# Power Quality Improvement Using Load Tap Changer Case Study: Iwofe Injection Substation

Bestman U. Obi[1], Dikio C. Idoniboyeobu[2], Sepribo L. Braide[3]
[1, 2, 3]Department of Electrical Engineering, Rivers State University, Nigeria

***Abstract- Power quality is an important factor to consider when dealing with distribution of electrical power to final consumers. Though there are several methods employed to improve power quality but in this research load tap changer is used because of its simplicity and economical value. Electrical Transient Analyzer Program (ETAP) is used to model and simulate the Iwofe injection network, on simulation it was discovered that the network was characterized by low power factor, high power losses and under voltage which causes the buses to be flagged critical. After Application of the optimization technique the power factor increased to 90.20% and power losses reduced to 0.168MW respectively leading to increase in performance, voltage stability and accommodation of real power in the system.***

***Indexed Terms- Distribution Network, Iwofe Injection Substation, Load Tap Changer, Power Factor, Power Quality***

## I. INTRODUCTION

Electricity can be considered as one of the major commodities that rapidly drive the development of a country; as such it is paramount that the quality of electrical power generated and supplied should be optimal. Electrical power quality can simply be defined as frequency, voltage, current and power stability or can be seen as a set of electrical standard in which electrical devices can operate, function or perform effectively without impair or loss function. Poor power factor and under voltage are the major causes of poor electrical power quality in the distribution network because most loads attached under the distribution network are characterized as nonlinear loads which causes distortion to the wave shape and phase shift of current and voltage in the network[1]. Electrical power quality can be improved in several ways which include load tap changer, synchronous condenser, shunt transformer, harmonic filter, synchronous motor and condenser [2].

For many years, transformers have remained an integral part of power systems of the transmission and distribution network. Transformers are basically electrical devices that transform voltage from high to low conversely, from low to high of an alternating current depending on the rating and load demand. Transformers have windings which in turn have tap changers drawn from it to enable voltage regulation. Transformer tap changer is a mechanism used to make variation to the voltage rating of the transformer and they are mainly found on the high voltage part of the transformer. Tap changers are usually operated when there is voltage fluctuation at the load side.

There are two types of tap changers, no load tap changer (NLTC) and on load tap charger (OLTC). The no load tap changer is one which require a must de-energization before voltage variation can be performed and an infrequent variation of turn ration while on load tap changer is one which permit voltage variation during operation, where power interruption during variation is impermissible and they can be generally operated either electronically assisted, fully electronic or mechanically.

Power factor can be defined as the ratio between the active power (real power) used by load to do work and the apparent power flowing to the circuit [1]. The real power is simply the product of current and power, and it is the required power necessary to carry out work while apparent power is the product of the current and voltage without considering the phase difference between them and they are used for power network ratings of conductors, switchgears circuit breakers and transformers. Due to non-linear loads that stores electrical energy and returns the energy to the supply and due to the distortion of the sinusoidal wave shape, the apparent power at some point is greater than the real power. A power factor showing less than one depicts that current and voltage are out of phase, and creates power which returns back to the supply [1].

Non- linear loads draw harmonic current and produces reactive power which is not used for work. If reactive power increases, the current and voltage displacement angle increases also, then the power factor decreases. Conversely, if the harmonic distortion current increases, then the power factor decreases [3]

The total power factor will usually be lower than displacement power factor in the presence of harmonics. However, the correction of displacement and distortion power factor will lead to the correction of the total power factor in the system

Generally, positive power factor is desirable in power system to improve voltage regulation and minimize losses, improve stability and efficiency of the system. Nearly unity or 1 power factor is desirable on the load. Power factor correction is very necessary in power system to cancel the effects of capacitive and inductive properties of the loads [1]. Situations of purely linear loads which is very rare, simple capacitor banks may be installed in the system to improve the stability of the network [3].

## II. ETAP LOAD FLOW ANALYSIS OF THE NETWORK

The Iwofe injection substation considered in this study is located at University of Education (UOE), Aker road with incoming 33kv lines from Rumuolumeni Auxiliary transformer of 0.1MVA. The Iwofe 33/11kv injection substation consist of 15MVA transformer with 7 feeders, high tension (HT) and low tension (LT) lines, circuit breaker, conductors, isolators and ring mains. The distribution networks consist of 42 11/0.415kv distribution transformers of different ratings attached to several types of loads in the area. They are inputted and used for the modeling of the entire network using ETAP, fig. 1 below shows the line diagram of the Iwofe injection network including the different line parameters and the sizes of the transformers in the area.

