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Development of an Improved Electrical Power Distribution for Old Port Harcourt Township

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ABSTRACT: *Development of an Improved Electrical power 11KV Distribution Network is a research conducted for Old Port Harcourt Township, Rivers State, which is necessary for the planning, operation, future expansion and improvement of power distribution by the utility in charge of electricity distribution in the area. The analysis was conducted to tackle and solve the problem of low voltage profile experienced due to the overloading of the system, and the size and distance covered by the distribution lines. It is also geared to tackle and solve the problem of frequent power outages experienced mainly to copper loss (I^2R) along the feeder lines and excessive loading on the power transformers at the Marine Base injection substation. A detailed survey was carried out and the bus and line input data, power and distribution transformers' capacity and loadings on the transformers were obtained. Electrical Transient Analyzer Program (ETAP) was used to model and simulate the network after Fast Decoupled Load Flow Method (FDLFM) has been used to analyze the existing 11KV distribution network. Transformer Load Tap Changing (LTC) and Optimal Capacity Placement (OCP) where the optimization methods used for the improvement of the 11KV distribution network. It is seen before optimization that, the power injected into the network was 27.87MVA. The total loss from the network amounted to 7.90MVA, with an average voltage drop of 19.72% along the feeder lines. After Transformer Load Tap Changing (LTC), the power injected into the system became 28.78MVA. The total loss from the network and average voltage drop along the lines were 7.82MVA and 19.64% respectively. But after Optimal Capacity Placement (OCP), the power injected into the network, total loss from the network and average voltage drop along the feeder lines were 29.683MVA, 6.35MVA and 6.73% respectively; a significant improvement of the network from before optimization and even after Transformer Load Tap Changing (LTC) was done on the power transformers at the Marine Base injection substation. It is also seen that the capacitor's operating cost during planning period increases with time but cannot be compared to the increase in profit and savings due to loss reduction over the same period of time; as the savings being a result of loss reduction far exceeds the cost of operation over same period of time.*

Keywords*: Distribution Network, Optimal Capacitor Placement, Load Tap Changing, Fast Decoupled Load Flow, Power Factor, Voltage Profile, Power Losses.*

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I. INTRODUCTION

Consumption of electricity by consumers must be achieved by the transmitting or conveying of electrical power via a network of transmission and distribution systems. Thus, the distribution system network is that link between the sub-station fed by the transmission network and the consumer meter. Practically, in Nigeria which is a developing country, the demand for electricity far outweighs the supply, bringing about low power generation. Apart from the low power generation encountered in Nigeria, other factors that has contributed to inefficient and unreliable power supply include governmental inconsistent and unreliable reform policies, inefficiency in power generation, transmission, distribution, consumption and the incompetent work force of the energy companies; which in turn are narrowed down to the poor or ineffective voltage control system, poor transmission networks, highly overloaded transmission feeders due to lack of planning, faulty distribution system on the part of the electrical suppliers, voltage drop along the line and from the distribution system due to the flow of current and load variations on the consumer end, damage to substation, transmission and distribution network, short circuit or overloading of electrical mains, and tripping of power system. These shortcomings over the years have resulted to unreliable and unhealthy voltage profiles and frequent power outages. An efficient power supply system is one that seeks to overcome the above shortcomings and delivers better quality of power to local consumers and industrial users [1].

For distribution systems, the load flow analysis is a very important and fundamental tool that enhances planning for the future expansions as well as determining the best operation of the existing system. The principal information obtained from the power-flow study is magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line, thereby analyzing the distribution system in normal steady state operations. Due to the non-linear nature of this problem, numerical methods are employed to obtain a solution that is within an acceptable tolerance [2]. There are several different methods of solving the resulting non-linear system of equations. The Gauss-Seidel method, Newton-Raphson's method and its decoupled versions, and the Holomorphic Embedding Load-flow Method (HELM) are few of these methods. The main features of the HELM are that it is direct (that is, non-iterative) and that it mathematically guarantees a consistent selection of the correct operative branch of the multi-valued problem, also signaling the condition of voltage collapse when there is no solution [3].

The Fast-Decoupled Load Flow Method (FDLFM) is an improved modification of the Newton-Raphson's method. This method, due to its simple calculations, fast convergence and reliable results became the most widely used method in load flow analysis. However, for networks with high resistance to reactance (R/X) ratios or heavy loading (low voltage) at some buses, the FDLFM does not converge well. For these cases, many efforts and developments have been made to overcome these convergence issues. Some of them targeted the convergence of systems with high R/X ratios and others, with low voltage buses [4].

