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Estimation and Determination of Load Adequacy of Transformer and Distribution Network of Ogo-Oluwantan Distribution Network, Mokuro-Ibode Road, Ile-Ife

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Abstract
This study aims at estimating and determining load adequacy of a typical transformer and distribution network using Ogo-Oluwantan distribution network, Mokuro-Ibode Road, Ile-Ife as a case study. This is essential in a rapid growing load demands in order to determine adequacy of an existing transformer (check for overloading) and propose a new transformer when necessary in an existing distribution network. It involves extensive review of the literature, the historical evolution of power distribution networks and the growing significance of relief transformers in maintaining stable power supply during unforeseen events were explored. In order to achieve the aim of this research, load demand estimation of the existing distribution network was carried out, the network layout containing three feeders; feeder 1, feeder 2 and feeder 3 were produced using ArcMap software. Also, the adequacy of the existing distribution transformer was assessed by measuring the connected loads on the distribution network using clamp meter, digital multi-meter, cables, terminal connectors and load flow analysis was performed to determine the load demand of the transformer and the voltage profile of the distribution network. The load demand estimation on the distribution network showed that the measured currents for feeder 1, feeder 2, and feeder 3 are 252.13 A, 843.07 A and 353.07 A respectively. The voltage profile showed that the voltage levels recorded at the nodes are not within the permissible ±10% voltage deviation recommended for load buses. The least voltage recorded at the secondary terminal of the transformer was 366 V which is 88.27% of the designed voltage level of 415 V. The results indicated that the existing distribution transformer of the study area is not adequate.

Keywords: *Load, estimation, permissible, load flow, distribution, network, maximum*

1.0 Introduction

The problem associated with the planning of upgrading an existing distribution network is very complex since the network develops gradually with load growth geographically [1]. The main problem that electric utilities in developing countries face today is that power consumption is high, yet supply expansion is hampered by limited resources, environmental concerns, and other societal considerations. Research efforts are being directed towards developing methodologies for optimal design, planning, and expansion of modern electrical distribution system [2].

The application of Distribution Energy System was investigated to reduce the load rate of transformers by avoiding the problem of low utilization rate caused by the traditional method of increasing transformer capacity [3]. The transformer considered has overloading problem only at peak period. The use of curve fitting method using Fourier series to model historical load data of distribution transformer was investigated by [4]. Deterministic load demand obtained from the consumer load forecast was used for optimal sizing of distribution transformer. The results obtained were compared with the sizes of existing distribution transformers. The researchers in [5] investigated the impact of voltage fluctuation on the residential and commercial customers in a distribution network. In the research, a digital multimeter was used for measurement at the consumer point of common coupling (PCC) and the result compared with the standard nominal voltage of 240 V. Linear regression model was used to calculate the voltage deviations. According to [6], the voltage quality in low-voltage distribution network was investigated using the method of measurement of successive load points where the network data were obtained through physical survey. The obtained data were used to model the distribution network on MATLAB/SIMULINK software for computational analysis. The results obtained showed that voltage deviation is outside the permissible range of ± 5% [7]. Analysis on a highly loaded distribution network was carried out by [8]. Measurement were taken on the medium voltage and low voltage substation but the transformers and low voltage buses were not modelled in the research. The distribution system was modelled for simulation and the analysis of the voltage profile was investigated with the voltage drop and power losses calculated during simulation.

This study estimates and determines load adequacy of a typical transformer and distribution network using Ogo-Oluwantan distribution network, Mokuro-Ibode Road, Ile-Ife as a case study.

2 Materials and Methods

2.1 Load Estimation of the Distribution Network

In order to estimate the load demand of the existing distribution network considered in this study, the measured load data at each bus started with development of Geographical Information System layout using ArcGIS software, CorelDraw and AutoCAD. The Ogo Oluwantan distribution network is within the coordinates: A (7.505406, 4.586265); B (7.505406, 4.592642); C (7.496778, 4.586265) and D (7.496778, 4.592612). The major steps followed for collecting the required data are as follows:

a) Field work/GIS survey
b) Downloading images from Google Earth Pro
c) Geo-referencing the image using Universal Map Downloader (UMD)
d) Forming the database using Ms-Excel, Ms-Word and AutoCAD

The developed GIS layout of distribution network of the study area, Ogo Oluwantan distribution Substation and network is presented in Figure 1.