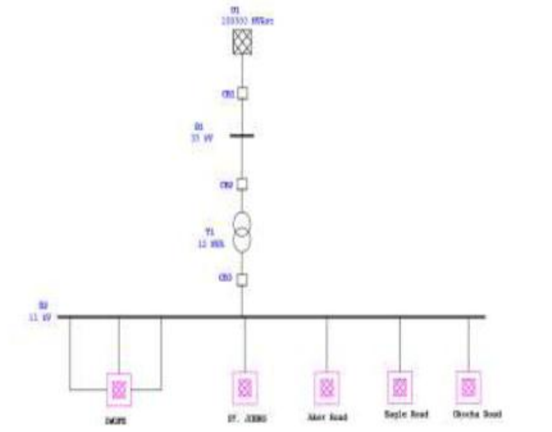

Fig. 1, the Injection Substation of Iwofe

## III. SIMULATION OF THE IWOFE NETWORK

The diagrams below show the load flow analysis of the iwofe injection substation and its attached distribution networks (Iwofe 1, Iwofe 2, Iwofe 3, st. Johns, Aker Road, Eagle Cement Road and Okocha Road), it illustrate the application of the optimization technique before and after simulation in the network in ETAP.

### A. The State of the Network before Application of the optimization technique

The buses of the iwofe injection substation where all flagged critical from the load flow analysis carried out using ETAP due to high level of under voltage and poor power experienced in the network as shown below.

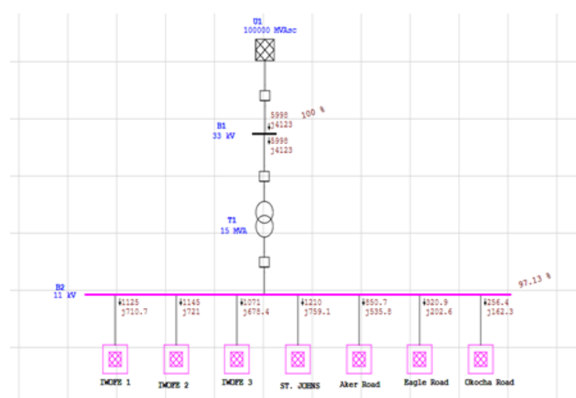


Fig. 2, Iwofe Injection Substation before Application of Optimization Technique

The inputted power into the injection network is (5998 + j4123) MVA and attached distribution networks are (1125 + j710.7) KVA, (1145 + j721) KVA, (1071 + j678.4) KVA, (1210 + j759.1) KVA, (850.7 + 535.8) KVA, (320.9 + j202.6) KVA, (256.4 + j162.3) KVA for Iwofe 1, Iwofe 2, Iwofe 3, st. Johns, Aker Road, Eagle Road and Okocha Road respectively. The branch summary report the total power losses of 0.181MW and power factor 82.41% in the network which causes voltage instability and losses of real power both on the injection substation and distribution end.

- Iwofe 1 Distribution Network before Application of Optimization Network

The iwofe 1 distribution network contains 9 distribution transformers (Life Forte Hospital, Creative Star & Studio, Deeper Life Junction, Ap Filling Station, Chief Kante Isera, NDDC close, Grace Amazing Plaza, Glorous Covenant Church and Silvertem Plaza)and Buses which were all flagged critical due to high level of under voltage and poor power factor experienced in the network as shown in fig. 3 below.

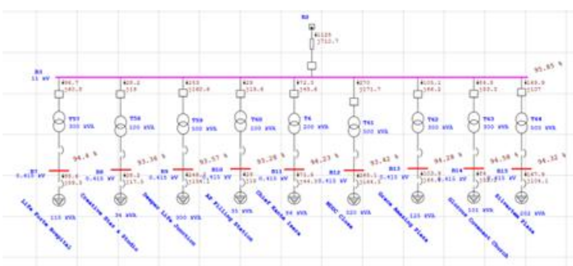

Fig. 3, Iwofe 1Distribution Network before Application of Optimization Network

Fig. 3, shows the power inputted (1125 + j710.7) and attached individual buses (95.6 + j59.3) KVA, (28.2 + j17.5) KVA, (248.7 + j154.1) KVA, (29 + j18) KVA, (71.5 + j44) KVA, (265.1 + j164.3) KVA, (103.9 + j64.1) KVA, (84 + j52.1) KVA, (167.9 + j104.1) KVA and voltages across each bus is 94.4%, 93.36%, 93.57%, 93.28%, 94.23%, 93.42%, 94.28%, 94.32% respectively.

