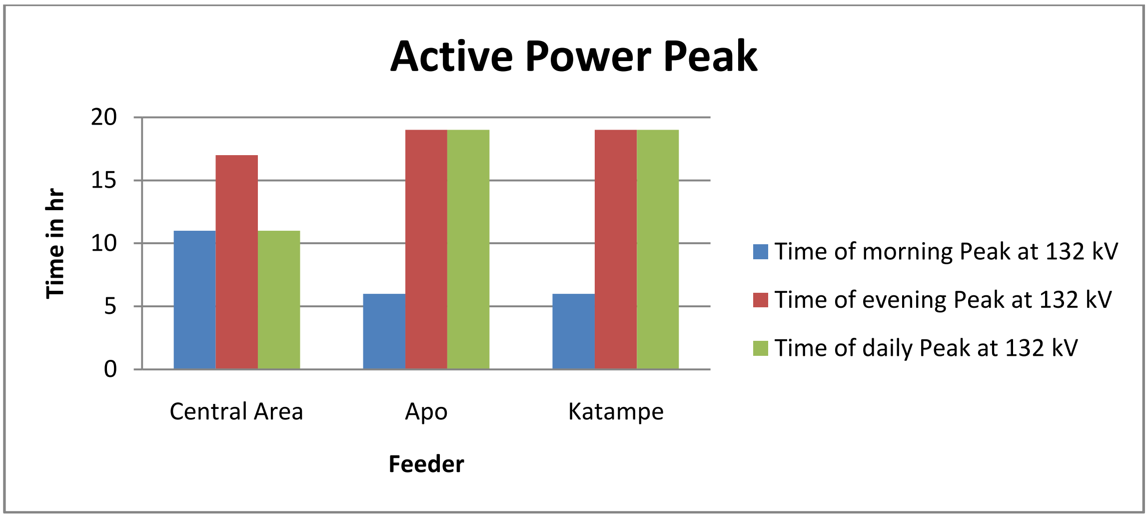


**Figure 3.3** Active Power peak charts of 132kV lines

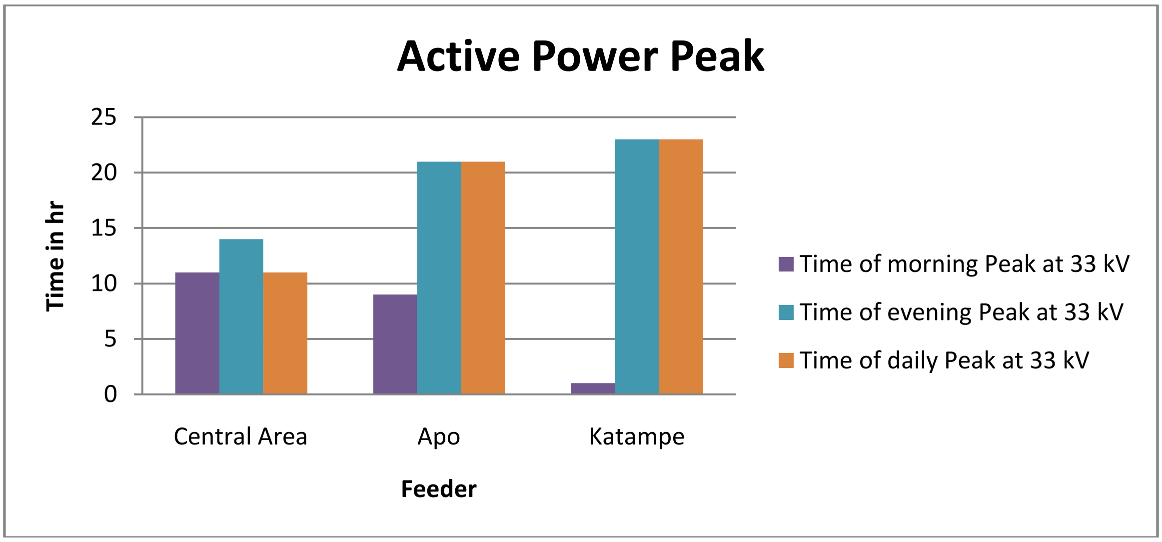
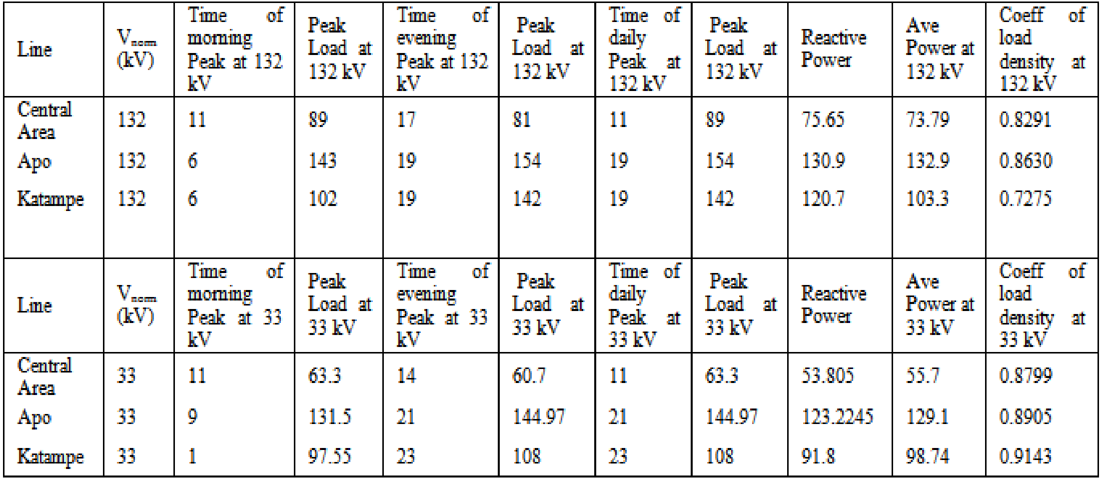


