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Enhanced Voltage Stability and Loss Minimization through Optimal Placement and Sizing of Dstatcom in Distribution Networks

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ABSTRACT

Integrating Distributed Static Compensators (DSTATCOM) into distribution networks improves voltage profiles, reduces power losses, and enhances stability. This paper optimizes DSTATCOM placement and sizing within the 34-bus Thinkers Corner 6.0 MVA, 33/11KV distribution network in Enugu, Nigeria, using Particle Swarm Optimization (PSO) in MATLAB R2017b. The Backward-Forward Sweep method was employed to simulate load flow analysis, both with and without DSTATCOM, to assess real and reactive power losses, voltage profiles, and voltage stability indices. Validation of the model was performed using the IEEE 33-bus system to ensure the robustness of the approach. Results show that DSTATCOM integration reduces losses, stabilizes voltage, and improves network efficiency.

1. INTRODUCTION

Modern distribution systems face complex challenges such as voltage instability, high power losses, and fluctuating voltage profiles due to increasing demand and the integration of distributed generation (DG) sources (Bollen, 2000; Saravanan et al., 2007). Distribution networks, which are responsible for delivering electricity to end users, experience the highest levels of power loss across the electrical grid, typically ranging between 5–13% of total generated energy (Abdelaziz et al., 2016). As load demand continues to grow, the voltage level at buses decreases, which can lead to voltage collapse, particularly in industrial zones (Ramesh et al., 2019). Additionally, voltage drops tend to increase with the distance from the central substation, creating the need for localized reactive power compensation to maintain voltage stability (Gao et al., 2018).

Reactive power compensation is essential in distribution systems to enhance voltage profiles and prevent voltage collapse (Mahdad and Bouktir, 2011). A lack of sufficient reactive power leads to declining bus voltages, which can initiate a chain reaction affecting other areas in the network (El-Fergany and Abdelaziz, 2014). Maintaining voltage stability becomes increasingly challenging in large-scale networks operating close to voltage instability limits (Del Valle et al., 2008). FACTS controllers such as the

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DSTATCOM provide an efficient solution by injecting or absorbing reactive power to stabilize voltage and improve power quality (Hingorani & Gyugyi, 2000). Compared to traditional methods such as capacitor banks or Static Var Compensators (SVCs), DSTATCOM offers superior regulation, faster response to load changes, and minimal harmonic emissions, making it an ideal choice for modern distribution networks (Sanam et al., 2016).

The integration of optimization techniques is crucial to ensuring that DSTATCOMs are placed and sized optimally to maximize their benefits. Various optimization methods, such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and hybrid algorithms, have been proposed for optimal DSTATCOM placement and sizing (Saravanan et al., 2007). PSO, a popular meta-heuristic algorithm, is well-suited for this task due to its simplicity and ability to achieve global optima (Kennedy & Eberhart, 1995). PSO has been successfully applied to a range of power system optimization problems, including voltage stability improvement and loss minimization (Moghaddam et al., 2019). Recent studies highlight that integrating PSO with load flow models, such as the Backward-Forward Sweep (BFS) method, ensures accurate modeling and analysis of DSTATCOM's impact on voltage stability and power losses (Baklouti et al., 2022).

This paper focuses on the Thinkers Corner distribution network, a real-world 34-bus, 33/11 kV system in Enugu, Nigeria that suffers from substantial power losses and voltage instability. The primary goal is to determine the optimal placement and size of DSTATCOM using PSO to minimize losses, improve voltage profiles, and enhance system stability. The performance of the network is analyzed using MATLAB R2017b, with and without DSTATCOM, to quantify improvements in voltage stability, power loss reduction, and operational efficiency. The approach is validated using the IEEE 33-bus system to ensure the generalizability of the proposed solution.

1.1. DSTATCOM Components

A DSTATCOM is a shunt-connected device that regulates voltage by injecting or absorbing reactive power. It utilizes a Voltage Source Converter (VSC) with Insulated Gate Bipolar Transistors (IGBTs) or similar switches to enhance voltage stability, reduce fluctuations, and improve the power factor. Key components are illustrated in Figure 1.

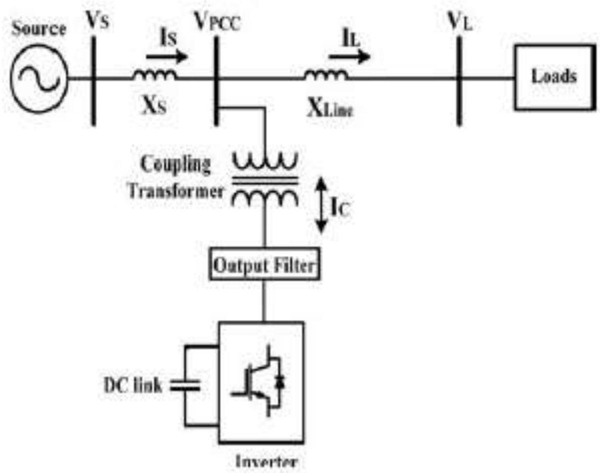

Figure 1. Block diagram of DSTATCOM circuit

A DSTATCOM comprises key components for efficient reactive power compensation. The Voltage Source Converter (VSC) converts DC voltage from the capacitor to synchronized AC voltage for reactive power exchange (Hingorani and Gyugyi, 2000). The capacitor maintains DC voltage and buffers energy (Miller, 1982), while the coupling transformer connects the DSTATCOM to the grid, ensuring safe power exchange and electrical isolation (Singh et al., 2015). Filters remove high-frequency harmonics, producing a sinusoidal output (Zhao and Zhang, 2010).

