ISSN: 6314 -6515
Volume 9, Number 2, 2025
International Journal of Innovations in Engineering and Environmental Science

# OPTIMUM LOCATION OF DISTRIBUTED GENERATION ON OSHOGBO REGION 132KV POWER SYSTEM NETWORK USING ARTIFICIAL BEE COLONY OPTIMIZATION ALGORITHM

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## ABSTRACT
This work consists of identifying the location for placements of FACTS device (STATCOM) on the Oshogbo region 132 kV power system network for overall optimum performance of the network. The Oshogbo region 132 kV network is one of the regional power systems grids in Nigeria on which research work is very minimal. Also, the network experiences low performance as a result of some of the buses not performing optimally especially because of the low voltage levels at some of the buses. This research work is therefore embarked upon to improve the performance of the Oshogbo network by investigating the exact placement of both single and double STATCOM for overall optimum performance of the network. This research work models the Oshogbo region 132 kV network by collecting lines and bus data information from the transmission company of Nigeria (Oshogbo region 132 kV). These data is then used to develop a MATLAB / Simulink model of the network using the Power Systems Analysis tool box. After modelling the network, determination of the optimum location of STATCOM is done programmatically using the Particle swarm optimization Algorithm. At the end of this research work and after performance evaluation, it is seen that for single STATCOM placement, the algorithm detected bus 11 (Ibadan north bus) and for double placements, the algorithm detected bus 2 (Ganmo bus) and bus 11 (Ibadan North bus). In each of these detections, STATCOM injected reactive power and for the double placements 43% of improvement in power system performance was observed. The overall effect of these placement is the fact that the voltages at each buses was improved significantly to almost 1 pu.

***KEYWORDS: MATLAB, PSAT, STATCOM, PSO, FACTS devices, TCN***

## INTRODUCTION
The efficient operation of power transmission networks is essential for ensuring a reliable and sustainable electricity supply. Power losses during transmission and distribution pose a significant challenge to power systems, leading to decreased system efficiency and increased costs.
In Nigeria, the Transmission Company of Nigeria (TCN) is responsible for the operation and maintenance of the national transmission grid and handles Voltages of 330kV and 132kV.
The national Grid is further divided into nine (9) regions by the TCN which are Enugu, Shiroro, Osogbo, Lagos, Port Harcourt, Kaduna, Abuja, Bauchi and Benin regions.
The Osogbo Region, located in southwestern Nigeria, encompasses a 330kV and 132kV networks that play a vital role in supplying electricity to various cities and industries in the region. The Transmission Company of Nigeria (TCN) operates the Osogbo Region 132kV network, which serves as a critical backbone for transmitting electrical power across the region. To address the issue of power losses, it is necessary to explore innovative solutions that can optimize the network's performance and minimize losses.

The Osogbo region 132kV transmission network experiences high power losses. For example, on the Osogbo/Akure/Ado-Ekiti 132kV line, 136kV injected into the line at Osogbo usually show up as low as 114kV at the Akure 132kV transmission station and as low as 109kV at the Ado-Ekiti 132kV transmission station leading to poor voltage profile, low power transfer capacity and poor power supply to the end-users. The option of conventional methods such as installation of new transmission lines, changing the conductor of the Transmission Line/Terminal Equipment, increasing the operating voltage of the transmission line, such as upgrading the voltage from 132kV to 330kV etc used to address the power loss challenges have not been effective and are not cost effective. Therefore, there is a need to investigate the use of FACTS devices and optimization algorithms to minimize power losses and improve the performance of the transmission network.