Load estimation of the existing network is required in order to determine the present loading capacity of the distribution network of Ogo Oluwantan distribution substation. The load estimation was carried out by measuring the current load capacity of the transformer with digital clamp-meter from the feeder pillar of the distribution transformer. Also, current measurements (in Amperes) for each household, businesses shop, local factory were carried out at different nodes across the distribution network.

2.2 Estimating the adequacy of the existing Transformer

Estimating the adequacy of an electricity distribution transformer involved assessing whether the transformer can handle the load demand effectively without overloading or causing voltage fluctuations. This was achieved by obtaining the transformer's technical specifications which include its rated capacity in kilovolt-amperes (kVA), voltage ratings and impedance and collection of data on the load demand in the area served by the transformer. This included both the connected load (total capacity of all loads connected to the transformer) and the maximum demand. For simplified and standardized way of illustrating the connections and relationships between various elements in the distribution network, a line diagram of the existing network was drawn as shown in Figures 2 to 4. The Figure 2 shows the households as connected to the nodes or buses in the distribution network. Figure 3 displays span distances which were used to determine the route length from the existing transformer while Figure 4 represents the number of nodes/buses available in the entire distribution network under study.

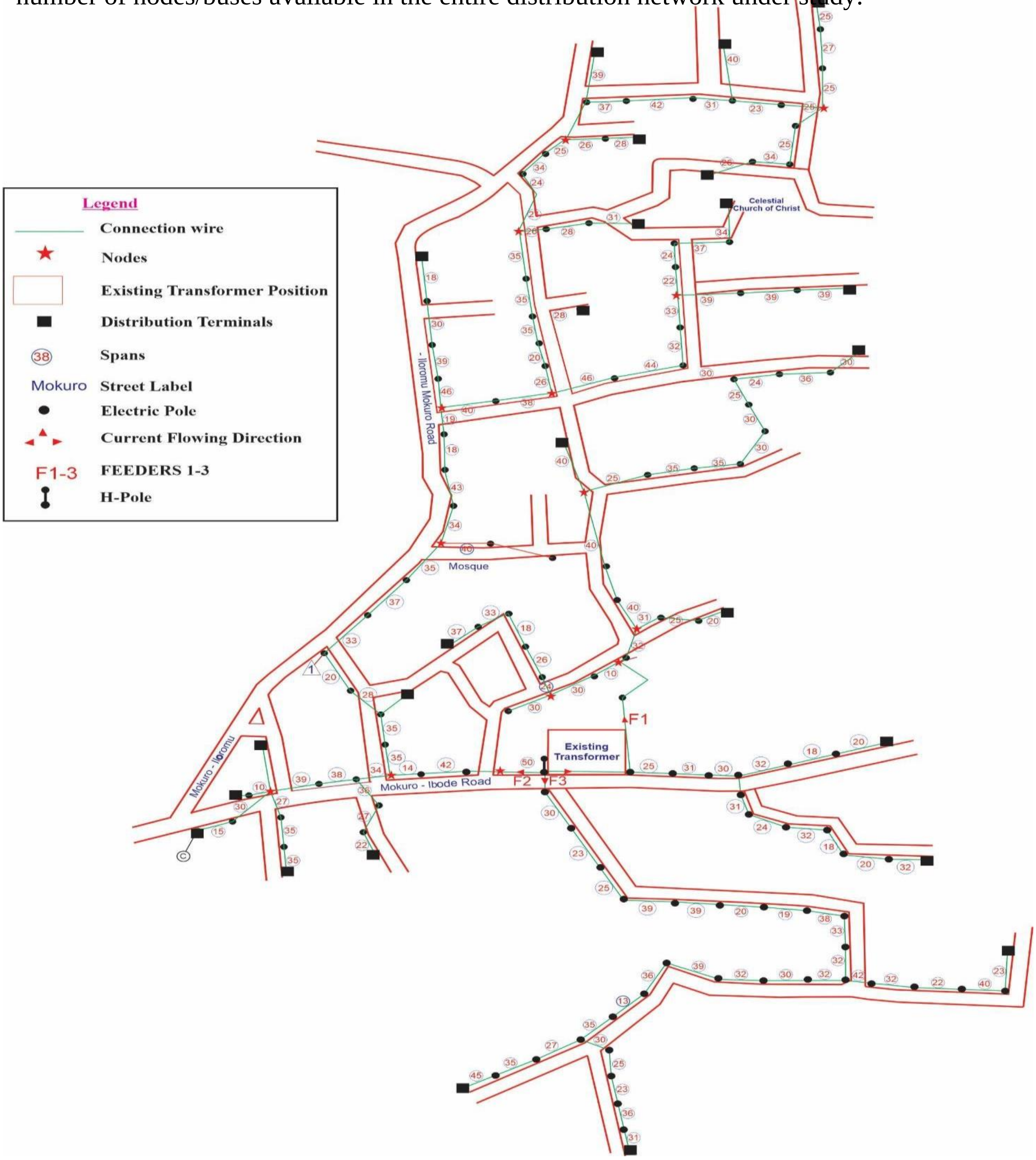

Figure 1: GIS layout of Ogo-Oluwantan Distribution Substation and Network

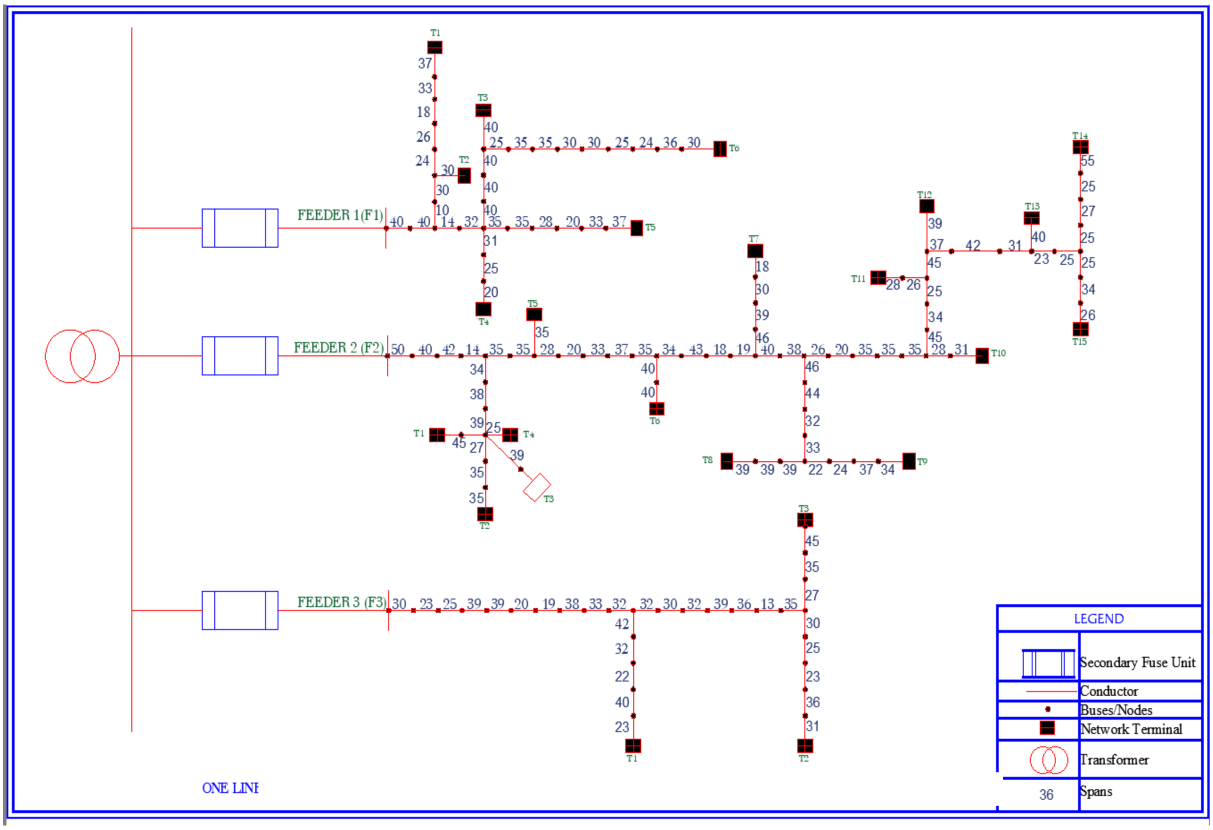

Figure 2: One Line Diagram Network Topology showing Span distances

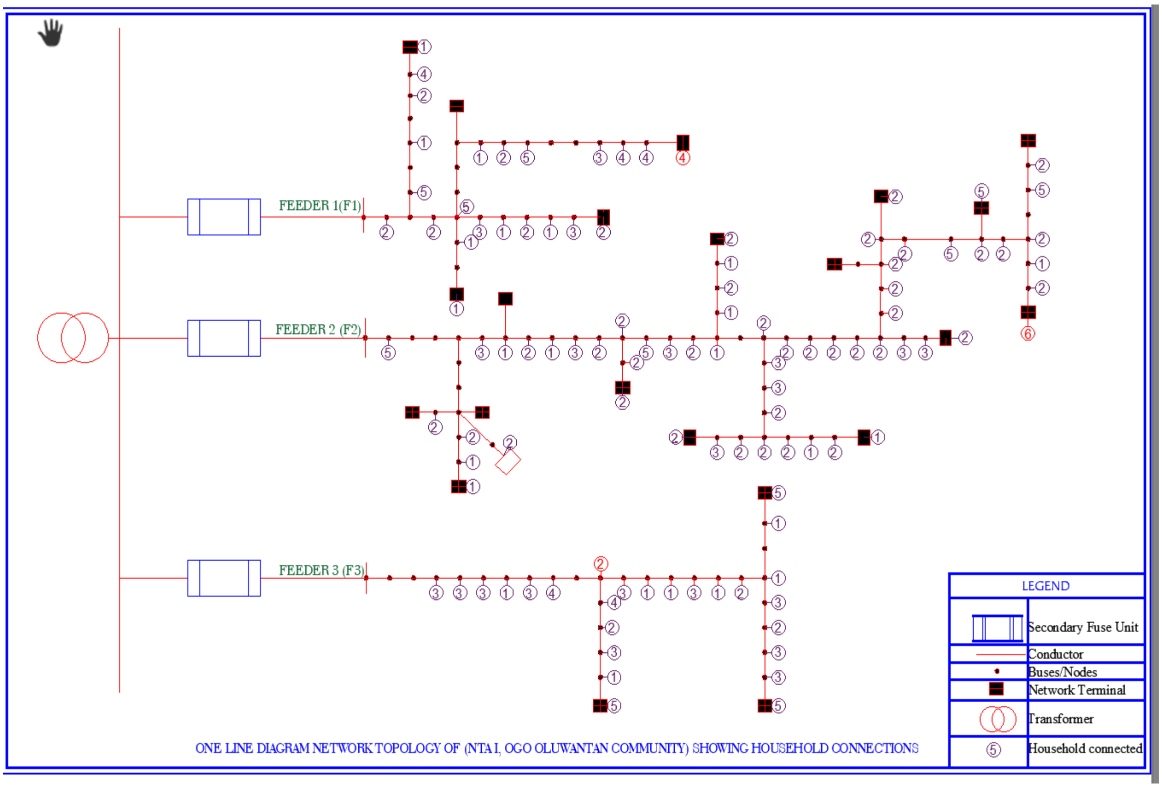

Figure 3: One Line Diagram Network Topology showing buses/nodes

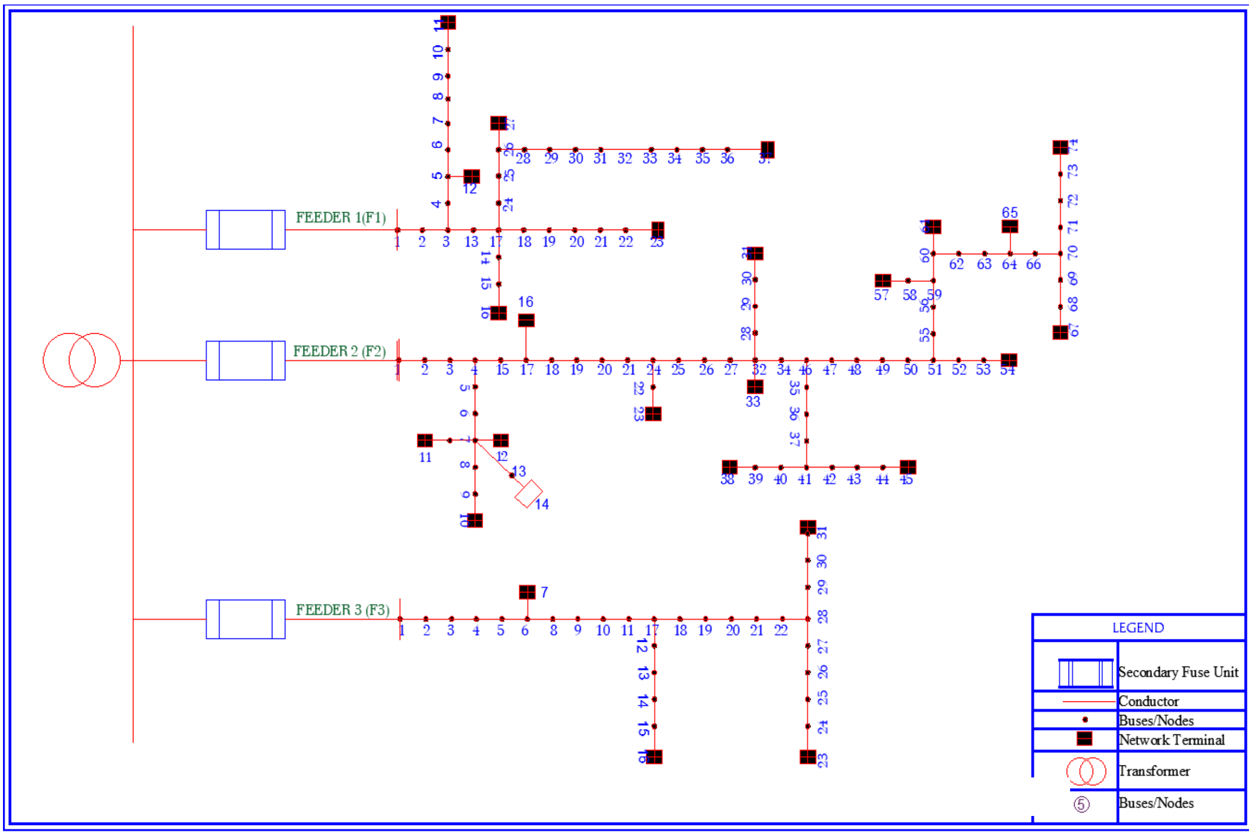

Figure 4: One Line Diagram Network Topology showing Household connections

2.3 Mathematical and Simulation Analysis Method

A. Mathematical Approach

At first, the distribution transformer's maximum amperage loading capability was compared to the size of the transformer and the associated load. It was then established through this analysis that the transformer was overloaded. The ideal transformer sizing was accomplished by matching the appropriate transformer capacity with the amount of load connected to that transformer.