1.2. DSTATCOM Working Principles

The DSTATCOM regulates reactive power exchange by generating or absorbing power to maintain voltage stability. It injects reactive power (capacitive mode) during under-voltage conditions and absorbs it (inductive mode) during over-voltage conditions (Bollen, 2000). The system voltage is continuously measured and compared with a reference, directing the Voltage Source Converter (VSC) to adjust reactive currents as needed (Hingorani & Gyugyi, 2000). The reactive power is given by:

$$Q = V * I \sin(\theta) \quad (1.1)$$

Where Q is the reactive power, V is the voltage, I is the current, and θ is the phase angle between them (Akagi & Kanazawa, 1984). Operating in near-unity power factor improves efficiency and power transfer. The DSTATCOM also functions as an active filter, injecting harmonic currents to reduce Total Harmonic Distortion (THD) and balance loads (Rashid, 2011).

2. METHODOLOGY

This section presents the methodology used to conduct the research. It begins with an overview of the Thinkers Corner distribution network, followed by the optimization approach for DSTATCOM placement and sizing. Particle Swarm Optimization (PSO), implemented in MATLAB R2017b, served as the optimization tool for determining the optimal location and size of the DSTATCOM unit. Below is a detailed breakdown of the methods applied.

2.1. Network Description and Data Acquisition

The Thinkers Corner network, operating at 11 kV with a 6.0 MVA capacity, receives power from the 33 kV Enugu substation via the New Haven transmission station. It features one main feeder, several radial sub-feeders, and 33 transformers supplying 34 load points with an average load of 4636.5 kW and 2873.5 kVAR. Network data, including transformer ratings, line impedances, and load conditions, were collected through collaboration with EEDC (Enugu Electricity Distribution Company) personnel. IEEE 33-bus system data was also obtained, and all parameters were converted to per-unit (p.u.) for consistent power flow analysis (see appendix).

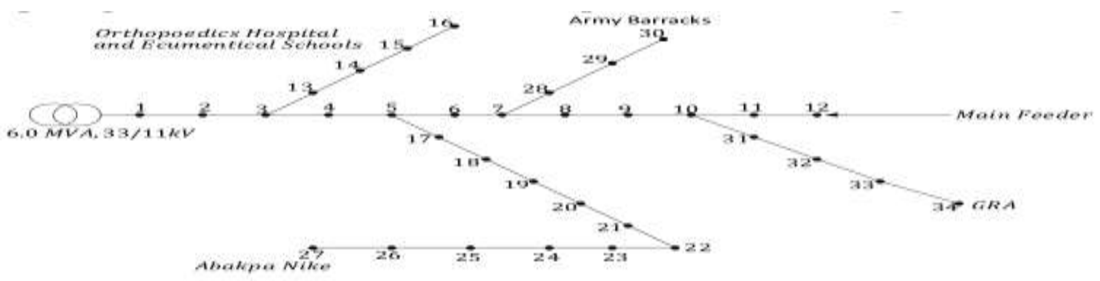

Figure 2: One - Line Diagram of 34 Bus Thinkers' Corner Distribution System

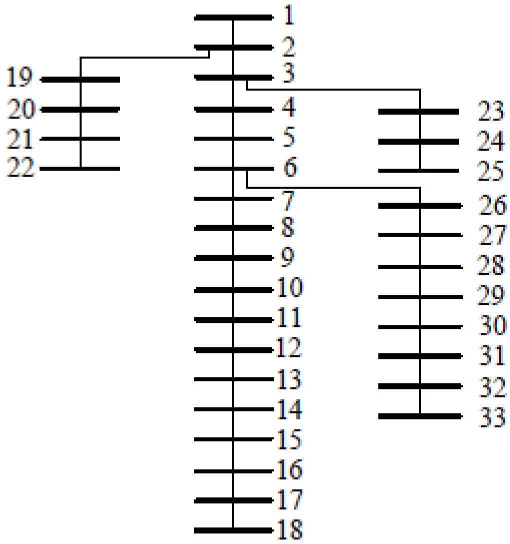

Figure 2: One - Line Diagram of 33 Bus IEEE Distribution System

2.2. Modeling the Network and System Simulation

The DSTATCOM was modeled and integrated into the Thinkers Corner network using MATLAB R2017b. A direct load flow simulation without DSTATCOM established baseline metrics, including power losses, voltage profiles, and stability indices. The efficient Backward-Forward Sweep method was used for this radial system. The base case scenario employed the following equation to compute current injection at each bus:

$$I_i^k = \left(\frac{P_i + jQ_i}{V_i^k}\right) \quad (2.1)$$

where I_i^k is the equivalent current injection at the Kth iteration for bus i, and V_i^k denotes the voltage magnitude at that iteration.

The simulation proceeded by solving for branch currents using the Bus Injection to Branch Current (BIBC) matrix:

$$[I_{branch}]=[BIBC][I_{node}] \quad (2.2)$$

Branch currents were then used to iteratively update nodal voltages based on Kirchhoff's Voltage Law (KVL), using the Branch Current to Bus Voltage (BCBV) matrix:

$$V^{k+1} = V_1 - [BCBV][I_{branch}] \quad (2.3)$$

The solution converged when the difference in successive voltage magnitudes across all nodes was less than 1×10^{-5} p.u.

2.3. Incorporating DSTATCOM in Load Flow Analysis

During each iteration of the forward sweep, the voltage magnitude at the node where the DSTATCOM was placed was regulated to 1 p.u**.** The DSTATCOM adjusted its reactive power injection Q_{inj} based on the voltage deviation at the connected bus. The injected reactive power was computed as:

$$Q_{inj} = \frac{V_{bus}}{X}\left(V_{ref} - V_{bus}\right) \quad (2.4)$$

where:

Q_{inj} = Reactive power injected or absorbed by the DSTATCOM

V_{bus} = Voltage magnitude at the connected bus

V_{ref} = Reference voltage (1 p.u.)

