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Optimal Placement of Capacitor Bank on Ondo 132/33KV Transmission Substation

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AOA and TDE conceptualized the idea. Author FTO was immensely involved in neplan simulation. Author AAA performed and interpreted the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Introduction: Relevancies of electrical power system to consumers cannot be overemphasized. This requires healthy operation of such system. 132/33KV network is an important network within the transmission system and its importance calls for effective and efficient operation. However, due to the long distance at which the transmission line span, the nature of the lay (either overhead or underground) and type of cable used, there are series of voltage instability and power loss along the transmission network which are threat both economically and technically to both electricity providers and consumers because of the cost implication of the losses and effect on the stability of the network.

Aims: This research aims is to seek optimal placement of a capacitor bank to proffer solution to both voltage instability and power loss problem by simulating Ondo 132/33KV transmission network using NEPLAN software.

Methodology: The network model was developed using NEPLAN software. The voltage profile and power loss with and without capacitor bank were determined from power load flow solutions using Newton-Raphson method.

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Results: Effects of optimal placements of capacitors along the studied transmission line is established.

Conclusion: Proper installation of capacitor bank is also found to enhance performance with an accompanied improvement in voltage profile along the buses.

Keywords: Power loss; voltage instability; NEPLAN; capacitor bank; transmission network.

1. INTRODUCTION

Ondo 132/33KV network in Ondo State, Nigeria usually experience increase in power losses and low voltage profile. This is majorly due to the excessive use of inductive loads by various industries within the environment been an industrial hub in the state. The led to an increase in the electric load. Often time such increase is accompanied with low power factor which leads to huge transfer of reactive power from the utilities through the network. The main disadvantage of this problem is increase in the network losses, poor voltage regulation, poor power factor, poor efficiency overloading and less reliability for continuity of supply. It is necessary to improve the working of the power transmission systems to reduce these unfavorable conditions by compensating for the reactive power for inductive loads. The reactive power source must be very close to the load for efficient operation and improvement of the system.

According to [1], system improvement has to be planned properly with these five objectives:

I. to reduce losses in the sub transmission system,
II. to improve the voltage regulation
III. to improve the continuity of supply,
IV. to improve the power factor in the sub-transmission and distribution system
V. to compensate reactive power in substation.

The researchers therefore suggested the use of capacitor bank in transmission system to improve the power factor and voltage regulation. According to [2], shunt capacitor bank improves the power factor, increase voltage level on the load and reduces current flow through the transmission lines. The main reason of installing a capacitor bank is to reduce electricity costs. An inappropriate installation without enough study give rise to a great variety of technical problem.

2. BACKGROUND AND RECENT TRENDS IN EFFECTS OF CAPACITOR BANK

Reference [3] discussed one of the most common and efficiency in distribution network for power factor improvement and voltage regulation control which is shunt capacitor bank. The most important parameter in power factor improvement and voltage regulation process is the location and value of the capacitor bank. They also discussed issues should be considered in capacitor bank location select. In this paper, simulation of IEEE 14 bus on MATLAB Simulink was used with genetic algorithm to select capacitor bank location and values base on fitness function. Result showed construability of genetic algorithm in cost and power factor values depend on client demand by Capacitor bank location optimization location and value.

Voltage profile and power losses on the distribution system is a function of real and imaginary power loading condition [4]. This can be effectively managed through the controlled real and reactive power flow by optimal placement of capacitor banks (CB) and distributed generators (DG). [4] presented Adaptive Particle Swarm Optimization (APSO) to efficiently tackle the problem of simultaneous allocation of DG and CB in radial distribution system to revamp voltage magnitude and reduce power losses. The modification to the conventional Particle Swarm Optimization (PSO) was achieved by replacing the inertial weight equation (W) in the velocity update equation, based on the particle best experience in the previous iteration. The inertial weight equation is designed to vary with respect to the iteration value in the algorithm. The proposed method was investigated on IEEE 30-bus, 33-bus and 69-bus test distribution systems and results show a significant improvement in the rate of convergence of APSO, improved voltage profile and loss reduction.