Equations (1) to (3) are used to determine the percentage loading of the existing distribution transformer.

$$T_{AR} = \frac{R_P + Y_P + B_P}{3} \quad (1)$$

where T_{AR} is Transformer average reading, R_P is Red phase, Y_P is Yellow phase and B_P is the blue phase

$$T_{CC} = \frac{T_{PR}\,(kVA)}{0.415 \times \sqrt{3}} \quad (2)$$

where T_{CC} is the Transformer current capacity, T_{PR} is the transformer power rating in kVA and

$$T_L\,(\%) = \frac{T_{AR}}{T_{CC}} \times 100\% \quad (3)$$

where T_L (%) is the Transformer percentage loading based on the connected load.

The status of the distribution transformer was determined by comparing the result obtained in Equation (3) with the stipulated compliance code as indicated in (Awochi, Idoniboyeobu, &

Braide, 2019) for under loading (0-40%), optimal loading (41-79%) and overloading (80% and above).

B. Simulation Approach

The distribution network was modelled on NEPLAN software to determine the adequacy of the existing transformer for supplying power to the coverage area.

For accurate modelling of the existing network, the external grid supply was regarded as impedance and the parameters required was the network impedance which will be obtained from the short circuit current and the value of the impedance to admittance ratio of X/R. The line parameters were calculated using Equations (4) to (6).

$$R = \rho \frac{L}{A} \quad (4)$$

where ρ is the resistivity of the line, L is the length between two nodes and A is the area of the conductor and R is the resistance of the line.

$$L = 2 \times 10^{-7} (\frac{D_m}{0.778r}) \quad (5)$$

$$X_L = 2\pi f L \quad (6)$$

where L is the inductance of the line, D_M is the distance between two nodes in meters, r is the radius of the conductor, f is the frequency of the network and X_L is the inductive reactance of the line.

The load flow module of NEPLAN software was used to obtain the voltage profile and losses on the existing distribution network. The software application technique relies on the factors of simulation algorithm and the element models used for the algorithm. The algorithm used for the load flow calculation in NEPLAN software was based on node analysis method which is expressed in Equation (7)

$$I_n = Y_n \times U_n, n = 1,2, \ldots, n \quad (7)$$

where, I_n is the vector of the node current, Y_n is the node admittance matrix and U_n is the vector of the node voltage.