X = Equivalent reactance of the DSTATCOM

if the required reactive power exceeded the DSTATCOM's maximum capacity Q_{max}, the reactive power injection was capped:

$$Q_{\text{inj}} = \min\left(Q_{\text{calc}}, Q_{\text{max}}\right) \quad (2.5)$$

Where:

$$Q_{\text{calc}} = \frac{V_{bus}}{X}\left(V_{ref} - V_{\text{bus}}\right) \quad (2.6)$$

Q_{calc} is the calculated reactive power required to maintain voltage at 1 p.u.

Q_{max} = Maximum reactive power capacity of the DSTATCOM

If capped, the remaining reactive power imbalance was treated as a negative load, added to the system's reactive power demand at that bus:

$$Q_{\text{load, adj}} = Q_{\text{load}} - Q_{\text{inj}} \quad (2.7)$$

The adjusted reactive power injection was then incorporated into the load flow computations during the backward sweep.This iterative process continued until convergence was achieved, meaning that the voltage deviation across all buses was within an acceptable tolerance, typically:

$$|V_i^{new} - V_i^{old}| < \epsilon \quad (2.8)$$

Where:

V_i^{new} = Updated voltage at bus i

V_i^{old} = Previous voltage at bus i

ϵ = Convergence tolerance ($1*10^{-5}$ p.u.)

By continuously regulating reactive power injection, the DSTATCOM maintained the voltage at 1 p.u. while minimizing power losses and ensuring stable network operation.

2.4. Optimization Using Particle Swarm Optimization

PSO was employed to determine the optimal size and location of the DSTATCOM. In the PSO algorithm, each particle represents a candidate solution with a specific position and velocity. The algorithm iteratively updates the particle velocities and positions using the following equations:

$$v_i^{k+1} = wv_i^k + c_1r_1\left(p_i^k - x_i^k\right) + c_2r_2\left(g^k - x_i^k\right) \quad (2.9)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (2.10)$$

Where v_i^{k+1} is the updated velocity of the i-th particle, $x_i^{k+1}$is the new position, w is the inertia weight, and c_1 and c_2 are cognitive and social coefficients, respectively. Random variables r_1 and r_2 introduce diversity to prevent premature convergence.

2.5. Optimization Algorithm for DSTATCOM Placement and Sizing

The following steps outline the implementation of the proposed optimization technique for optimal

DSTATCOM placement and sizing in the Thinkers Corner radial distribution system (RDS):

- Determine the number of DSTATCOM units for deployment.
- Input line and load data of the RDS.
- Define system constraints, PSO parameters (population size, Wmax, Wmin, C1, and C2), and the maximum iterations.
- Initialize particles randomly, with each particle representing a DSTATCOM size and position.
- Perform base-case load flow to evaluate bus voltages and real/reactive power losses.
- Identify candidate buses for DSTATCOM placement based on voltage stability indexes.
- Apply the PSO algorithm to optimize the fitness function iteratively.
- Select the optimal DSTATCOM size and location.
- Re-run load flow with the integrated DSTATCOM to assess the improved voltage profile and power loss reduction.
- Display the optimal solution.

2.6. Problem Formulation

This optimization aims to minimize losses, improve voltage profiles, and enhance voltage stability. Each objective is formulated individually and the overall objective function is constructed by amalgamating these terms with their respective weighting coefficients.

i. Loss reduction : The total line losses in the distribution system are computed as follows:

$$F_1 = \sum_{i=1}^{NBr} R_i \times I_i^2 \quad (2.11)$$

In this context, F_1 represents the first component of the objective function, which is associated with system losses. The variable I_i denotes the current flowing through the i^{th} line, while R_i represents the resistance of the same line. Furthermore, NBr signifies the total count of branches within the system.

ii. **Voltage Profile Improvement** : The objective function for improving the voltage profile is expressed as:

$$F_2 = \sum_{i=1}^{NBus} (V - V_i)^2 \quad (2.12)$$

The second component of the objective function, denoted as F_2, pertains to the enhancement of the voltage profile. It involves the difference between the bus voltage (Vi) and the reference voltage (V), which is set at 1 per unit (p.u.).

iii. **Voltage Stability Improvement:** The voltage stability index (VSI) is introduced to identify the node most vulnerable to voltage collapse. The VSI is calculated for every bus, with values ranging from zero (indicating instability) to one (indicating stability). In practical assessment, the VSI is computed for all buses using Equation (2.13), with the weakest node having the lowest value, thereby initiating the voltage collapse event. Employing load flow calculations for all buses within the given system, the VSI is determined, and the values are arranged in ascending order. Maximizing the VSI of nodes becomes imperative to avert voltage collapse scenario.

$$VSI(t+1) = |V_t|^4 - 4[P_{t+1} \times X_t - Q_{t+1} \times R_t]^2 - 4[P_{t+1} \times$$

$R_t + Q_{t+1} \times X_t]|V_t|^2$
(2.13)
$F_3 = min(VSI(t+1))$
(2.14)

Where F3 is the objective function for voltage stability index, VSI (t+1) is the voltage stability index at bus t+1, t and t+1 are the sending and receiving bus number, P_{t+1} and Q_{t+1} are active and reactive power demands at bus t+1, respectively, Vt is the voltage of the sending bus, Rt, t+1, Xt, t+1 are the resistance and reactance of branch.