This project sets to tackle the low voltage profile and excessive power losses experienced in the Electrical Power Distribution network for Old Port Harcourt Township. This was achieved by executing Transformer Load Tap Changing (LTC) on the 2 x 15MVA transformers at the Marine Base Injection substation feeding the network and then increasing the power factor of the network by strategically installing 104 x 300kvar capacitors in the network via Optimal Capacitor Placement (OCP) technique.

II. LITERATURE REVIEW

There have been many researches and works on load flow analysis and improvement techniques of distribution systems. Some related works but not limited to those listed are reviewed below:

- The Fast-Decoupled Newton Raphson method was used in [5] to analyze the electrical supply to Abule-Egba part of Lagos State, via Agbefa 11KV feeder. It was revealed by analysis that the voltage profile of the buses was very low and the magnitude of the active and reactive power flow were poor. The problem was corrected by the placement of appropriately sized and strategically placed capacitors close to load end to support the system with reactive power.
- The Fast decoupled and Newton-Raphson load flow methods were used in [1] to analyze the Port Harcourt Town 33KV Distribution Network. According to them, the major problems encountered in this network is the frequent power outages caused by heavy I^2R losses in the line, low voltage experienced, poor power factor at load end, overloading of feeder transformers and inadequate size of conductors of the network. The writers recommend that reactive power needed by the network be supplied by capacitors located optimally at strategic points so as to improve the power factor at load end, thereby improving the voltage profile of the buses and reduce branch power losses.
- Investigations were made in [6] as to the causes and effects of voltage drops on the 11KV GMC sub transmission feeder in Tarkwa, Ghana. It was realized that the main causes of voltage drop on the feeder were due to Hot Spots (poor jointing and terminations), under-size conductors, non-uniform conductor material and overloading of the feeder. They proposed that a pressure test should be conducted on the feeder and a proper fault maintenance be carried out on the feeder. Also, that operating voltage should be increased so that power could be transmitted in reduced currents to enhance the reduction of I^2R losses.
- In [7], a novel method for designing an electrical distribution network within Damaturu town was presented. According to their findings, the town is supplied by two highly overloaded feeders due to series of developmental expansion of the town. Supplying the Alimarimi feeder and Maiduguri road feeder are 2 x 7.5MVA transformers at the injection substation. These have resulted to the epileptic power supply to the areas covered by the feeders. After much analysis the new design recommended the use of 2 x 15MVA transformers at the injection substation serving Alimarimi road feeder and the Maiduguri road feeder, thereby, tackling the problem of overloading on the installed power transformers.
- The authors in [8] stated that the electrical power distribution system in Nigeria is constantly challenged by the ever-increasing load demand. This increase in load demand could be checked by performing a load flow analysis on the present distribution network to see the true performance of the network with its steady state operational values. According to them most distribution substation's irregular supply and under-voltage in the system are due to the weak and obsolete nature of the system infrastructures and thus, experiences high

energy losses. This has led to the increased rate of load shedding by the utility company as a way of controlling the challenge. Their research was actually carried on Dumez 11KV feeder network. The work was modeled and simulated in DIsilent Power Factory 2016 and ETAP 7.0. Results from both environments, similar in nature, showed violation of voltage statutory limits; but where improved by Distributed Generation (DG) technique.

III. METHODOLOGY

3.1 Electrical Distribution Network for Old Port Harcourt Township

The One Line View (OLV) of the 11KV distribution network of Old Port Harcourt Township is shown in Fig. 1 with its respective sub-networks which are fed by Marine Base 33/11KV injection substation via 4 sets of feeders. Fig. 1 shows how power is sent from the Marine Base 33/11KV injection substation via a set of 2 x 15MVA power transformers to the feeders conveying power to the area of study. These feeders are the Amadi-North feeder, Station Road feeder, Borokiri feeder and the Flour Mill feeder; with each having 48, 36, 33 and 36 11/0.415KV substations feeding different areas. The Amadi-North and Station Road feeder are fed from one of the power transformers and the other power transformer feeding Borokiri and Flour Mill feeder.

