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Improvement of Electricity Supply to a Semi Urban Community Using STATCOM

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Abstract

Power system distribution losses and bus voltage magnitude deviations are critical issues that require attention in improving electricity supply to the consumers. It is a global concern, however this study is conducted in Okwuzi town 11kV power system consisting of one power transformer and seven (7) distribution transformers with a total demand of 2.8MW, High power losses and less voltage stability issues are some challenging problem in the town. Load flow analysis of the 11KV distribution network using embedded Newton Raphson method in Electrical Transient Analysis Program (ETAP) software and utilizes to analyze the system with the application of Particle Swarm Optimization (PSO) algorithm to find the KVAR size and location of Static Synchronous Compensator (STATCOM) for reducing power losses and improve the voltage profile, From the evaluation, the critical bus recorded is bus 9 with optimal size of about 2500KVAr. A load flow analysis revealed that the active power loss and reactive power loss in the existing network is 85.63kW and 193.7167KVAr respectively. With the integration of STATCOM, active power loss and reactive power loss reduced significantly to the values of 67.03kW and 143.71KVAr. The result also revealed that when STATCOM was penetrated into the network, all the bus voltage magnitude falls within IEEE statutory limit, hence electric power supply to the study area has improved.

***Keywords**: PSO, Electrical Transient Analysis Program, KVAR, STATCOM, Reactive Power Loss, Real Power Loss, Embedded Newton Raphson Method, Statutory Limit*

1.0 INTRODUCTION

It is a known fact the electric power generated by power stations do not match the units demanded by consumers in developing countries like Nigeria[1]. The distribution system which is the last part of the power and controls the supply of electricity to consumers, experiences some electrical losses. These losses may be as a result of factors like system failure, overloading of the system, excessive reactive power consumption by the load etc. Some devices in the distribution system do not meet their specified voltage deviation limit (0.95≤ 1.05Pu). So, such device can consume a high amount of current, which leads to a large voltage deviation and power loss in the network.

Therefore, attaining acceptable voltage level in the distribution system, so that electrical loads connected to system will perform satisfactorily is a daunting task [2].

Improvement of electricity supply to the consumers through system power loss reduction and voltage stability enhancement is an essential aspect of maintaining a reliable and efficient power network. Therefore, investing in the assessment of power losses and mitigation is beneficial for economic and environmental reasons, as well as for the overall reliability and functionality of the power network [3]. The conventional method of distribution line upgrading is highly capital demanding with limited expansion in power capacity. The problem of losses can be minimized by appropriate VAR management scheme through the deployment of sizable electronic controllers like Static Compensator (STATCOM) which is the main concern of this study, as it delivers effective reactive power coupled with better ability to provide fast and continuous response during inductive and capacitive mode compensation [4]. This give the regulators confidence that proper allocation is being made to utilities. Cost effective approaches to utilities to reduce waste and allows utilities to document energy savings, then improve the overall performance of the system.

1.2 Statement of the Problem

The study case power system network (11kV distribution network of Okwuzi, Omoku in Rivers State) is characterized with high power losses resulting to blackout and epileptic power supply in the area. Some of the reason responsible for the high power losses include: aging of the conductors, poor voltage regulation because of absence of VAR support, far distance from the main substation and overloading of some distribution transformers.

Although, in electric power system, power loss often occurs when utilities supply electricity to the consumers through distribution lines. Ideally, the active and reactive power losses should be as low as possible, also, the voltage magnitude should be within the specified limit by the statutory authority [5]. In order to improve power supply to the study area, the system performance must be enhanced by reducing power losses and improve bus voltage profile.

This study proposes the placement of STATCOM at the critical bus of Okwuzi, Omoku 11kV distribution network using Particle Swarm Optimization (PSO) technique embedded in Electrical Transient Analyzer (ETAP) software.

1.3 Aim of the Study

The aim of this research is to improve electricity supply to semi urban community in Nigeria via power loss reduction and bus voltage profile improvement with the penetration of STATCOM in the 11kV distribution network supplying the area

In order to achieve the aim of this study, the objectives outlined for this research work include:

(i) To carry out load flow study of the existing 11kV network using Newton Raphson method in ETAP and record power losses and bus voltage profile

(ii) To size an appropriate STATCOM using PSO in ETAP and placed it at the critical bus of the network, then perform load flow study for the second time.
(iii) To validate the improvement of power supply by the network, compare the power losses and bus voltage magnitude with and without STATCOM placement.