- Iwofe 2 Distribution Network before Application of Optimization Network

The iwofe 2 distribution network has a total of 9 distribution transformer (Amodis House, Octavi Lounge, Total child, Deliden guest House, City Crown, Jodan Pharmacy, First Bank, Elder Anthony Avenue, Peperoni) and Buses which were all flagged critical due to high level of under voltage and poor power factor experienced in the network as shown in fig. 4 below.

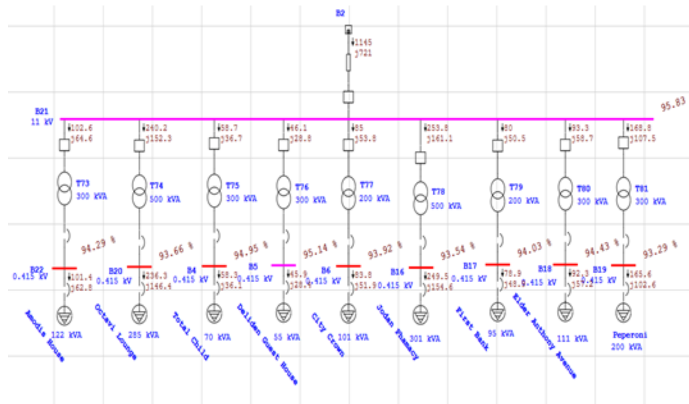

Fig. 4, Iwofe 2 Distribution Network before Application of Optimization Network

The power inputted from fig. 4, is (1145 + j721) KVA and attached individual buses are (102.6 + j64.6) KVA, (240.2 +152.3) KVA, (58.7 + j36.7) KVA, (46.1 + j28.8) KVA, (85 + j53.8) KVA, (253.8 + j161.1) KVA, (80 + j50.5) KVA, (93.3 + j58.7) KVA, (168.8 + j107.5) KVA and voltage across each buses are 94.29%, 93.66%, 94.95%, 95.14%, 93.92%, 93.54%, 94.03%, 94.43%, 93.29% respectively.

- Iwofe 3 Distribution Network before Application of Optimization Network

The iwofe 3 distribution network is constituted of 7 distribution transformer (U.O.E, Biddel Filling Station, Erics Junction, Emmi School, Police Station, Goodness Super Market, Church of Jesus Christ) and Buses which were all flagged critical due to high level of under voltage and poor power factor experienced in the network as shown in fig. 5 below.

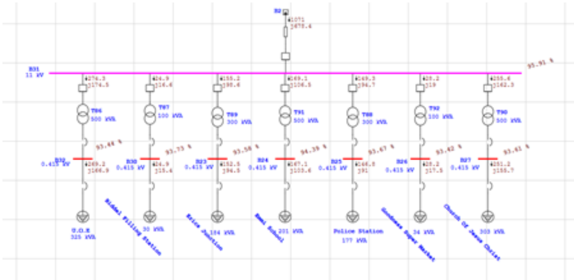

Fig. 5, Iwofe 3Distribution Network before Application of Optimization Network

The inputted power into fig. 5, is (1071 + j678.4) and attached individual buses (269.2 + j166.9) KVA, (24.9 + j15.4) KVA, (152.5 + j94.5) KVA, (167.1 + j103.6) KVA, (146.8 + j91) KVA, (28.2 + j17.5) KVA, (251.2 + j155.7) KVA and voltages across each buses are 93.44%, 93.73%, 93.58%, 94.38%, 93.67%, 93.42%, 93.61% respectively

- St. Johns Distribution Network before Application of Optimization Network

Fig. 6 shows the St. Johns section of the feeder in the Iwofe injection substation. The feeder is made up of 8 distribution transformers (Ozumba Street, Joetex Plaza, Grand Imaco Communication, Anibros Filling Station, Stake Primary School, Captain Woke, Iriata Street, and Town Hall) and buses which were flagged critical due to high level of under voltage and poor power factor experienced in the network as shown in fig. 6 below.

