Voltage Profile Improvement in Distribution Network Under Maximum Loading. (A case Study)

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***Abstract*— This research study the state of Auchi distribution network under maximum loading without load shedding. ETAP was used to modelled the network and Newton Raphson load flow algorithm was used to simulate the network under maximum loading of the transformer without and with reinforcement using capacitor bank. The result shows that at maximum loading without load shedding in the network majority of the consumer voltage level (0.415 kV) fall below the ± 10% and the 11 kV fall below the ± 5% and the total active loss in the system is 3815 KW. This implies that if there is adequate supply from transmission company and load shedding is not allow Auchi distribution network will not be able to supply the consumer with good quality of voltage. Also, the results after reinforcement with capacitor bank indicate that majority of the bus voltage fall within the permissible range and the total active loss in the network reduced to 3700 kW. This research recommends that for distribution Network to delivered good quality of voltage to consumer without loadshedding there is need to reinforced the network by integrating capacitor bank at some buses where there is voltage violation.**

Keywords—Load, Voltage, Newton Raphson, Capacitor Bank

I. Introduction

Nigeria's electricity sector has been under reform since the electricity cooperation of Nigeria (ECN) until the Power Holding Company of Nigeria (PHCN). However, there is no total solution to the problem of interrupted power supply experienced by the citizens [1]. Nigeria's grid network is divided into three major sectors which, are the Generating Company of Nigeria (GENCO), the transmission company of Nigeria (TRANSCO), and the distribution company of Nigeria (DISCO); all the activities of this sector are regulated by Nigeria Electricity regulating commission (NERC) [2]. Private investors own the DISCO and the GENCOs, and Transco is been handled by the government. Disco is being given day-to-day allocation based on the amount of power generated by Genco. Also, each Discos's hourly daily load head is being sent to the transmission company based which will invariably be sent to Genco to determine the power capacity being generated.

However, [3] established that there is a mismatch between the power supplied by the Transco and the hourly day-ahead sent by Disco, this implies that one of the two parties cannot fulfill the agreement of supply. Also, the load-shedding in the distribution network has been a problem for the consumer. The classification of tariff band, which allows the disco to give priority to one customer over the other, also increases the problem the consumer faces. The expected hours of supply to consumer varies with the tariff band, as presented in Figure 1[4]

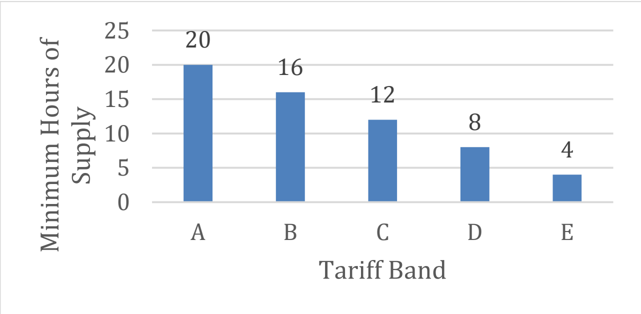


Figure 1: Tariff band and Minimum hours of supply

The variation in the hours of supply to customer based on the tariff band has caused the overloading of the distribution network as consumer tends to overload the system whenever there is supply to them which invariably will lead to a fault in the power system network, when there is no proper control.

Since load-shedding is part of the regular routine in the Nigeria distribution network, measuring the performance of any distribution station using a steady state load will not give the complete representation of the operating state of the network. The poor voltage quality experienced under maximum loading is not favorable to the consumer, which tends to destroy equipment. NERC, which is the regulating agency to monitor the supply of the electricity chain in Nigeria, only deals with the availability of supply but not the quality. The DISCOS can claim to supply a consumer for expected hours in which the consumer may not be able to use the supply due to poor voltage quality.

Furthermore, recently the consumer has made an investment in a distribution network as all the facilities needed to supply electricity to any area is provided by the people living there. This has also caused a great setback in the Nigerian electricity sector.

Also, the regulating agency Nigerian Electricity Supply and Installation Standards Regulations (NESIS) that should enforce the law of phase balance in buildings tends not to be active in there responsibility as many facilities in Nigeria operate on a single phase but connects all three phases to the building, which allowed them to change to another phase if the previous is of low quality or out of service. This led to overloading, which sometimes destroy the phase of the transformer.