2.0 LITERATURE REVIEW

2.1 Brief Review of Related Works

Several researchers have explored different approaches or way to improve electricity supply through assessment and mitigation of power losses and voltage deviation in power system network. Some authors have used analytical technique to size the VAR compensating device while some others have used either heuristic or evolutionary algorithm techniques.

According to [6], they presented a paper on the utilization of analytical technique to determine the numbers and sizes of relief transformers needed to reduce power losses of the subjected network. Newton Raphson power flow method embedded in Dig silent (15.1) Power factory was used for simulation.

According to [7], they presented a paper on the usage cuckoo search algorithm (CSA) to determine the optimal size of DG and DSTATCOM to reduce power losses of study case network. To determine the location of DG and DSTATCOM, a loss sensitivity factor (LSF) and Voltage stability index (VSI) were applied.

According to [8], they carried out a study on the power loss reduction and voltage profile improvement on a 33kV distribution network using analytical method to determine the size of capacitor bank to penetrate for reactive power compensation. Electrical Transient Analyzer program (ETAP) was used for the simulation.

According to [9], they presented a paper on the utilization of Particle Swarm Optimization (PSO) for optimal sitting and sizing of D-STATCOM to minimize power loss maximize voltage profile in radial distribution network. Voltage stability index (VSI) was used to identify suitable placement of the D-STATCOM.

According to [10], they examine the application of static synchronous compensator (STACOM) on the Nigeria 330kV in order to reduce system losses and stabilize the system voltage thereby providing additional capacities for the consumers

3.0 MATERIALS AND METHOD

3.1 Materials Used

Materials used in this research include electrical transient analyzer program (ETAP) software, excel software as well as single line diagram of study area network, line / bus data and route length of the line. The transformer and load data as shown in Figure 3.1 was obtained from the utility company, First Independent Power Limited.

Table 3.1: Transformer and Load Data at Okwuzi(Omoku) at 0.8 PF

BUS ID	TRANSFORMER (MVA)	INPUT/OUTPUT (KV)	UNIT	LOAD (MVA)
2-3	15	33/11	1	2.6
5-6	1	11/0.415	1	0.325
7-8	0.75	11/0.415	1	0.325
9-10	0.5	11/0.415	1	0.325
9-11	0.5	11/0.415	1	0.325
9-12	0.5	11/0.415	1	0.325
9-13	0.5	11/0.415	1	0.325
9-14	0.5	11/0.415	1	0.325
9-15	0.5	11/0.415	1	0.325

Source: First Independent Power Limited (2023)

3.2 Load Flow Analysis

3.2.1 Newton Raphson Load Flow Formulation.

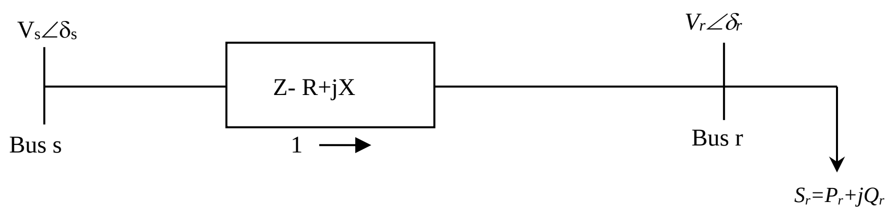

Figure 3.2: One-Line Diagram of a Two-Bus Power System Model

The expression for current flow in a power system network in polar form is given as [11]

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_t| \angle (\theta_{ij} + \delta_j) \tag{3.1}$$

To determine the real power at a given bus given as;

$$P_i = |V^* I_i + jQ_i| \tag{3.2}$$

This can be rearranged in polar form as

$$P_i = |V_i|\angle(-\delta_i)\sum_{j=1}^{n}|Y_{ij}||V_t|\angle(\theta_{ij}+\delta_j) + jQ_i \tag{3.3}$$

Equation 3.3 can be separated- the real and the imaginary portion for easy estimation in a network and are obtained in Equation 3.4 and 3.5 respectively.