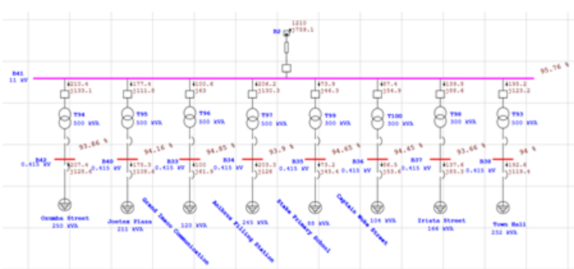

Fig. 6, St. JohnsDistribution Network before Application of Optimization Network

From fig. 6, it can be seen that the supplied power is (1210 + j759.1) KVA and the attached individual buses (207.4 + j128.6) KVA, (175.3 + j108.6) KVA, (100 + j61.9) KVA, (203.3 + j126) KVA, (73.2 + j45.4) KVA, (86.5 + j53.6) KVA, (137.6 + j85.3) KVA, (192.6 + j119.4) KVA and voltages across each buses are 93.86%, 94.16%, 94.85%, 93.9%, 94.65%, 94.65%, 93.66%, 94% respectively.

- Aker Road Distribution Network before Application of Optimization Network

Fig. 7 shows the sectional view of the feeder in the Iwofe injection substation. The Aker Road feeder is made up of 5 distribution transformers (Mission Plaza, Wine and Milk Store, Anglican Church, prince Ameachi Street, Chief Sunny Ameachi Street) and buses which were flagged critical due to high level of under voltage and poor power factor experienced in the network as shown in fig. 7 below.

From the fig. 7, it can be seen that the supplied power is (850.7 + j535.8) KVA and the attached individual buses (149.9 + j92.9) KVA, (263.8 + j163.5) KVA, (79.3 + j49.2) KVA, (249 + j154.3) KVA, (87.5 + j54.2) KVA and voltages across each buses are 94.81%, 93.75%, 95.45%, 93.89%, 94.85% respectively.

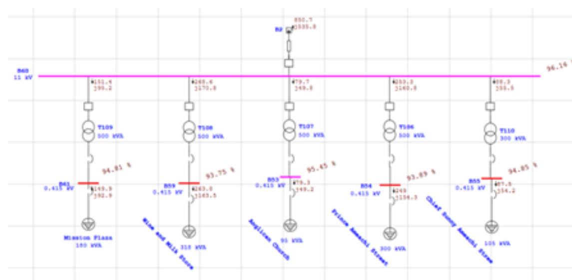

Fig. 7, Aker RoadDistribution Network before Application of Optimization Network

- Okocha Road Distribution Network before Application of Optimization Network

The Okocha Road distribution network contains 2 distribution transformers (Ejiofor Bar and Sure Foundation School)and Buses which were all flagged critical due to high level of under voltage and poor power factor experienced in the network as shown in fig. 8 below.

Fig. 8, shows the power inputted (256.4 + j162.3) and attached individual buses (99.8 + j61.9) KVA, (151.4 + j93.8) KVA, and voltages across each buses are 94.57%, 94.55% respectively.

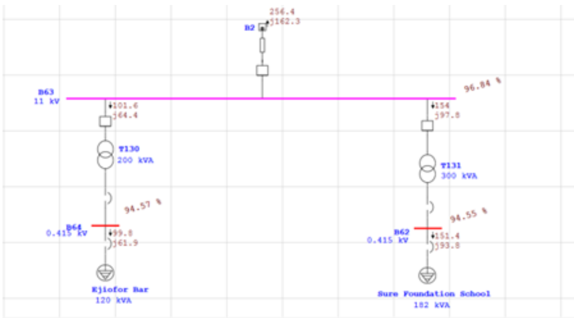


Fig. 8, Okocha RoadDistribution Network before Application of Optimization Network

- Eagle Road Distribution Network before Application of Optimization Network

The Eagle Road distribution network contains 2 distribution transformers (Meko Petra Filling Station and Christian) and Buses which were all flagged critical due to high level of under voltage and poor power factor experienced in the network as shown in fig. below.

Fig. 9, shows the power inputted (320.9 + j202.6) and attached individual buses (102.3 + j63.4) KVA, (212.4 + j131.6 KVA, and voltages across each buses are 94.44%, 94.85% respectively.