Yogesh et al. [1] showed how shunt capacitor bank improves the power factor, increases voltage level on the load and reduces current flow through the transmission lines. A major reason of installing a capacitor bank is to increase power factor voltage level [1]. Therefore, the capacitor banks are designed for long-term use should be considered. Capacitor have fixed parts, initial cost is low, up keep costs are minimal, and they are compact, reliable, and highly efficient and can be installed basically three possibilities to correct loads individually, in groups or centrally. In this paper, model of 12 MVAR rating of shunt capacitor bank is designed installation for 33 kV bus bar is Mhasrul 132/33 kV substation in Nasik.

Rewar et al. [5] presented benefit of shunt capacitor banks in distribution network on voltage, losses, and lines loading. 12.66 kV, 33 IEEE Bus system was simulated using Mi-Power power system analysis software to verify it effectiveness.

Bhola et al. [6] carried out a load flow study on 132KV and 33KV sub- stations to detect effect of group shunt compensation. It was discovered that if reactive power is supplied near the load, the line current will be reduced or minimized, reducing power losses and improving voltage regulation at the load terminals. The leading current drawn by the shunt capacitors compensate the lagging current drawn by the load.

Mohan and Aravindhababu [7] presented a new algorithm for optimal locations and sizing of static or switched shunt capacitor in order to enhance voltage stability in addition to improving the voltage profile and minimizing losses. This method found the optimal location and determined the size and type of capacitor bank to be placed to enhance the voltage stability besides improving the voltage profile and reducing the system losses.

Gagari et al. [8] presented an approach in order to determine the size of capacitor in power system to minimize investment cost and energy loss and for improving power factor.

Al-Naseem and Adi [9] suggested that when designing a compensation scheme one should attempt to achieve the most economical solution in which the saving achieved in the equipment cost is significantly greater than the procurement cost of reactive power

Deepti Randive and Varsha Tandon [10] presented an analysis of reactive power control and voltage stability in power systems. It identified a new model used to enhance voltage stability and exposed several key issues that had remained as research challenges in this area. The steady state voltage and reactive power control in distribution systems can be properly controlled by coordinating the available voltage and reactive power control equipment, such as on-load tap-changers, substation shunt capacitors and feeder shunt capacitors. It began with an overview of reactive power and voltage stability in transmission, distribution and load, and the importance of providing reactive power locally. It explained the need to improve the voltage stability of power system, as well as the increasing requirements for energy quality and security. It also discussed the techniques that were adopted in controlling and monitoring of the rate of power flow in the entire power system topology. This investigated the system to an optimal level in order to reduce losses and ensures sufficiency of reactive power control during normal and emergency conditions and to prevent voltage

Nadjafi and Hajivand [11] discussed the use of capacitor banks in distribution system which has many outstanding usages include improving the power factor of a system, voltage profile, and reliability besides the reducing of the power flow losses of the component’s reactive due to the compensation. These benefits depend greatly on how capacitors are placed in the distribution system. Hence, in order to achieve the high reliable construction, switching capacitor has been placed to improve the main challenges of the network designing (reliability and reduce power loss) in the radial distribution system.

Most of earlier researchers do not emphasize on effect of proper placement of capacitor bank along transmission line. Therefore, this research is aimed at assessing the effect of optimal placement of capacitor bank along a typical transmission line with the aim of reducing power line losses which is key to system stability.

Legha and Torkizade [12] discussed of growing trend of power industry, losses and how to reduce it. Capacitor form is one of the main ways to reduce losses. In this journal article the effects of capacitor was analysed for the effects of compensating reactive power, voltage profile and power factor before and after capacitor placement. The result showed a recovery rate of the network parameters with suitable installation of the capacitor.