The overall objective function (F) is mathematically formulated as follows:

Minimize $(F) = min\left(W_1 \times F_1 + W_2 \times F_2 + W_3 \times \frac{1}{F_3}\right)$
(2.15)

The weights were assigned as $W_1 = 0.4$, $W_2 = 0.3$, $W_3 = 0.3$, giving higher priority to power loss minimization.

2.*6 System constraints*

- **Limit on voltage deviation**
  The voltage levels across all buses within the system should adhere to acceptable limits.
  $V_m^{min} \leq |V_m| \leq V_m^{max}$
  (2.16)
  The system voltage is restricted with 0.95pu ≤ Vm ≤1.05 pu.

- **Compensation for reactive power**
  The amount of reactive power introduced into the system by DSTATCOM is bounded by lower and upper constraints, as depicted in the following equation:
  $Q_m^{min} \leq |Q_m| \leq Q_m^{max}$
  (2.17)
  The reactive power injected by DSTATCOM is restricted by 10KVar ≤Qm≤1000KVAr.

- **Thermal limit**
  The thermal capacity of the lines limits the amount of power that can flow through them:
  $|S_{ij} \leq S_{ijmax}|$
  (2.18)
  Here, S_{ijmax} represents the maximum capacity of the line connecting bus i and bus j. The power flow across the lines is constrained with S_{ijmax} = 100 MVA.

3. RESULTS AND DISCUSSION

This section presents the findings from the load flow analysis, Particle Swarm Optimization (PSO), and Voltage Stability Index (VSI) approaches applied to the Thinkers Corner distribution network and the IEEE Standard 33-bus system. The implementation of the algorithms was executed using Matlab R2017b, with the parameters for the PSO algorithm detailed in Table 1

Table 1: Parameter value for PSO simulation

PopulationValue	20
Iteration no	30
Wmin	0.4
Wmax	0.9
C1	1
C2	1

The initial power loss, bus voltages, and voltage stability index for Thinkers Corner distribution network and IEEE's system was calculated using a backward-forward sweep load flow algorithm. Subsequently, the PSO method, guided by a bus-based voltage stability index analysis, was employed to determine the optimal location and size of the DSTATCOM. The effectiveness of the simulation results for both networks was evaluated under two specific scenarios:
Case 1: Simulation of the System Without DSTATCOM

Case 2: Simulation of the System With DSTATCOM

3.1. **Simulation of Thinkers Corner**

The comparative analysis of the performance metrics of the simulation of Thinkers Corner distribution system without DSTATCOM and with the integration of a single DSTATCOM are presented in Table 2. Without DSTATCOM, the system recorded 644.92 kW of real power loss, 183.36 kVAR of reactive power loss, a minimum voltage magnitude of 0.8603 p.u., and a Voltage Stability Index (VSI) of 0.5477 p.u. With the integration of a 1000 kVAr DSTATCOM at bus 8, real power loss decreased by 54.6% to 292.77 kW, and reactive power loss dropped by 48.2% to 95.071 kVAR. Voltage magnitude improved to 0.95 p.u (between IEEE's standard of 0.95-1.05 p.u), with the Voltage Stability Index (VSI) increasing to 0.8144 p.u. This optimal configuration significantly enhanced the system's overall performance, as reflected in the reduced power losses and improved voltage stability.

Table 2: performance evaluation of (Thinkers Corner)

No	Parameters	Base(Case)	PSO (case)
1	Active power loss	644.92 KW	292.77 KW
2	Reactive power loss	183.36 KVAr	95.071 KVAr
3	Minimum VSI	0.5477	0.81438
4	Minimum voltage	0.8603	0.95pu
5	Dstatcom location		Bus 8
6	Dstatcom size		1000KVAr
7	Active power loss%		54.6%
8	Reactive power loss%		48.2%

Figure 3 shows the base case voltage profile and the voltage profile after compensation with DSTATCOM in Thinkers Corner network, while Figure 4 shows the base case voltage stability index and the voltage stability index after compensation with DSTATCOM.

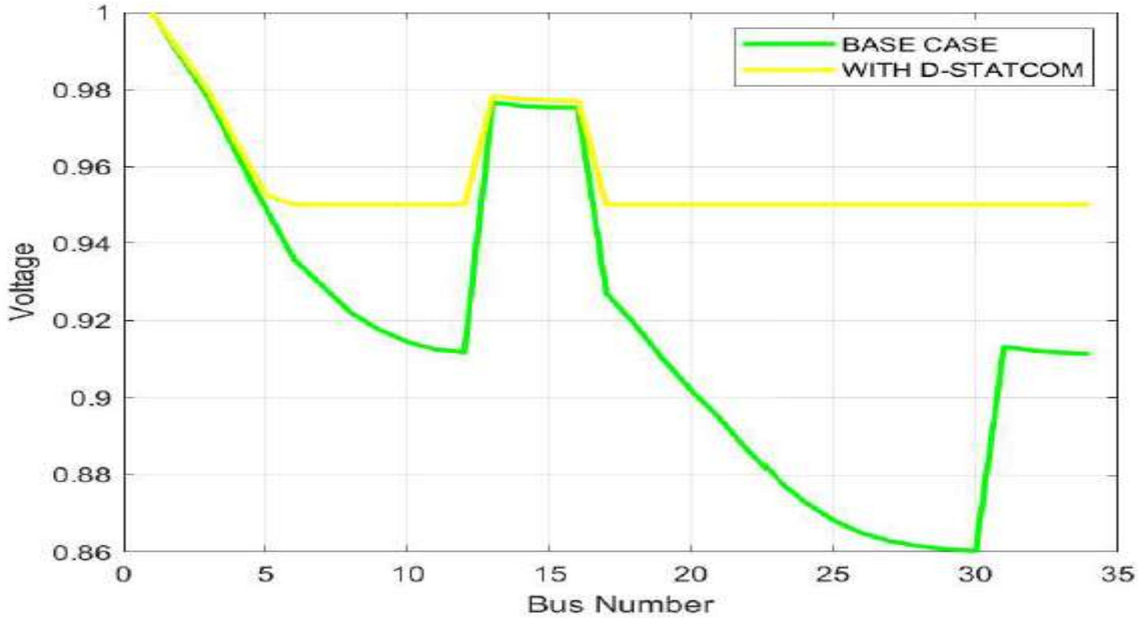

Figure 3: Base case voltage profile and after compensation of Thinkers Corner (TC) with DSTATCOM

