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Power Factor Correction in Iwofe Injection Substation; Impact on the Distribution Network

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ABSTRACT : *Electrical power is an essential commodity necessary for the development of an economy of any country. It is expedient that electrical power is supplied constantly in good quality and form to the end users. This research deals with power factor correction carried out in Iwofe injection substation to improve the low power factor, voltage drop, huge financial and power losses experienced in the network. The network is constituted of five feeders namely Iwofe, St. Johns, Aker Road, Eagle Road and Okacha Road which was analyzed, modeled and simulated using Electrical Transient Analyzer Program (ETAP). The network details such as Mega-Watts of the injection substation, power and distribution transformers' capacity, bus input data, line input data, and loads on the transformers were obtained from the network and used for the load flow analysis in Etap. Capacitor Bank was used as the optimization technique in this research to improve the standard of the network. It was discovered before the application of the optimization technique that all the buses of the feeders were flagged critical as a result of high power loss of 0.181MW and low power factor of 82.41% but at application of the optimization technique there was a significant improvement of the network, the power loss and power factor became 0.168MW and 90.20% respectively. It was recommended that an adequate installation of a capacitor bank is advisable to improve the iwofe substation network power profile.*

KEYWORDS –*Power Factor Correction, Iwofe Injection Substation, Capacitor Bank, Actual and Reactive Power, Voltage Drop, Power Loss*

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I. INTRODUCTION

Electrical power system is composed of several electrical techniques and components used to generate, transfer and consume electrical energy. Electrical power system can be divided into three major sectors which are the generation, transmission and distribution sectors. The generation sector consist of components deployed to generate electrical power while the transmission and distribution sectors are characterized by several components deployed to transfer and distribute the generated electrical power to the final end users which consumed the electrical power. The end users include homes, hospitals, industries, churches, etc. the final end users consume the electrical energy through electrical loads. Electrical loads are any components that uses electrical energy in the form of current, they can transform electrical energy into other forms like work, light, heat example of electrical loads include light bulbs, motors, television, resistors, capacitors, etc. these electrical loads can be categorized into three basic parts which are the resistive loads, Capacitive loads and inductive loads. There difference depends on how they consume electrical energy. In some cases, they are generally referred to as linear and non-linear loads. Linear loads do not alter the sinusoidal wave shape of the alternating current and the wave shapes are in phase with one another, changing polarity at the same time and consume all the energy in the load while non-linear loads alters the sinusoidal wave shape of an alternating current and changes the phase of current and voltage (i.e voltage and current are out of phase). Electrical energy is stored in a non linear load in magnetic or electric field which causes the phase difference in the wave shape and then return to the power network. Due to the large numbers of non-linear loads connected to the distribution system that alters sinusoidal waveform drawn from the electrical energy source and generates electrical energy which then returns to the source, creates power factor problems in the distribution system.

Power Factor is the ratio of the actual power needed to do the work within customer premises to the power delivered by the utility. The power needed by the customer for operation is measured in Kilowatts (KW). The amount of power delivered by the utility is measured in Kilovolt Amperes (KVA). KW divided by KVA is the power factor. Having a power factor of 1.0 is ideal and impracticable. Appliances and machinery within customer premises discharge reactive power, measured in Kilovolt Amperes Reactive (KVAR). More KVAR present on the utility system results in a lower power factor, and higher currents present on the wires. Because thermal losses on the wires are proportional to the square of the current, a 12 % increase in current will result in a 25% increase in thermal losses related to the increased current. Similarly, a 10% current reduction will result in a 19% drop in thermal losses and provide the corresponding energy savings (0.9 x 0.9 = 0.81) [1].

The substations are where the utilities reduce the voltage (usually greater than 11,000 volts) from the transmission wires to lower voltages for distribution throughout the service area. The voltages are further reduced to the range of 220 volts at the transformers on the utility poles or in underground vaults located near the customer premises. The problem with implementing power factor correction at the substations is that the reactive power present on the distribution system, not serviced by those capacitors, is inducing thermal losses. Furthermore, the distribution system, with its lower voltages and higher currents, already accounts for the majority of the losses on the system. In addition, more thermal losses occur on the customer side of electric meter, within the customer premises [2]. On the Transmission and Distribution System, 50% of the energy lost and almost 75% of the energy losses occur on the lower voltage Distribution Portion of the system. The inadequate capacity on the distribution system is becoming an issue of great concern as distribution transformer could cause failure leading to loss of energy and finance. In the pursuit of alleviating part of that problem, It is either there is an effective increment of capacity in the distribution system or by removing the reactive load.

In power system, electrical loads with a negative power factor consumes more current than electrical loads with a positive power factor for the same amount of useful energy supplied. If power system operates on negative power factor loads, the capital cost of operation will be very high due to the generation of high currents, increases energy loss and leads to installation of larger equipment and wire in the generation, transmission and distribution networks. Because of huge cost of operating negative power factor loads utilities charge higher cost to customer attached to the network. Therefore, it is more expedient for utilities and customers to operate on a positive power factor.

