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Problems of Nigerian Local Electric Distribution Networks: A Case Study of a University Environment in the South West Region

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ABSTRACT: The aim of this study was to characterize the operations of local power distribution networks in Nigeria. An 11 kV/0.4 kV network was selected in the South West region with a peculiarity of having its own local generators supporting the mains utility supply. The data included logged data from the power supply company and the local distribution station. Electronic mapping of the network (using Global Positioning System equipment) was carried out to establish spatial coordinates of network elements. Supply and consumer oriented reliability indices were computed for the network. Node voltages and phase currents were measured using multimeters and clamp-on meters under existing supply conditions. Power flow was calculated under ideal full loading condition in order to assess the voltage and current and losses profiles of the network. Analysis of results showed poor and unacceptable operational reliability indices values and power quality by loading and voltage requirements. Remedial measures were proposed to improve the network.

Keywords: power supply, local distribution network, reliability.

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INTRODUCTION

Local distribution networks (LDNs) are crucial in delivering generated energy to the consumers at a safe voltage and quality as well as at minimal costs. This has been a challenge in the Nigerian context for decades. While management of similar networks in the developed world are concerned with tasks of optimization of service in competitive conditions (Chowdhury *et al.*, 2003), the Nigerian power system is yet on the issues of providing and maintaining sufficient electricity for development and consumer satisfaction. Managing the power system for optimal supply satisfaction has become the craved task in the background of acute shortage of generating capacity nationwide. In many instances it is not clear if shortage of generation is the only cause of poor service, particularly in local or community distribution networks. In any case, analysis of the existing system is important to diagnosing and mitigating service problems, a requirement that is rarely practiced in the local networks according to power concepts and principles. A reference (Uwaifo, 1998) gave detailed nominal operational framework parameters of the Nigerian distribution system but no study on extant problems. Some other references (Nadezhdin and Melodi, 2005; Melodi, 2006) addressed generation and load flow scenarios and solutions for transmission and sub transmission lines, and did not address local power supply network issues. About 1842 billion naira was committed to improving the service delivery of the Nigerian power system between 1999 and 2008 but without achieving the desired productivity (Vanguard Newspaper, 2008). This situation has remained chronic till date. This may be blamed on lack of adequate studies of the problems for optimal technical-economical solutions.

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In the Nigerian Electricity Distribution System (NEDS), 33kV lines for primary distribution emanate from the 132kV transmission substations to 33 kV/11 kV injection substations of urban centers and rural communities. 11 kV is stepped down to 0.4 kV, consumer voltage (Uwaifo, 1998). Currently, Nigeria suffers from inadequate power generation, causing grievous load shedding at the distribution levels. The estimated demand was about 10 GW as against 6 GW generation capacity (Urban Development Bank of Nigeria (UDBN), 2008). Typical consumer complaints on NEDS include: frequent electricity outages, which destabilize established user work timetables, timelines, and comfort; poor lighting, especially at night times; and suppression of loads by power quality and adequacy requirements.

This study selects an 11 kV/0.4 kV LDN supplying a University community as a case or sample. The community is composed of administrative, academic, commercial and domestic loads, and the users are mostly literate and organized. Planning and construction of more structures as office complexes are in progress. The network is fed at 11 kV from 132 kV/33 kV main substation by a 100 mm^2 aluminum conductor, tagged in this study as Fdr.Iles.11 and 6.69 km long. The trunk supplied 48 distribution transformers (2009 count), and more additions are proposed. The line support poles are mainly of reinforced concrete type; a few are wooden. The 11 kV line is run to an 11kV panel incorporating oil circuit breakers (OCB). The output from the panel is connected to two feeder lines, tagged in this study as Fdr.Kek.11 and Fdr.Nla.11. These two 11kV feeders connect 13 distribution transformers (DTs). There is a local distribution station (LDS) equipped with five diesel generators and connected to the main DT substation for independent generation. These generators are owned by the community. Their ratings, ages, and fuel consumption rates are shown in Figure 3. The study network may be supplied from two existing district feeders at 33 kV.

