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Assessment of 11kV Distribution Network for Power Loss Minimization using Analytical Technique for Capacitor Sizing

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Abstract: The need to carry out a comprehensive assessment of 11KV distribution network for power loss has become inevitable. Unstable power supply from the grid could be as a result of instability and power losses in the transmission and distribution systems, which is unhealthy to the consumer's power system operators, as well as power system equipment and operations. This work was done by carrying out load flow studies of the standing 11kV distribution network using embedded algorithm of Newton Raphson Method in ETAP Software; the losses were determined and minimized by the integration of capacitor banks (300kVar) in the critically overloaded buses and load flow was performed again. The results obtained indicates that three (3) out of the eighteen (18) distribution transformers were critically overloaded. The net real and reactive power losses are 57.92kW and 86.9kVar respectively. When reactive power was injected through capacitor banks into the system, the result shows that all the transformers and buses are better loaded, and the new net real and reactive power losses reduced to 46.18kW and 69.27kVar respectively. There is a 20% reduction in power loss and all the bus voltages fall within ±5% of nominal voltage as declared by IEEE.

Keywords: Active power, Reactive power, Power loss, Capacitor bank, Distribution network, ETAP Software

I. INTRODUCTION

Electricity has proven to be essential for all areas of human endeavour, it has been broadly acknowledged as a basic human need and proclaimed as an index for socio-economic growth, industrialization and technological advancement of any country [1]. In distribution systems, losses experienced in terms of power is high as against typical transmission systems due to the presence of high current, low voltage and high $^R/_X$ ratio; it is therefore imperative to carryout accurate loss minimization for efficient electrical power distribution. The unpredictability and exponential increase in energy demand has resulted in difficulties in planning and operating large interconnected power systems; in this manner making power systems more complex, prone to faults, less secured and unreliable [2-3]. The economic consideration and task of distribution network operators (DNO) is to minimize losses in their networks. Various techniques have been proposed by researchers for power loss reduction in distribution system, but penetration of shunt capacitor banks still remain a good option in residential area network when procurement and maintenance cost is put into consideration [4-5]. The problem of definite sizing and placement of the capacitor banks in the distribution network can be overcome by the usage of an accurate technique in order to enhance the network capacity for improved power quality.

II. RELATED WORKS

Power loss minimization problem cannot be over emphasized as a research topic, as several scholars have focused on the transmission and distribution loss reduction and enhancement of voltage stability to improve the power system at higher reliability and efficiency. Various approaches have been explored and applied to solve the power loss minimization issues, and in all of these, they have presented different forms of loss minimization tools, problem formulations, method employed and solution obtained [6-9].

Firstly, the authors in reference [10] presented a paper on the optimal sizing and sighting of distributed generators (DGs) for minimizing power losses and voltage deviation. They used Grid based Multi-objective Harmony Search Algorithm (GtMHSA) to choose the optimal size and location of the DGs. The approach was tested on Debre Markos Feeder 3 and a MATLAB program was developed to implement the location and sizing of DGs on the feeders. In reference [11], the authors presented a study on capacitor placement under variable load conditions to reduce power loss in a distribution system. They used a mixed integer linear programming algorithm and re-gradation of loads. The methodology was tested on a desired distribution network and the net present value (NPV) of the capacitor placement in the network was considered as the objective function, defined based on the network losses. Simulations were done in MATLAB software.

The results obtained from the study show that for the residential load, the active power loss before capacitor bank installation was 20.547 KW. However, when the capacitor bank was placed, the active losses using MIQP, PSO, and TLBO algorithm were 3.923 KW, 412 KW, and 428 KW respectively, with the NPV of MIQP being maximum. For the commercial load, the active power loss before installing the capacitor was 20.632kW, and the power loss obtained after installing the capacitor in various ways was 3.89, 4.10, and 4.26kW for MIQP, PSO, and TLBO, respectively. For the industrial load, the power loss before capacitor bank installation was 20.334 kW, and the resulting power loss after optimization was 4.0, 4.18, and 4.36 kW for MIQP, PSO, and TLBO, respectively. They concluded that the power loss reduction of the MIQP method was 80%. According to [12], The power loss minimization in the distribution network using Heuristic Approach for capacitor placement and sizing the technique was tested on a realistic network which is the Enugu state. According to [13], they presented a paper on distribution system power loss minimization using inherent structural characteristics theory method (ISCT) which is based on circuit law to determine the location of reactive power compensator without carrying out load flow analysis. According to [14], it is necessary to optimize location and size of capacitors for power loss reduction in radial distribution system network. They propose, the use of diffusion and update Technique Based Algorithm (DUTA) for suitable allocation and optimal sizing of capacitor banks needed. The technique was implemented in MATLAB and test on IEEE 15 bus and IEEE 33 bus distribution system with different study cases. According to [15], they presented a paper aimed at power loss minimization and reduction of cost due to losses, as well as network voltage stability improvement in distribution system through using shunt capacitor allocation.