The materials needed for this research were obtained from field survey from Port Harcourt Electricity Distribution (PHED) company. After survey, line data, bus data, transformer loadings and ratings, including the Mega-Watt of Marine Base injection substation were sourced out. The network was then modeled and simulated in ETAP 16.00 using the Fast-Decoupled Load Flow method. After simulation, it was seen that the voltage profile of the entire network was low, the loss of power from the network was high and the system was operating on a much lower Power Factor (PF). Transformer Load Tap Changing (LTC) was then introduced to the power transformers so as to increase the voltage of the upstream buses at the injection substation. After then, shunt capacitors were installed on the 11KV buses at load end to raise the entire system's Power Factor, which then improved the voltage profile of the network and reduced losses from the network; automatically releasing system capacity.

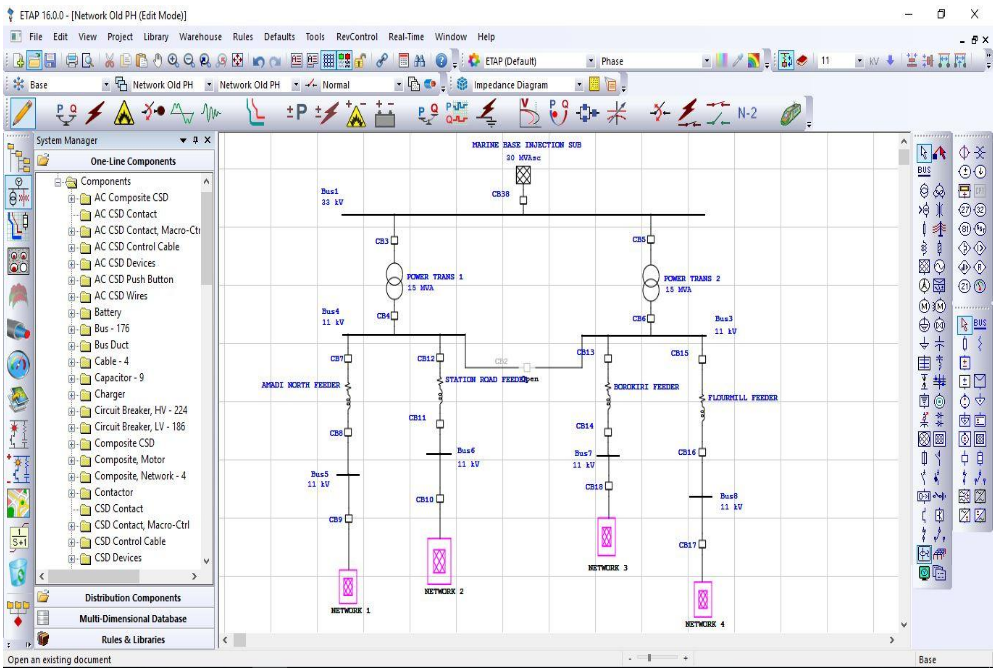

Fig. 1 Present electrical power distribution for Old Port Harcourt Township

3.2 Transformer Load Tap Changing (LTC)

Number of taps = 33 (16 to each side of the rated tap)

Maximum allowable variation $= \pm 10\%$

A single step $= \pm 0.625$% of the nominal rating.

3.2.1 On power Transformer 1

Tap position based on operating condition = Step 3

Percentage increase = 1.875%

Voltage rise= 1.875% x $11KV$

$= 0.21KV$

Bus 4 Voltage profile after LTC = 10.38KV + 0.21KV
= 10.59KV

3.2.2 On Power Transformer 2

Tap position based on operating condition = step 8
Percentage increase = 5%
Voltage rise $= 5\% \times 11KV = 0.55KV$
Bus 3 voltage profile after LTC = 10.41KV + 0.55KV
=10.96KV

Table 1: Complex Load on Distribution Transformers

Complex Load Demand = Transformer Capacity x Percentage loading on Transformer
At $PF = 0.85,$ $qF = 0.53$

S/N	Feeder/Transformer ID	Transformer Capacity	Transformer Loading	Complex Load demand (KVA)	Active Load (KV)	Reactive Load (Kvar)
1.	Amadi-north/NEPA Waterfront	500	0.85	425	361.25	225.25
2.	Station Road/ Police Headquarters	500	0.66	198	168.3	104.94
3.	Borokiri/Niger Street	500	0.55	275	233.75	145.75
4.	Flour Mill/Fisherman Estate	500	0.49	245	208.25	129.85

Total active load on transformers = 361.25KW + 168.3KW + 233.75KW +208.25 KW = 971.55KW