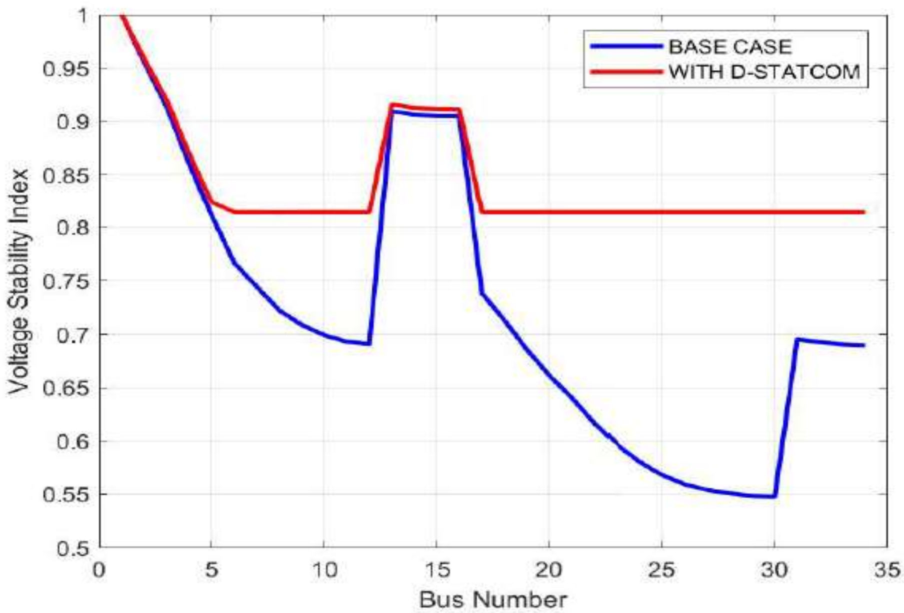

Figure 4 Base case voltage stability index and after compensation of Thinkers Corner (TC) with DSTATCOM

Figure 5 shows the base case active power loss of Thinkers Corner Network, while Figure 6shows the active power loss with DSTATCOM integrated.

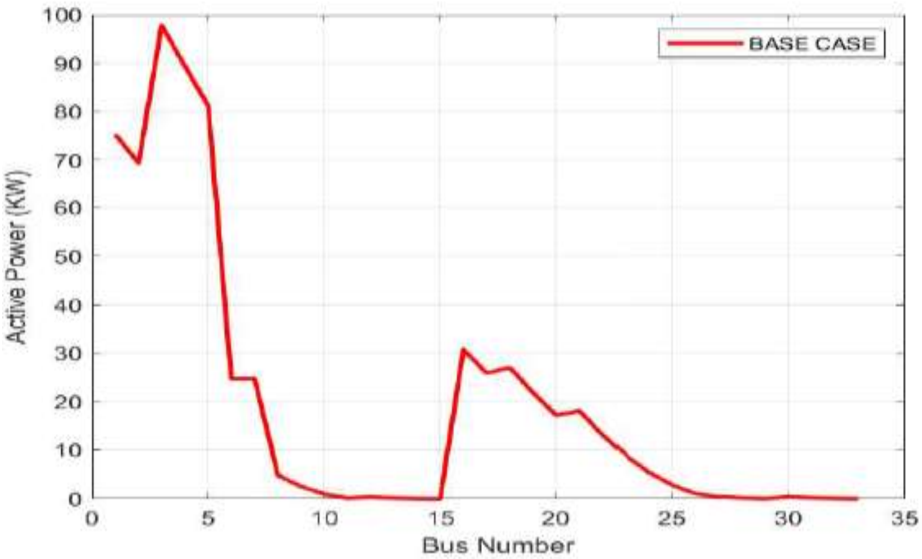

Figure 5: Base case active power loss of Thinkers Corner feeder

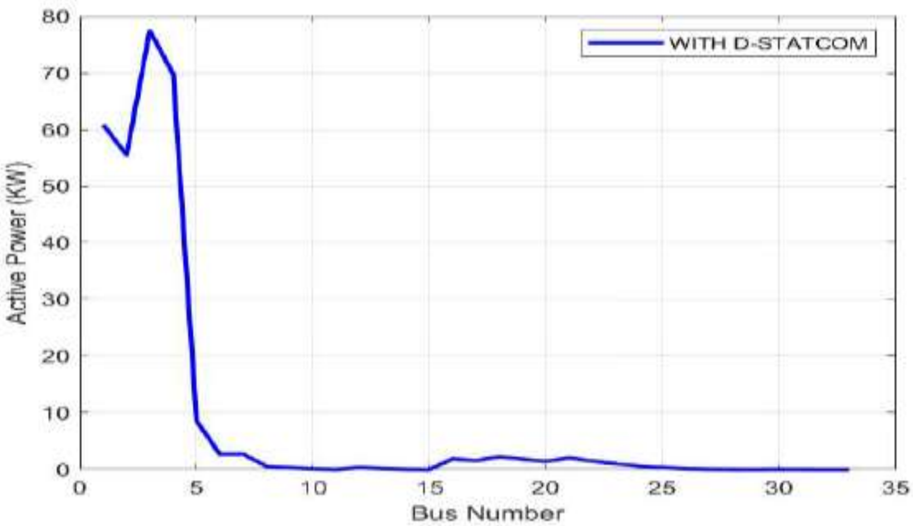

Figure 6: Active power loss of Thinkers Corner (TC) after compensation with DSTATCOM