$$P_i = \sum_{j=1}^{n}|Y_{ij}||V_t||V_j|\cos(\theta_{ij}+\delta_j-\delta_i) \tag{3.4}$$

$$Q_i = \sum_{j=1}^{n}|Y_{ij}||V_t||V_j|\sin(\theta_{ij}+\delta_j-\delta_i) \tag{3.5}$$

Equations (3.4) and (3.5) can be expanded by linear equations involving Jacobian matrix and be simplified as shown in equation (3.6)

$$\begin{vmatrix}\Delta P\\ \Delta Q\end{vmatrix} = \begin{bmatrix} j_1 & j_2 \\ j_3 & j_4 \end{bmatrix}\begin{bmatrix}\Delta\delta \\ \Delta V\end{bmatrix} \tag{3.6}$$

ΔP and ΔQ represent differences between specified values and calculated values respectively. ΔV and $\Delta\delta$. represent voltage magnitude and voltage angle respectively in incremental forms and sub-matrices J_1 through J_4 form the Jacobian matrix.

3.2.2 Particle Swarm Optimization Algorithm

This research collaborated on a PSO algorithm that relied on a population-based randomized algorithm. The first object randomized swarm is considered the most promising (fitness) method, has been obtained to date and has already been maintained. The pbest value is used to represent such a result. The second most frequent option is the global optimal, or gbest, which is assessed by the PSO compilers by watching the pbest readings and then setting both of the quantities. The particle's velocity is changed using Equation (3.7).

$$Vl_{x,y}^{new} = Vl_{x,y}^{old} - \propto (random\ (k)) + \beta(Pr_{x,y}^{gbest} - Pr_{x,y}^{old}) \tag{3.7}$$

The old and new voltage are expressed as $Vl_{x,y}^{new}$ and $Vl_{x,y}^{old}$. The global best and old power value are denoted as $Pr_{x,y}^{gbest}$ and $Pr_{x,y}^{old}$. Here, random is a randomized variable with a value of 0 to 1, and $\propto$ and β are acceleration coefficients. If the desired quantities are not discovered, Equation (3.8) updates the position.

$$Pr_{x,y}^{new} = Pr_{x,y}^{old} + Vl_{x,y}^{new} \tag{3.8}$$

The old and new power are denoted as $Pr_{x,y}^{old}$ and $Pr_{x,y}^{new}$. The new and updated voltage is denoted as $Vl_{x,y}^{new}$. When x= 1,2,3..., N and y = 1,2,3..., N are varied. More repetitions are required to reduce the inaccuracy to the point where the location can be determined in a single phase. The updated power is denoted in Equation (3.9).

$$Pr_{x,y}^{new} = (1-\propto)Pr_{x,y}^{old} + \propto Pr_{x,y}^{gbest} - \beta(random\ (k)) \tag{3.9}$$

$\propto$ and β are acceleration coefficients, and the global best power is denoted $Pr_{x,y}^{gbest}$. The old and new power are expressed as $Pr_{x,y}^{old}$ and $Pr_{x,y}^{new}$. $\propto$ runs between 0.1 and 0.5 and β runs between 0.1 and 0.7.

3.2.3 Problem Formulation, Objective Functions and Constraints.

The objective of the optimal placement and sizing of STATCOM is to minimize the total power loss in the distribution network with voltage profile improvement.

Min f = Min (PT loss) **(**3.10**)**

Constraints:

The reactive power injected by STATCOM to the system is limited by upper and lower boundary given:

$$Q_{min} \ll STATCOM \ll Q_{max} \tag{3.11}$$

The system voltage in all buses should be within an acceptable limit.

$$\boldsymbol{V_{min}} \ll V_i \ll V_{max} \tag{3.12}$$

V_i is the voltage of ith bus and i bus varies from 1 to number of buses

The expression for Voltage Stability Index is given by:

$$V.S.I = \frac{4ZQ}{V^2X} \tag{3.13}$$

Where,
Z= Impedance
X= Reactance
Q= Reactive power
V= Bus Voltage

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction of PSO optimized STATCOM

As shown in Figure 4.1, when a single PSO optimized STATCOM of 2500kVar was penetrated at bus 9,all the defecting eight(8) buses(8,9,10,11,12,13 and 15) were upgraded from critical to normal and marginal load conditions.