2.4 Load Flow Analysis

The load flow analysis of the modelled distribution networks was carried out using extended Newton-Raphson algorithm. The mathematical expression for the Newton Raphson load flow analysis is as expressed in Equations (8) – (10) [9]:

$$I_n = \sum_{j=1}^{n} Y_{ij} V_j \quad (8)$$

The complex power at bus i is given as:

$$P_i - jQ_i = V_i * I_i \quad (9)$$

The Jacobian matrix gives the linearized relationship between small changes in voltage angle $\Delta\delta_i^{(k)}$ and voltage magnitude $\Delta|V_i^{(k)}|$ with the small changes in real and reactive power, $\Delta|P_i^{(k)}|$ and $\Delta|Q_i^{(k)}|$. This is expressed in Equation (10) as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 J_2 \\ J_3 J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (10)$$

Drop Voltage and Electrical Power Loss

Voltage drops on electrical distribution systems include drop voltage on feeder, distribution transformer and line of low level distribution and electrical installation of consumer. The power loss and voltage profile of the modelled distribution network on NEPLAN software was computed using Equations (11) - (14).

The power loss of any line between buses in a distribution system is given as:

$$P_{loss(ij)} = \left(\frac{P_j - jQ_j}{V_j^*}\right)^2 * R_{ij} = \frac{{P_j}^2 + {Q_j}^2}{V_j^2} * R_{ij} \quad (11)$$

$$Q_{loss(ij)} = \left(\frac{P_j - jQ_j}{V_j}\right)^2 * X_{ij} = \frac{P_j^2 + Q_j^2}{V_j^2} * X_{ij} \quad (12)$$

The total Real and Reactive power loss in a network is then given as:

$$P_{(total\ losses)} = \sum_{t=1}^{nl} P_{loss(ij)} \quad (13)$$

$$Q_{(totallosses)} = \sum_{t=1}^{nl} Q_{loss(ij)} \quad (14)$$

where R_{ij}, X_{ij} is the line resistance and reactance between bus I (sending end) and j (receiving end), $P_{ij,}$ Q_{ij} is the real and reactive power, $V_{i,}$ V_j is the magnitude bus voltage at bus I (sending end) and bus j (receiving end), and nl is the number of lines.

3.0 Results and Discussions

A. Load Estimation of the distribution network

The load measurement on Ogo-Oluwantan distribution network with an installed transformer capacity of 500 kVA (695.6 A) was carried out on node by node basis throughout the length of the distribution network using clamp meter, digital multimeter and terminal connectors. The measurement results are shown in Tables 1 - 3 for the three (3) feeder units of the distribution bus-bar chamber. The loads on the low voltage buses were assumed to operate at a power factor of 0.8. Data obtained from the measured loads at different nodes were used in the evaluation of voltage profile of the distribution network using NEPLAN software. For better analysis of the network, the distribution network under study was classified into three feeders -feeder 1, feeder 2, and feeder 3 as presented.

Table 1: Load Measurement on Feeders Unit 1, 2 and 3 in Ampere

Nodes	Feeder 1	Feeder 2	Feeder 3
N1	20.60	29.40	3.40
N2	22.67	14.60	--
N3	--	--	--
N4	--	11.13	17.20
N5	--	--	17.13
N6	7.80	11.33	13.60
N7	4.33	--	4.27
N8	--	14.60	15.33
N9	--	11.40	23.07
N10	5.67	11.47	13.47
N11	5.13	26.87	8.67
N12	5.07	9.20	13.00
N13	6.40	9.73	17.87
N14	--	5.27	16.07
N15	4.47	19.00	11.67
N16	--	9.27	17.53
N17	17.07	--	4.60
N18	28.20	10.60	7.73
N20	6.40	19.00	4.27
N21	--	21.60	10.13
N22	10.40	14.00	7.67
N23	21.47	24.67	--
N24	4.67	23.33	7.47
N25	--	9.33	26.27
N26	7.80	9.80	12.60
N27	4.20	12.00	9.67
N28	--	13.93	16.20
N29	13.33	17.60	15.27
N30	--	13.80	26.93
N31	--	14.27	26.92
N32	14.13	9.27	
N33	--	21.07	
N34	14.07	18.13	
N35	14.53	11.33	
N36	13.73	10.40	
N37		11.80	