Peyman et. al. (2022) investigated the application of DG devices (distribute generation) and the Grasshopper optimization algorithm for power loss minimization in the Nigerian 132kV transmission network. The study focused on the Osogbo-Akure-Ado Ekiti 132kV line and found that the use of DG and the Grasshopper optimization algorithm can significantly reduce power losses in the transmission network. The results showed that the optimal placement of the UPFC at specific points on the transmission line can reduce power losses by up to 36.79%.
Another study by Johnson and Ogunseye (2023) investigated the use of FACTS devices (Static Synchronous Compensator, STATCOM) and the Particle Swarm Optimization (PSO) algorithm for power loss minimization in the Nigerian transmission network. The study focused on the 330kV transmission network and found that the use of STATCOM and PSO can significantly reduce power losses in the network. The results showed that the optimal placement of the STATCOM at specific points on the transmission line can reduce power losses by up to 22.6%.
Blaabjerg et. al. (2018), in his paper "Optimizing Power Loss on Nigerian Weak Transmission Line Using Facts Devices and Genetic Algorithm" which focused on Nigerian 330kV transmission network proved that with appropriate placement of DG device(s) using Genetic algorithm, the voltage profile is being improved and the line losses are being minimized compared to when the network had no DG device.
Also, in a study conducted by Adebanji Oluwaseun (2021), the author determined the optimal placement and sizing of D-STATCOM on a typical Nigerian Radial Distribution Network for power loss reduction using Particle Swarm Optimization (PSO) algorithm as optimization technique on Ayepe 15 MVA, 33/11kV injection substation located at Osogbo, Osun State. The work presented the effectiveness of optimization approach in reducing the active power loss on a distribution network.

**MATERIALS**

This work entails modelling the Oshogbo region 132 kV power system transmission network, therefore information about the network was obtained from the Transmission Company of Nigeria (TCN), Oshogbo region 132 kV. The triplicate information gotten from the TCN, Oshogbo region 132 kV are in the form of the transmission lines interconnection, the line data information and the load data information. Figure 1 presents the transmission lines interconnection of the TCN, Oshogbo region 132 kV network.

ISSN: 6314 -6515
Volume 9, Number 2, 2025
International Journal of Innovations in Engineering and Environmental Science

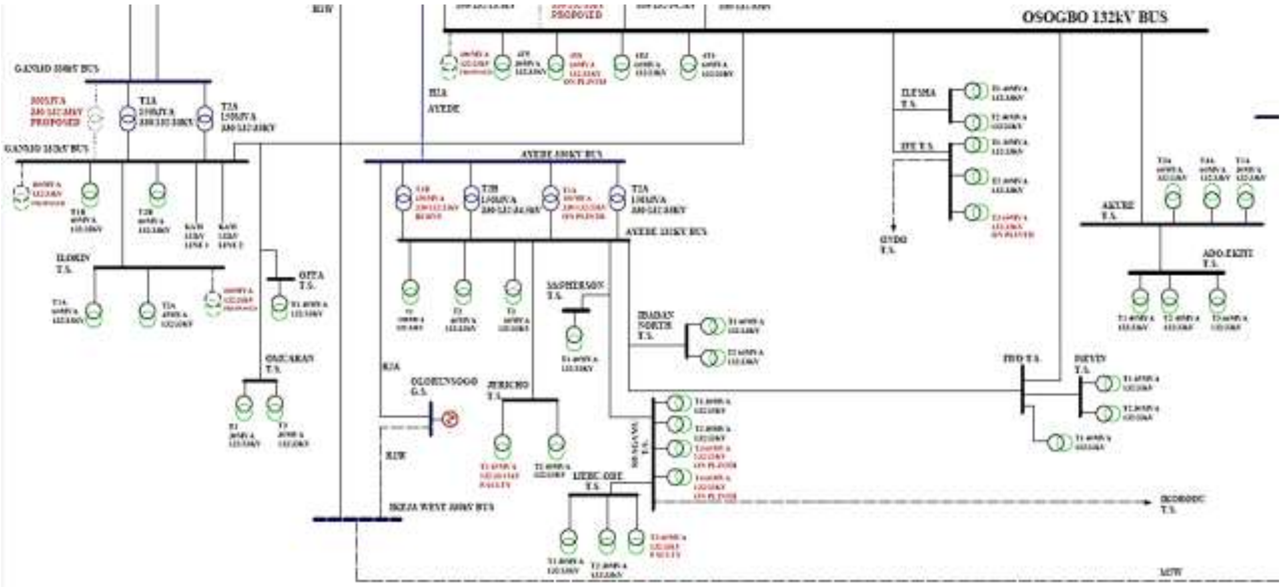



Figure 1 TCN Oshogbo region 132 kV network (TCN, 2022)