Most of earlier researchers do not emphasize on effect of proper placement of capacitor bank along transmission line. Therefore, this research is aimed at assessing the effect of optimal placement of capacitor bank along a typical transmission line with the aim of reducing power line losses which is key to system stability.

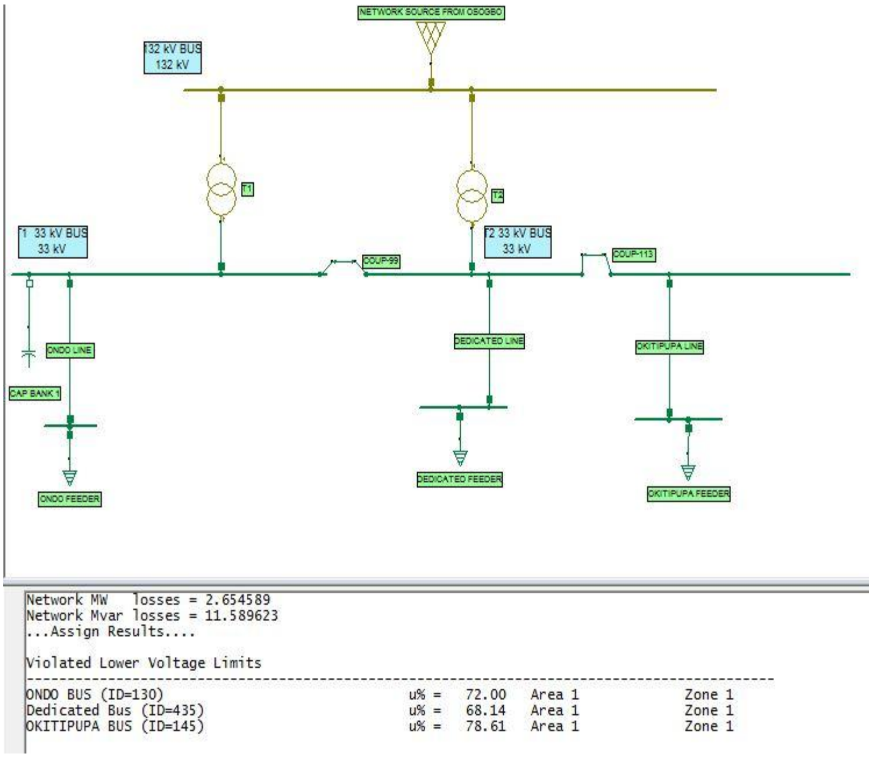
2.1 Ondo 132/33KV Substation Supply Source

The Ondo 132/33kV transmission substation is situated at Ondo City in the central part of Ondo State. The station is fed at 132kV voltage from Osogbo 330/132kV Transmission Station (Area Control Centre, ACC), [13]. The substation has two power transformers namely T1 and T2 respectively and both rated 30MVA. The substation also has three outgoing 33KV feeders namely Ondo 33 kV feeder, Dedicated 33 kV feeder and Okitipupa 33kV feeder respectively

3. RESEARCH METHODOLOGY

The methodology that was used in this study are:

(a) carried out comprehensive literature review
(b) the following data were obtained system data from Ondo 132/33kV transmission substation's logbook
    (i) Transmission line parameters such as the length of the lines in km, shunt admittance (resistance and reactance in Ω/km respectively) and line capacitance in μF/km.
    (ii) Busbar parameters are the rated bus voltages in kV, the frequency in Hz and the bus type (generator bus, slack bus or load bus).
    (iii) The load parameters such as load flow type (PQ), active power (P) in MW, reactive power (Q) in MVAR, apparent power (S) in MVA, load current (I) in A, the power factor (PF) and the dynamic model (constant Z) were obtained.
(c) Modelled 132/33kV Transmission Substation from data obtained using software called NEPLAN
(d) carried out load flow analysis of the network using Newton Raphson Method
(e) Identified the bus voltages under two scenarios were considered for this project. They are:
    (i) Load flow and voltage profile under base case without capacitor bank
    (ii) Load flow and voltage profile under base case with capacitor bank



```
Network MW   losses = 2.654589
Network Mvar losses = 11.589623
...Assign Results....

Violated Lower Voltage Limits
----------------------------------------------------------------------------------------
ONDO BUS (ID=130)                               u% =   72.00   Area 1          Zone 1
Dedicated Bus (ID=435)                          u% =   68.14   Area 1          Zone 1
OKITIPUPA BUS (ID=145)                          u% =   78.61   Area 1          Zone 1
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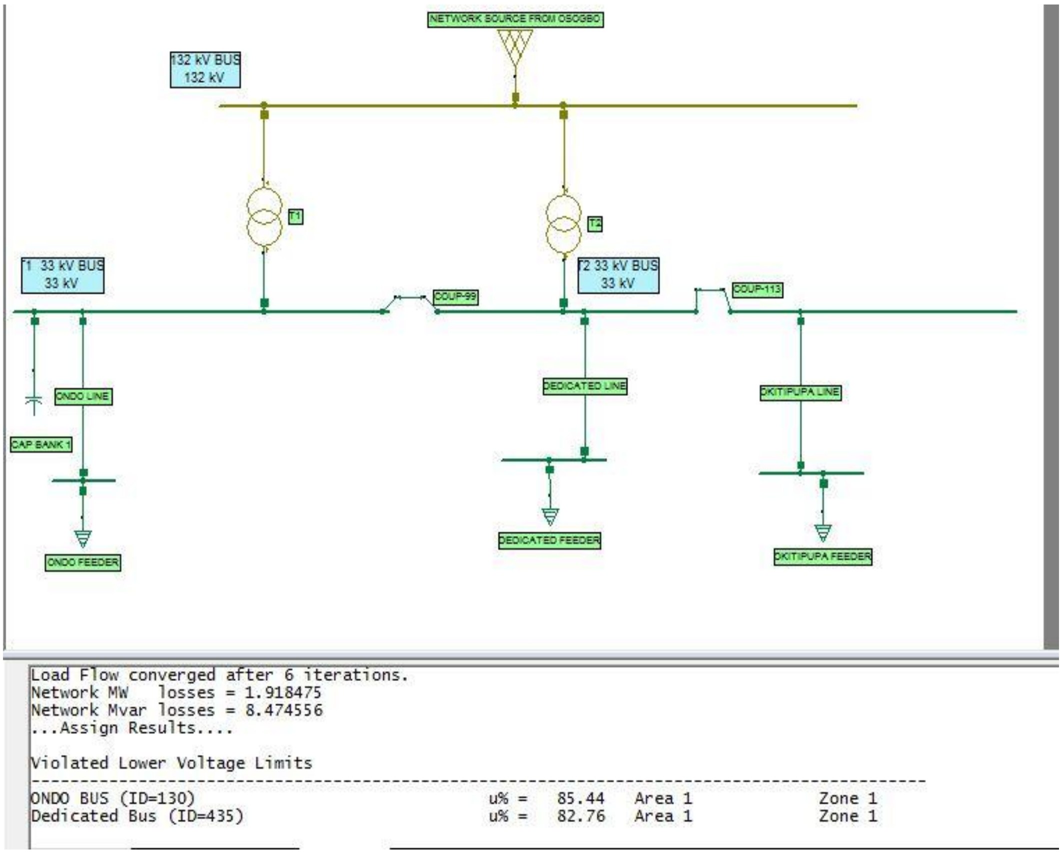
Fig. 1. Modelling of Ondo 132/33kV network without Capacitor Bank



```
Load Flow converged after 6 iterations.
Network MW   losses = 1.918475
Network Mvar losses = 8.474556
...Assign Results....