[5] study the load flow analysis of eleven bus 330kV network of Nigeria grid system using Newton Raphson load flow algorithm. The findings show that 4 buses out f the eleven buses operate outside the ±5% voltage deviation.The research recommends installing a source of reactive power in the network to improve the voltage level, which will help in the network's voltage stability. [6] investigated the application of the photovoltaic system for voltage stability improvement of weak national grids. The work examined two scenarios of increasing large-scale photovoltaic level: centralized large-scale solar photovoltaic and the critical bus and dispersed large-scale solar photovoltaic. The research results show a baseline insight on the potential application of large-scale solar photovoltaics in weak grids to address the voltage stability problems in the power system while utilizing the abundant solar resources to meet the country's increasing energy demand. However, the application of PV systems cannot sustain voltage level improvement throughout the day since there is variation in solar irradiance.

[7] examined the integration of solar photovoltaic distributed generation in Nigeria power system network. The model uses 28 buses for 330kV with 19 interconnected distributed generators for voltage control. The work did not analyze the energy demand on the buses where the distributed generator was integrated into the power grid. The reverse power flow and power swing phenomenon was not considered, posing a threat to the entire grid if implemented practically. [8] examined the load flow analysis of a distribution network in Tehran metro (line 2) using ETAP with a distributed power system. Comparison of three common load flow techniques, Newton-Raphson, Fast Decoupled, and Accelerated Gauss-Seidel, used to perform simulation on the network. The results of load flow assessment (total generation, loading, demand, and power losses) were obtained and analyzed. The findings revealed that Newton Raphson algorithm is the most accurate among the three tested algorithms. Also, the researcher established that to improve speed performance and computational accuracy in power system analysis, using powerful software like ETAP is very practical and helpful, and it also offers a better view of the power network.

The literature reviewed focuses on the use of DG for voltage improvement in transmission and distribution networks. This method of DG for voltage level improvement in the power system may not sustain the voltage level of the network for 24 hours due to the variation in renewable energy sources (Solar and wind), which serves as the sources of distributed generation in most cases. However, there are various techniques can be used to improve the problem of poor voltage quality, including load reconfiguration, capacitor bank, distribution generation (DG), and static var compensator [9].

The use of any of these can improve the quality of voltage. Load reconfiguration cannot be used in Nigeria since most of the consumers buildings are not operating under the three-phase balance system. Also, the use of DG, which majorly operates with renewable energy, may not be active all day due to the seasonal variation of the resources; for example Photo Voltaic Module cannot generate power for 24 hours, and also the wind is not common in all parts of the country [10]. The best approach to improve the voltage quality of distribution networks in Nigeria is the use of a capacitor bank or static var compensator. This research focuses on the improvement of voltage quality of the distribution network in Nigeria under maximum loading using a capacitor bank on Auchi township distribution Network as a case study.

II. RESEARCH METHOD

The distribution network data was obtained, which included the transformer, distribution lines, and maximum loading based on the fuse rating. All 11 kV and 0.415 kV buses of Auchi electricity company were modeled using all information and data source, which includes: transformer rating, the height of poles, size of 11kV conductor cable, Fuse rating of the secondary side of the transformer, and Lines length. The existing Auchi distribution was modeled and the load flow simulation was carried out. The simulation result was studied and observed critically to determine the point in the network where the station does not supply good-quality voltage.

Load Flow Evaluation of the Model

Load flow calculation using Newton–Raphson approach, ETAP uses the Newton–Raphson method for calculating load flow solutions. ETAP product information explained that load flow analysis is an essential tool in the process of planning, designing, and operating power systems under different operating conditions and equipment configuration and further explained that the load flow calculates branch flows and bus bar voltages based on specified "set points" (active/reactive power generation, generator voltage, transformer tap positions, etc.). The simulation was evaluated using different operation scenarios based on Newton-Raphson Algorithm in which a nonlinear equation system is solved by an iterative method as presented in Equations (1) and (2)

$$P_i = \sum_{k=1}^{n} |V_i|\,|V_k|\,|Y_{ik}| cos(\theta_{ik} - \delta_i + \delta_k) \quad (1)$$

$$Q_i = \sum_{k=1}^{n} |V_i|\,|V_k|\,|Y_{ik}| sin(\theta_{ik} - \delta_i + \delta_k) \quad (2)$$