The line data of the Oshogbo region 132 kV network is presented in table 1
Table 1 Line data information (TCN line technical data, 2024)

| Node | | Line length (km) | Rating (MVA) | Resistance (Ω/km) | Reactance (Ω/km) | Susceptance (μS/km) |
|---|---|---|---|---|---|---|
| From | To | | | | | |
| Ganmo | Ilorin | 10.5 | - | 0.2712 | 0.4640 | 0.0701 |
| Ganmo | Offa | 44.73 | - | - | - | - |
| Offa | Oshogbo | 47.6 | 66.6 | 0.2712 | 0.4640 | 0.0701 |
| Oshogbo | Iwo | 80 | 66.6 | 0.2712 | 0.4640 | 0.0701 |
| Iwo road | Iseyin | 91 | 90 | 0.2220 | 0.4181 | 2.7368 |
| Iwo road | Ibadan North | 36 | 90 | 0.2220 | 0.4181 | 2.7368 |
| Ibadan North | Ayede | 14 | 90 | 0.2220 | 0.4181 | 2.7368 |
| Ayede | Jericho road | 6 | 90 | 0.2220 | 0.4181 | 2.7368 |
| Oshogbo | Ilesha | 17 | 90 | 0.2220 | 0.4181 | 2.7368 |
| Ilesha | Ife | 19 | 90 | 0.2220 | 0.4181 | 2.7368 |
| Ife | Ordo | 58 | 90 | 0.2220 | 0.4181 | 2.7368 |
| Oshogbo | Akure | 200 | 66.6 | 0.2712 | 0.4640 | 0.0701 |
| Akure | Ado-Ekiti | 35 | 192.5 | 0.1383 | 0.3920 | 4.0312 |

The load data of the Oshogbo region 132 kV network is presented in table 2

Table 2 Load data information (TCN line technical data, 2024)

| Bus | Bus type | Active Power (MVA) | Reactive Power (MVar) |
|---|---|---|---|
| Oshogbo | Slack | - | - |
| Ganmo | Load | 22.0548 | 7.1706 |
| Ilorin | Load | 21.1257 | 6.7209 |
| Offa | Load | 3.9888 | 1.2602 |
| Omuaran | Load | 9.1594 | 2.1003 |
| Illesa | Load | 3.3978 | 1.3442 |
| Ife | Load | 1.1819 | 0 |
| Jerico | Load | 9.3071 | 2.9404 |
| Ayede | Load | 40.9918 | 10.3605 |
| McPherson | Load | 1.5922 | 0 |
| Ibadan North | Load | 15 | 3 |
| Iwo | Load | 15.8 | 5.742 |
| Iseyin | Load | 10.2296 | 3.2318 |
| Ado-Ekiti | Load | 4 | 0.5 |
| Akure | Generator | 1.0 | - |

The MATLAB release 2016a software that is equipped with the Power Systems Analysis Toolbox (PSAT) is used for the purpose of modelling and simulating the Oshogbo Region 132 kV power system network.

## Methods

The technique employed in order for the milestone activity of this research work to be completed is listed below:

i. Modelling the Oshogbo region 132 kV network (base case)
ii. Developing the Particle Swarm Optimization algorithm (PSO)
iii. Optimal placement and sizing of static synchronous compensator (STATCOM)

### *Oshogbo region 132 kV model (base case)*

The Oshogbo region 132 kV network is modelled using the PSAT toolbox of MATLAB. The model is presented in figure 2. This model represents the transmission network without any placement of FACTS device or application of any optimization technique. This is referred to as the