3.2. Simulation of IEEE 33- Bus System

Table 3 compares the IEEE 33-bus system's performance with and without DSTATCOM. Without DSTATCOM, the system recorded 282.41 kW real power loss, 188.95 kVAR reactive power loss, a minimum voltage magnitude of 0.8814 p.u., and a Voltage Stability Index (VSI) of 0.6036 p.u. With a 986.95 kVAr DSTATCOM at bus 5, real power loss dropped by 50.2% to 140.73 kW, and reactive power loss decreased by 54.8% to 85.36 kVAR. The minimum voltage magnitude improved to 0.95 p.u., and the Voltage Stability Index (VSI) rose to 0.8145 p.u. This strategic implementation contributes to the system's improved performance, underscored by the reductions in power losses and voltage stability enhancements.

Table 3: performance evaluation of (IEEE 33-bus)

No	Parameters	Base(Case)	PSO (case)
1	Active power loss	282.41 KW	140.73 KW
2	Reactive power loss	188.95 KVAr	85.355 KVAr
3	Minimum VSI	0.60356 pu	0.81449 pu
4	Minimum voltage	0.8814p.u	0.95pu
5	Dstatcom location		Bus 5
6	Dstatcom size		986.94 KVAr
7	Active power loss%		50.2%
8	Reactive power loss%		54.8%

Figure 7 shows the base case voltage profile and the voltage profile after compensation with DSTATCOM in IEEE's 33-bus system, while Figure 8 shows the base case voltage stability index and the voltage stability index after compensation with DSTATCOM.

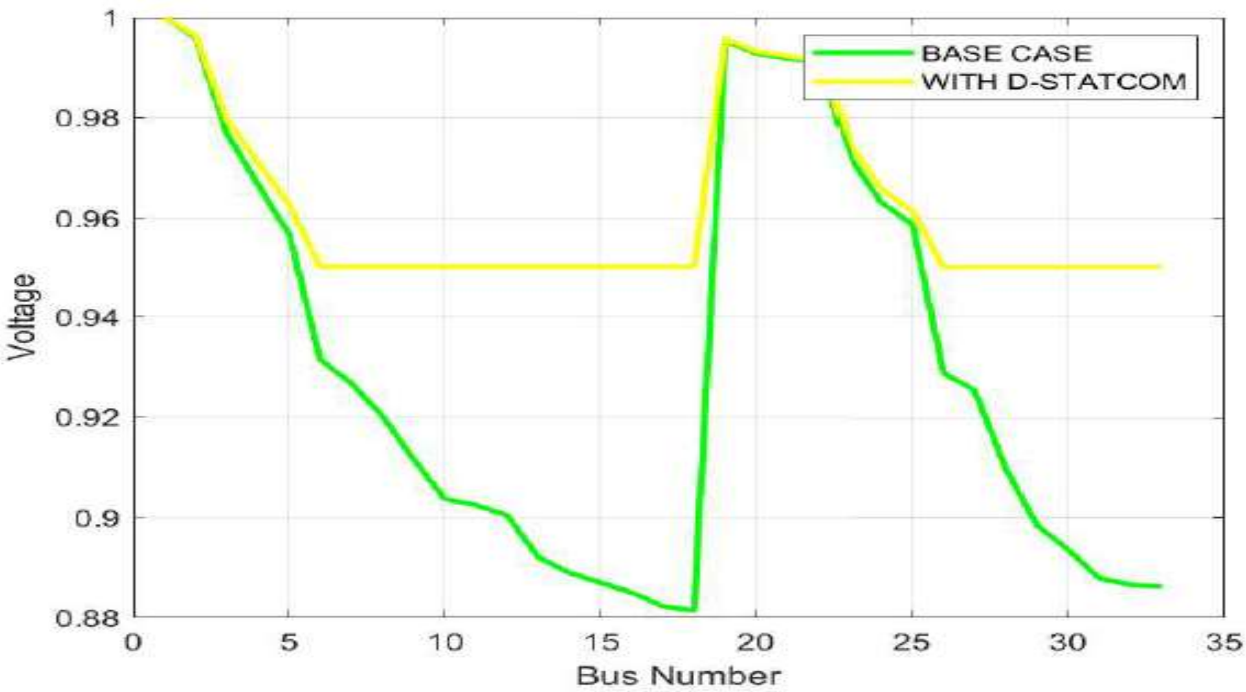

Figure 7: Base case voltage profile and after compensation of IEEE 33-bus with DSTATCOM