3.3 Power Factor of Existing Network

$$PF = \frac{KW}{KVA}$$

$$KVA = [(KW)^2 + (KVar)^2]^{1/2}$$

Power injected into the network = 22631+j16272

$$KVA = [22631^2 + 16272^2]^{1/2}$$

$$KVA = 27873.65$$

$$PF = \frac{22631}{27873.65} = 0.81$$

3.4 Capacitor required for PF Improvement

$cKvar = KW(tan\,\theta_1 - tan\,\theta_2)$

PF of existing network = 0.81

$\theta_1 = cos^{-1}(0.81) = 35.9^0$

Desired PF = 0.96

$\theta_2 = cos^{-1}(0.96) = 16.3^0$

For a network containing just the above loads calculated, the size of capacitor needed to improve PF from 0.81 to 0.96 will be:

$cKvar = 971.55(tan35.9^0 - tan16.3^0)$

$cKvar\ 419.18Kvar$

Hence, preferred size of shunt capacitor bank will be 2 x 300Kvar.
The total size of capacitor required to improve the entire Old Port Harcourt Distribution network's PF from 0.81 to 0.96 was obtained from simulations from Optimal Capacitor Placement Module in ETAP 16.00.

IV. RESULTS AND DISCUSSION

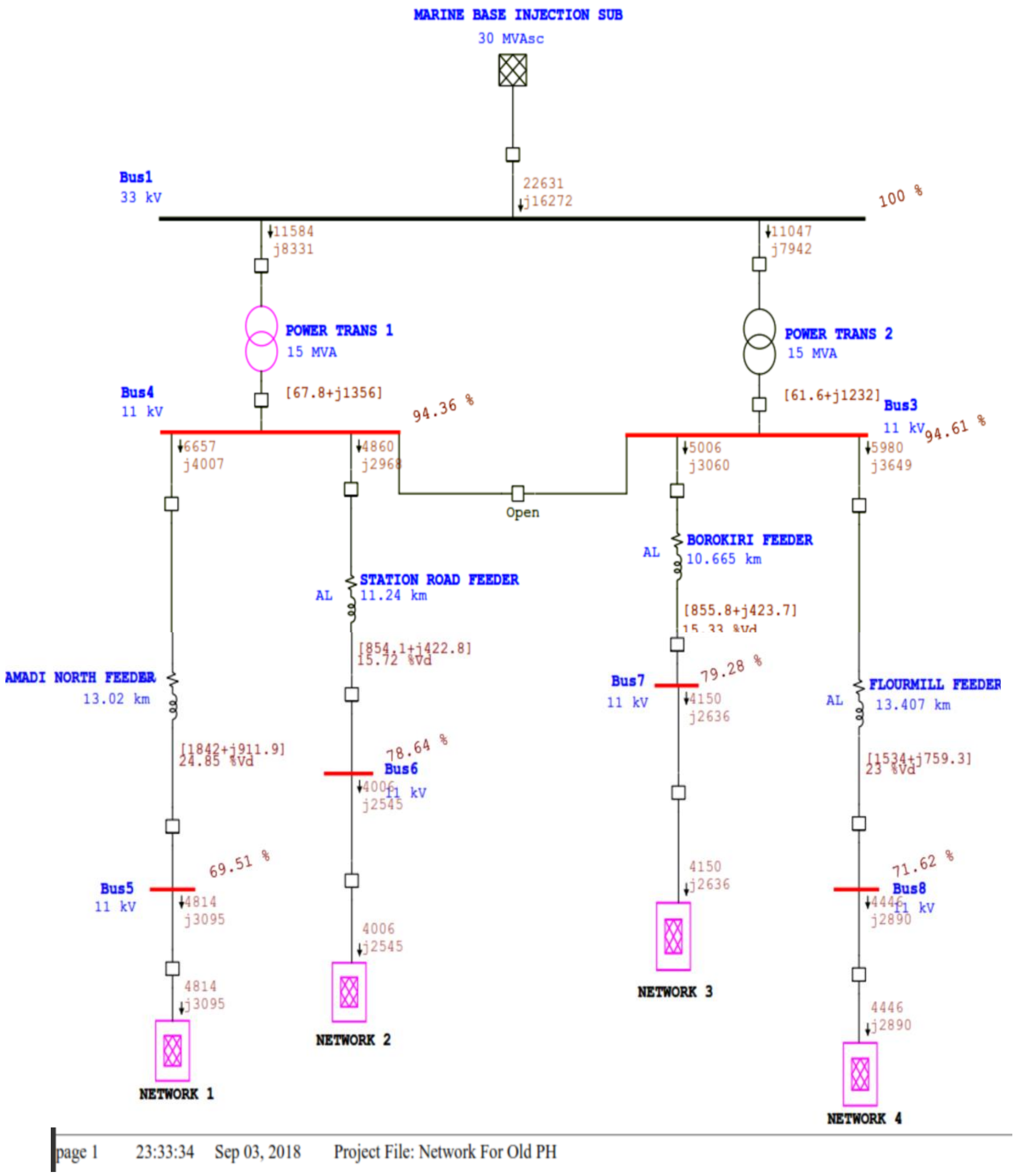

Fig. 2: Load Flow Analysis of Old Port Harcourt Township 11KV Distribution Network before Optimization