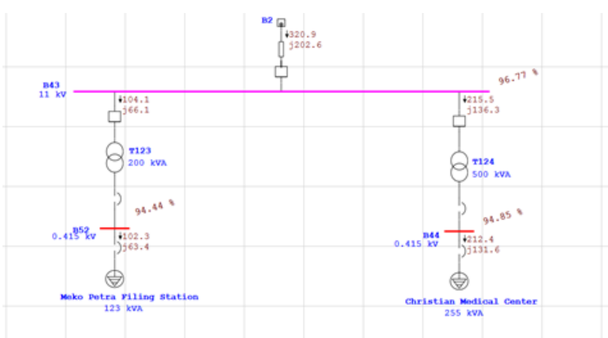


Fig. 9, Eagle RoadDistribution Network before Application of Optimization Network

B. The State of the Network After Application of the optimization technique

The state of the Iwofe injection substation after the Application of optimization techniqueis as shown below in fig. 10. From fig. 10it can be clearly seen that at optimization the network performance improved drastically. The power factor increased from 82.41% to 90.20% while the power losses reduced drastically from 0.181MW to 0.168MW causing a huge improvement in the power supplied, voltage stability, power factor and real power accommodation in the entire network. The improved inputted power becomes (1144 + j721.5) KVA, (1164 + j732.1) KVA, (1089 + j688.4) KVA, (1230 + j771) KVA, (865.1 + j544.1) KVA, (326.5 + j205.8) KVA, (260.9 + j164.8) KVA.

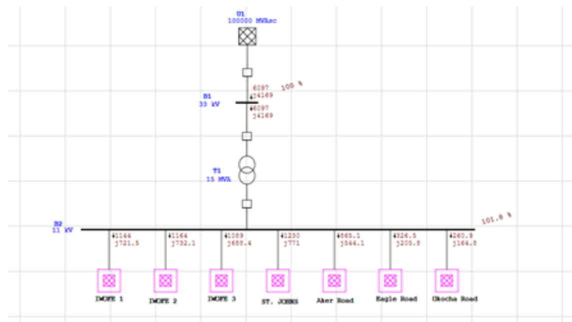

Fig. 10, Iwofe Injection Substation Network after Application of Optimization Technique

- Iwofe 1 Distribution Network after Application of Optimization Network

The Iwofe 1 distribution network section can be seen in fig. 11 below, after the application of the optimization technique, there was a rapid improvement in the network performance. The power, voltage profile and real power improved drastically, the inputted power increased to (97.4 + j60.4) KVA, (28.7 + j17.8) KVA, (253.2 + j157) KVA, (29.5 + 18.5) KVA, (72.8 + j45.1) KVA, (270.1 + j167.4) KVA, (105.8 + j65.1) KVA, (85.6 + 53.1) KVA, (171.1 + j106) KVA, and voltages across the buses 99.17%, 98.17%, 98.37%, 98.09%, 99%, 98.22%, 99.35%, 99.1% respectively.

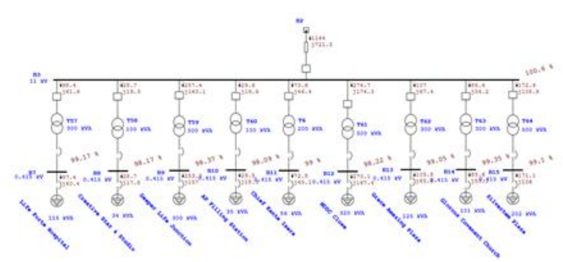

Fig.11, Iwofe 1 Distribution Network after Application of Optimization Network

- Iwofe 2 Distribution Network after Application of Optimization Network.

The Iwofe 2 distribution network section can be seen in fig. 12 below, after the application of the optimization technique, there was a rapid improvement in the network performance. The power, voltage profile and real power improved drastically, the inputted power increased to (103.3 + j64) KVA, (240.8 + j149.2) KVA, (59.4 + j36.8) KVA, (46.7 + 29) KVA, (85.4 + j52.9) KVA, (254.2 + j157.5) KVA, (80.4 + j49.3) KVA, (94 + j53.3) KVA, (168.7 + j104) KVA, and voltages across the buses 99.06%, 98.46%, 99.89%, 98.7%, 98.34%, 98.8122%, 99.2%, 98.09% respectively.