Where i and k are two connected adjacent bus bars. P_i and Q_i are active and reactive power at the resolved bus, V_i and V_k are voltages at the resolved and adjacent bus, Y_{ik} is the mutual admittance between resolved and adjacent buses, θ_{ik} is the voltage angle between the resolved and adjacent bus, δ_i is the power angle at resolved bus and δ_k is the power angle at the adjacent bus. For a normal load condition, loads are represented as constant PQ loads. Equations (1) and (2) only solve nonlinear functions; therefore, a numerical iteration method is required to find the solution, and there are different methods available for solving nonlinear equations (1).

$$P = P_0 \left[aP\left(\frac{V}{V_0}\right)^2 + bP\left(\frac{V}{V_0}\right) + \mathrm{c}P \right] \quad (3)$$

The Jacobian matrix gives the linearized relationship between small changes in voltage angle $\Delta\partial_i^{(k)}$ and voltage magnitude $\Delta|V_i^{(k)}|$ with the small changes in real and reactive power $\Delta|P_i^{(k)}|$ and$\Delta|Q_i^{(k)}|$ and is written as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (4)$$

Where J1, J2, J3 and J4 are element of Jacobian matrix and can be determined from power equations (1) and (2) as follows:

The off-diagonal and diagonal elements of J_1 are:

$$\frac{\partial P_I}{\partial \delta_K} = V_i V_k Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \text{ for } k \neq I \quad (5)$$

and

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{k=1,k\neq i}^{n} V_i V_k Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \quad (6)$$

The off-diagonal and diagonal elements of J_2 are:

$$\frac{\partial P_I}{\partial V_K} = V_i Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \text{ for } k \neq I \quad (7)$$

and

$$\frac{\partial P_i}{\partial V_i} = 2 V_i Y_{ii} \cos\theta_{ii} + \sum_{k=1,k\neq i}^{n} V_k Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \quad (8)$$

The off-diagonal and diagonal element of J_3 are:

$$\frac{\partial Q_I}{\partial \delta_K} = -V_i V_k Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \quad (9)$$

and

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{k=1,k\neq i}^{n} V_i V_k Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \quad (10)$$

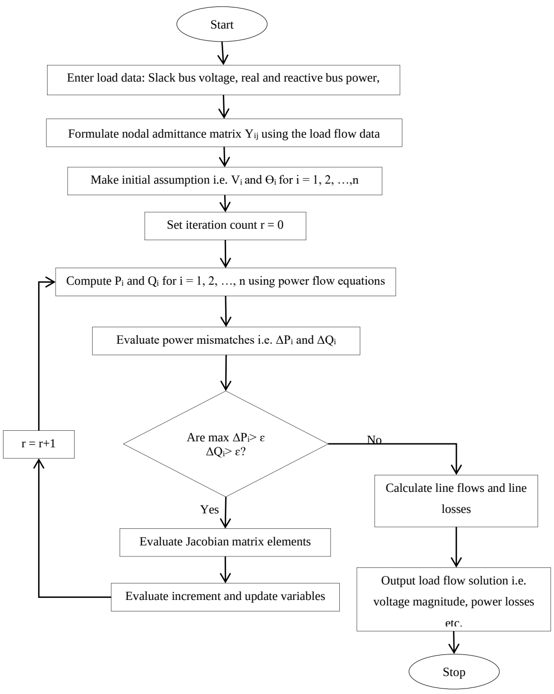
The off-diagonal and diagonal elements of J_4 are:

$$\frac{\partial Q_I}{\partial V_K} = V_i Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \text{ for } k \neq I \quad (11)$$

And

$$\frac{\partial Q_i}{\partial V_i} = 2 V_i Y_{ii} \cos\theta_{ii} + \sum_{k=1,k\neq i}^{n} V_k Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \quad (12)$$

The flowchart of the Newton Raphson method which was selected majorly because of the high accuracy and fast rate is shown in Figure 2



Compensation of Auchi Network with Capacitor Bank

To improve the voltage profile of the network capacitor bank was introduced into the network based on the low voltage profile at the consumer buses (0.415 kV). 6 banks of 100kvar capacitor were integrated into the consumer side of the following transformer First bank, Prison, Jattu road, UBA bank, Olele junction road, discoli, warranke, ugnidane, former zenith, shagadi, kayaco road, Neuty road, Sulaiman, NNPC, Usokeli 1, Usokeli 2, constant momoh, setraco junction Auchi college Oki village and Egelor. A capacitor bank was used to reinforce the network under maximum loading, assuming that there is no load shedding, to improve the consumer's voltage profile level.