III. MATERIALS AND METHOD

The research materials such as distribution line data, station data, bus parameters and other relevant data were obtained from Port Harcourt Electricity Distribution (PHED) Company, and others were computerized for purposes of analysis and specialized software Electrical Transient Analysis Program (ETAP), for simulation and analysis. Model was used to model the network. In a second case of load flow where the 11kV line was modelled using capacitor bank and placed on the load buses. With this, Real Power, Voltage Magnitude and phase angle were realized. Modelled calculation becomes;

$$Q_c = P \times (\tan(\cos^{-1}(pf_1)) - \tan(\cos^{-1}(pf_2))) \tag{1a}$$

Were,
P: Injected Power to the bus
pf_1: Initial power factor
pf_2: Desired power factor

The current received at bus i from the generator or power grid is given as;

$$Y_{i1}V_1 + Y_{i2}V_2 + .. + Y_{ik}V_K = \sum_{i,k=1}^{n} Y_{ik}V_k \tag{1b}$$

Considering magnitude and phase angle, the voltage and admittance will be given as;

$$V_k = V_K \angle \delta_k \quad \text{(Voltage at the bus k)} \tag{2}$$

$$Y_{ik} = Y_{ik} \angle \theta_{ik} \ \text{(Admittance between bus i and bus k)} \tag{3}$$

Substitute equations (2) and (3) into equation (1b)

$$I_i = \sum_{i,k=1}^{n} Y_{ik} \angle \theta_{ik} V_k \angle \delta_k \tag{4}$$

$\delta_i, \delta_k\ are\ phase\ angles\ of$ bus i and k, while θ_{ik} is the angular difference between bus i and k.

Conjugate of the injected current at bus i will be;

$$I_i^* = \sum_{i,k=1}^{n} Y_{ik} \angle -\theta_{ik} V_k \angle -\delta_k \tag{5}$$

Apparent power available at bus i will be;

$$S_i = V_i I_i^* = P_i + jQ_i \tag{6}$$

$$P_i + jQ_i = V_i \angle \delta_i \sum_{i,k=1}^{n} Y_{ik} \angle -\theta_{ik} V_k \angle -\delta_k \tag{7}$$

Rearranging equation (7) gives;

$$P_i + jQ_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \angle (-\theta_{ik} + \delta_i - \delta_k) \tag{8}$$

But,

$$\delta_{ik} = \delta_i - \delta_k \tag{9}$$

$$-\theta_{ik} = \theta_{ki} \tag{10}$$

Substitute the relations in equations (9) and (10) into equation (8)

$$P_i + jQ_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \angle (\theta_{ki} + \delta_{ik}) \tag{11}$$

From the equation (3.18), the active real and imaginary power will be;

$$P_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \cos\left(\theta_{ki} + \delta_{ik}\right) \qquad (12)$$

$$Q_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \sin\left(\theta_{ki} + \delta_{ik}\right) \qquad (13)$$

Equations (12) and (13) are used to obtain calculated values of real and reactive power.

$$\Delta P_i = \left|P_i^{sp} - P_i^{cal}\right| \qquad (14)$$

Were,
P_i^{sp}: the specified real bus powers at power exchange sequence i, and
P_i^{cal}: the computed real bus powers at power exchange sequence i, using equation 12

Similarly, the reactive power changes may be expressed as:

$$\Delta Q_i = \left|Q_i^{sp} - Q_i^{cal}\right| \qquad (15)$$

Were,
Q_i^{sp}: the specified reactive bus powers at power exchange sequence i, and
Q_i^{sp}: the computed reactive bus powers at power exchange sequence i, using equation 20.

In most cases, the power generated and demanded, as well as the line admittances, were given while the bus voltages and phase angles are obtained by making an initial guess and solving using a load-flow program.

