Assessing Voltage Quality In A Typical Low Voltage Network

Olajiga B.O, Olulope P.K

ABSTRACT: The power outage in Ado Ekiti is disturbing and has produced a negative effect on the life and economy of the people. This study presents investigation of power supply challenges in Ado-Ekiti Low Voltage Distribution network with the specific focus on the development of an algorithm for its improved performance. In this work, voltage quality problem and its cause was investigated. Load flow of the Llow Voltage (LV) network was carried out using impedance modeling with the aid of MATLAB/SIMULINK. Results obtained from the analysis were applied to develop algorithm for improved performance of the LV network while measures for improved LV performance were formulated from the developed algorithm. The analysis indicated that the voltage drop on the LV network is within the range (0.87p.u-0.94p.u). Voltage deviation is completely outside the permissible range of ±6%.

Index Terms: Low voltage, Distribution network, Voltage quality, Load flow, Reactive power, active power, voltage deviation.

1. INTRODUCTION

Electricity consumers are more concerned about the performance of low voltage networks because it is the final link in electric power delivery which carries power closer to the load points from the power distribution station to the various end users. From the low side of the service transformer to the customer, the service level operates at utilization voltage. Power is obtained from the distribution feeders through service transformers, which reduces voltage from primary to utilization voltage (the voltage at which consumers use electricity) and onto secondary circuits that directly feeds the electrical consumers. The utilization voltage in Nigeria is 240/415V. Despite its low voltages, short distances and nature of its equipment, the low voltage system is a significant one in the power system. In fact over 90% of a typical utility sales passes through the LV network. It is the final link to the revenue (Leewillis, 2004). There have been incessant power outages, voltage drop and rise during peak and off–peak periods on the LV network. These are the major electricity supply challenges being experienced in Ado Ekiti low voltage distribution networks. The voltage quality is poor when it is compared with standard requirement of LV system (+_6% of nominal voltage). In most of the literature such as, (Ewesor, 2010) stated that line voltage depends on the load and the distance over which the power is transported. According to (Ricardo, 2014),the inherent characteristic of LV distribution networks includes random variation of residential load demand at different time periods. This variation is based on load demand (Fredrik, 2005) confirmed that electrical faults result in the overloads is due to the passing the current through the conductor which is above the permissible value and faults due to real power deficit occurs due to mismatch in the power generated and consumed and results in the frequency deviation and collapse of grid.

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(Lakervi, 1996) stated that voltage control equipment are operated in such a way that the voltage provided to LV customers remains within the required limits, despite varying voltage drops due to changing loads and alterations in network configurations. (Piotr et al, 2008) concludedin his work that in building a simulation model for determination of voltage drop and deviation values in a low voltage power line, the model input data are related to; length of the power line, distance from the receiving points to the powerline start, cross-section of conductors, number of consumers, and value of power consumed by the consumers.

2. METHODOLOGY

The following methods were used to achieve the study objectives. This was carried out with deterministic impedance modelling of the LV network using MATLAB/Simulink program. The voltage profile of the LV network was assessed using the method of successive load points. From the physical survey of the LV network, components such as: distribution transformer, cables sizes and length of LV (0.415kV) line parameters were used in the representative model for computational analysis. The loading profiles of the network were injected into the model. Relevant data and information were collected from the utility company. The following documents were collected: Ado-Ekiti single line diagram, inventory of distribution transformers with their loading, feeders loading and route lengths with conductor sizes and capacity. The single line diagram shows how feeders are arranged and connected, span length and positions of all distribution transformers on each feeder.

2.1. Physical Survey and Inspection of the LV network

The LV network was inspected, components such as: distribution transformer, underground cables and the 0.415kV lines were closely observed, weaknesses, sizes of Aluminum conductor used were identified. Route lengths of the LV circuit were also measured.

2.2. Determining Loading Profiles of the LV Circuits

Loadings on the LV circuits were measured; apparent load/current (I) was recorded on each circuit for further computations to determine the values to be imputed into the model. The measured values were resolved into its Active power (P) and Reactive power (Q). These are evaluated as in equations 2.1, 2.2 and 2.3 (Mehta, 2005).

$$I = \frac{(R+Y+B+N))}{3}, \text{A} \quad (1)$$

$$P = \frac{\sqrt{3} * V_l * I_A * Cos\phi}{1000}\ kW \quad (2)$$

$$Q = \frac{\sqrt{3} * V_l * I_A * Tan\ \phi}{1000}\ , kVar \quad (3)$$

Where R, Y, B and N represent load/current measurement on the red, yellow, blue phases and the neutral respectively.