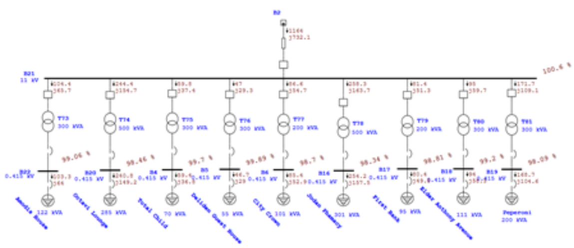

Fig.12, Iwofe 2 Distribution Network after Application of Optimization Network

- Iwofe 3 Distribution Network after Application of Optimization Network

The Iwofe 3 distribution network section can be seen in fig. 13 below, after the application of the optimization technique, there was a rapid improvement in the network performance. The power, voltage profile and real power improved drastically, the inputted power increased to (274.3 + j170) KVA, (25.4 + j15.7) KVA, (155.4 + j96.3) KVA, (170.3 + j105.5) KVA, (149.5 + j92.7) KVA, (28.7 + j17.8) KVA, (255.9 + j158.6) KVA, and voltages across the buses 98.24%, 98.52%, 98.38%, 99.16%, 98.46%, 98.23%, 98.4% respectively.

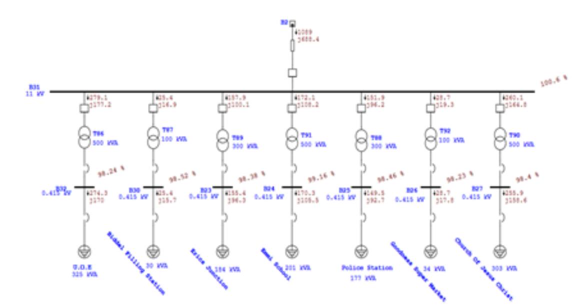

Fig.13, Iwofe 3 Distribution Network after Application of Optimization Network

- St. Johns Distribution Network after Application of Optimization Network

Fig. 14 shows the St. Johns distribution network below, after application of the optimization technique, there was a rapid improvement in the network performance. The power, voltage profile and real power improved drastically, the inputted power increased to (211.4 + j131) KVA, (178.6 + j110.7) KVA, (101.8 + j63.1) KVA, (207.2 + j128.4) KVA, (74.6 + j46.2) KVA, (88.1 + j54.6) KVA, (140.2 + j86.9) KVA, (196.2 + j121.6) KVA and voltages across the buses 98.65%, 98.94%, 99.61%, 98.68%, 99.41%, 99.22%, 98.45%, 98.78% respectively.

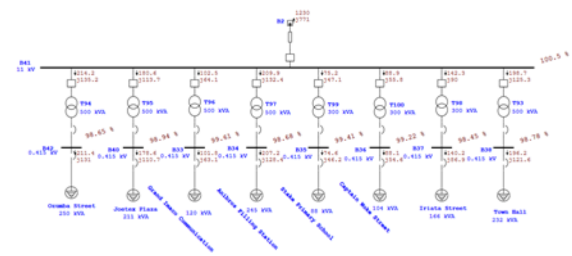

Fig.14, St. Johns Distribution Network after Application of Optimization Network

- Aker Road Distribution Network after Application of Optimization Network

Fig. 15 shows the Aker Road distribution network below, after application of the optimization technique, there was a rapid improvement in the network performance. The power, voltage profile and real power improved drastically, the inputted power increased to (152.7 + j94.7) KVA, (268 + j166.5) KVA, (80.8 + j50.1) KVA, (253.7 + j157.2) KVA,and voltages across the buses 99.56%, 98.54%, 100.2%, 98.67%, 98.6% respectively.

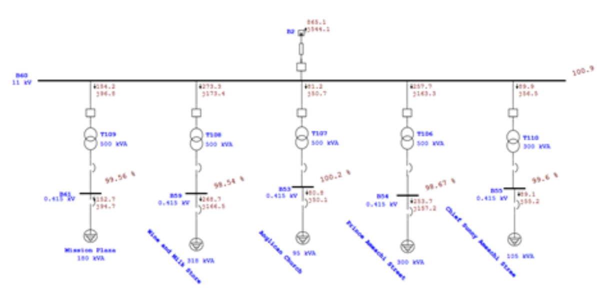

Fig.15, Aker Road Distribution Network after Application of Optimization Network

- Okocha Road Distribution Network after Application of Optimization Network

Fig. 16 shows the OkochaRoad distribution network below, after application of the optimization technique, there was a rapid improvement in the network performance. The power, voltage profile and real power improved drastically, the inputted power increased to (101.7 + j63) KVA, (154.3 + j95.6) and voltages across the buses 99.34%, 99.31% respectively.