The problem comprises general user complaints of poor power supply service; there are prolonged power outages, which compel the running of independent generators for long hours on expensive diesel fuel. The results are heavy costs on fueling and maintenance of generators, disruption of electricity-dependent commercial, domestic and academic activities, noise pollutions and poisonous carbon emissions from dozens of small gasoline generators, run by individual units and business outfits.

The specific objectives of the study are to determine internal conditions contributing to problems of electricity distribution in a selected LDN, and evaluate the performance and reliability of the LDN at normal mode. This study is expected to provide some information, useful for corrective measures and proper planning of LDN conditions and operations in the study community and districts in general.

MATERIALS AND METHODS

Mapping of Study Network

The 11 kV network was mapped using a global positioning system (GPS) device (GARMIN 60) in order to create a diagram (Figure 1) with accurate spatial coordinates of lines, poles and transformers. However, the 0.4 kV network was mapped using visual judgment (Pabla, 2004), and at an average inter-pole span length of 50 m. Where necessary, a metric measuring wheel was used to verify the distances between poles. The mapping included buildings and roads in order to provide a true representation of the electricity network relative to structures in the area. Mapping of the 0.4 kV network is applicable for verification of the optimal locations of DTs in view of voltage drop and losses estimations (Willis, 1997). From the map obtained, a single line sketch of the 11 kV and 0.4 kV networks was produced as in (Figure 2); types and sizes of major network elements, and data of power outage were obtained from the control station. Physical inspection of power facilities including the LDS, overhead lines and DT substations was carried out. Some conditions were captured in photos and analyzed in comparison with standards.

LDS Generators

Number, age and capacities of diesel generators in the LDS were considered and there fuel consumption rate at full loading were estimated in per kVAhr. The results are charted and shown in Figure 3.

Causes of Power System Outages in Study Network

Some references identified causes of power outages as follows: ageing of power system components; increase in demand for energy that strains the system beyond limit; lightning strikes, overgrown vegetation, which causes short circuits faults; severe weather storms, which do fell overhead lines or cause short circuit; violations of reliability regulations; old fashioned and inadequate monitoring and protection systems (Bryar, 2004); vandalization and animal attack (Adeyemo and Abutu, 2004); and load shedding in circumstance where there is power generation deficit (Pabla, 2004; Rao, 2008).

Identification of outage causes in the study LDN is by studying the outage records, differentiating them by causes, and determining their relative frequencies. The obtained values were graphed and presented in Figure 4.

Estimation of Reliability of Study Network

A major ingredient of network study, required by both suppliers and consumers, is reliability (Pabla, 2004). Reliability is the ability of a power system to satisfy load requirement with assurance of continuity and quality. More work has been done over the years in reliability assessment of generation and transmission zones than distribution. However, distribution system contributes the most to the unavailability statistics; 72.6% of average unavailability per customer year occurs in the 11kV or less voltage levels (Billinton and Allan, 2008). This statistics reinforce the need to be concerned with the reliability evaluation of distribution systems. In order to reflect the severity or significance of a system failure, customer-oriented indices are evaluated. These indices take into account the number of customers involved. They are: System Average Interruption Frequency Index, SAIFI; System Average Interruption Frequency Index, SAIDI; Customer Average Interruption Duration Index CAIDI; and Average Service Availability Index, ASAI (Chowdhury, Agarwal, and Koval, 2003; Billinton and Allan, 2008; Strongman, 2004).

$$SAIFI = \frac{\sum_{cust} N_{cust} I_{cust}}{\sum_{cust} N_{cust}}, [\text{interruptions/(yr} \cdot \text{customer)}] \quad (1)$$

where $\sum_{cust} N_{cust} I_{cust}$ - total number of customer interruptions per year, $\sum_{cust} N_{cust}$ - total number of customers served.