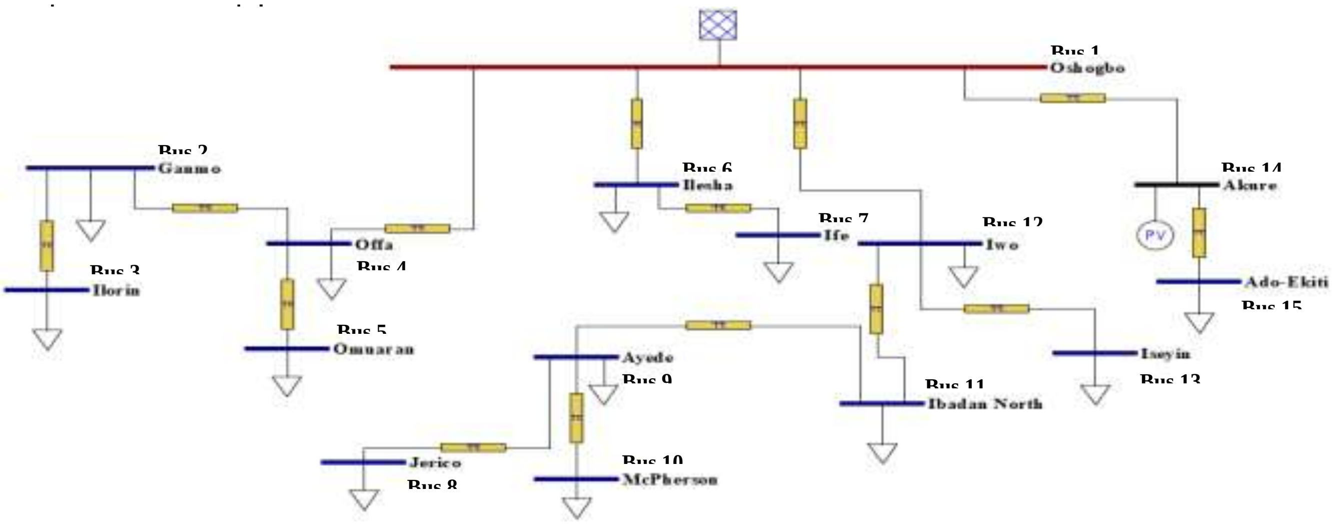



Figure 2 Base case model for Oshogbo region 132 kV

***PSO Algorithm***

In particle swarm optimization, each member of the population is called a particle. Each particle contains its position and velocity. Each individual particle executes searching in the search space according to its velocity, the best position found in the whole swarm (GBEST) and the individual's best position (PBEST). The algorithm starts with randomizing particle positions and their velocity, and the evaluation of the position of each particle is calculated from the objective function of the power system analysis.

PSO-based optimum placement of FACTS uses Particle Swarm Optimization (PSO) to select optimal placement of FACTS in a power system network to improve the voltage profile of the network.

*Working principle*

(a) Objective function

A function is defined that reveals the cost of moving the particle from one location to another. The particle that moves with the least cost is said to be the particle with particle best (PBEST). The PBEST becomes global best (GBEST) if it remains the least cost of moving the overall particle after the iterations.

The swarm uses the fitness function (objective function) described in equation (1) (Devabalaji & Ravi, 2016) to navigate toward the optimum solution.

$$swarm\ fitness\ function = \sqrt{\left(\sum_{i=1}^{n}(V_i - 1)^2\right)} \tag{1}$$

Where $V_i$ is the per unit voltage in the ith bus and n is the total number of buses

This fitness function shows the deviation of the bus voltages from 1.0 pu and the minimum of these voltage deviations gives the best result. Moving the particle involves multiplying the particle by it velocity.

The velocity equation is updated in every iteration using equation 2

$$v_{ij}(t+1) = w(t)v_{ij}(t) + c_1 r_1\left(pbest_{ij}(t) - x_{ij}(t)\right) + c_2 r_2\left(gbest_{ij}(t) - x_{ij}(t)\right) \tag{2}$$

Where $v_{ij}(t)$ and $x_{ij}(t)$ denote the jth velocity and position of the ith particle. The parameter w(t) denotes the weights employed ( randomly selected at the beginning of the iteration) while the variables c and r are social variable that are also randomly initialized.

$x_{ij}$ is the position of the particles.

(b) Swarm Initialization:

A population of "particles" (representing placements of STATCOM) is initialized randomly across the network.

(c) Iteration and Optimization:

Each particle updates its position (i.e., the bus locations) based on its own experience and the experiences of other particles in the swarm. Equation 3 shows how the position of the particle is updated.

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \tag{3}$$

The objective function is used to evaluate the quality of each particle's position, and particles move towards locations with the least cost values.

(d) Optimal Bus Selection:

After a set number of iterations, the PSO algorithm converges to at the busses considered optimal for improvement of the voltage profile.

## Results

The result presented in this chapter is designed to evaluate the performance of the modelled Oshogbo region 132 kV network. The result is therefore presented using different scenarios listed below.

i. PSO results
ii. Oshogbo region 132 kV base case power flow simulation
iii. Oshogbo region 132 kV single STATCOM placements
iv. Oshogbo region 132 kV double STATCOM placements
v. Comparison of base case, single and double STATCOM

### *PSO results*

The PSO algorithm, in this research work, created a Search space for the particle swarm. The search is essentially a virtual space, for the swarm to move. This space is essentially all possible solution (i.e. optimum placement and sizing). The results for the hyperspace is presented in figure 3.