N38	30.53
N39	9.20
N40	9.73
N41	10.67
N42	9.73
N43	9.13
N44	10.27
N45	--
N46	20.93
N47	25.73
N48	10.40
N49	25.80
N50	25.40
N51	11.67
N52	15.00
N53	--
N54	12.00
N55	11.93
N56	--
N57	--
N58	16.87
N59	--
N60	26.00
N61	--
N62	--
N63	--
N64	--
N65	4.53
N66	5.07
N67	4.53
N68	4.80
N69	6.27
N70	7.13
N71	--
N72	17.93
N73	--
N74	11.27

B. Estimating the Adequacy of the Existing Transformer

The NEPLAN model of the existing distribution network is shown in Figure 5. The node to node distances were used to calculate the line parameters used for the modelling and it is shown in Table 1. Also, from load demand estimation on the distribution network, the measured currents for Feeder 1, Feeder 2, and Feeder 3 are 252.13 A, 843.07 A and 353.07 A respectively giving a total current of 1448.27 A.

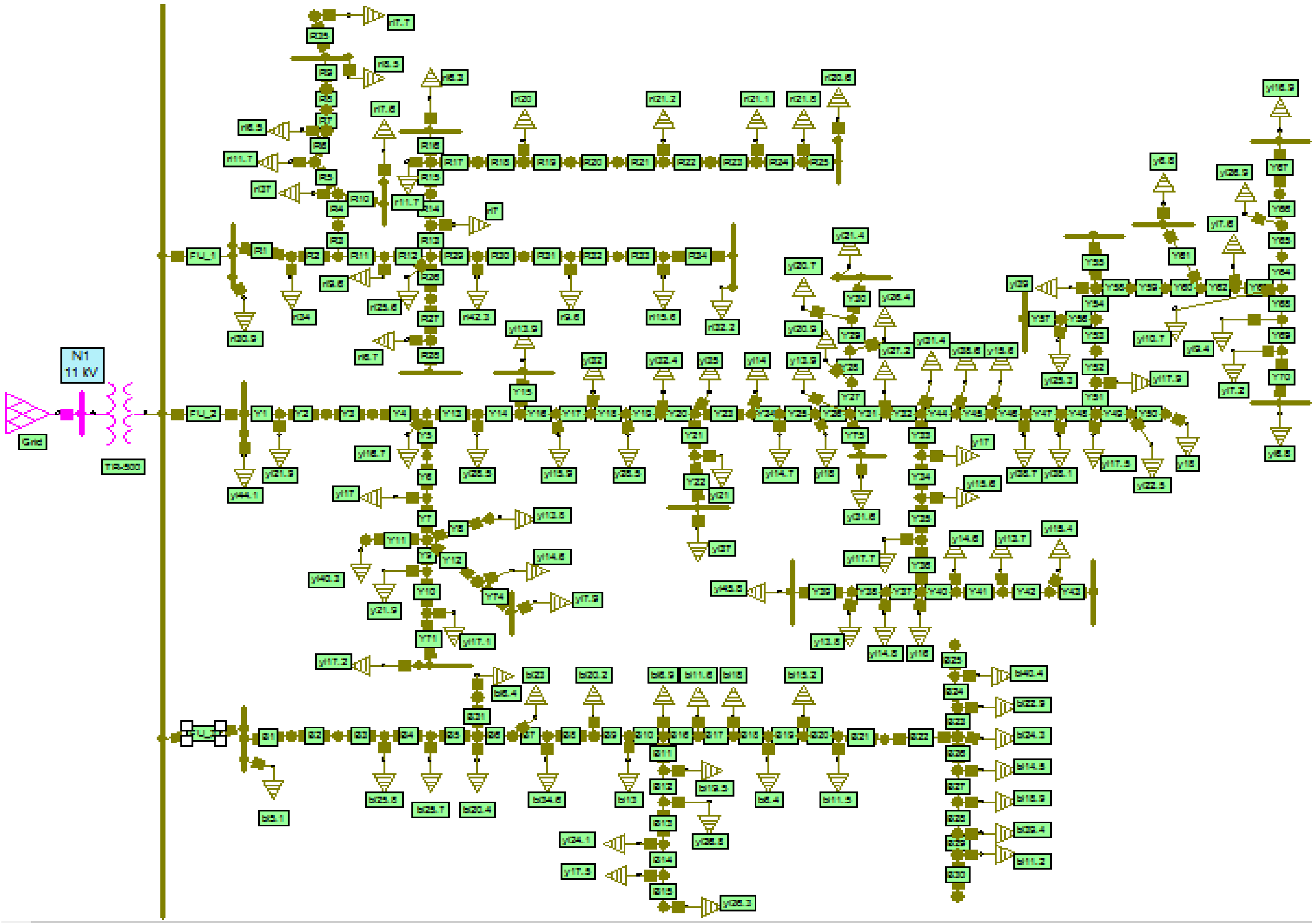

Figure 5: NEPLAN model of the existing distribution network

The load flow result of the existing distribution network showing the voltage profiles in Feeder 1, Feeder 2 and Feeder 3 are shown in Figure 6. The voltage profile showed that the voltage levels recorded at the nodes are not within the permissible ±10% voltage deviation recommended for load buses. The least voltage