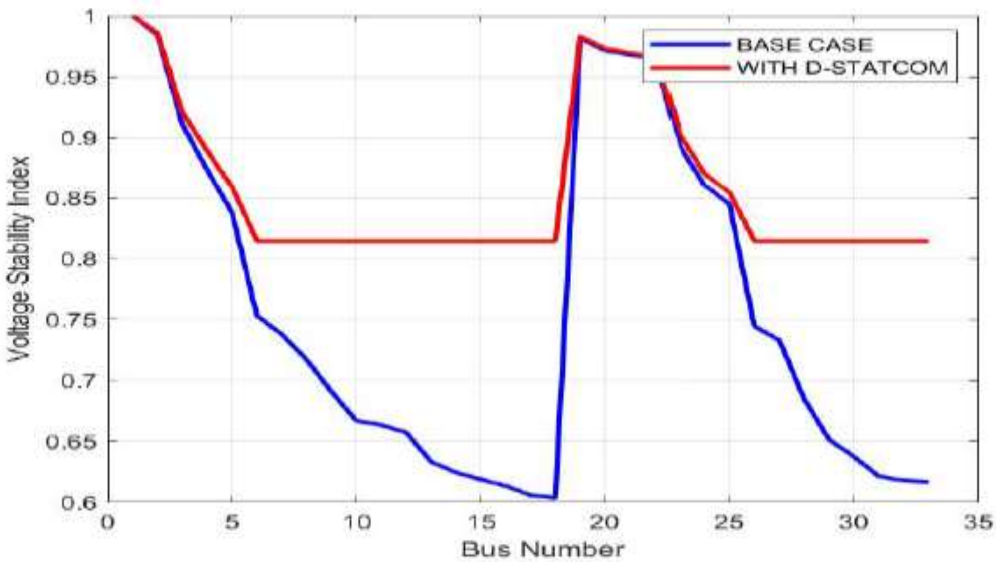

Figure 8 Base case voltage stability index and after compensation of IEEE 33-bus with DSTATCOM

Figure 9 shows the base case active power loss of IEEE's 33-bus system, while Figure 10 shows the active power loss with DSTATCOM integrated.

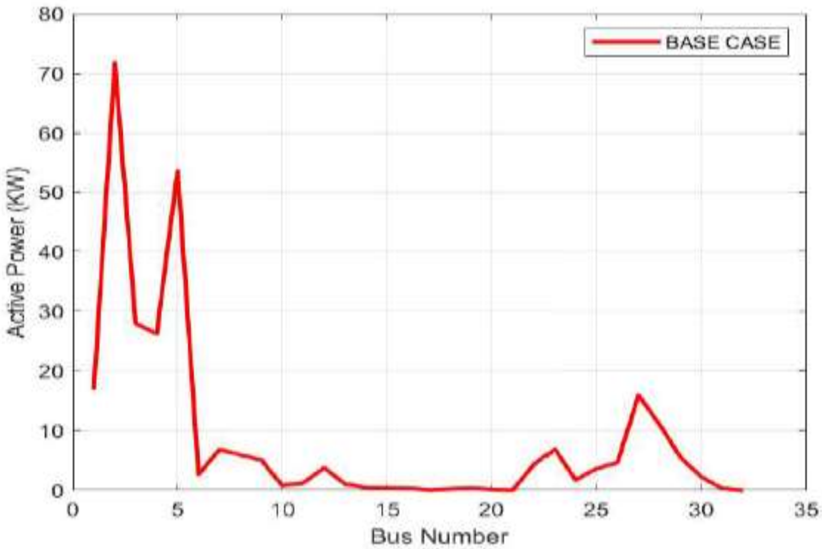

Figure 9: Base case active power loss of IEEE 33-bus feeder

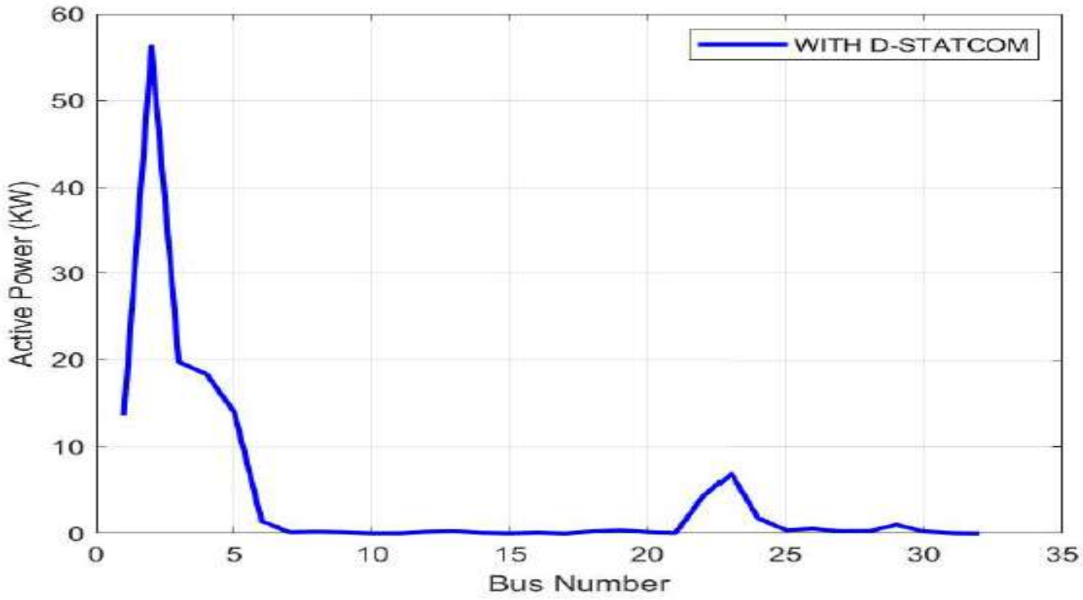

Figure 10**:** Active power loss after compensation of IEEE 33-bus with DSTATCOM

4. CONCLUSION

This study implemented a PSO-based method to optimize the placement and sizing of a DSTATCOM in the Thinkers Corner 34-bus distribution network. Key objectives—reducing power losses, improving voltage profiles, and enhancing voltage stability—were achieved. The bus-based voltage stability index helped streamline the optimization, and the Backward-Forward Sweep load flow method evaluated system performance. Results showed that placing a 1000 KVAr DSTATCOM reduced real power loss by 54.6% and reactive power loss by 48.2%, while significantly improving voltage stability and profiles. The PSO algorithm proved effective in identifying the optimal solution, and the validation on the IEEE 33-bus system confirms the robustness of the approach. This research demonstrates that a single, optimally placed DSTATCOM can effectively enhance system performance in radial distribution networks.