III. RESULTS AND DISCUSSION

The results presented the load flow analysis of the Auchi distribution Network and techniques used to improve the network's voltage profile and power factor. Simulation of Auchi Distribution Network without the placement of capacitor Bank. The Auchi distribution network model consisting of five composite networks is presented in Figure 3a to Figure 3e

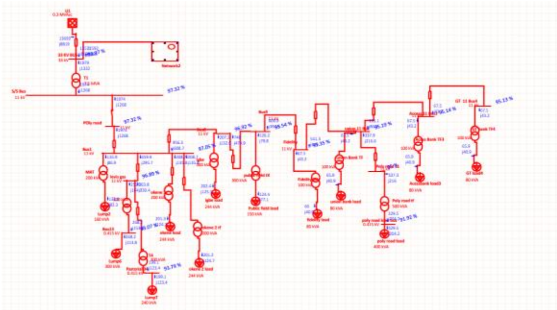


Figure 3a: Model of Auchi Distribution Network from grid

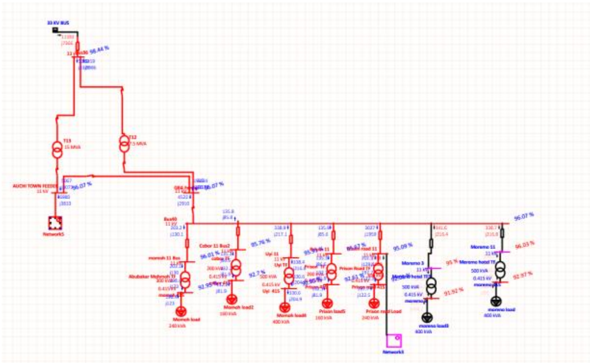


Figure 3b: Model of Auchi Distribution Network from GRA Feeder

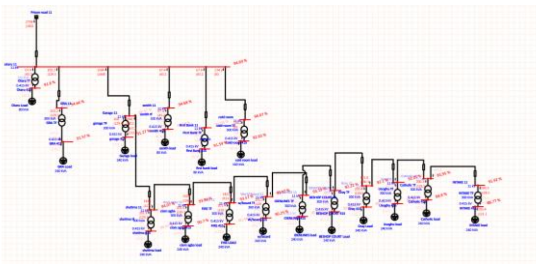


Figure 3C: Model of Auchi Distribution Network From Prison Road

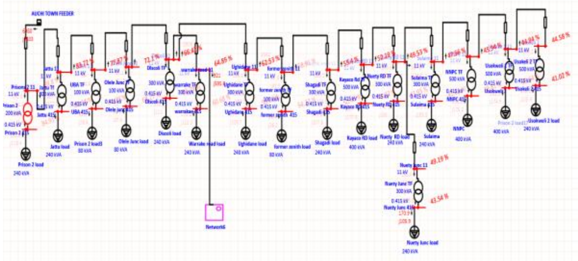


Figure 3d: Model of Auchi Distribution Network from Auchi town Feeder

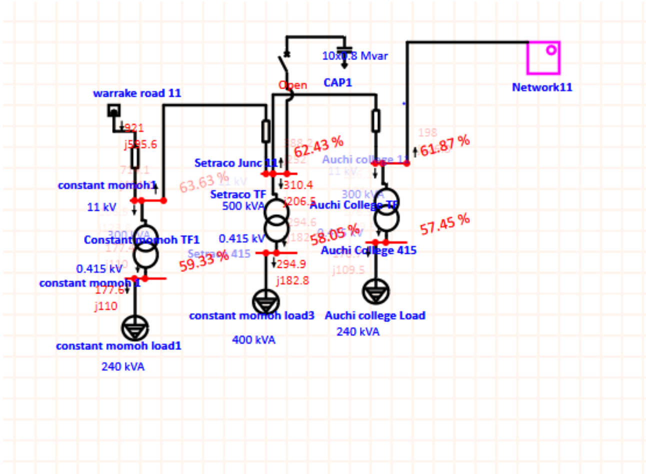


Figure 3e: Model of Auchi Distribution Network From Warrake Road

The voltage profile of all the 11 kV and 0.415 kV Buses in the Auchi distribution Network without a capacitor bank.

The results of the voltage profile of 11 KV and 0.415 KV in the network under maximum loading without the placement of the capacitor bank is presented in Figure 4 and 5, respectively.