The net power balance is then expressed as the sum over all bus power sequence exchanges as:

$$\Delta P_{net} = \sum_{i}^{n} \Delta P_i^2 \qquad (16)$$

and,

$$\Delta Q_{net} = \sum_{i}^{n} \Delta Q_i^2 \qquad (17)$$

In the ETAP Software, power flow equations and its solution are made possible by the use of Newton Raphson method. The network under investigation is a 6.35km length power distribution system network in Marine Base Port Harcourt comprises of incoming 33kV grid, with eighteen (18) distribution transformers with incoming voltage level of 11kV, with cumulative load capacities of 3215.84kW as shown in Fig. 1, shows the line diagram of the study case network without capacitor bank before simulation. When a capacitor bank of size 100kVar each was penetrated to bus 5, bus 10 and bus 11 as shown in Fig. 2, Shows that all, the overloaded transformers were successfully upgraded to normal loading conditions.

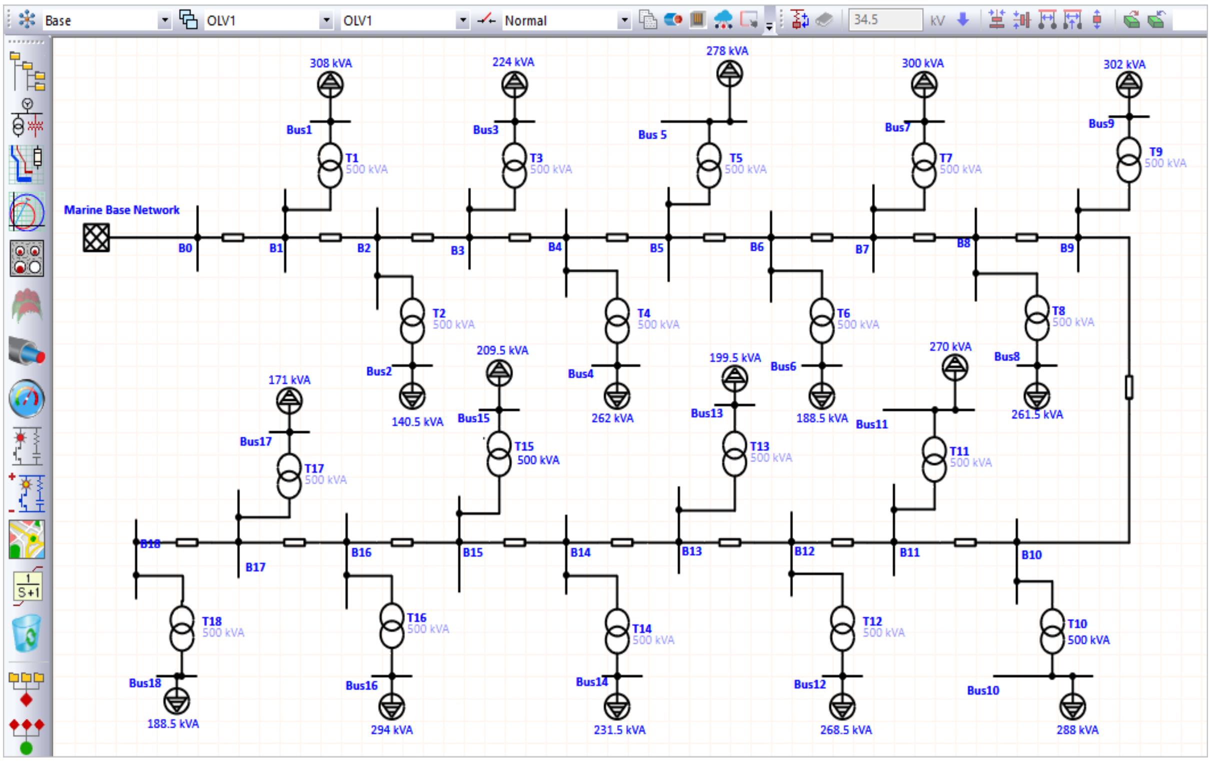

Fig. 1 Diagram of 11kV Distribution Network Modelled in ETAP Software (without Capacitor Bank)