$$SAIDI = \frac{\sum_{cust} N_{cust} \Delta O_{cust}}{\sum_{cust} N_{cust}}, [\text{hrs/customer}] \quad (2)$$

where $\sum_{cust} N_{cust} \Delta O_{cust}$ - sum of customer interruption duration per year, hrs.

$$CAIDI = \frac{\sum_{cust} N_{cust} \Delta O_{cust}}{\sum_{cust} N_{cust} I_{cust}}, [\text{hrs/interruption}] \quad (3)$$

$$ASAI = \frac{\Delta A}{\Delta D}, [\text{p.u.}] \quad (4)$$

where ΔA – customer hours of available service per year, ΔD – customer hours demanded.

One year (2008) data of daily power outage were used to compute SAIDI, SAIFI, CAIDI, and ASAI for the period, in which it was assumed that the LDN is one maximum demand consumer. A graph of the results is presented in Figure 5 to Figure 8.

Power quality estimation

The aspects of quality treated include voltage profile and voltage imbalance. Low voltage (LV) distribution is generally unbalanced because: single-phase loads are predominant; distribution lines are never transposed; conductor configurations are not symmetrical. The effect of unbalanced loads on power losses is significant (Global Energy Consulting Engineers, 2004; Geracimov, et al., 2002).

Actual readings of voltages and currents were taken at different points of the network using digital meters. For each point, voltage deviations/drop statistics ($Volt.dev._{stat.}$) per nominal line voltage (U_{nom}) were estimated, graphed (Figure 9), and analyzed. The statistics are maximum, minimum, and average values.

$$Volt.dev_{stat.},\% = \frac{U_{stat.}}{U_{nom}} \qquad (5)$$

where $U_{stat.}$ is statistical mean of voltage readings, kV.

Also, voltage imbalance coefficients ($VIC,\%$) were estimated for LV lines, and the results are presented in Figure 10. According to Lipkin and Geracimov *et al*, *VIC* is determined as in Equation 6 and Equation 7**:**

$$VIC,\% = \frac{\left|\vec{U}_0\right|}{U_{nom}} \times 100 \qquad (6)$$

where $\vec{U}_0$ is balancing complex voltage at the neutral of the three phase line, and U_{nom} is nominal voltage of line.

$$\vec{U}_0 = U_a e^{j\theta} + U_b e^{j(\theta-120)} + U_c e^{j(\theta+120)}, U_a \neq U_b \neq U_c \qquad (7)$$

where U_a, U_b, and U_c are amplitude voltages at phases a, b and c conductors respectively, θ is phase angle.

Consumer Load Estimation

The LDNs of Nigerian districts are deficient in reliable data on single consumer demands. This may be due to metering and irregular power supply problems. As a result, load estimation of the study area was done using the maximum utilization coefficient (K_{max}) method (Lipkin, 1996; Geracimov, et al., 2002). This method requires an inventory of all individual and groups of consumer objects and their nominal power ratings. The maximum demand P_{max} is computed as in Equation 8.

$$P_{max} = \underbrace{f(n_э, m, K_u}_{K_{max}} \times \underbrace{f(K_u P_{nom})}_{P_{av}} \qquad (8)$$

where *m* is the ratio of largest appliance in a group $P_{nom.max}$, to the smallest $P_{nom.min}$; $n_э$ - effective number of appliances with different ratings in a group; K_u - utilization factor of appliance or group of appliances.