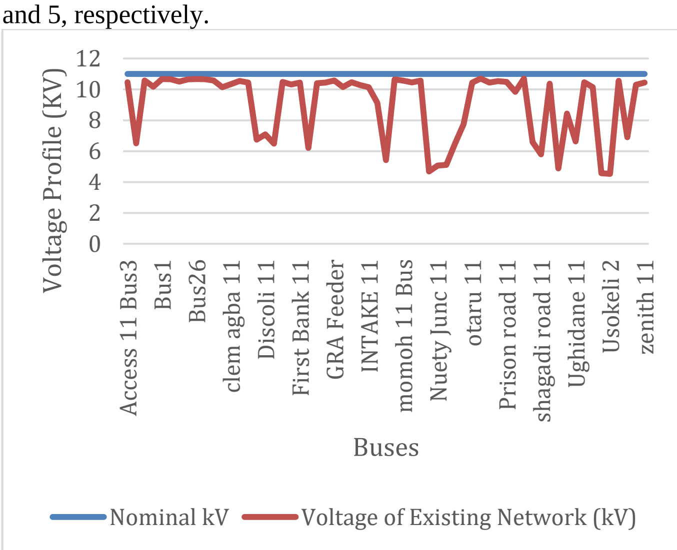


Figure 4: The operating voltage and nominal Voltage Profile of 11 kV buses of the Network without Reinforcement.

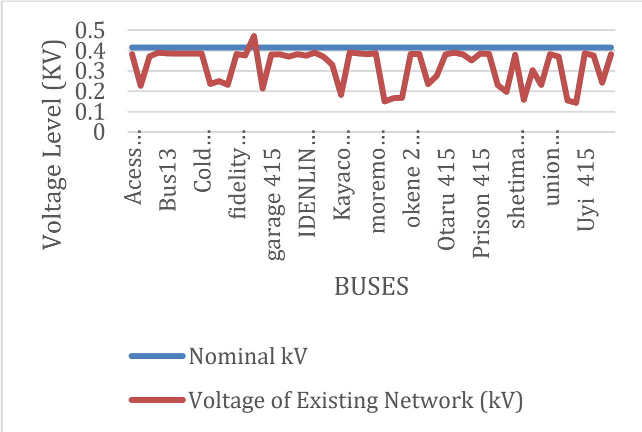


Figure 5: The operating voltage and nominal Voltage Profile of 0.415 kV buses of the network without reinforcement

The results show that many of the substations under the network experience poor voltage quality at maximum loading, which is below the 5% deviation recommended standard for 11 kV lines. This implies that the operating voltage below 10.45 kV or above 11.55 kV does not conform to the standard, which may affect consumer appliances. Also, the operating voltage of all the 0.415 kV buses presented in Figure 4, shows that the voltage quality deviates from the acceptable range of plus or minus 10% of the nominal voltage, which is 0.3735 kV and 0.4565 kV. This implies that the Auchi distribution network tends not to supply good voltage quality to the consumers at maximum loading of 80%. The rating of the transformers fuses in the network without consideration for load shedding. This indicates that even with increased generating capacity, the Auchi distribution network may be unable to supply good voltage quality to consumers without load shedding.

Voltage Profile after reinforcement with Capacitor bank

To improve the present state of the network at maximum loading capacitor bank is placed in the network. The network was simulated with the introduction of a capacitor bank using the Newton-Raphson algorithm. The voltage profile of the 11 kV and 0.415 kV buses in the network after reinforcement of some buses with capacitor banks is presented in Figures 6 and 7, respectively.

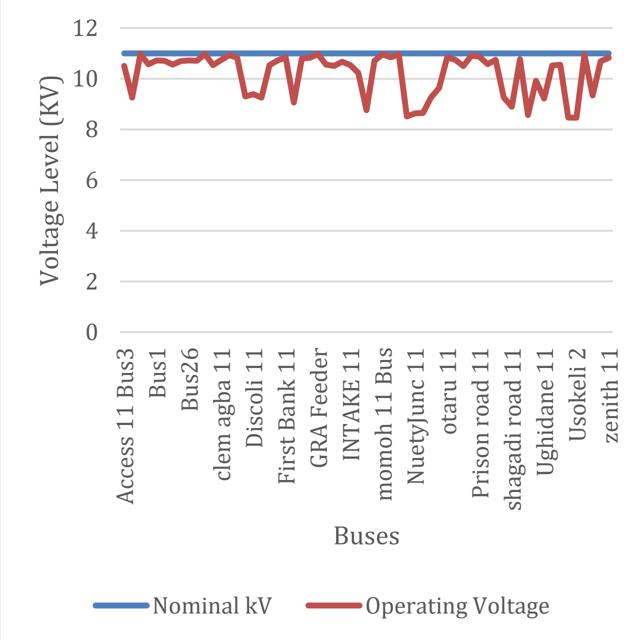


Figure 6: The operating voltage and nominal Voltage Profile of 11 kV buses after reinforcement with capacitor bank