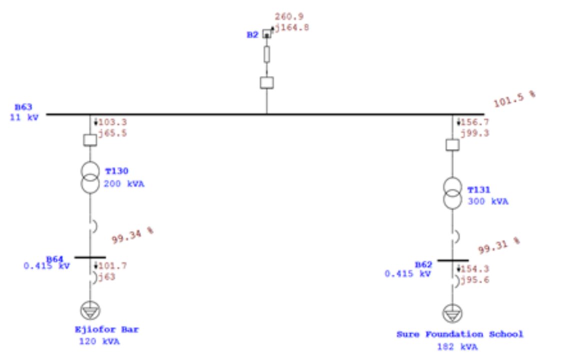


Fig.16 Okocha Road Distribution Network after Application of Optimization Network

- Eagle Road Distribution Network after Application of Optimization Network

Fig. 17 shows Eagle Road distribution network below, after application of the optimization technique, there was a rapid improvement in the network performance. The power, voltage profile and real power improved drastically, the inputted power increased to (104.2 + j64.6) KVA, (216.4 + j134.1) and voltages across the buses 99.21%, 99.6% respectively.

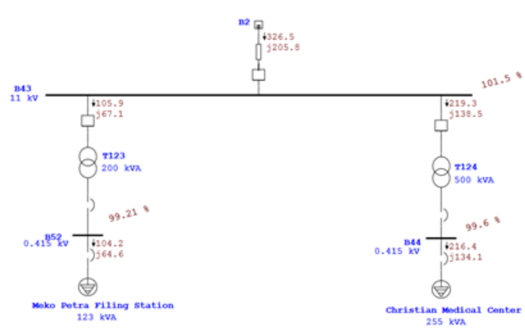


Fig.17 Eagle Road Distribution Network after Application of Optimization Network

C. Comparison of Results before and After Optimization

The following diagrams below are list of comparison made from results obtained from the buses performance before and after optimization of the individual distribution networks.

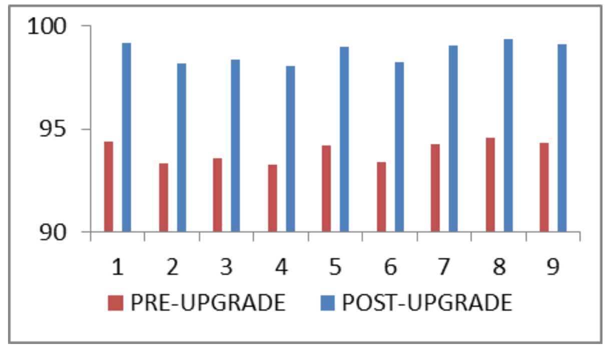


Fig. 18 Comparison of Results before and After Optimization (Iwofe 1)

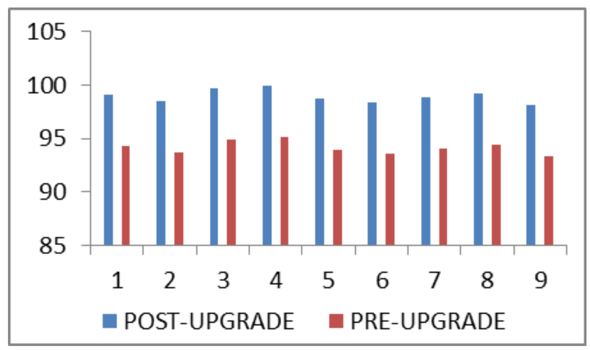


Fig. 19 Comparison of Results before and After Optimization (Iwofe 2)