The maximum reactive power demand, Q_{max}, is computed as a function of the average reactive power demand, Q_{av}, as in Equation 9.

$$Q_{max} = \begin{cases} 1.1Q_{av}, for\ n_э \leq 10 \\ Q_{av}, for\ n_э > 10 \end{cases} \qquad (9)$$

Power-flow Calculation in 11 kV lines

The line phases are in horizontal formation; the cross sectional area of each phase conductor is $100\,mm^2$. The calculated specific line impedance, for an ambient temperature of 40°C, is $0.0003 + 0.00033\,\Omega m^{-1}$. Also, impedances of the DT (13 in number) were computed and an impedance model for the 11 kV network was sketched for normal mode computation (see Figure 11). The power flow and voltage profiles were computed using sequential approximation method (Lipkin, 1996; Geracimov, et al., 2002). The results of power demand on the DTs are shown in Figure 13.

RESULTS AND DISCUSSION

The mapping of the DN revealed all the network objects and their relative spatial coordinates, and can be useful in assessing proper locations of DT substations (see Figure 1). It was applied in producing a single line sketch of the LDN for subsequent analysis (see Figure 2). The study of 365 days power outage records for the 11 kV line that supplied the study network shows that there were 875 power outage events on the feeder, which is distributed into the following causes: 67% - due to load shedding; 19% - due to open circuit and earth faults; 13% - for routine or preventive maintenance and/or connection of additional networks; 1% due to general system failure (see Figure 4). Only once was an outage as a result of a problem within the study LDN; its maintenance seemed better than the main feeder from the district.

Figure 5 shows that monthly system reliability is unstable and can vary from 0.49 to 0.92. SAIDI for the study year was 3132 hours (about 4 months equivalent); SAIFI = 875 times; CAIDI = 3.6 hours per interruption; and ASAI = 0.64 (see Figure 6). These values indicate a very poor performance of LDNs in the study area and district, for example, the minimum standard ASAI is 0.999 as observed in developed countries. The value of CAIDI indicates inadequacy in the speed at which repairs are carried out in the district network. Figure 7 shows the percentage distribution of outage causes assuming that there is no generation deficit (load shedding problems). Faults outage is highest (59 %). Furthermore,

Figure 8 shows that the major contributor to very poor ASAI is load shedding, and without it the ASAI of LDNs will be a lot better – 0.91.

Figure 1: Map of study network

Figure 2: Single line diagram of the study network

Figure 3: Diesel Generators of study network and fuel consumption rates

Figure 4: Causes of Outages on Fdr.Iles.11 Feeder (2007 -2008)

Figure 5: Dynamics of SAIFI, SAIDI, CAIDI and ASAI for a year

Figure 6: Comparison of Reliability Indices of 11 kV Network with Other Locations

Figure 7: Causes of Outages (without Load Shedding)

Statistics of the measurements of voltage (in Figure 9) show that the voltage reaching the community is $-10\,\%$, which is inadmissible and falls outside $\pm 6\,\%$ allowed by regulation on $11\ kV$ LDNs in Nigeria (NERC, 2005). As a result of the LV, which is aggravated during peak periods, many household appliances could not be energized; air conditioners, electric cookers, washers etc could not be used on the supply system. Hence the LDN has a lot of suppressed load by voltage requirement; these could be accommodated when quality of supply reaching the appliances improves. Consequently, metering of currents does not show the true electricity demand.

Assessment of measurements of phase voltages by coefficient of voltage imbalance shows that the LV lines of some DTs have inadmissible load distribution per phase (see Figure 10). The acceptable cases (2) range between 0.4% and 3.1%; the others (5) range between 6.5% and 41.5%; the maximum permissible is 4 % (Geracimov, et al., 2002). This is a problem associated with not following regulation when distributing load per phase at the LV lines. This may be characteristic of LV distribution systems in the entire district.

When the voltage reaching the main transformer of the LDN is within permissible limit, then computations of power flow and voltage profile show that the expected voltage drop for all the load nodes at 11 kV will be within the approved limit of ±6%. The maximum voltage drops for Fdr.Nla.11 and Fdr.Kek.11 feeders are -1.73% and -2.1% respectively of the nominal voltage of 11kV. The 11 kV network has sufficient capacity by voltage quality requirement. Comparing this finding with results of voltage measurements, it can be deduced that the present cause of poor quality voltage in the local network is the supply system to the community.