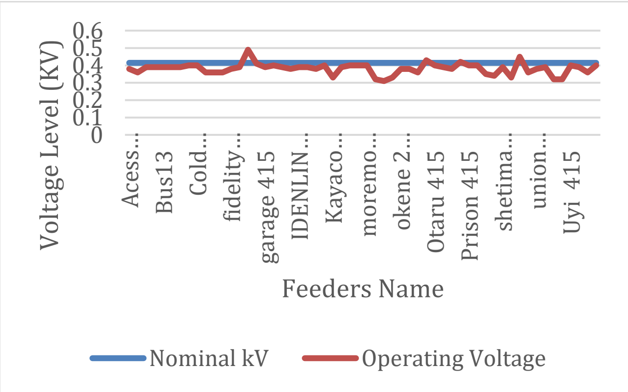


Figure 7: The operating voltage and nominal Voltage Profile of 0.415 kV buses after reinforcement with capacitor bank.

The results presented in Figure 6 to Figure 7. show the operating voltage of all the 11 kV and 0.415 kV buses at maximum loading of the transformers, respectively, after reinforcement with the capacitor bank. The results show that the majority of the operating voltage indicates improvement in operating voltage compared to the base case. However, some of the operating voltage at some buses does not conform to the plus or minus 5% voltage deviation for 11kV buses and 10% voltage deviation for 0.415 kV buses but there were significant improvements in the voltage profile of the network. This implies that the transformers in the Auchi distribution network can be loaded up to 80% without load shedding if the network is being reinforced by a capacitor bank. There is a need to strengthen the Auchi distribution network with a capacitor bank to perform better by avoiding load shedding if there is enough supply from the transmission company since the present network cannot supply good voltage quality at maximum loading without reinforcement.

Comparison in Voltage profile of the existing and reinforced network.

The results presented in Figure 8 and 9 shows the the voltage profile of the 11 and 0.415 kV buses when Auchi network is not reinforced and when it is reinforced respectively.

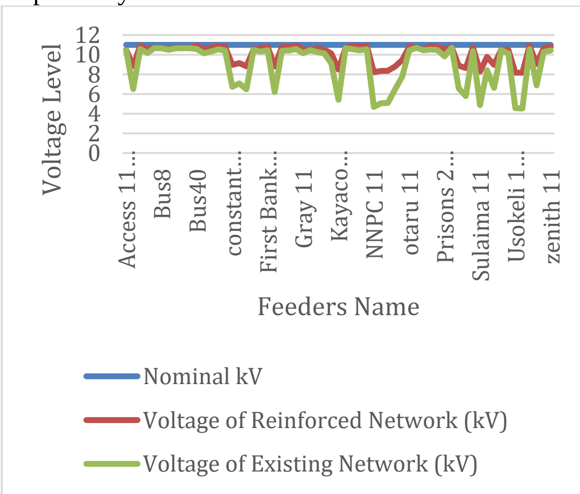


Figure 8: Comparison between the 11 kV voltage level of Reinforced and Existing Network.