Power factor correction is simply, the tendency of removing the reactive power without the supply [3]. The purpose of power factor correction in the power system is to prevent sinusoidal wave shape distortion and the difference in phase of current and voltage created by non-linear loads, and increase the reliability of the system. One of the ways of eliminating power factor problem is applying active and passive power factor correction methods.

II. TRANSFORMERS LOADING

Table I: Distribution transformers capacity and loading in the electrical power distribution network

S/N	ID of Transformer	Capacity of Transformer (KVA)	Loading	Capacity of Lumped Load (KVA)
IWOFE				
1	LIFE FORTE HOSPITAL	300	0.383	115
2	CREATIVE STAR AND STUDIO	100	0.34	34
3	DEEPER LIFE JUNCTION	500	0.6	300
4	AP FILLING STATION	100	0.35	35
5	CHIEF KANTE ISERO	200	0.175	35
6	NDDC CLOSE	500	0.64	320
7	GRACE AMAZING PLAZA	300	0.417	125
8	GLORIOUS COVENANT CHURCH	300	0.337	101
9	SILVERTEN PLAZA	500	0.404	202
10	U. O. E.	500	0.65	325
11	BIDDEL FILLING STATION	100	0.30	30
12	ERICO JUNCTION	300	0.647	194
13	EMI SCHOOL	500	0.402	201
14	POLICE STATION	300	0.59	177
15	GOODNESS SUPERMARKET	100	0.34	34
16	CHURCH OF JESUS CHRIST	500	0.606	303
17	AMODIA HOUSE	300	0.407	122
18	OCTIVI LOUNGE	500	0.41	205
19	TOTAL CHILD	300	0.233	70
20	DELIDEN GUEST HOUSE	300	0.183	55
21	CITY CROWN	200	0.505	101
22	JORDAN PHARMACY	500	0.602	301
23	FIRST BANK	200	0.475	95
24	ELDER ANTHONY AVENUE	300	0.37	111
25	PEPPERONI	300	0.667	200
AKER ROAD				

1	MISSION PLAZA	500	0.36	180
2	WINE AND MILK STORE	500	0.636	318
3	ANGLICAN CHURCH	500	0.19	95
4	PRINCE AMEACHI STREET	500	0.6	300
5	CHIEF SUNNY AMEACHI STREET	300	0.35	105
EAGLE ROAD				
1	MEKO PETRA FILLING STATION	200	0.615	123
2	CHRISTIAN MEDICAL CENTER	500	0.51	255
ST JOHNS				
1	OZUMBA STREET	500	0.5	250
2	JOETEX PLAZA	500	0.422	211
3	GRAND IMACO COMMUNICATION	500	0.24	120
4	ANIBROS FILLING STATION	500	0.49	245
5	STAKE PRIMARY SCHOOL	300	0.293	88
6	CAPTAIN WOKE STREET	300	0.346	104
7	IRIATA STREET	300	0.553	166
8	TOWN HALL	500	0.464	232
OKOCHA ROAD				
1	EJIOFOR BAR	200	0.6	120
2	SURE FOUNDATION SCHOOL	300	0.607	182

III. SIMULATION OF THE IWOFE INJECTION SUBSTATION IN ETAP

Fig. 1, shows the overall connection of the iwofe 33/11kv electrical power injection network and it is represented by one line diagram as shown below. The network consists of a 15MVA transformer with five 11KV (feeders) sub-networks feeding from the injection substation. The five sub-networks which are Iwofe, St. Johns, Aker Road, Eagle Road and Okocha constitute a total of 42 11/0.415kv distribution transformers of different ratings installed in the network. ETAP software which uses Neton-Raphson method [4] is used for the load flow analysis.

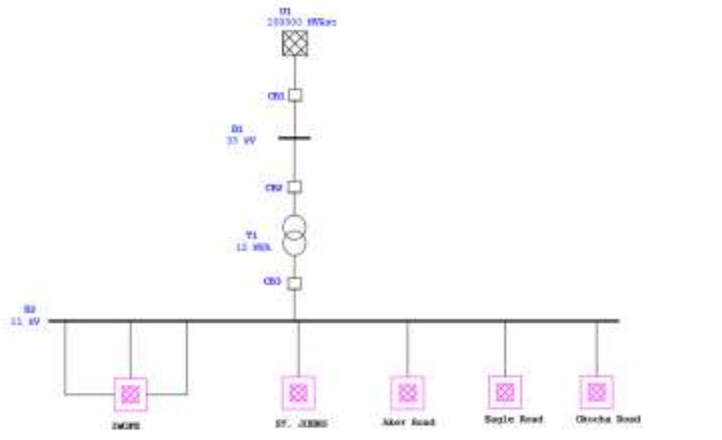

Fig. 1. The iwofe electrical power injection network

IV. LOAD FLOW ANALYSIS

The following below are the load flow analysis carried before the application of optimization technique using ETAP. The figures show the entire and individual distribution networks.