**Figure 3.4** Active Power peak charts of 33kV lines

**Table 3.1:** Summary of the Peak load demand



| Line | $V_{nom}$ (kV) | Time of morning Peak at 132 kV | Peak Load at 132 kV | Time of evening Peak at 132 kV | Peak Load at 132 kV | Time of daily Peak at 132 kV | Peak Load at 132 kV | Reactive Power | Ave Power at 132 kV | Coeff of load density at 132 kV |
|---|---|---|---|---|---|---|---|---|---|---|
| Central Area | 132 | 11 | 89 | 17 | 81 | 11 | 89 | 75.65 | 73.79 | 0.8291 |
| Apo | 132 | 6 | 143 | 19 | 154 | 19 | 154 | 130.9 | 132.9 | 0.8630 |
| Katampe | 132 | 6 | 102 | 19 | 142 | 19 | 142 | 120.7 | 103.3 | 0.7275 |
| Line | $V_{nom}$ (kV) | Time of morning Peak at 33 kV | Peak Load at 33 kV | Time of evening Peak at 33 kV | Peak Load at 33 kV | Time of daily Peak at 33 kV | Peak Load at 33 kV | Reactive Power | Ave Power at 33 kV | Coeff of load density at 33 kV |
| Central Area | 33 | 11 | 63.3 | 14 | 60.7 | 11 | 63.3 | 53.805 | 55.7 | 0.8799 |
| Apo | 33 | 9 | 131.5 | 21 | 144.97 | 21 | 144.97 | 123.2245 | 129.1 | 0.8905 |
| Katampe | 33 | 1 | 97.55 | 23 | 108 | 23 | 108 | 91.8 | 98.74 | 0.9143 |

## IV. CONCLUSION

This study focussed on evaluating the performance of the power network in Abuja District. It considered the duration of power interruptions caused by load-shedding and system collapse. An analysis of the results from load flow calculation showed that the system is characterised by high voltage drops and power losses. Finally, the Abuja PDN is currently inadequate to distribute the demand without load shedding. This research has provided quantitative analysis essential to the operation and development of the 132 kV and 33 kV network.

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