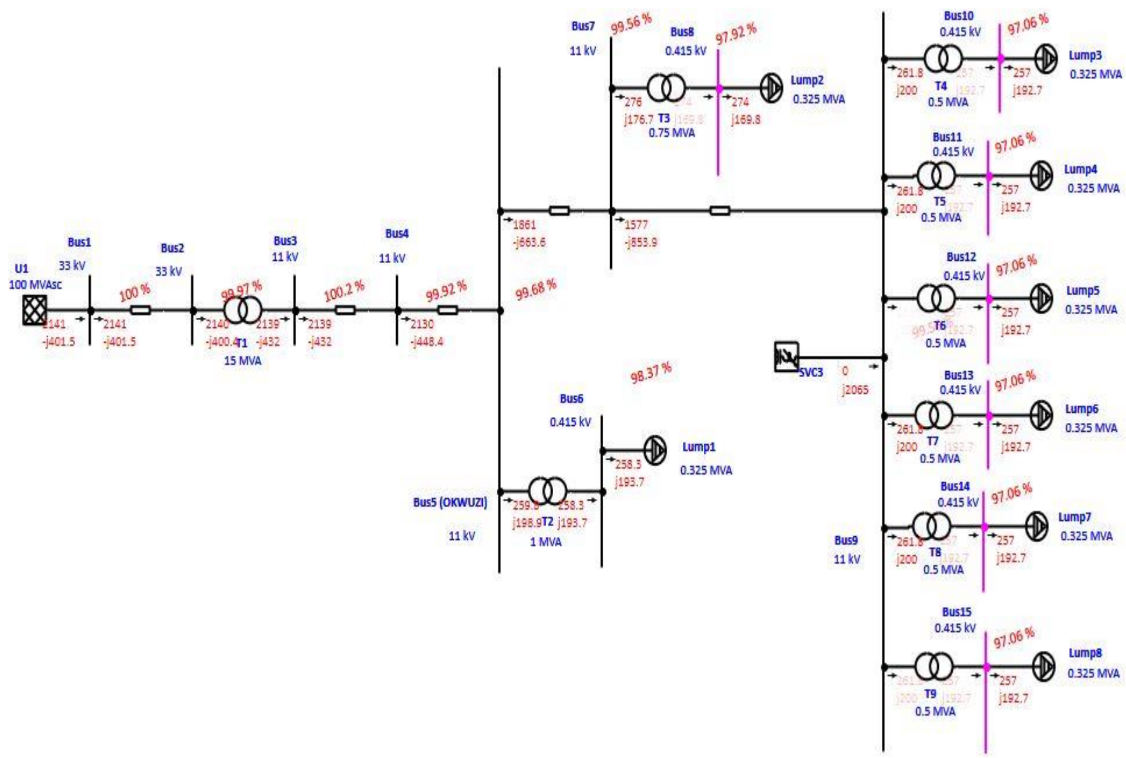

Figure 4.1: One Line Diagram of the Test Case Network with STATCOM Injection.

4.2 Bus Voltage With and Without STATCOM

The simulation result of bus voltage profile of the study case network before and after optimised STATCOM based compensation is presented as shown in Table 4.1. Without penetration of STATCOM, seven (8) buses namely; 8, 9, 10, 11,12,13,14 and 15 were overloaded and facing under voltage issues with percentage voltage magnitude of 94.17, 95.1, 92.52, 92.52, 92,52, 92.52,92.52 and 92.52 respectively. The integration of 2500Kvar PSO optimised STATCOM at bus nine (9) resulted in an enhancement of the bus voltage magnitude in the system and fall within IEEE +/-5% permissible voltage drop level The defective buses 8, 9, 10, 11, 12, 13, 14 and 15 were upgraded from critical position to marginal position with percentage voltage magnitude of 97.2, 99.56, 97.06, 97.06, 97.06, 97.06, 97.06 and 97.06 respectively. Moreover, the resulting bus voltage profile comparison is presented in Figure 4.2.