- **Network before Application of Optimization Technique**

Fig. 2, shows the individual sub-networks (feeders) of the Iwofe injection network before the application of the optimization technique; it is observed that all the buses of the sub-networks (Iwofe, St. John, Aker Road, Eagle Road and Okocha Road) were reported or flagged critical from the load flow analysis performed using ETAP simulation except that of the 33KV injection substation bus. The total power supplied into the network is (5998 + j4123) MVA and the individual power of the sub-networks are (1145 + j721) KVA, (1125 + j710.7) KVA, (1071 + j678.4) KVA, (1210 + j759.1) KVA, (850.7 + j535.8) KVA, (320.9 + j202.6) KVA (256.4 + j162.3) KVA respectively. From the branch losses summary report, the percentage (%) voltage drop across the distribution transformers T1, T58, T59, T60, T61…T130 are 2.87, 2.49, 2.28, 2.57, 2.44…2.27 respectively, which amounts to a total power loss of 0.181MVA and power factor of 82.41% in the network, these accounts for the high voltage drop and power losses experience in the Iwofe injection network.

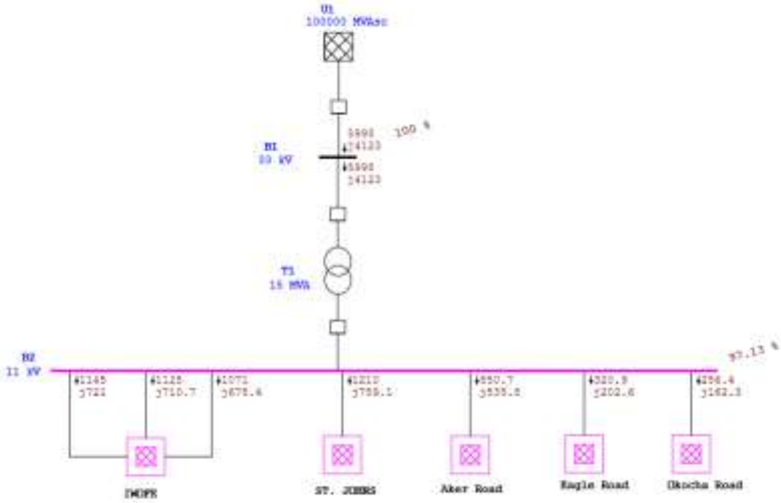

Fig. 2. Analysis of the Injection Network before the Application of Optimization Technique

- **Distribution network before application of optimization technique**

Fig. 3, shows the iwofe section of the distribution network, with a total of 25 distribution transformers installed in the network. On simulation, it is observed that the entire buses of this feeder are flagged red indicating the level of under voltage as shown below. The real and reactive power input on Bus 21, Bus 3 and Bus 31 on the feeder level are 1.145MW, 1.125MW, 1.071MW and 0.721Mvar, 0.711Mvar, 0.678Mvar respectively.

Bus 21, which has a voltage level of 95.8% with a total of 9 distribution transformer and power factor 84.6% which is very low. Each of the distribution transformers has an input real and reactive power of 0.103MW, 0.240MW, 0.059MW, 0.046MW, 0.085MW, 0.254MW, 0.80MW, 0.093MW, 0.169MW and 0.065Mvar, 0.152Mvar, 0.037Mvar, 0.029Mvar, 0.054Mvar, 0.161Mvar, 0.051Mvar, 0.059Mvar, 0.107Mvar.

Bus 3 has a voltage level of 95.9% with a total of 9 distribution transformers and a power factor of 84.6% which is low. Each of the distribution transformers has an input real and power of 0.072MW, 0.097MW, 0.028MW, 0.253MW, 0.029MW, 0.270MW, 0.085MW, 0.170MW and 0.046Mvar, 0.061Mvar, 0.019Mvar, 0.0161Mvar, 0.020Mvar, 0.172Mvar, 0.066Mvar, 0.053Mvar, 0.107Mvar.

Bus 31 has a voltage level of 95.9% with a total of 7 distribution transformers and a power factor of 84.5% which is low. Each of the distribution has a voltage level of 93.44%, 93.23%, 93.58%, 94.39%, 93.67%, 93.42%, 93.61%. All these constitute to the voltage and power losses experience in the Iwofe feeder and injection substation.