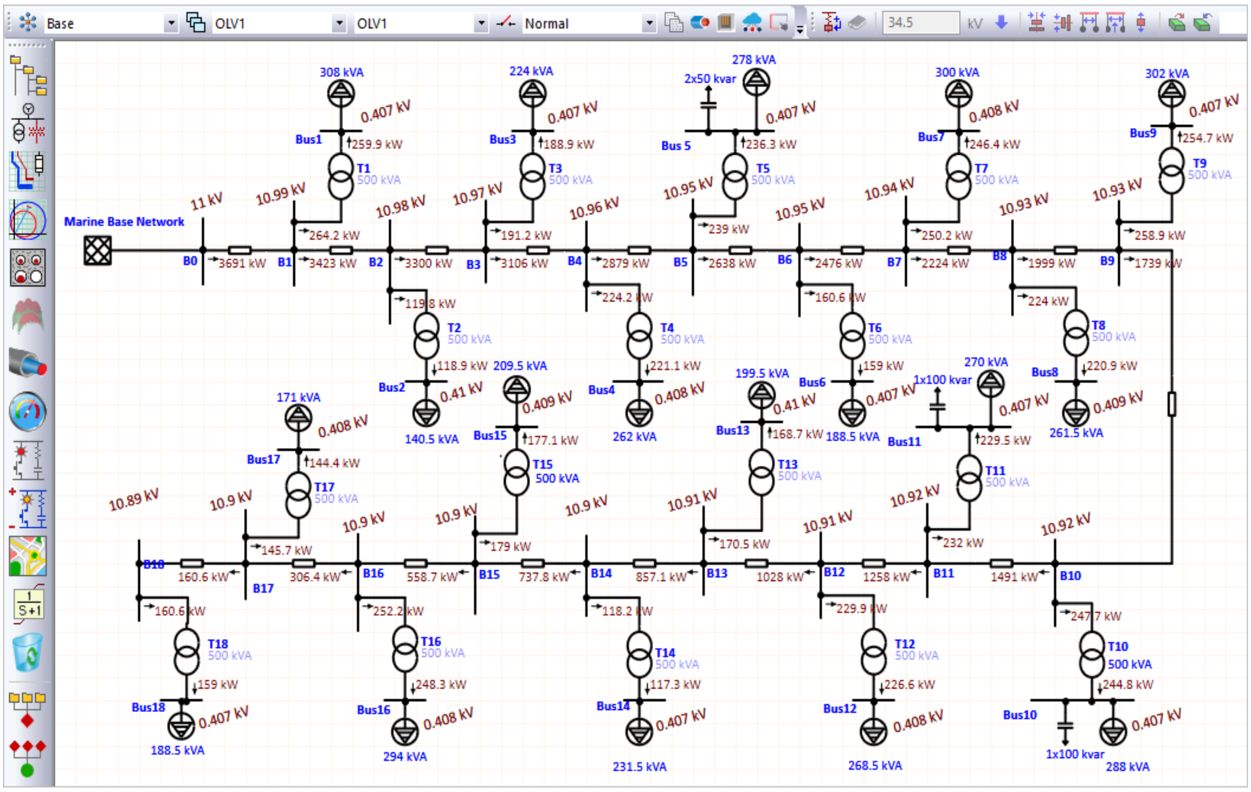

Fig. 2 Diagram of 11kV Distribution Network Modelled in ETAP Software (with Capacitor Bank)

IV. RESULTS AND DISCUSSIONS

The voltage drops in the three branches namely, T_5- B_5, T_{10} – $B1_{10}$ and T_{11} – B_{11} were very high without capacitor bank penetration as shown in Fig. 3; but when capacitor bank penetrated, the voltage drops reduces significantly. The total voltage drops before capacitor bank penetration is 34.33%, but with capacitor bank inclusion gives 20.27%.