Table 4.1; Bus Voltage Magnitude Before and After Compensation

Bus id	Nominal Voltage (kV)	% Voltage W/O STATCOM	% Voltage with STATCOM
Bus 1	33	100	100

Bus 2	33	99.89	99.97
Bus 3	11	98.70	100.18
Bus 4	11	97.71	99.92
Bus 5	11	96.72	99.68
Bus 6	0.415	95.38	98.37
Bus 7	11	95.85	99.56
Bus 8	0.415	94.17	97.92
Bus 9	11	95.1	99.56
Bus 10	0.415	92.52	97.06
Bus 11	0.415	92.52	97.06
Bus 12	0.415	92.52	97.06
Bus 13	0.415	92.52	97.06
Bus 14	0.415	92.52	97.06
Bus 15	0.415	92.52	97.06

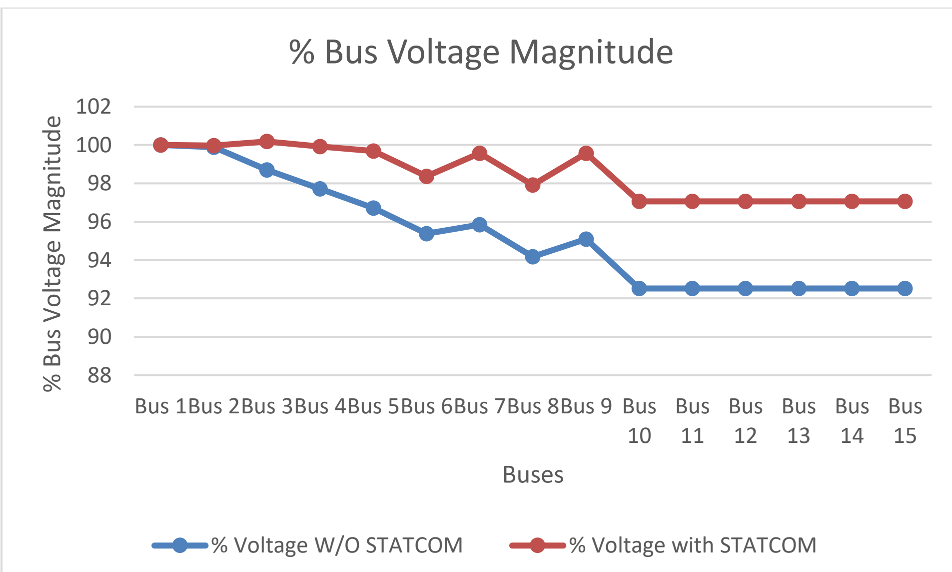

Figure 4.2: Comparison of Bus Voltage Profile with and without Compensation

4.3 Line Losses With and Without STATCOM

The line losses of each branch element with and without penetration of STATCOM are presented as shown in Table 4.2

Table 4.2: Line Losses Before and After Compensation

ID	kW Losses WO-STATCOM	kvar Losses WO-STATCOM	kW Losses W STATCOM	kvar Losses W-STATCOM
Line1	1.56	-0.0233	1.01	-1.05
Line2	14.09	25.65	9.06	16.36
Line3	14.1	25.66	9.06	16.36
Line4	10.84	19.67	7.5	13.49
Line5	8	14.44	6.2	11.09
T1	2.46	49.15	1.58	31.59
T2	1.54	5.38	1.48	5.18
T3	2.08	7.29	1.98	6.95
T4	5.16	7.75	4.86	7.29
T5	5.16	7.75	4.86	7.29
T6	5.16	7.75	4.86	7.29
T7	5.16	7.75	4.86	7.29
T8	5.16	7.75	4.86	7.29
T9	5.16	7.75	4.86	7.29
	Total = 85.63	**Total = 193.7167**	**Total = 67.03**	**Total = 143.71**

The comparison of active power loss for each branch is as shown in Figure 4.3, it is observed that there is a huge reduction in active power loss with the application of STATCOM, the maximum active power losses values with and without STATCOM recorded was 9.06 and 14.1kW, while, the minimum values recorded were 1.01 and 1.54kW.