2.3. Modeling and Simulation of the LV Networks

The loading profiles obtained were injected into the model representative of the network impedance; hence the voltage load point was obtained using method of successive load point voltage balance. This allowed the voltage profiles to be determined and hence the distribution of voltages received at the tail-end of the LV circuits.

Assumptions:

(i) Constant conductor impedance (No thermal model used)
(ii) Constant conductors' separation
(iii) Loads are constant current sources
(iv)Transformer sending voltage is constant; equal to nominal.

2.4. Model Description

The distribution network was modelled from generation to the LV circuits. Both generation and transmission were lumped and represented as Grid 33kV with capacity of 60MVA being the installed capacity at Ado 132/33kV transmission station. Ado Mains injection substation 2No, 15MVA power transformers at Ado Mains injection substation were also represented with its associated 11kV feeders and line breakers. The 11kV feeders were model with the route lengths in kilometers, line parameters and load demands/allocation. Each feeder load demand was represented by series RLC load attached to each feeder as showned in Figure 1. However, two distribution transformers were selected for the analysis and representation of the LV network. This was done considering the circuits route lengths, being the longest and shortest circuit/feeder. The selected transformers were represented with their capacities and the associated LV networks represented appropriately with the line distances from the transformers, line parameter per kilometer and each circuit load attached accordingly. The nature of load considered in the model is linear. From the model Olujoda 300KVA transformer is attached to Ajilosun 11kV feeder, it has 2No LV circuits namely; Winners road (1.98km) and Celestial road (4.4km). National Bank 500KVA transformer was also connected to Okesha 11kV feeder with 3No LV circuits namely; Ijigbo Rd (1.2km), First Bank Area (0.8km) and Kings Market (0.5km). Voltage on each busbar was measured during the simulation, however, the voltage profile at the beginning and far end of 415V feeders. The network single line diagram and its simulation Model are represented in Figure 1 and 2 respectively while Figure 3 represent the chart showing Voltage profile along the selected circuits. Summary of Load flow /simulation results is contained in Table 1.

2.5. Development of Algorithm for Assessing Voltage Profile on Typical LV Networks

In order to improve the LV network performance/ voltage profile, an algorithm of the sequence of steps for determination of voltage profiles along low voltage circuit to indicate when the quality would be outside the predetermined standards for immediate reinforcement and correctional measures.

2.5.1. Algorithm

Step 1: Initialize the parameters; I, Z, $V_{0,}$ and K. Choose the initial values for the parameters. I is the load current, Z represents the line impedance per kilometer, V_0 is the nominal voltage at the transformer point and K is the load points where supply is being tapped to customer premises (number of spans/poles from transformer point).

Step 2: Define the successive load points; K = 0, 1, 2…N.
This is the specified maximum number of iteration the program/ test may run.

Step 3: Compute the progressive LV route length;
L = k*0.045
K is the number of spans/poles from the transformer point as in step 2, while 0.045km is the standard LV span length between two poles (45m).

Step 4: Compute voltage at point K; V_k = (I *Z *L^ 2)/ 2

Step 5: Determine voltage drop on the line up to point K; $\Delta V = (V_0 - V_k)$
This is the difference between the nominal voltage and voltage at load point K.
Step 6: Compute the percentage voltage deviation;
$\%\Delta V = (\Delta V / V_0)*100$

Step 7: Compare the computed value of percentage voltage deviation with the predetermined standard limit allowed for LV voltage deviation. If ($\%\Delta V \leq 0.94V_0$) then, go to step 2. In this case we are still within the specified limit.

Loop: K = K + 1

Else, output: Poor Voltage Quality, install more intermediate distribution transformer to reduce LV circuit length.
End.