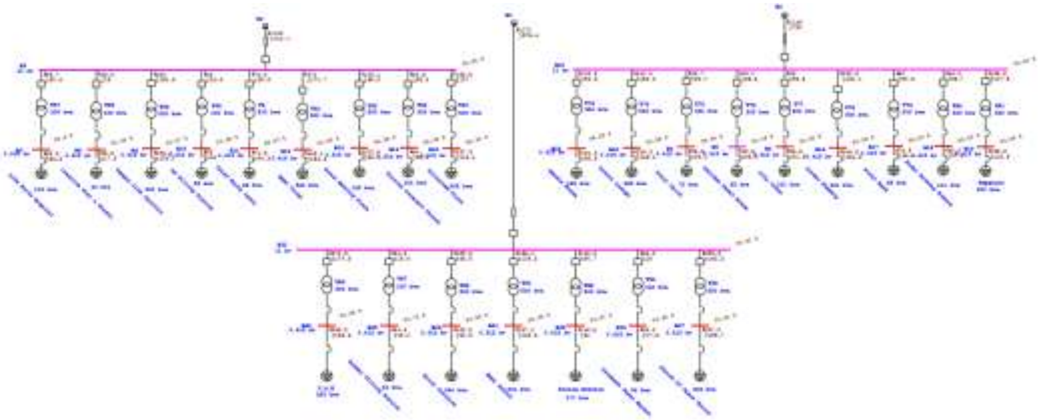

Fig. 3. Analysis of the distribution network before the application of optimization technique, sub-network 1 (Iwofe)

- **Aker road distribution network before application of optimization technique**

Fig. 4. Shows the sectional view of the Aker Road Feeder, the feeder has a total of 5 distribution transformers installed in the network. The buses of this network were flagged critical after simulation from the load flow analysis performed using Etap. The real and reactive power of the feeder is 0.851MW and 0.536Mvar, power factor 84.6%, and voltage level 96.2. Moreso, each of the distribution transformers with bus 54, 53, 59,

61, 55, has an input real and reactive power of 0.253MW, 0.080MW, 0.269MW, 0.151MW, 0.088MW and 0.161Mvar, 0.056Mvar, 0.171Mvar, 0.095Mvar, 0.056Mvar, voltage level 94.8%, 93.8%, 95.6%, 93.9%, 94.9% and power factor 84.4%, 84.8%, 84.4%, 84.7%, 84.7%. All these constitute to the voltage and power losses experience in the injection substation.

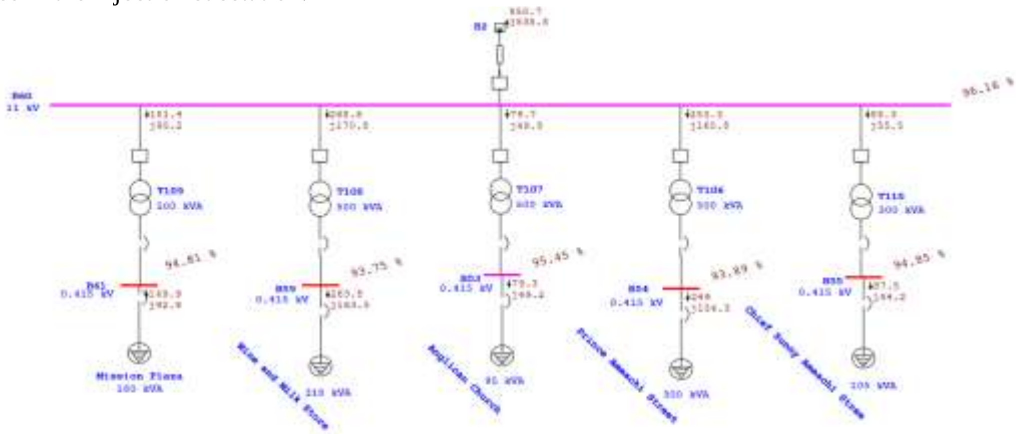

Fig. 4. Analysis of the distribution network before the application of optimization technique, sub-network 2 (Aker Road)

- **Eagle Road Distribution Network before Application of Optimization Technique**

Fig. 5, shows the Eagle Road section of the injection. The feeder has a total of 2 distribution transformers installed in the network. The buses of this network were flagged critical after simulation from the load flow analysis performed using Etap. The real and reactive power of the feeder is 0.321MW and 0.203Mvar, power factor 84.6%, and voltage level 96.8. Moreso, each of the distribution transformers with bus 52, 44 has an input real and reactive power of 0.104MW, 0.215MW and 0.066Mvar, 0.136Mvar, voltage level 94.4%, 94.8%, and power factor 84.4%, 84.5% See All these constitute to the voltage and power losses experience in the injection substation.