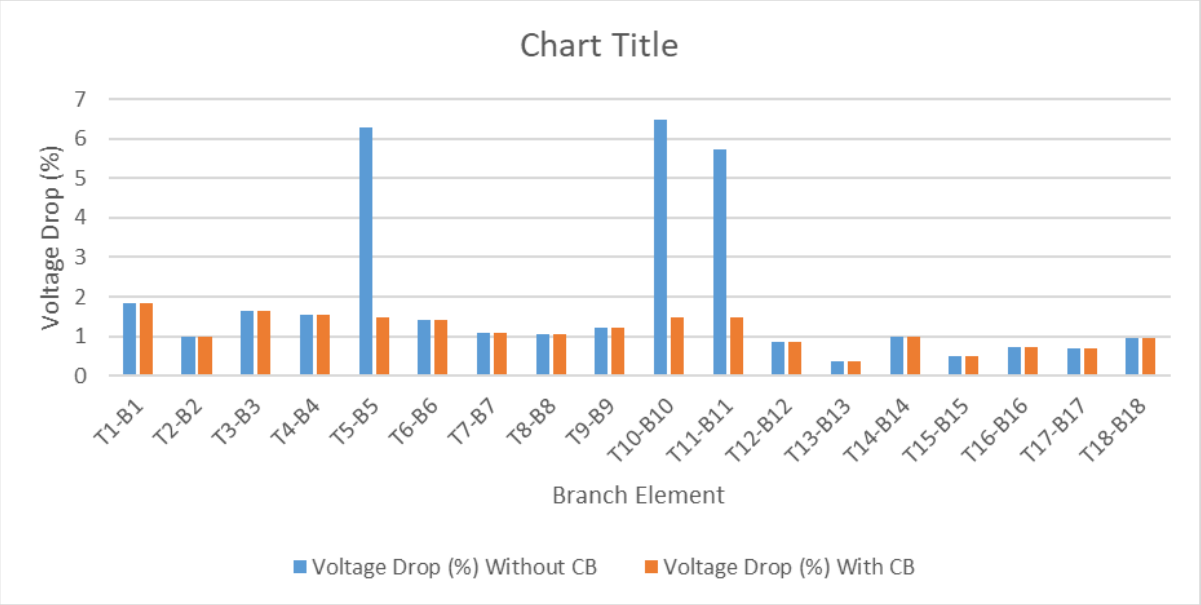

Fig. 3 Plot of Voltage Drop, with and without Capacitor Bank

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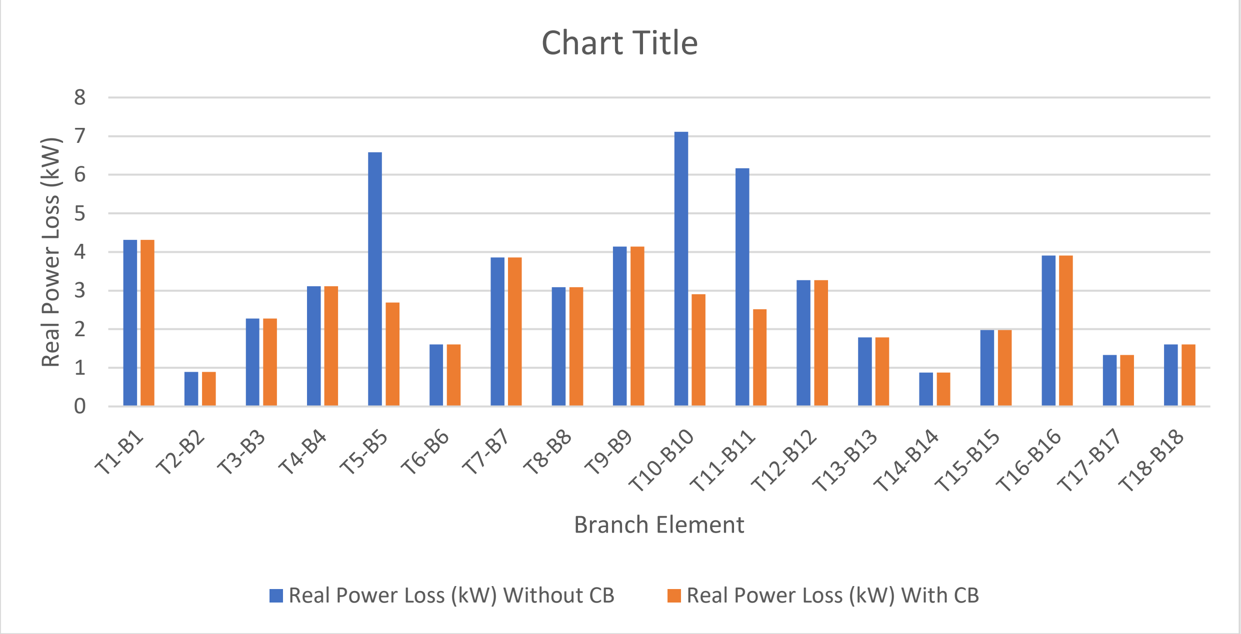

Fig. 4 Plot of Real Power Loss with and without Capacitor Bank

The chart shown in Fig. 4, presented results that shows the real power loss in all branches are almost the same for with and without capacitor bank, except the three (3) branches which capacitor bank were placed. The total real power loss without capacitor bank is 57.92kW while for that with capacitor bank is 46.18kW. Results as shown in Fig. 5 indicates three buses (3) out of eighteen buses were overloaded and such facing problems of under voltage in the existing network.