Fig. 2 shows the results after simulation of the 11KV electrical power distribution for Old Port Harcourt Township before optimization. All the buses in the network were flagged critical, except the 33KV bus at the injection substation.

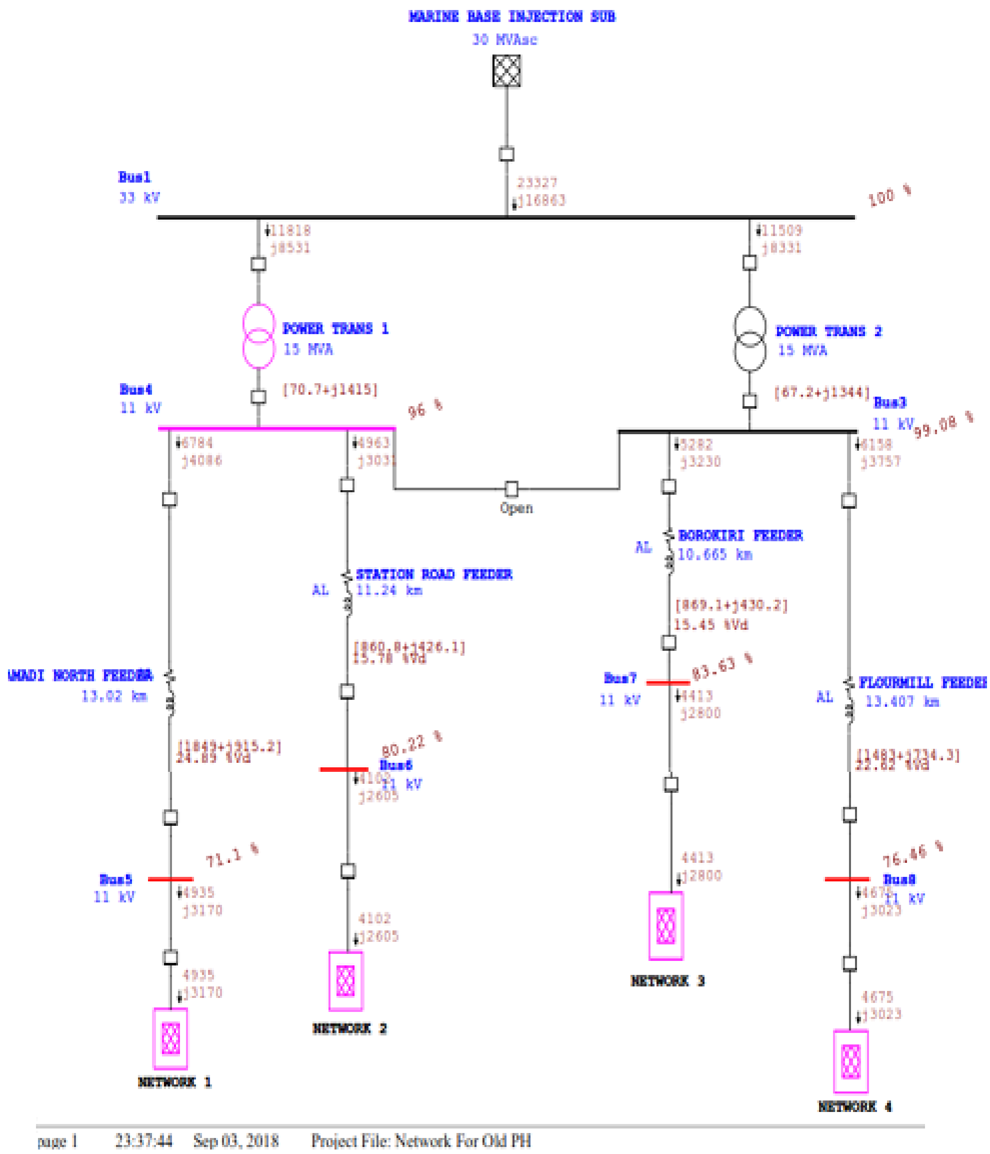

Fig. 3 Load Flow Analysis of Old Port Harcourt Township 11KV Distribution Network after LTC