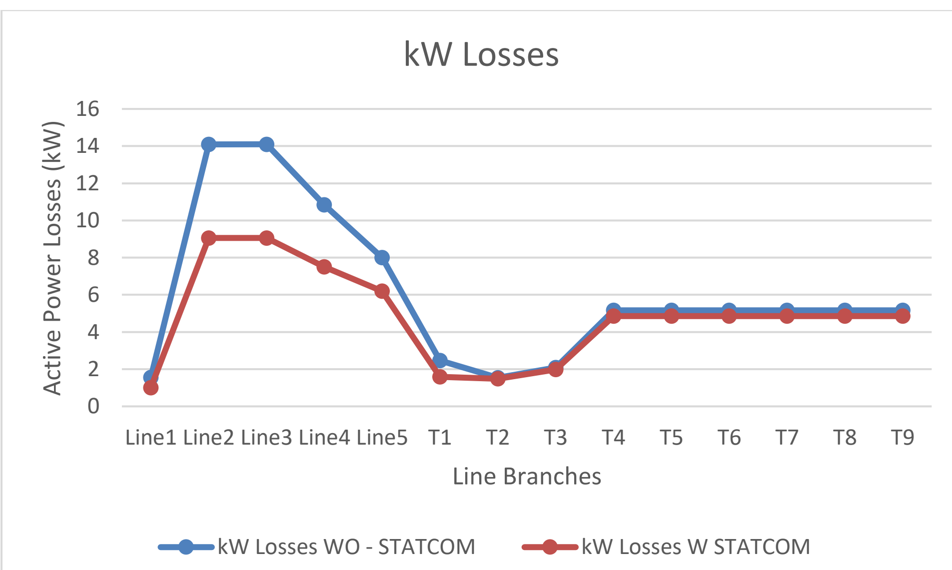

Figure 4.3: Plot of Active Power Losses versus Line Branches

Similarly, as shown in Figure 4.4 which depicts the comparison of reactive power loss, it is noted that there is significant reduction in reactive power loss with the deployment of STATCOM, the maximum reactive power losses with and without STATCOM recorded were 31.59 and 49.15kVAr while the minimum values recorded were -1.05 and -0.023kVar.

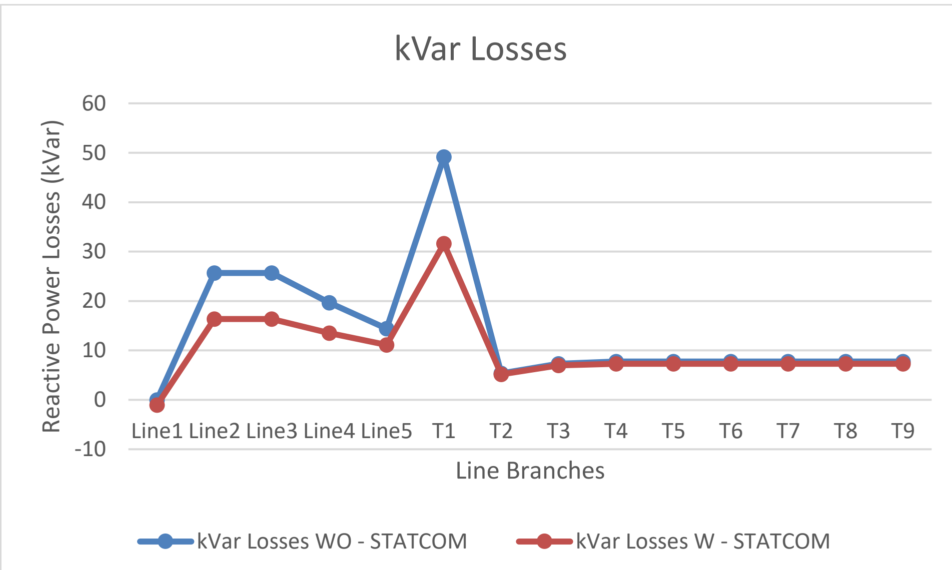

Figure 4.4: Plot of Reactive Power Losses versus Line Branches

5.0 CONCLUSION

Power losses and voltage deviation assessment could help in improving power supply to the study area, boost revenue generation for the utility through customer satisfaction. Under this study, each branch power losses and bus voltage profiles were assessed through load flow analysis of the 11kv Okwuzi, Omoku distribution network using Electrical Transient Analyzer Program (ETAP) as the simulation tool. With the help of PSO algorithm embedded in ETAP, the optimal location and KVAr capacity was determined for the proposed STATCOM incorporation. The voltage profile of all the buses was found within the IEEE-315 standard limits (0.95≤ V≤ 1.05pu) when the proposed STATCOM was penetrated optimally within the system. Moreover, there was significant reduction in both active and reactive power losses when PSO optimized STATCOM was incorporated into the network.

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