However, after integration of capacitor banks, the buses 5, 10 and 11 were upgraded from critical position to good loading condition and fall within the IEEE limit ±5% of nominal voltage.

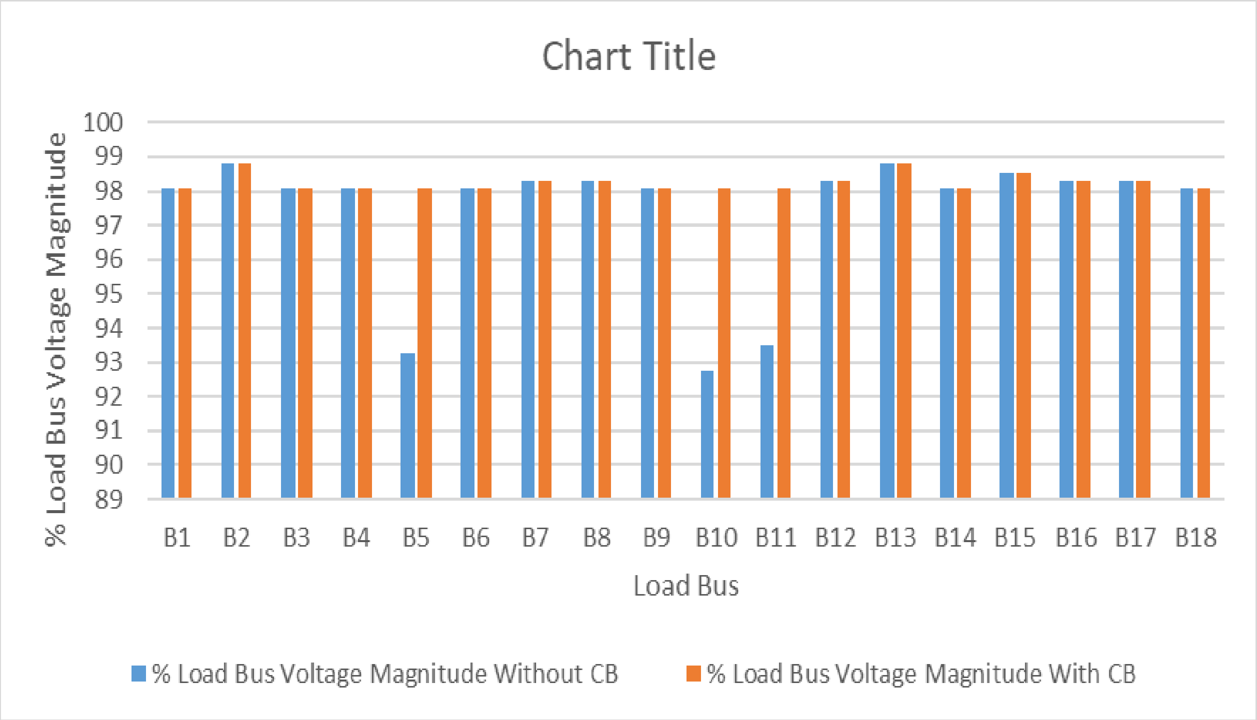

Fig. 5 Plot of Percentage % Load Bus Magnitude with and without Capacitor Bank

V. CONCLUSION

In concern economics today, it has been accepted that socio-economic growth, technological advancement and industrialization can be attained quickly with regular, reliable and stable power supply. Power loss in the distribution network can lead to epileptic power supply to domestic, commercial and industrial consumers, thereby hampering development. This erratic power supply in the distribution network can be alleviated by improving upon loss minimization in the system. If a stable power system is desired, then, power system evaluation and loss minimization is paramount which prove the need to the research work. The distribution line data were collected from PHED and analysed.

ETAP software was used to carry out load flow analysis of 11kV Marine Base Distribution Losses from the load flow. The determined losses in 11kV distribution network were reduced with the penetration of sizable capacitor banks at the most imparted buses. Then validating the percentage loss reduction in improving loss minimization in the study case distribution network by comparing the results of losses with and without Capacitor Bank inclusion. In comparison the results obtained showed the present status of the network having active and reactive power losses as 57.92kW and 86.9kVar respectively. When a 100kVar capacitor banks each was penetrated into bus 5, bus 10 and bus 11, the active and reactive power losses reduced to 46.18kW and 69.27kVar respectively. This indicates that when a capacitor bank (300kVar) is injected into the system, the real and reactive power losses then reduced by 20%. Other parameters that improved are voltage profile, percentage voltage drop, real and reactive power flow.

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