Fig. 3 shows the results of simulation after transformer Load Tap Changing was done on the power transformers at the Marine Base injection substation. The primary windings of the transformers were altered by systematically increasing their tap positions with respect to their operating conditions. On power transformer 1, the tap position was kept on step 3 (+1.875%), a voltage rise of 0.21KV. Whereas on Power transformer 2, the tap position was kept on step 8 (+5%), a voltage rise of 0.55KV.

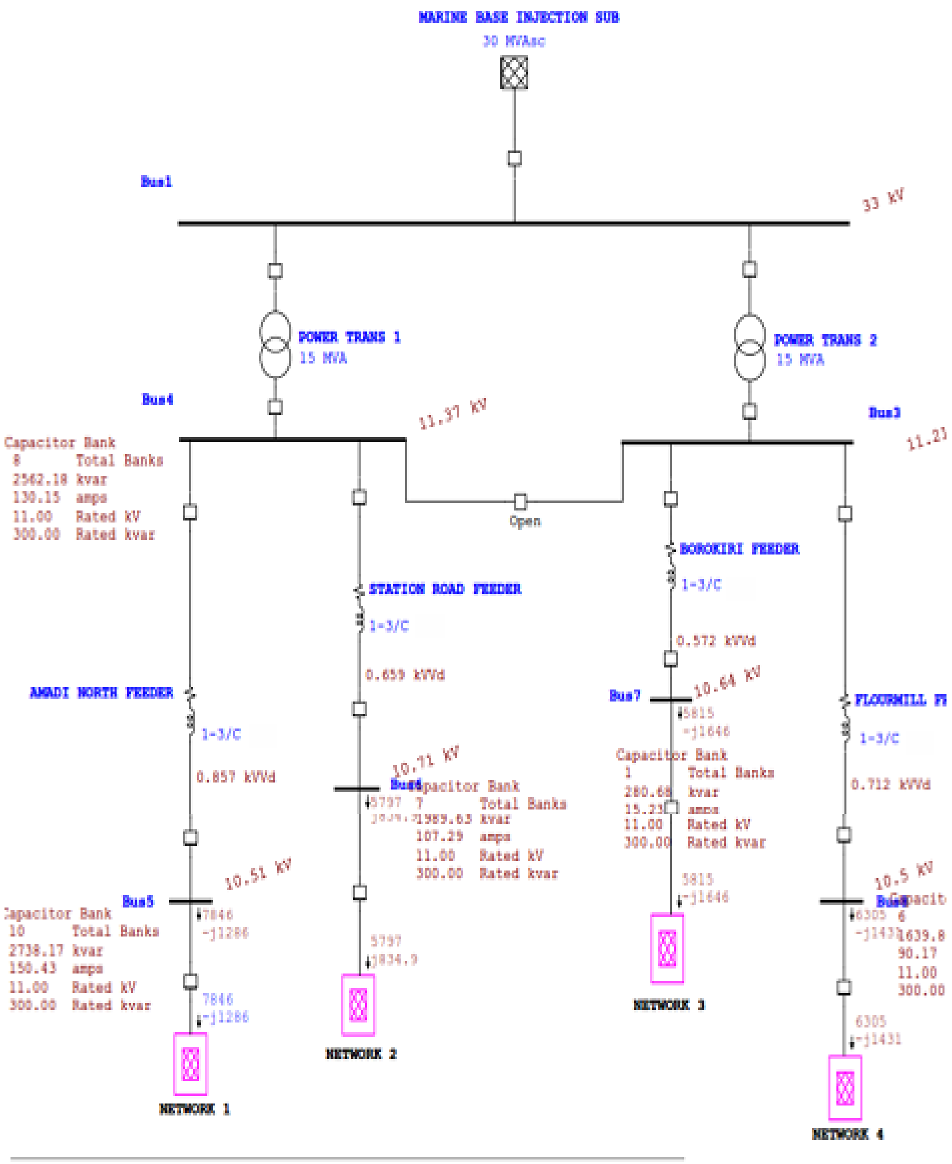

Fig. 4 Result of OCP Analysis of Old Port Harcourt Township 11KV Distribution

Fig.4 shows the results of simulation after Optimal Capacitor Placement. With the installation of 104 x 300Kvar shunt capacitors, the power factor was improved from 0.81 to 0.96 accounting for the improvement of the network's voltage profile and reduction of power losses.