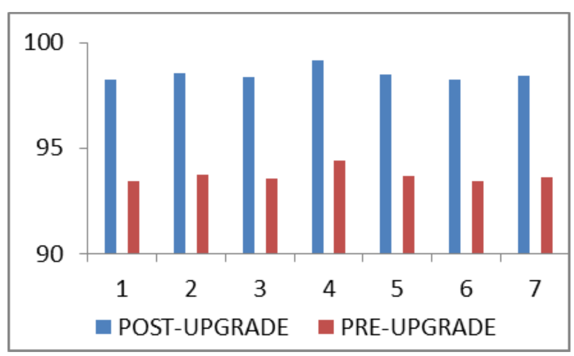


Fig. 20 Comparison of Results before and After Optimization (Iwofe 3)

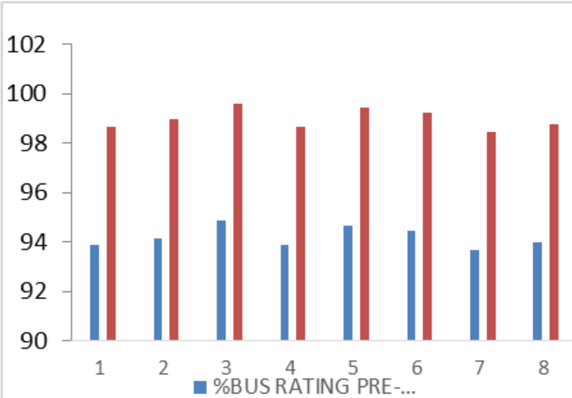


Fig. 21 Comparison of Results before and After Optimization (St. Johns)

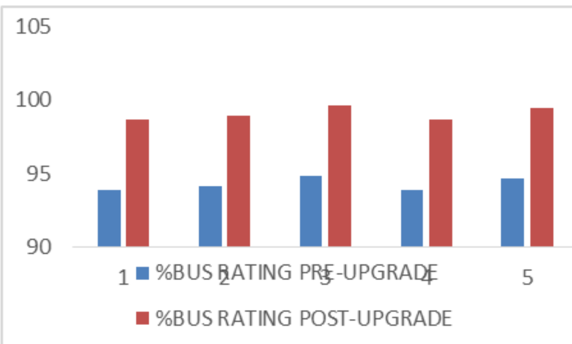


Fig. 22 Comparison of Results before and After Optimization (Aker Road)

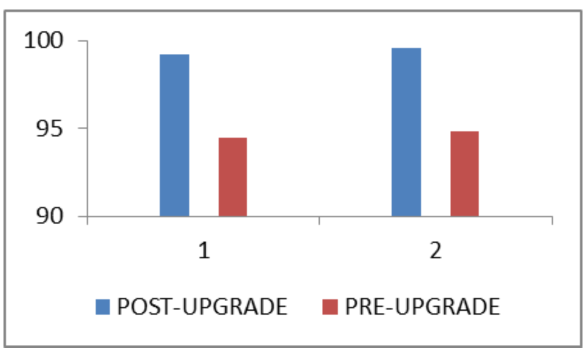


Fig. 23 Comparison of Results before and After Optimization (Eagle Road)

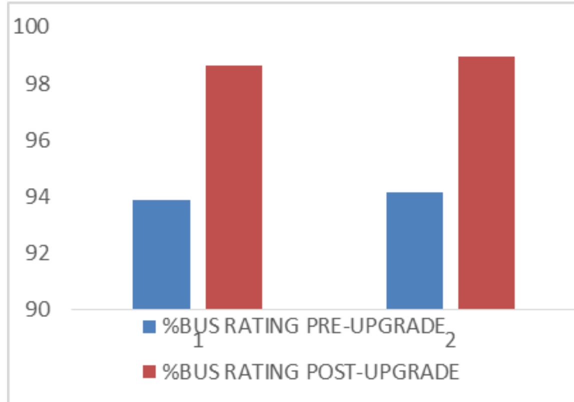


Fig. 24 Comparison of Results before and After Optimization (Okocha Road)

## IV. CONCLUSION

The Iwofe injection substation analysis carried out using load tap changer as an optimization technique in ETAP software shows the state of the network before optimization to have under voltage, low power factor and high power losses which resulted to constant load shielding and interruption of power supply in the iwofe area.

However, on optimization it was reveal that the power factor increased to 90.20% and power loss reduced to 0.168MW which drastically improved the network performance, voltage stability, reduction of power loss and increase accommodation of real power in the network. From the analysis and results obtained, this procedure can be useful to improve power quality with a cheaper capital cost. Preventive maintenance should be carried out constantly, replacing weak insulators and joints to improve the performance of the network [4].

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