The estimated loads for the LDN is about 4 MVA, and the power factor is 0.79 – quite low, though at about the electricity supply company minimum limit (0.8); also, the efficiency of network is estimated at about 95%. 3 DTs are overloaded (see Figure 13). No 11 kV line (100 mm2) is loaded up to 20% of its capacity; however, 6 overhead LV lines and one cable are overloaded (range = 1.1 – 4.1) (see Figure 14). These imply that when SAIFI tends to zero (power supply interruption minimal), then overload relays will disconnect these DTs and lines in order to avoid permanent damage due to thermal overloading. Considering the results of load estimation above, if the diesel generators are to supplement the existing public supply, at CAIDI of about 2.4 hrs (2 hr 24 mins), ASAI of 0.64 and fuel consumption (FR) of 756 L/hr or $0.23\ litres/kVAhr$ (Diesel Service and Supply, 2009; Generator Joe, 2010), then total volume of diesel fuel ($V_T, litres$) required for period T (hrs) will be given by Equation 10.

$$V_T = FR \times (1 - ASAI) \times LF \times P_{\max} \times T \quad (10)$$

where LF is load factor (assumed – 0.8), P_{max} is daily power demand (assumed 3883 kW at unity power factor).

$$V_{year} = 0.23 \times (1 - 0.64) \times 0.8 \times 3883 \times 8764 = 2{,}504{,}653\ litres/yr$$

This quantum of fuel may cost about N376 million per annum at N150 per litre. This is quite prohibitive for the community if it tries to improve ASAI to 1.0 using its diesel generators. In this situation internal load shedding is inevitable if community diesel generators are to supply power when there is outage from the electricity supply company. Minus load shedding, ASAI will be 0.91, and the litres of fuel required to cover the outage periods will drop to 538,500 litres/yr. The cost of this volume of fuel is still very high. Moreover, an inspection of the LDS generators and panels shows that the 1x630 kVA and 2x250 kVA generators are very old: 24 yrs and 15yrs respectively as at 2008 (see Figure 3). This may cause increase in maintenance/repair costs.

Plates 1 to 3 reveal vegetative disturbances of the lines: tall trees and bushes lined some 11 kV and LV routes and should be cleared; there were creepers on some of the poles. Vermin was observed on some poles: ants had a mound at the top of a pole that could cause earth leakage (Plates 4 and 5). A wooden pole had been attacked by termites and may collapse and cause short circuit fault (See Plate 5). Inadmissible sagging of some LV Lines was observed, even though wooden separators were used to separate the phases (See plate 6).