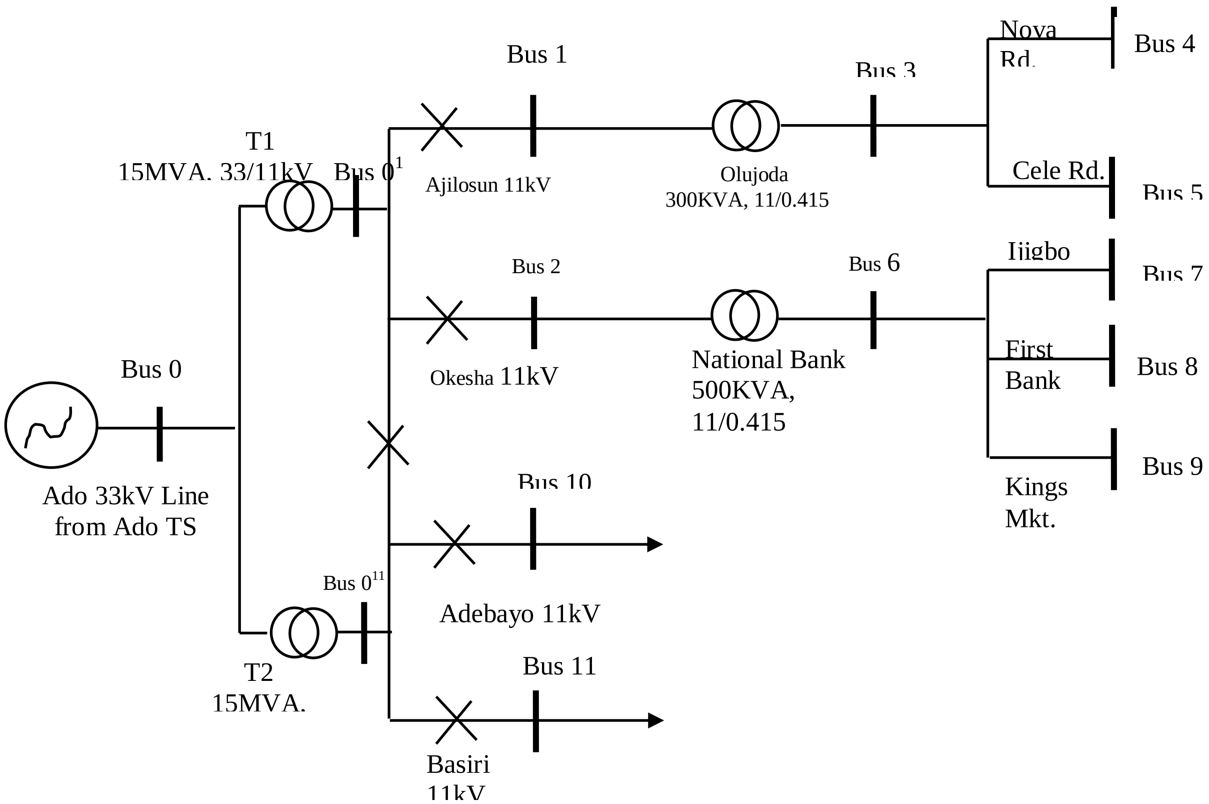

Figure 1: *Single Line Diagram of the Simulated Network*

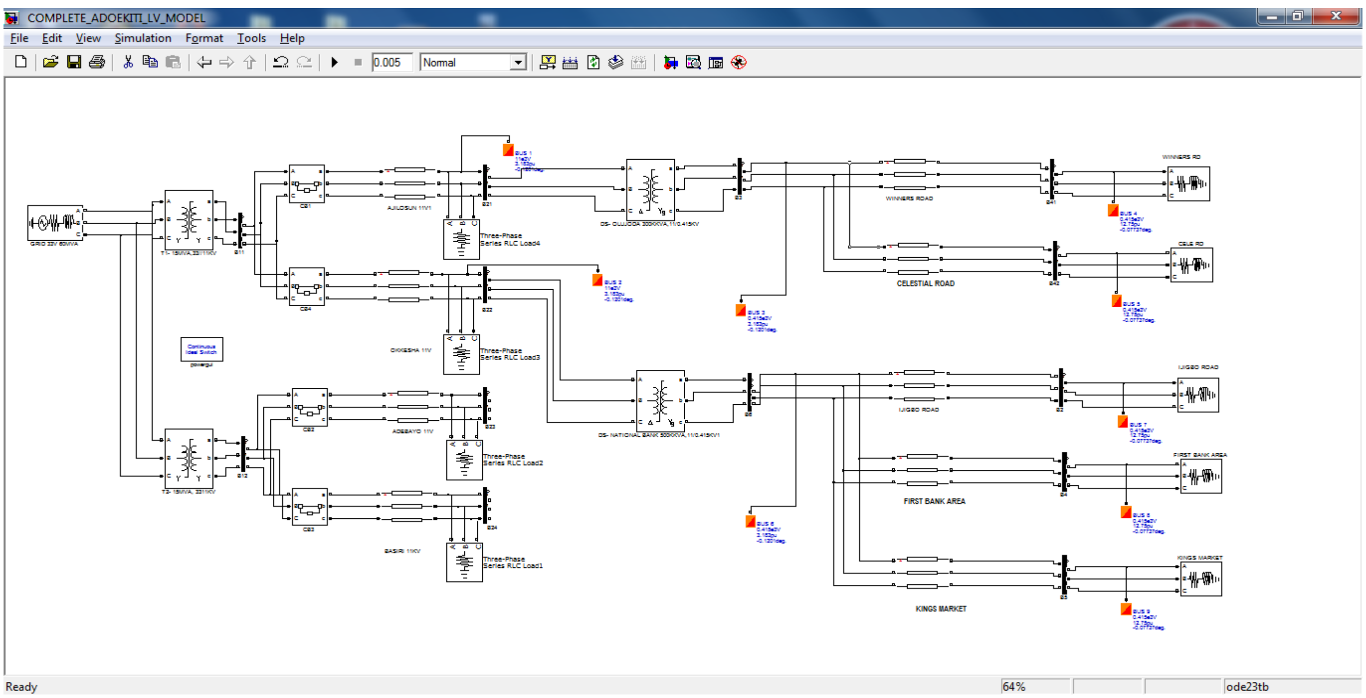

Figure 2: *Simulation Model of the LV Network*

Table 1: *Summary of Load Flow/Simulation results*

LENGTH (KM)	VOLTAGE PROFILES (P.U.)				
	WINNERS (BUS 4)	CELESTIAL RD. (BUS 5)	IJIGBO RD. (BUS 7)	FIRST BANK RD. (BUS 8)	KINGS MKT (BUS 9)
0.1	0.931	0.93	0.936	0.936	0.937
0.2	0.93	0.929	0.935	0.935	0.936
0.3	0.929	0.928	0.935	0.934	0.936
0.4	0.928	0.926	0.934	0.932	0.936
0.5	0.927	0.925	0.933	0.931	0.936
0.6	0.926	0.924	0.933	0.93	
0.7	0.925	0.922	0.932	0.929	
0.8	0.924	0.921	0.931	0.928	
0.9	0.923	0.92	0.93		
1.0	0.922	0.918	0.93		
1.5	0.917	0.912			
2.0	0.912	0.905			
2.5		0.898			
3.0		0.891			
3.5		0.883			
4.0		0.876			
4.5		0.868			

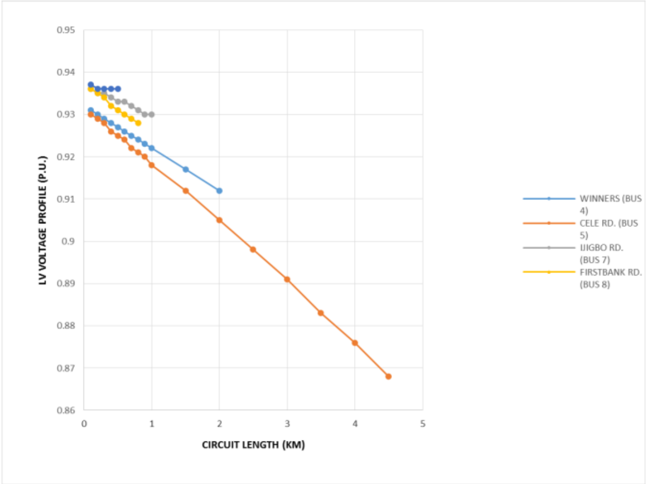

Figure 3: *Voltage Profile along Selected Circuits*

4.1. RESULTS AND DISCUSSION

From Table 1.0, the voltage profile of the LV network could be viewed, the voltage profile ranges between 0.868-0.936p.u. The voltage profiles indicated that there was voltage drop below the statutory limit (0.94p.u) of the nominal voltage. It was observed that the longest circuit among LV circuits, Olujoda/Celestial (BUS 5) with 4.4km route length dropped to 0.870p.u, while the shortest circuit, National Bank/King Market (BUS 9) with 0.5km length remains at 0.936p.u.This is shown in the chart in Figure 3. It shows from the result that length of LV circuit plays a vital role in shaping the voltage quality when properly controlled.

5. CONCLUSION

The load flow voltage profile analysis indicated inadequacy and demand immediate reinforcement for an improved performance. The voltage deviation of the LV network falls within the range of 0.87p.u-0.94p.u under shortest and longest LV circuits' conditions. This is completely outside the permissible range of ±6% (0.94p.u-1.06p.u). This is an indication that the LV network voltage has poor quality. Algorithm for the determination and monitoring of voltage profiles along the low voltage circuit was developed for the LV network in anticipation for an improved performance.

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