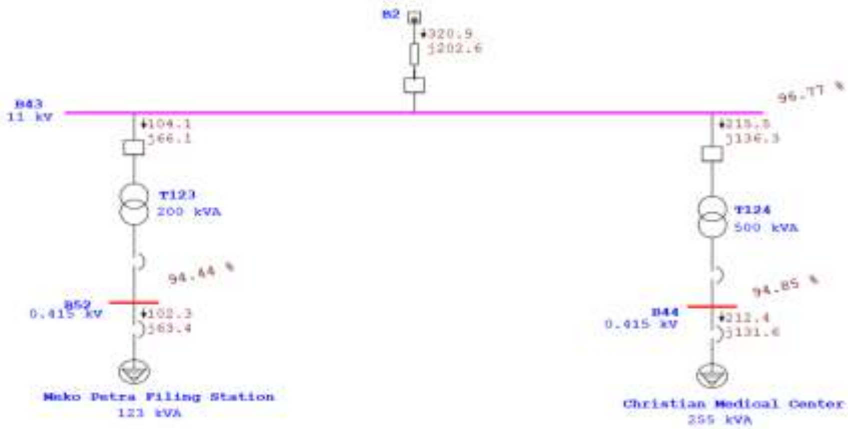

Fig. 5. Analysis of the distribution network before the application of optimization technique, sub-network 3 (Eagle Road)

- **St. Johns Distribution Network before Application of Optimization Technique**

Fig. 6, shows the sectional view of the St. Johns Feeder. The feeder has a total of 8 distribution transformers installed in the network. The buses of this network were flagged critical after simulation from the load flow analysis performed using Etap. The real and reactive power of the feeder is 1.210MW and 0.759Mvar, power factor 84.7%, and voltage level 95.8. Moreso, each of the distribution transformers with bus 42, 40, 33, 34, 35, 36, 37, 38, has an input real and reactive power of 0.195MW, 0.210MW, 0.177MW, 0.101MW, 0.206MW, 0.140MW, 0.074MW, 0.087MW and 0.123Mvar, 0.133Mvar, 0.112Mvar, 0.063Mvar, 0.130Mvar, 0.089Mvar, 0.046Mvar, 0.055Mvar, voltage level 93.9%, 94.2%, 94.9%, 93.9%, 94.7%, 94.5%, 93.7%, 94% and power factor 84.6%, 84.5%, 84.6%, 84.8%, 84.5%, 84.5%, 84.7%, 84.7% respectively.

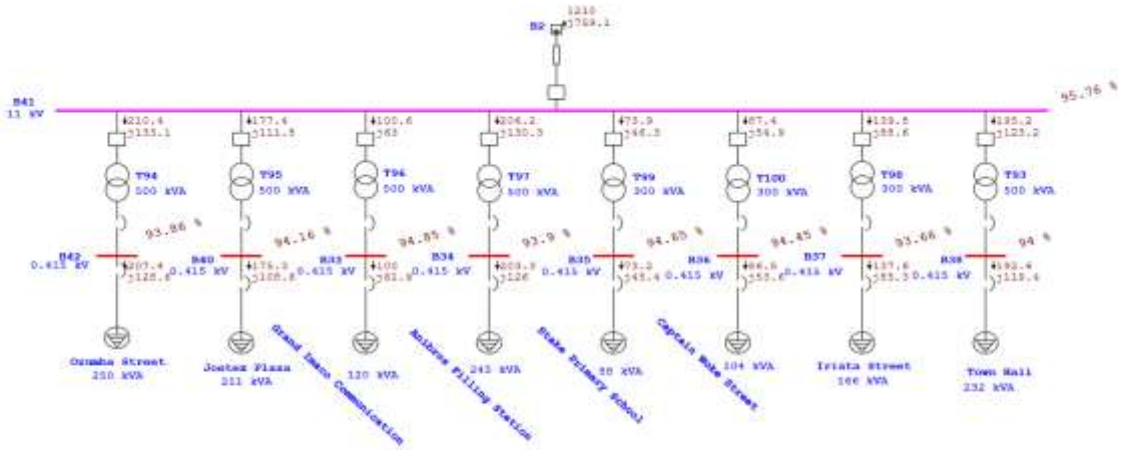

Fig. 6. Analysis of the distribution network before the application of optimization technique, sub-network 4 (St. Johns)

- **Okocha Road Distribution Network before Application of Optimization Technique**

Fig. 7, shows the Okoacha Road section of the injection. The feeder has a total of 2 distribution transformers installed in the network. The buses of this network were flagged critical after simulation from the load flow analysis performed using Etap. The real and reactive power of the feeder is 0256MW and 0.162Mvar, power factor 84.5%, and voltage level 96.8. Moreso, each of the distribution transformers with bus 64, 62 has an input real and reactive power of 0.102MW, 0.154MW and 0.064Mvar, 0.098Mvar, voltage level 94.6%, 94.6%, and power factor 84.4%, 84.4% See. All these constitute to the voltage and power losses experience in the injection substation.