Figure 8: ASAI and CAIDI with and without Load Shedding

Figure 9: $Volt.dev_{stat},\%$ **at 11 kV/0.4kV DTs.**

Figure 10: Voltage imbalance coefficients at selected load nodes of network

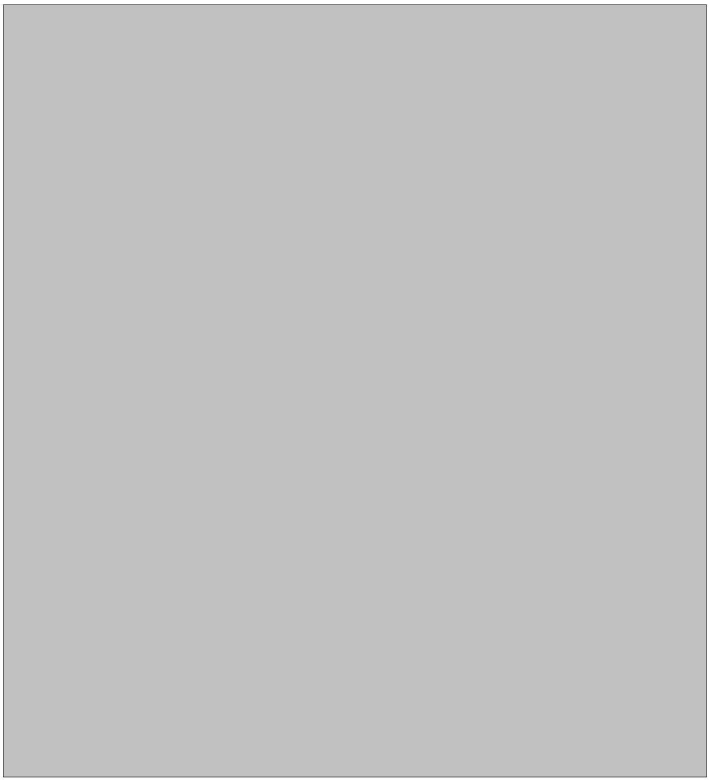

Figure 11: Impedance Diagram of Network

Figure 12: Calculated 11 kV Network Normal Mode Profile

Figure 13: Loading of DT substations

Figure 14: LC of 11 kV and 0.4 kV lines

Plate 1: Pole overshadowed by very close and tall trees

Plate 2: Creepers climbing a pole

Plate 3: LV pole overgrown with bush and with creeper at the top

Plate 4: Ant infested pole with a mound on it creeper at the top

Plate 5: Wooden pole attacked by termites

Plate 6: Sagging of LV lines with wooden separator in the middle of the span

CONCLUSIONS AND RECOMMENDATIONS

In this paper, the LDN of electricity supply to a community in Nigerian district DNs was examined as a case study; practical measurements and power supply calculation methods were employed in the study. From an analysis of the results the following conclusions and recommendations are made:

i. Load shedding due to generation deficit in the national pool is largest contributor to poor reliability of the LDN.

ii. A principal problem with the LDN was poor mains supply voltage, and low power supply availability. A better voltage and power supply profile can be provided at 33 kV. This solution is recommended for other 11 kV feeders in the district.

iii. 11 kV lines should be extended rather than further extending the LV lines in order to minimize power losses and voltage drops on the lines. Also, the present connections of loads per phase do not comply with regulations in many lines; this contributes to reduction of power supply quality. Corrective reconnections should be carried out in order to mitigate the effects of voltage imbalance, especially in lines where it exceeds 4%.

iv. Additional DT substations are required to relieve the existing overloaded ones, e.g., D:SOS – 2x1 MVA, G:O'NLA – 2x500 kVA, V:O'Kek – 2x850 kVA. In addition, the DTs are doubled to further improve reliability, according to standard regulation (Geracimov *et al*, 2002; NERC 2005).

v. The LDS generators are quite old and need replacement. A replacement with 4x1000kVA generators, having digitally controlled outputs, is recommended. All four are programmed to come into operation at preset values of load demand. Such automatic control system reduces outages and ensures smooth transition from mains supply to back-up generators and vice-versa. It ensures quick response to changes in demand. In addition, the control panel should be equipped with power logger. The use of these generators has a close resemblance to distributed generation arrangement and could be studied for full integration as one. In its current back-up status, its exploitation to cover existing deficit from the district supply comes at prohibitive fuelling costs. It can only be employed to cover emergency or critical needs only.

vi. In view of the high cost of generation, there is the need to control the use of electricity in the network; deployment of demand side load management and conservation of energy is recommended.

vii. The following strategies can be implemented to reduce CAIDI and SAIFI: automated call-out of troubleshooters and crews for faster supply restoration; regular monitoring of DT and line loading variations; deploying faulted circuit indicators on the mainline of circuits that exceed annual customer outage thresholds; and increasing troubleshooter staffing and hours of coverage. Furthermore, proper and consistent documentation of working mode profiles should be kept. Success in power supply management depends on accurate record keeping of events in the power system, and this aspect should be improved upon in NEDS.

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