Violated Lower Voltage Limits
------------------------------------------------------------------------------------------
ONDO BUS (ID=130)                              u% =   85.44   Area 1           Zone 1
Dedicated Bus (ID=435)                         u% =   82.76   Area 1           Zone 1
```

Fig. 2. Modelling of Ondo 132/33kV network with Capacitor Bank

3.1 Modeling of Ondo 132/33 KV Substation

NEPLAN was used for the network modelling because of its superior capability in handing load flow and network stability analysis. NEPLAN has capabilities to perform many operations in power system network such as: Load flow, Load flow with profiles, optimal separation points, optimal distribution network, optimal capacitor placement, voltage stability, transient stability etc. Fig. 1 and 2 show network modelling of Ondo 132/33kV network without capacitor bank and with capacitor bank respectively using NEPLAN software.

4. RESULTS AND DISCUSSION

The optimal location of the capacitor bank minimizes real and reactive power losses on the power system and also to boost the voltage profile of the lines. This was obtained using conventional Newton-Raphson iterative method of load flow in NEPLAN software which converges after six iterations. The results obtained with and without capacitor bank are shown in Table 1 and Table 2 below with effect on both real power loss, reactive power loss and voltage profile.

Table 1. Load Flow Results for the Buses without Capacitor Bank

	Name of Buses	V (kV)	v (%)	P Load Loss (MW)	Q Load Loss (MVar)	State	Remarks
1	T1	31.26	94.72	0.0895	1.2497	Normal	Good
2	T2	31.36	94.71	0.0895	1.2497	Normal	Good
3	Ondo	23.76	72.00	1.0180	3.5681	Low Voltage	Critical
4	Okitipupa	25.94	78.61	0.5598	2.4316	Low Voltage	Critical
5	Dedicated	22.49	68.14	0.8971	3.0904	Low Voltage	Critical

Table 2. Load Flow Results for the Buses with Capacitor Bank

	Name of Buses	V (kV)	v (%)	P Load Loss (MW)	Q Load Loss (MVar)	State	Remarks
1	T1	34.24	103.76	0.0813	1.1354	Normal	Good
2	T2	34.24	103.76	0.0811	1.1329	Normal	Good
3	Ondo	28.20	85.44	0.7218	2.4432	Average Voltage	Sustainable
4	Okitipupa	29.71	90.03	0.4261	1.792	Normal	Good
5	Dedicated	27.31	82.76	0.606	1.9709	Average Voltage	Sustainable

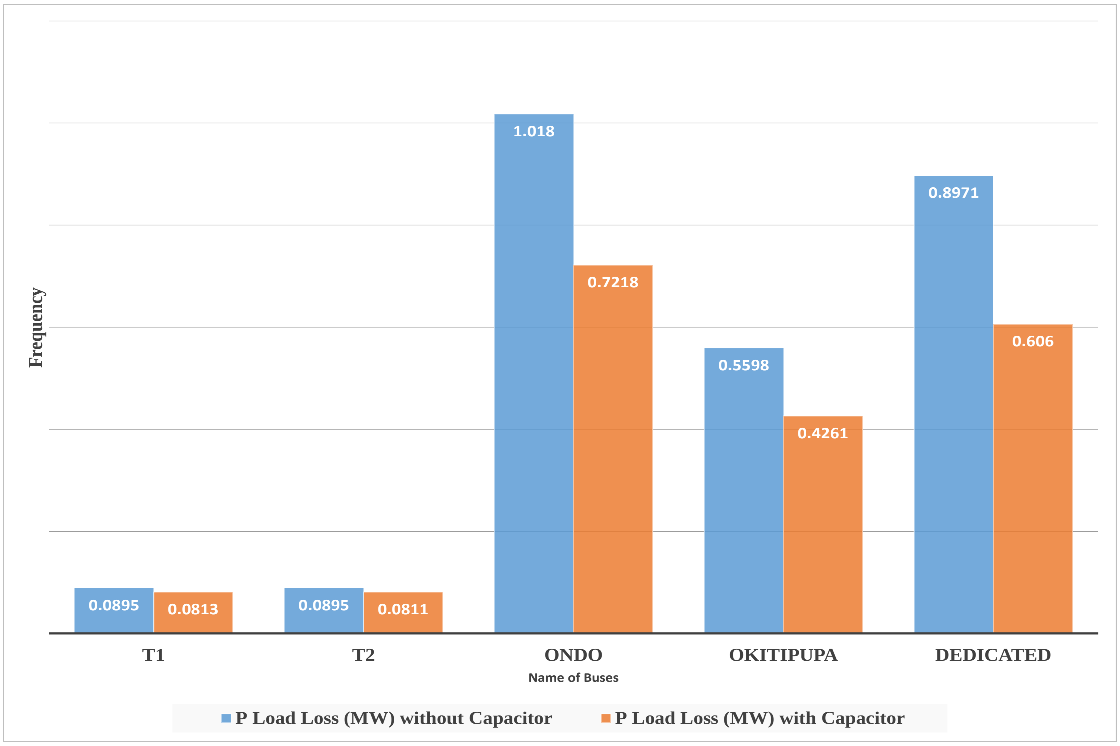


Fig. 3. Comparison of real power losses on the lines

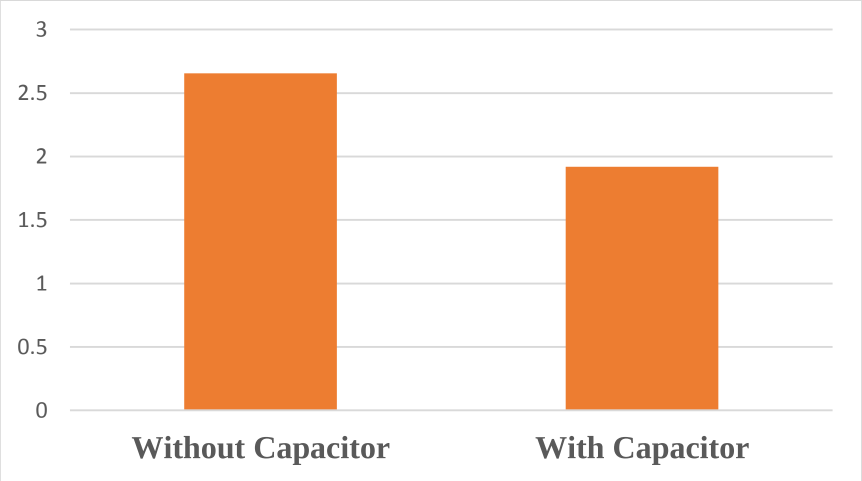


Fig. 4. Cumulative effect on active power loss

4.1 Comparison of Real Power Loss

The real power loss of the case study without capacitor and with capacitor banks are compared. The losses on each lines when the capacitor bank was introduced were reduced compare to without capacitor bank as shown in Fig. 3. Fig. 4 show the overall effect of the capacitor bank on active power on the entire network under consideration.