4.1 Power Factor of 11KV Distribution Network for Old Port Harcourt Township

4.1.1 Before Optimization

$$PF = \frac{22631KW}{27874KVA} = 0.81$$

4.1.2 After Transformer Load Tap Changing (LTC)

$$PF = \frac{23327KW}{28784KVA} = 0.81$$

4.1.3 After Optimal Capacitor Placement (OCP)

$$PF = \frac{28602KW}{29683KVA} = 0.96$$

Table 2: Comparing Results Before and After Optimization on 11kv Buses

Before Optimization				After Transformer LTC			After OCP		
Bus ID	**Bus Total Load (MVA)**	**AMP**	**Operation Voltage (%)**	**Bus Total Load (MVA)**	**AMP**	**% V**	**Bus total Load**	**AMP**	**%V**
2	5.301	388.5	71.6	5.569	382.3	76.46	7.454	409.9	95.448
3	12.872	714.1	94.6	13.407	710.2	99.077	13.928	717.2	101.909
4	13.464	748.9	94.4	13.735	750.9	95.999	16.587	842.6	103.324
5	5.724	432.2	69.5	5.865	433.0	71.105	8.818	484.4	95.537
6	4.746	316.7	78.6	4.859	318.0	80.218	6.129	330.5	97.337
7	4.916	325.5	79.3	5.226	328.0	83.632	6.125	332.4	96.727
8	5.302	388.6	71.6	5.567	382.2	76.460	7.013	385.7	95.448
9	0.684	50.1	71.6	0.728	50.0	76.460	1.189	65.4	95.448
10	5.723	432.1	69.5	5.866	433.0	71.105	9.149	502.6	95.537
11	0.754	55.3	71.6	0.823	56.5	76.460	1.949	107.2	95.448
12	2.247	164.6	71.6	2.282	156.7	76.46	2.713	149.2	95.448
48	4.745	316.7	78.6	4.859	318.0	80.218	6.249	337.0	97.337
49	1.320	88.1	78.6	1.354	88.6	80.218	1.948	105.0	97.337
50	1.357	90.5	78.6	1.390	91.0	80.218	2.387	128.7	97.337
66	4.916	325.5	79.3	5.226	328.0	83.632	6.773	367.5	96.727
67	0.890	58.9	79.3	0.963	60.4	83.632	1.795	97.4	96.727
69	1.538	101.8	79.3	1.635	102.6	83.632	2.477	134.4	96.727
70	0.448	29.6	79.3	0.478	30.0	83.632	0.638	34.6	96.727
126	0.987	74.5	69.5	1.013	74.7	71.105	1.623	89.1	95.537
127	0.576	43.5	69.5	0.589	43.5	71.105	1.343	73.8	95.537
128	0.933	70.4	69.5	0.957	70.7	71.105	3.034	166.7	95.537

Table 2 shows the results of simulation of before and after the various optimization techniques were conducted on the network. It takes into account the power injected and current flow into the 11KV buses, as well as their operating voltages for each case study (i.e. before optimization, after LTC and after OCP).