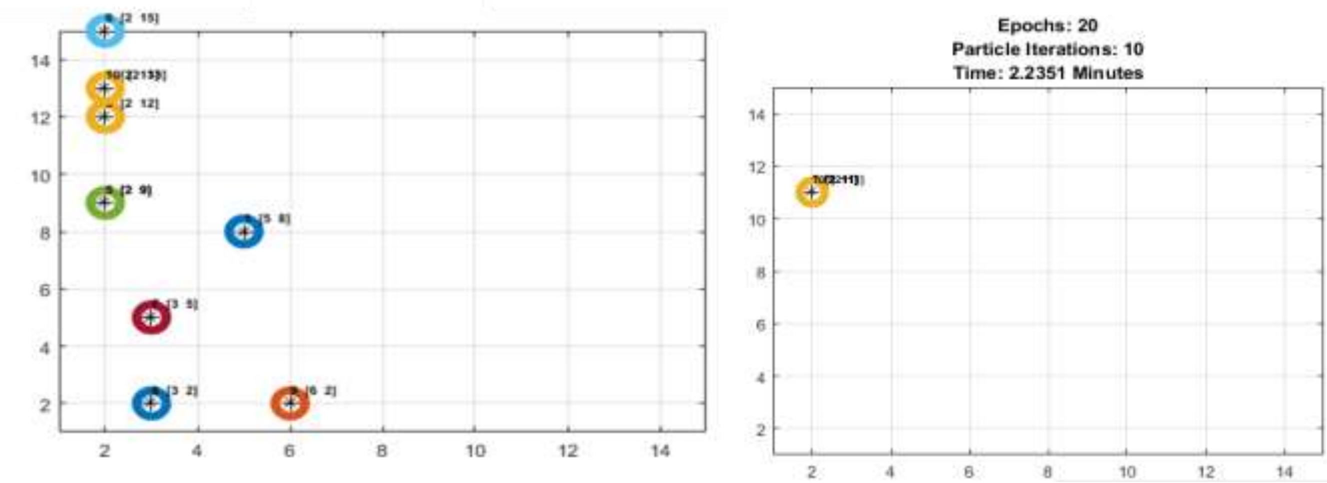



Table 3 PSO result for placements and sizing

| STATCOM placement and Size | | | |
|---|---|---|---|
| Single | Size | Double | Size |
| Bus 11 (Ibadan North) | 0.8 MW | Bus 2 and Bus 11 (Ganmo and Ibadan North) | 0.8 MW |

Figure 4 shows convergence plot for the PSO algorithm

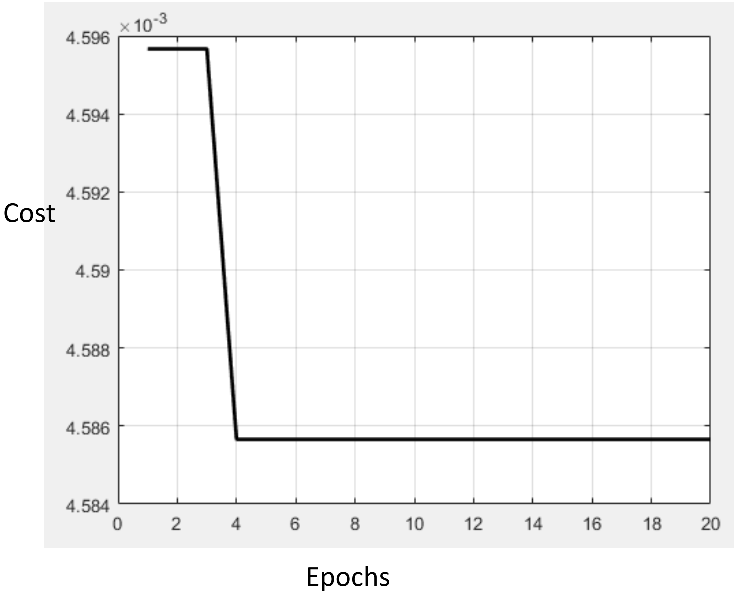



Figure 4 Convergence Plot

***Base case power flow simulation result***

Simulation result for base case scenario is presented in figure 5.