recorded at the secondary terminal of the transformer was 366 V which is 88.27% of the designed voltage level of 415 V. The 500 kVA transformer is therefore not adequate for supplying the available loads at Ogo-Oluwantan distribution network.

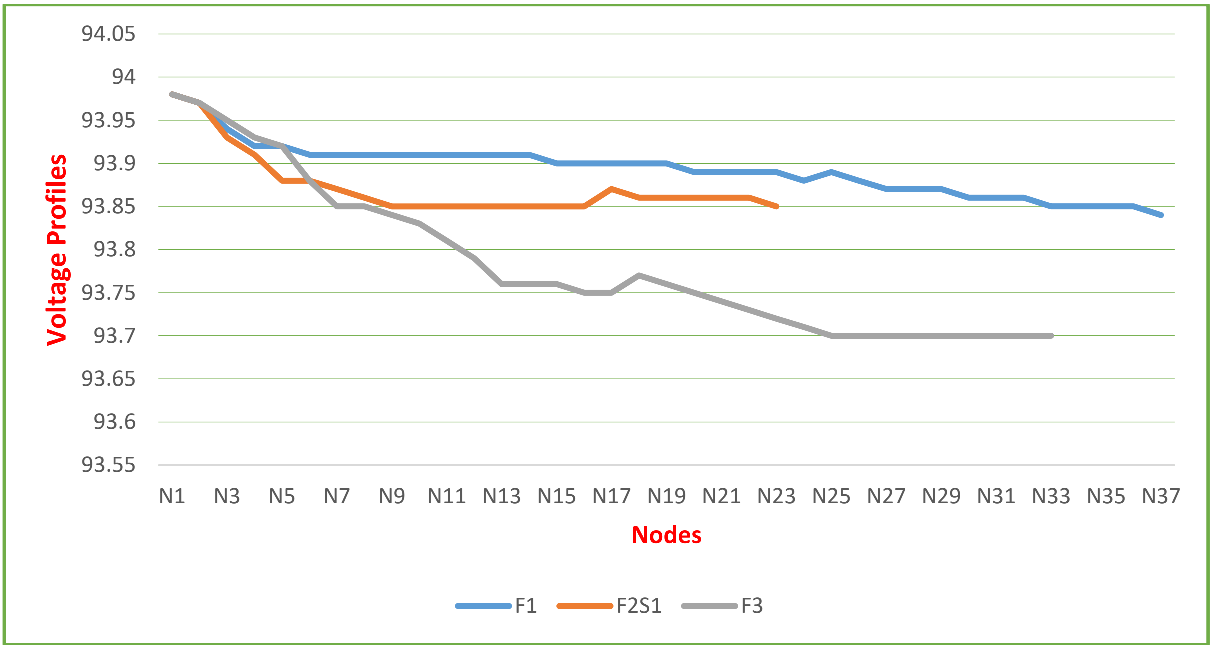

Figure 6: Voltage profile of Feeder 1, Feeder 2 and Feeder 3 of the existing network

4.0 Conclusion

In this research, the complexities of determining the capacities of distribution transformer and the distribution network for planning and management an existing distribution networks was considered, exploring methodologies, challenges, and existing trends. The adequacy of the existing distribution transformer was assessed by measuring the connected loads on the distribution network using clamp meter, digital multi-meter and terminal connectors and performing load flow to determine the loading of the transformer and the voltage profile of the distribution network. The voltage profile showed that the voltage values violate the permissible voltage levels for load buses which were caused by the overloading of the existing transformer for the area under study.

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