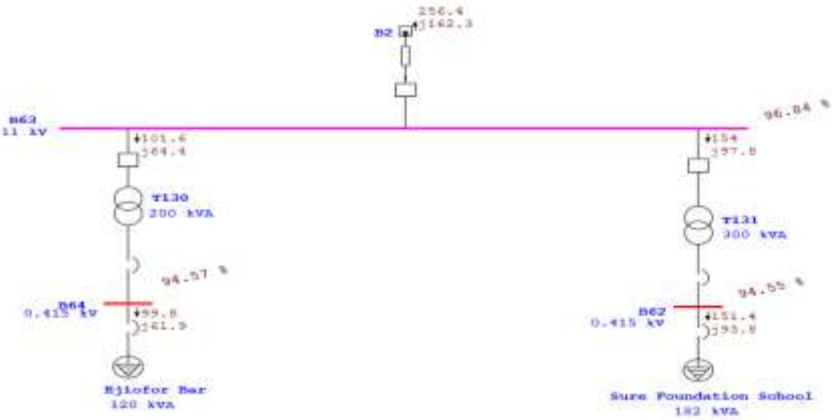

Fig. 7. Analysis of the distribution network before the application of optimization technique, sub-network 5 (Okocha Road)

- **Network with Application of Optimization Technique**

Fig. 8, shows the analysis of the iwofe injection substation network with the application of capacitor bank to the network. The capacity of the capacitor bank applied is 6.8Mvar, on application of the capacitor bank to the 11KV network, the power supplied and voltage profile to the sub-networks improved drastically and the line losses and drops along the sub-networks also greatly improved. The percentage (%) power factor and apparent power losses (MW) along the lines were initially 82.41 and 0.181 but drastically increased to 90.20% and minimized to 0.168MW respectively. It can be clearly seen that there is huge improvement in the power factor and losses in the network. The input power and voltage level to the sub-networks (Iwofe, St. John, Aker Road, Eagle Road and Okocha Road) are also drastically improved by the application of the capacitor bank to (1144 + j721.5) KVA, (1230 + j544.1) KVA, (865.1 + j544.1) KVA, (326.5 + j205.8) KVA, (260.9 + j164.8) KVA and 101.8% respectively. It can also be seen that the operating voltage of the bus also improved drastically as well as increase in the amount of real-power load supplied by the injection substation. This means that more real power (load) accommodation, voltage stability improvement, equipment loading and power loss reduction, and postponement of costly network upgrades.

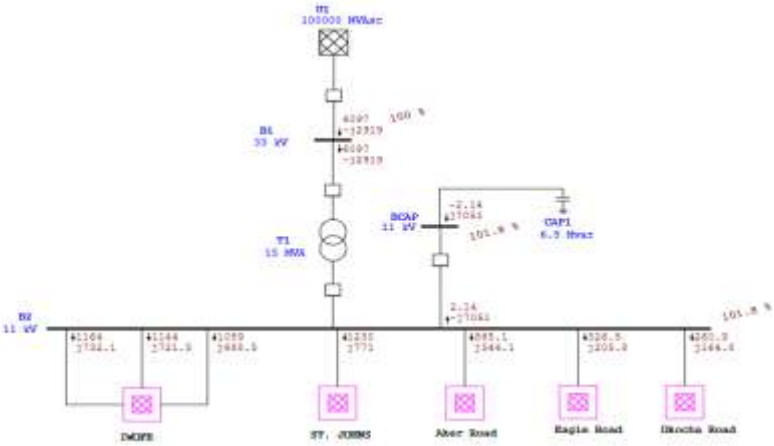

Fig. 8. Analysis of the injection network after the application of optimization technique

- **Iwofe distribution network after application of optimization technique**

Fig. 9, shows the iwofe section of the injection substation network with the application of capacitor bank to the network. On application of 6.8Mvar capacitor bank to the 11KV network, the power supplied and voltage profile to the feeder (Sub-Network I) improved drastically and the line losses and drops along the feeder also greatly improved. It can be observed that both the real and reactive power input improved greatly to 1.164MW, 1.144MW, 1.089MW and 0.732Mvar, 0.721Mvar, 0.688mvar at Bus 21, 3 and 31 respectively. It can also be seen that the operating voltage at Bus 21, 3 and 31 also has improved greatly to 100%, 100% and 100% respectively. This means that more real power (load) accommodation, voltage stability improvement, equipment loading and power loss reduction, and postponement of costly network upgrades.

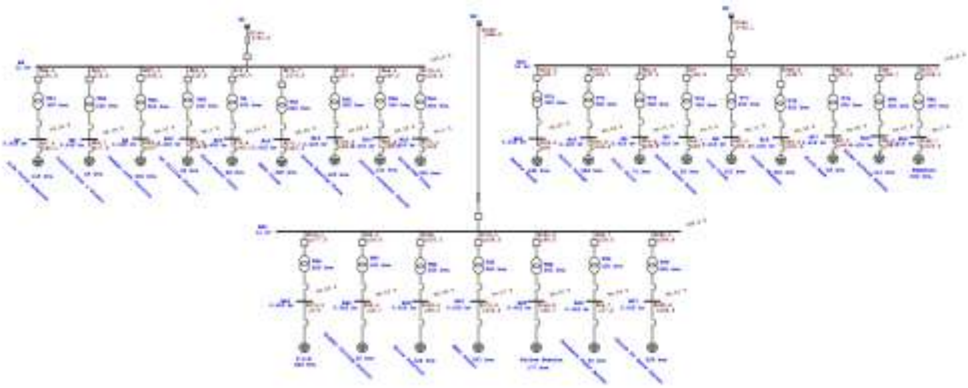

Fig. 9. Analysis of the iwofe distribution network after the application of optimization technique, sub-network 1