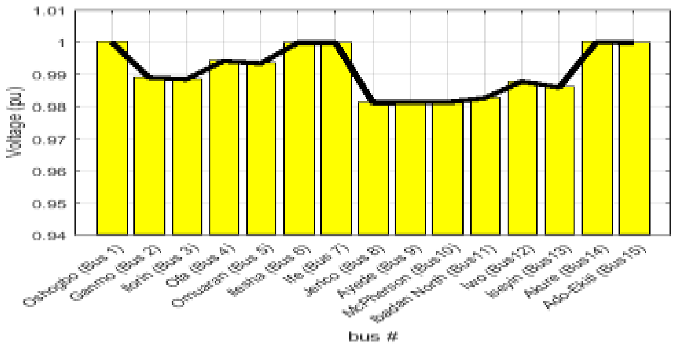
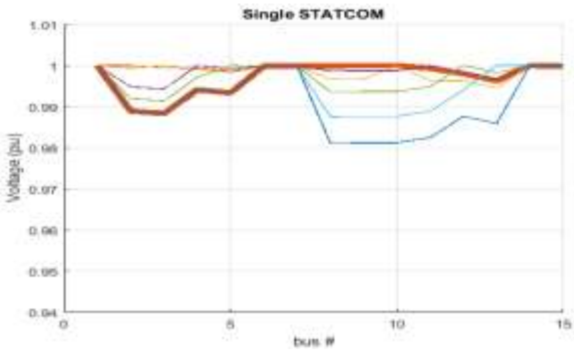



Figure 5 Oshogbo region 132 kV base case result

***Single STATCOM placement***

Result for optimum placement of single STATCOM on the Oshogbo region 132 kV network is presented in figure 6.



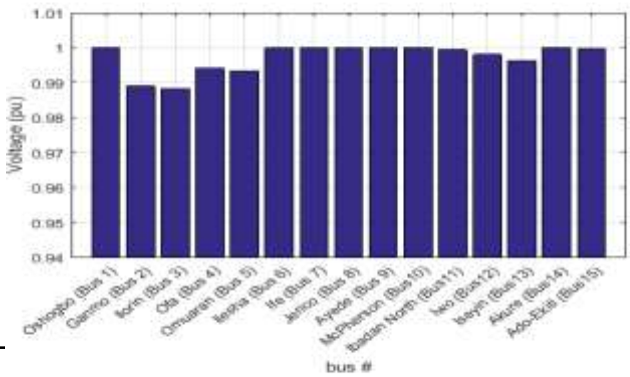




Figure 6 Voltage profile result for single STAT

***Double STATCOM placement***

Result for optimum placement of double STATCOM on the Oshogbo region 132 kV network is presented in figure 7.

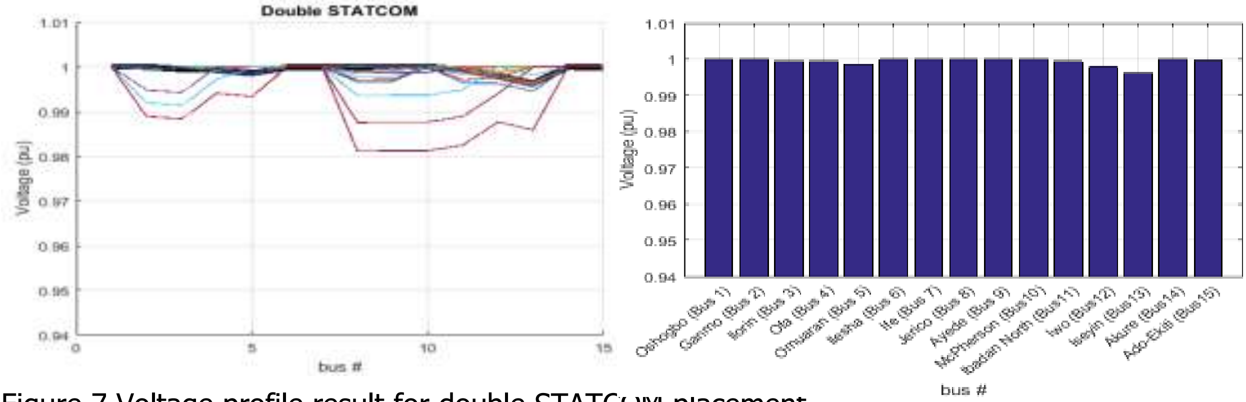



Figure 7 Voltage profile result for double STATCOM placement

***Base case and Single STATCOM placement compared***

Result for the comparison of base case and single STATCOM placements is presented in figure 8.