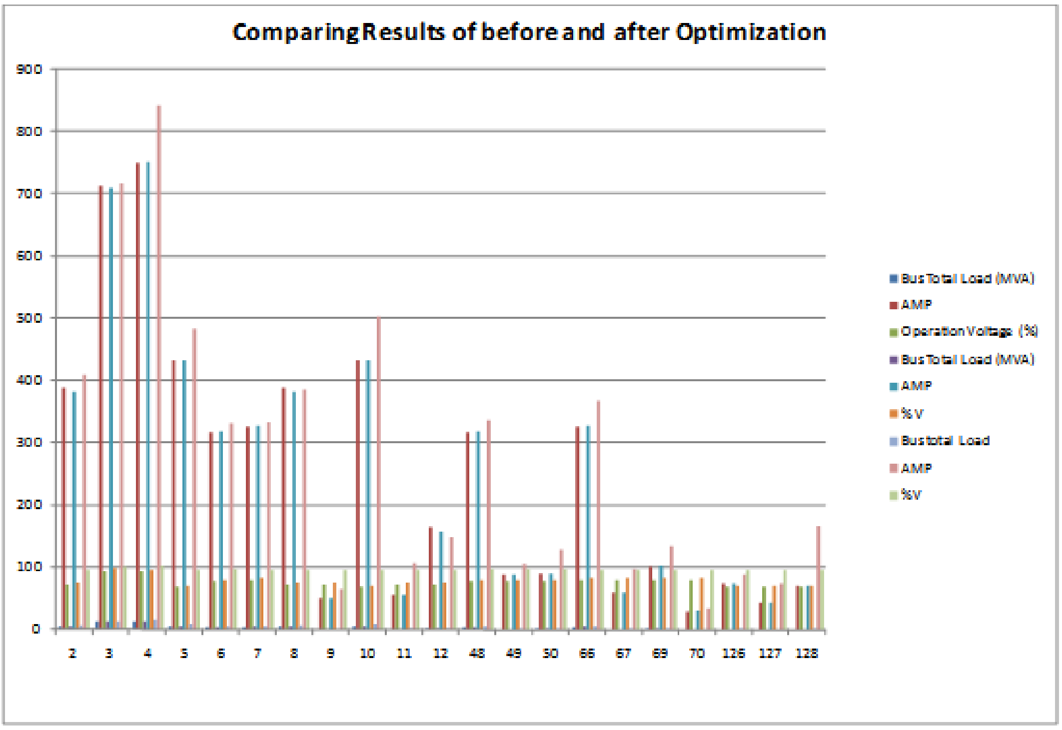

Fig. 5 Showing the comparison of results before and after optimization

Fig. 5 is a graph that shows the results of simulation of before and after the various optimization techniques were conducted on the network. It takes into account the power injected and current flow into the 11KV buses, as well as their operating voltages for each case study (i.e. before optimization, after LTC and after OCP).

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the power flow analysis of Old Port Harcourt Township 11KV distribution network, it is clearly seen that the network is highly overloading, bringing about the drastic drop in voltage profile and excessive loss of power. The introduction of optimization techniques gave rise to improvement in the power factor, which causes improvements in both the voltage profile of the network and reduction of power losses.

5.2 Recommendations

In line with the results from analysis of Old Port Harcourt Township 11KV distribution network, the following recommendations are highlighted:

- Bifurcation of feeders should be done.
- Feeders should be re-conducted with larger sizes and reduced length.
- Pressure testing should be done on feeders to correct all hot spots (high resistance points).
- Appropriately sized capacitors should be kept at strategically locations.
- A suitable size transformer should be installed at the Marine Base injection substation to free up loads on the existing 2 x 15MVA transformers.

REFERENCES

[1]. Idoniboyeobu, D. C. & Ibeni, C. (2017). Analysis for Electrical Flow Studies in Port Harcourt, Nigeria, Using Newton Rephson Fast Decoupled Techniques. American Journal of Engineering Research (AJER), 6(12), 230-240.

[2]. Grainger, J. J. & Stevenson, W. D. (1994). Power System Analysis. New York, USA: McGraw-Hill.

[3]. Antonio Trias (2012). “The Holomorphic Embedding Load flow method”. IEEE Power and Energy Society General Meeting 2011, 22 – 26.

[4]. Ochi, T., Yamashita, D., Koyanagi, K. & Yokoyama, R. (2003). The Development and Application of Fast Decoupled Load Flow Method for Distribution Systems with High R/X Ratios Lines. In 2013 IEE PES Innovative Smart Grid Technologies Conference, Washington DC, USA. Retrieved from https://waseda.pur.elsevier.com. 25th, July, 2016.

[5]. Abdulkareem, A., Awosope, C. O. A, Orovwode, H. E. & Adelakun, A. A. (2014). Power Flow Analysis of Abule-Egba 33KV Distribution Grid System with Real Network simulations. Journal of Electrical and Electronics Engineering, 9(2), 67 – 80.

[6]. Solomon Nunoo, Joseph C. Attachie & Franklin N. Duah (2012). An investigation into the causes and Effects of Voltage Drops on an 11KV feeder. Retrieved from https://www.researchgate.net/pubication/249649564. 27th June, 2018.

[7]. Abba Muhammad Adua, Abba Lawan Bukar, Danladi Muhammad Garba (2016). Design of an Electrical Distribution Network within Damaturu. International Journal of Scientific and Engineering Research, 7(2), 1484-1493.

[8]. Idoniboyeobu, D. C. & Udoha, E. E. (2017). A comparative Power Flow Analysis of Dumez 11KV Distribution Network in Nigeria. American Journal of Engineering Research (AJER). 6(12). 325-333.