- **Aker road distribution network after application of optimization technique**

Fig. 10, shows the sectional view of the Aker Road feeder with the application of capacitor bank to the network. On application of 6.8Mvar capacitor bank to the 11KV network, the power supplied and voltage profile to the feeder (Sub-Network 2) improved drastically and the line losses and drops along the feeder also greatly improved. It can be observed that both the real and reactive power input improved greatly to 0.865MW and 0.544Mvar at Bus 60. It can also be seen that the operating voltage at Bus 60 also improved greatly to 100.9%. This means that more real power (load) accommodation, voltage stability improvement, equipment loading and power loss reduction, and postponement of costly network upgrades.

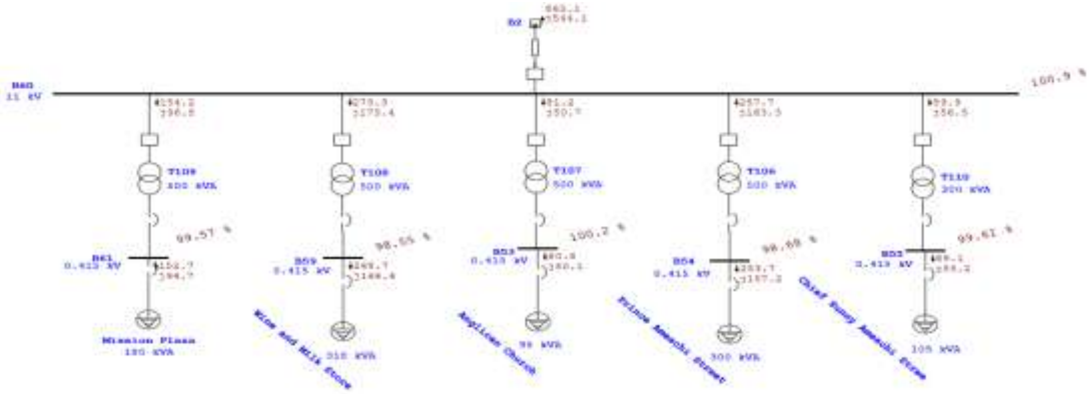

Fig. 10. Analysis of the aker road distribution network after the application of optimization technique,sub-network 2

- **Eagle road distribution network after application of optimization technique**

Fig 11, shows the iwofe section of the injection substation network with the application of capacitor bank to the network. On application of 6.8Mvar capacitor bank to the 11KV network, the power supplied and voltage profile to the feeder (Sub-Network 3) improved drastically and the line losses and drops along the feeder also greatly improved. It can be observed that both the real and reactive power input improved greatly to 0.326MW and 0.206Mvar at Bus 43. It can also be seen that the operating voltage at Bus 43 also has improved greatly to 101.5. This means that more real power (load) accommodation, voltage stability improvement, equipment loading and power loss reduction, and postponement of costly network upgrades.

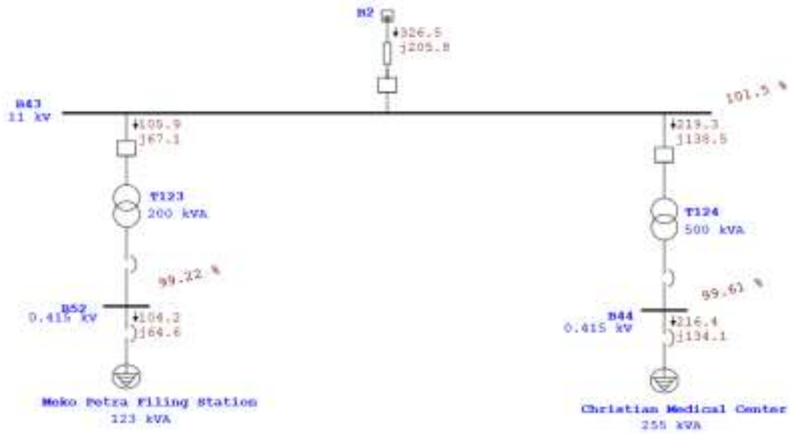

Fig. 11. Analysis of the eagle road distribution network after the application of optimization technique,Sub-Network 3

- **St. Johns distribution network after application of optimization technique**

Fig. 12, shows the sectional view of the St. Johns Feeder, with the application of capacitor bank to the network. On application of 6.8Mvar capacitor bank to the 11KV network, the power supplied and voltage profile to the feeder (Sub-Network 4) improved drastically and the line losses and drops along the feeder also greatly improved. It can be observed that both the real and reactive power input improved greatly to 1.230MW and 0.771Mvar at Bus 41. It can also be seen that the operating voltage at Bus 41 also has improved greatly to 100.5%. This means that more real power (load) accommodation, voltage stability improvement, equipment loading and power loss reduction, and postponement of costly network upgrades.