The real power loss was saved by 0.7361MW when shunt capacitor bank is optimally installed. Loss without capacitor bank is 2.6546MW which was reduced to 1.9185MW with capacitor bank.

4.2 Comparison of Reactive Power Loss

The reactive power is also reduced when the capacitor bank is installed optimally. Fig. 5 shows the relationship between the Var loss on the line with and without optimally place capacitor bank. A reduction of 3.115MVar was achieved. That is from 11.5896MVar without capacitor bank to 8.4746MVar with capacitor bank as shown in Fig. 6.

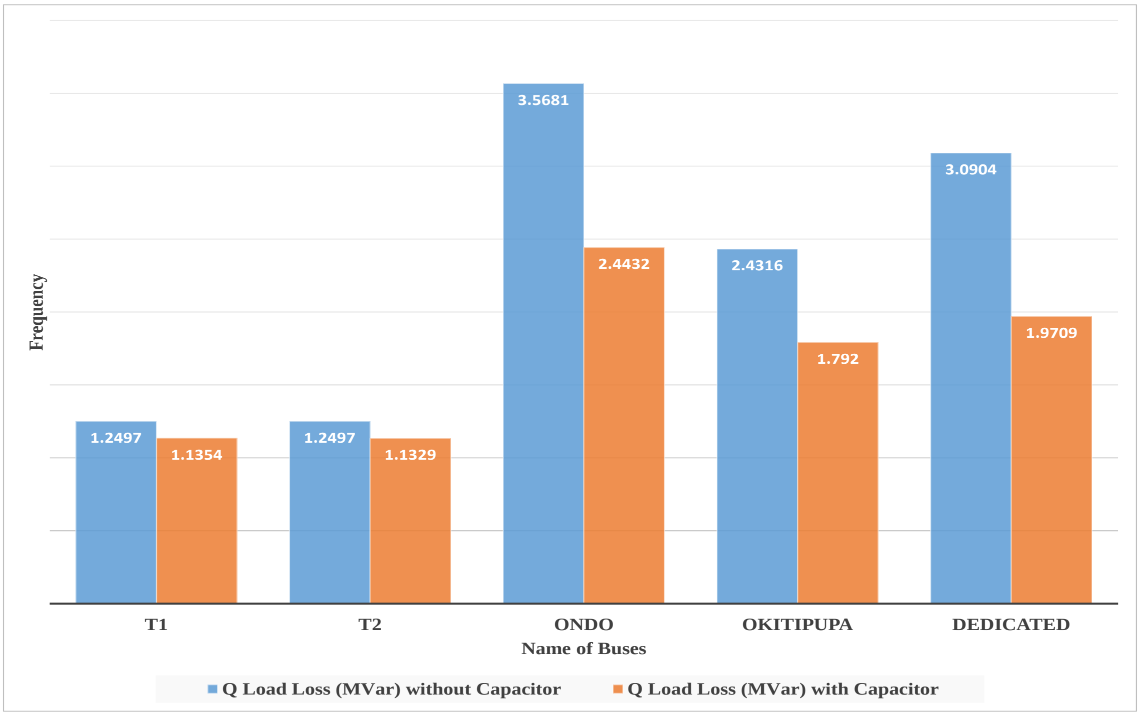


Fig. 5. Comparison of reactive power losses on the lines

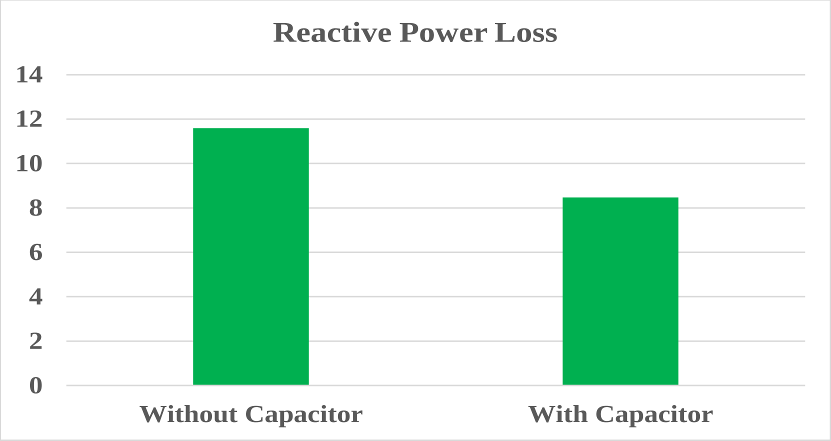


Fig. 6. Comparison of reactive power loss

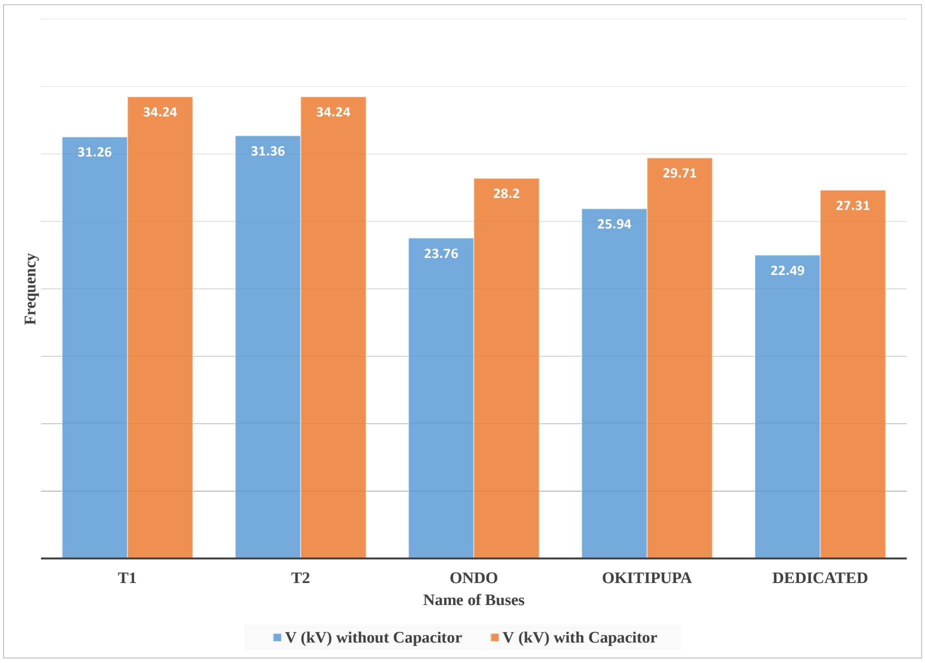


Fig. 7. Comparison of voltage profile

Table 3. t-Test Table

	V (kV) without	V (kV) with	V (%) without	V (%) with	P Load Loss (MW) without	P Load Loss (MW) with	Q Load Loss (MVar) without	Q Load Loss (MVar) with
Mean	26.962	30.740	81.636	93.150	0.531	0.383	2.318	1.695
Variance	17.278	10.944	156.568	100.569	0.190	0.087	1.114	0.319
t Stat	-9.808		-10.185		2.308		2.767	
P-value	0.001		0.001		**0.082**		**0.050**	

4.3 Comparison of Voltage Profile

The voltage profile either with or without capacitor bank are also presented in the chart form as shown in Fig. 7. When capacitor is installed at the optimal bus, voltage profile is increased at all buses as also shown in Fig. 7.

4.4 t-Test: Paired Two Sample for Means

The t-test for paired sample tests for the significant difference between each pair of:

(i) V (kV)
(ii) V (%)
(iii) P Load Loss (MW) and
(iv) Q Load Loss (MVar)

The aim is to observed effect of each variable with and without Capacitor. Observations under each variable are compared and the result is presented in the table above.

The Table 3 shows that there is a significant difference in the observation with variables (i) V (kV) and (ii) V (%). Although the capacitor usage has higher effect in the variable (iv) Q Load Loss (MVar) with an approximate P-value of 0.050 when compared to the rest variables.

5. CONCLUSION

This work has been able to establish effects of an optimally placed capacitor bank on transmission power network with Ondo 132/33kV network as a case study. The optimal installation of capacitor bank led to an improvement in voltage profile of all the 33kV buses. In which the bus with least voltage profile increased by 14.6% after compensation. Also placement of capacitor bank reduced power transmission losses on all the 33kV buses. Generally, it is not out of place that installation of capacitor bank affects overall system performance positively with an improvement in voltage profile and reduction of power losses of all the buses. With the improvement in voltage profile, there is voltage stability in the network.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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