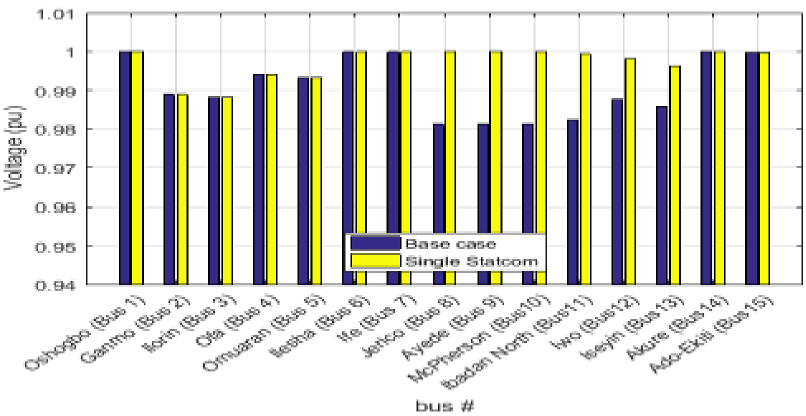



Figure 8 Voltage profile for base case and single STATCOM placements

***Single STATCOM and double STATCOM placement compared***

Result for the comparison of single and double STATCOM placements is presented in figure 9.

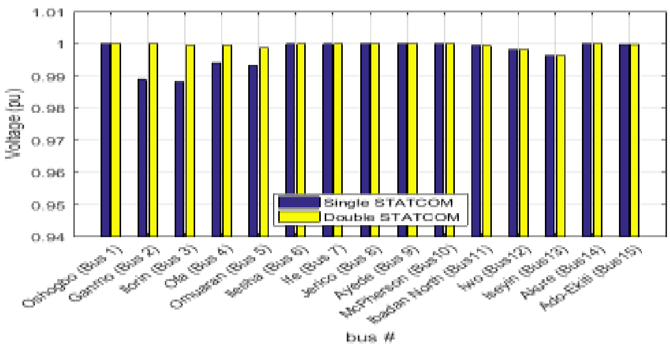



Figure 9 Voltage profile for single and double STATCOM placements

### *Base case, Single and double STATCOM placement compared*

Result for the comparison of base case, single and double STATCOM placements is presented in figure 10.

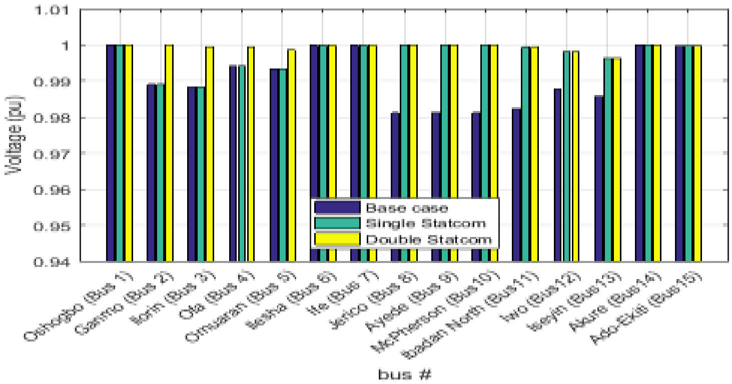



Figure 10 Voltage profile for base case, single and double STATCOM placements

### *Reactive power injections*

The amount of reactive power injected into the system by the STATCOM placements is compared with the reactive power at the base case.

Table 4 Reactive power injected

| S/N | STATCOM placement | Reactive Power (MVAR) |
|---|---|---|
| 1 | Single STATCOM | 0.943 |
| 2 | Double STATCOM | 1.350 |

## DISCUSSIONS

Discussion is presented in the same manner as the scenarios where presented.

Figure 3a presents the result for all the search paths for the swarm agents. This represents all the possible solutions that the swarm are gravitating towards. From figure 3 b) it is seen that the coordinates (2, 11), coloured yellow, is the solution or the final destination of all particles. The solution is gotten after running the PSO algorithm.

For single placements there will be 13 possible combinations since this is merely placing the STATCOM at the buses and avoiding the PV and slack bus. Again, for sizing the STATCOM, the STATCOM power 0.1 MW to 0.8 MW in increments of 0.1 MW is considered. This range is selected because above 0.8 MW, the power flow solution reveals some bus voltage above 1.05 pu. This is not practical and could cause system instability. Also, below 0.1 MW the power flow solution reveals that some bus voltages are below 0.95 pu, which reduces the performance of the network. Finally, moving from 0.1 to 0.8 with steps of 0.1 gives a width of 8. Therefore the total search spaces for the swarm in this research work is:

Search space = (78 + 13) x 8 = 728 search spaces.