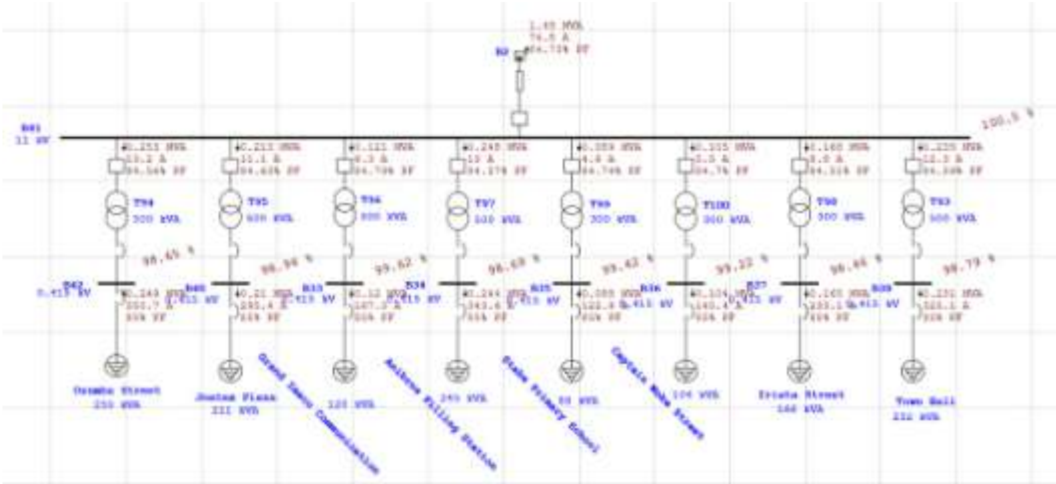

Fig. 12. Analysis of the St. Johns distribution network after the Application of Optimization Technique, Sub-Network 4

- **Okocha Road Distribution Network after Application of Optimization Technique**

Fig. 13, shows the sectional view of the Okocha Road Feeder, with the application of capacitor bank to the network. On application of 6.8Mvar capacitor bank to the 11KV network, the power supplied and voltage profile to the feeder (Sub-Network 5) improved drastically and the line losses and drops along the feeder also greatly improved. It can be observed that both the real and reactive power input improved greatly to 0.261MW and 0.165Mvar at Bus 41. It can also be seen that the operating voltage at Bus 41 also has improved greatly to 101.5. This means that more real power (load) accommodation, voltage stability improvement, equipment loading and power loss reduction, and postponement of costly network upgrades.

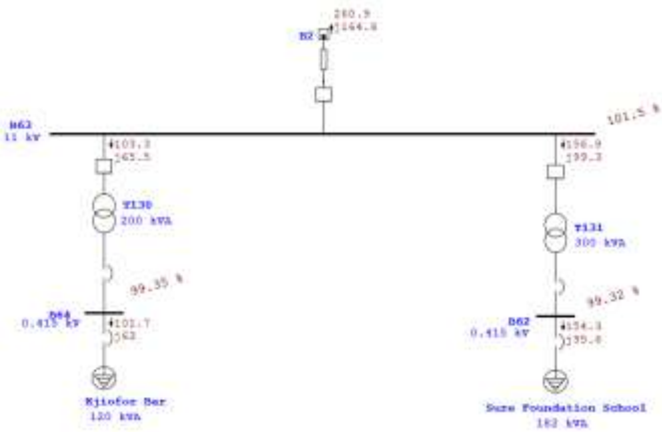

Fig. 13. Analysis of the okocha road distribution network after the application of optimization technique, sub-network 5

V. CONCLUSION

The analysis of the power flow of Iwofe injection network clearly shows the performance of the injection network before and after the application of the optimization technique. The network was characterized by low power factor which resulted in large line losses, low efficiency, large conductor size and cost, large KVA rating, large size of electrical equipment, poor voltage regulation and large voltage drops from the injected substation to the load end. And due to overloading, size and length of the feeder lines also accounts for the considerable losses of power and voltage in the network.

The introduction of the optimization technique i.e application of the required size and right placement of capacitor bank in the network increases the power factor and reduces the high current consumption in the network which leads to a reduction of reactive power and improvement of active power, system capacity as well as reduced systems consumption. The introduction of optimization technique raised the power factor to 90.20% and drastically reduced the apparent power losses to 0.168MW; this means that more real power accommodation, voltage stability improvement, equipment loading and power loss reduction, and postponement of costly network upgrades.

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