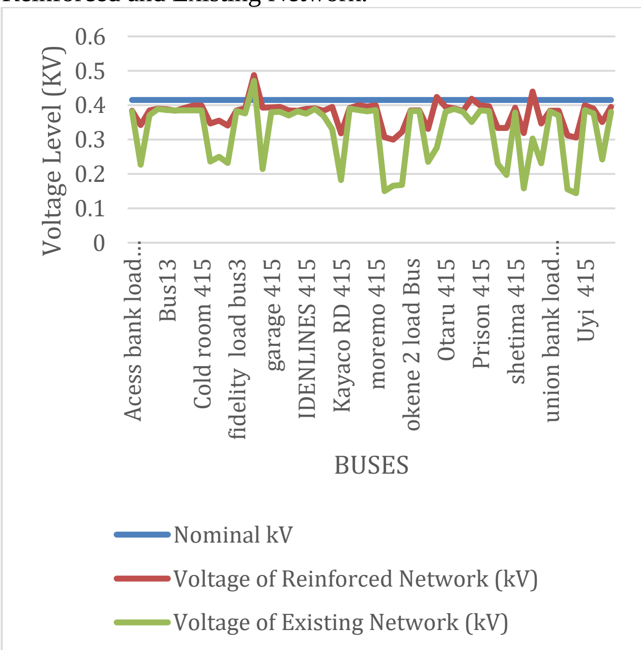


Figure 9: Comparison between the 11 kV voltage level of Reinforced and Existing Network

The results presented in Figure 8 and 9, show that there was an improvement in the voltage profile of all the buses when the capacitor bank was integrated into the network, as the operating voltage at maximum loading is close to the nominal voltage. This implies that introducing a capacitor bank supplied a reactive power into the network and reduced the voltage drop in the network.

Losses in the Network

The results of the active and reactive losses in the network before and after reinforcement with the capacitor bank were presented in Figure 9 and Table 1.

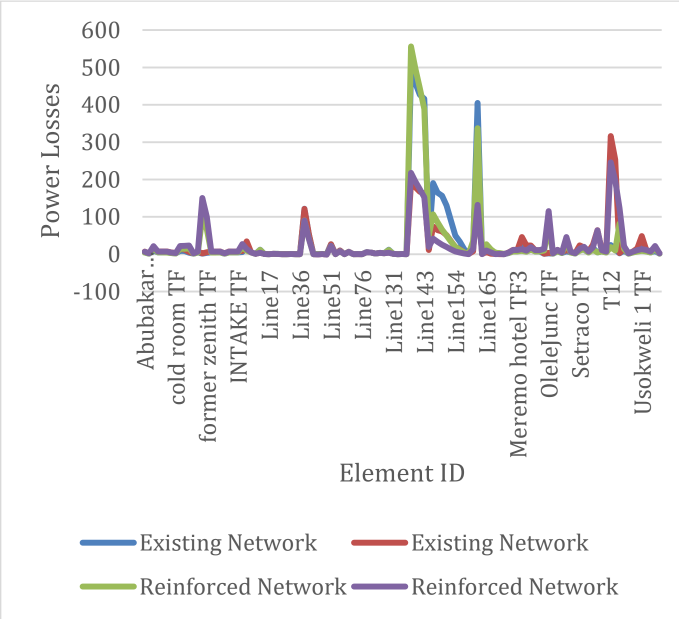


Figure 12: Power losses of the network with and without reinforcement.

Table 4.1: Active and Reactive losses in the existing and Reinforced Network

Parameters	Existing Network		Reinforced Network		Existing Network	Reinforced Network
	kW Losses	kvar Losses	kW Losses	kvar Losses	Power Factor	Power Factor
	3815	2696	3700	2839	0.88	0.92

The results were presented in Figure 9, and Table 1. shows the line losses, Transformer losses in the network after reinforcement with the capacitor bank. The results show that the total active losses in the network after reinforcement reduced to 3700kW compared to when the network was not reinforced. This implies that an addition of 115 kW can still be supplied to the consumer at the maximum loading of the transformer if it is being reinforced with a capacitor bank, which means the introduction of a capacitor bank into the network will not only increase the voltage profile of the network but also reduce the losses in the network and the total power that consumer can consume will increase which invariably will increase the revenue generation of the distribution company.

IV. CONCLUSION

In this research, the Auchi distribution network was considered a case study, and analyses was carried out on the system to determine the network situation at the maximum loading of the transformer. The research shows that the Auchi distribution network cannot operate effectively by supplying good voltage quality to the consumer at the maximum loading of the transformer, which is 80%. The quality of supply at 80% loading without load shedding is of poor quality, which also affects the power factor of the network. In order to improve the quality of supply and availability to consumer capacitor bank was used to reinforced the network at 80% loading, which improves the system's voltage quality, reduces the power losses in the network, and increases the power factor.

ACKNOWLEDGMENTS

We acknowledge the support of Benin Electricity company Staff for Data provided for this research work.

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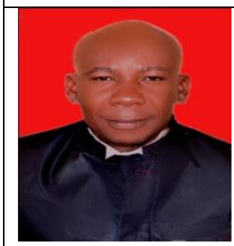

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