The particle then uses the algorithms described in chapter three to navigate toward the best result.

Figure 5 is the base case power flow simulation result. In this case there is no application of STATCOM. The results reveal the voltage profile, in per unit, of the Oshogbo region 132 kV network. Careful examination shows that all voltages exceed 0.95 pu and does not go beyond 1.05 pu which is shows that the network is properly modelled and very stable. However voltages in buses 8, 9 10, 11, 12, 13 seem to be far from 1.0 pu.

Figure 6 reveals the voltage profile for the 132 kV network for single STATCOM placement at bus 9. Two graphs are presented. The graph to the left is the voltage profile for the best voltage in the search space when single STATCOM is considered (the thickest profile). Other voltages in the search space (13 x 8) is shown fainted. The graph reveals the voltage with the least deviation from 1 pu which is the beast result from the swarm movement. This results occurs when STATCOM is placed at bus 9. To the right of figure 4.3 is the bar chart revealing the voltage profile for the best STATCOM placement. Again observe that all voltage are within 0.95 and 1.05 pu range.

Figure 7 reveals the voltage profile for the 132 kV network for double STATCOM placement at bus 2 and bus 9. Two graphs are presented. The graph to the left is the voltage profile for the best result in the search space when double STATCOM is considered (the thickest profile). Other voltages in the search space (78 x 8) is shown fainted. The graph reveals the voltage with the least deviation from 1 pu which is the best result from the swarm movement. It is seen that all voltages are almost 1 pu. This results occurs when STATCOM is placed at bus 2 and bus 9. To the right of figure 7 is the bar chart revealing the voltage profile for the best STATCOM placements. Again observe that all voltage are within 0.95 and 1.05 pu range.

Figure 8 reveals the voltage profiles for the 132 kV network after comparing base case and single STATCOM placement. The profile reveals that the voltage of the buses (bus 8 to bus 13) shown to have a low voltage profile in the base case consideration increases significantly.

Figure 9 reveals the voltage profiles for the 132 kV network after comparing single and double STATCOM placements. Further significant improvements in the voltage profile is observed.
Figure 10 compares base case, single and double STATCOM placements. It is seen that the bar graph of the double STATCOM placement gives the best voltage profile.
Table 4.2 reveals the reactive power injected by STATCOM into the network. It is seen that for single STATCOM placement 0.943 MVAR was injected into the system while for double STATCOM placement 1.350 MVAR is injected into the system. Injecting reactive power into a power system network improves voltage and reduces power losses in the system. This has shown that the system performance is satisfactory.

## CONCLUSION

This work modelled the Oshogbo region 132 kV power system network. Improved performance of the network is intended therefore a PSO algorithm was developed to help determine the optimum placement of STATCOM and sizing of the STATCOM. Placement of STATCOM improves the performance of the network in terms of voltage profile and reactive power injections. The PSO designed optimally placed STATCOM at bus 11 (Ibadan North) and for double STATCOM placements the PSO placed both at buses 2 (Ganmo) and 11 (Ibadan North) respectively. Optimum Sizing of the STATCOM by the PSO is 0.8 MW.
The following strong points can be drawn from this research work.

i. For single STATCOM placement, 0.943 MVAR of reactive power is injected
ii. For double STATCOM placements, 1.350 MVAR of reactive power signifying a further 43% improvement on the power system network
iii. All voltages were seen to be at approximately 1.0 pu with double placement of STAATCOM signifying efficient performance of the system

## RECOMMENDATION

Creation of search areas for the swarm intelligence produced a total of 728 search areas. After running the PSO algorithm the amount of computation was enormous for the average computer used to compute the algorithm. To produce more accurate results it is recommended to increase the search area by widening the increments in the range of power chosen (0.1 MW to 0.8 MW). This will take a toll on the computer during computation. It is, therefore, also, recommended that a computer with more processing power be employed for this purpose.

**Acknowledgement**
This research work wish to acknowledge the Tertiary Education Trust Fund (TETFund) for sponsoring this research and the entire management of the polytechnic for their support and encouragement.

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