References

Abdelaziz, A. Y., et al. (2016). Optimal reactive power dispatch for voltage stability enhancement using meta-heuristic algorithms. *Electric Power Systems Research, 136*, 31-40.

Akagi, H., and Kanazawa, Y. (1984). "Instantaneous reactive power compensators comprising switching devices without energy storage components." *IEEE Transactions on Industry Applications*, IA-20(3), 625-630.

Baklouti, S., et al. (2022). Optimal allocation of DSTATCOM for voltage regulation and power loss reduction using hybrid optimization. *Energy Systems*, *14*(2), 129-145.

Bollen, M. H. J. (2000). *Understanding Power Quality Problems: Voltage Sags and Interruptions*. IEEE Press.

Del Valle, Y., et al. (2008). Particle swarm optimization: Basic concepts, variants and applications in power systems. *IEEE Transactions on Evolutionary Computation, 12*(2), 171-195.

El-Fergany, A., and Abdelaziz, A. Y. (2014). A hybrid flower pollination algorithm for optimal DSTATCOM allocation. *International Journal of Electrical Power & Energy Systems, 64*, 1086-1094.

Gao, C., et al. (2018). Coordinated control of DSTATCOMs for voltage support in distribution networks with renewable energy sources. *Journal of Modern Power Systems and Clean Energy, 6*(3), 472-480.

Kennedy, J., and Eberhart, R. (1995). Particle swarm optimization. *Proceedings of the IEEE International Conference on Neural Networks*, 1942-1948.

Mahdad, B., and Bouktir, T. (2011). *Optimal power flow for large-scale power system with shunt FACTS using efficient parallel GA*. International Journal of Electrical Power & Energy Systems, 33(5), 1009-1018.

Moghaddam, R. F., et al. (2019). Optimal reactive power compensation using PSO-based DSTATCOM placement in distribution networks. *Energy Reports, 5*, 142-150.

Miller, T. J. E. (1982). *Reactive Power Control in Electric Systems*. Wiley, New York.

Ramesh, C., et al. (2019). Optimized DSTATCOM placement for voltage stability enhancement using PSO. *Journal of Electrical Engineering, 70*(1), 22-29.

Rashid, M. H. (2011). *Power Electronics Handbook: Devices, Circuits, and Applications*. Academic Press.

Saravanan, M., et al. (2007). Application of particle swarm optimization for optimal location of FACTS devices. *Electric Power Systems Research, 77*(3-4), 276-283.

Sanam, P., Sadeghi, S.H., and Behjat, M. (2016). *Optimal placement and sizing of DSTATCOM in distribution networks using PSO algorithm to improve voltage profile and reduce losses*. International Journal of Electrical Power & Energy Systems, 77, 360-370.

Singh, B., Solanki, J., and Joshi, A. (2015). "Control strategies for DSTATCOM for power quality improvement." *International Journal of Energy and Power Engineering,* 9(5), 176-184.

Hingorani, N. G., and Gyugyi, L. (2000). *Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*. IEEE Press, New York.

Zhao, W., and Zhang, Z. (2010). "Design of harmonic filters for power systems with DSTATCOM." *IEEE Transactions on Power Delivery,* 25(4), 2860-2866.

APPENDICES

Appendix 1: Data of Thinkers Corner 34-bus distribution network

Table 1: Thinkers Corner's line and bus data

LINE DATA						BUS DATA			
No	Sending node	Receiving node	Length (Km)	Resistance	Reactance	Bus No	Transformer (KVA)	Pload (KW)	Qload (KVAr)
1	1	2	0.6	0.195	0.08	2	500	230	142.5
2	2	3	0.55	0.195	0.08	3	300	230	142.5
3	3	4	0.55	0.299	0.083	4	500	230	142.5
4	4	5	0.5	0.299	0.083	5	500	230	142.5
5	5	6	0.5	0.299	0.083	6	500	75	48
6	6	7	0.6	0.524	0.09	7	300	230	130
7	7	8	0.4	0.524	0.09	8	300	230	1425
8	8	9	0.6	0.524	0.09	9	500	230	142.5
9	9	10	0.4	0.524	0.09	10	200	230	120
10	10	11	0.25	0.524	0.09	11	300	230	142.5
11	11	12	0.2	0.524	0.09	12	300	137	84
12	3	13	0.3	0.524	0.09	13	200	72	45
13	13	14	0.4	0.524	0.09	14	200	72	45
14	14	15	0.1	0.524	0.09	15	300	72	45
15	15	16	0.55	0.524	0.09	16	100	13.5	7.5
16	6	17	0.55	0.299	0.083	17	500	230	142.5
17	17	18	0.5	0.299	0.083	18	300	230	142.5
18	18	19	0.5	0.378	0.086	19	500	230	142.5
19	19	20	0.5	0.378	0.086	20	500	230	142.5
20	20	21	0.5	0.378	0.086	21	300	230	142.5
21	21	22	0.6	0.524	0.09	22	300	230	142.5
22	22	23	0.4	0.524	0.09	23	500	230	142.5
23	23	24	0.25	0.524	0.09	24	500	230	142.5
24	24	25	0.3	0.524	0.09	25	500	230	142.5
25	25	26	0.3	0.524	0.09	26	300	230	142.5
26	26	27	0.3	0.524	0.09	27	200	137	85
27	27	28	0.3	0.524	0.09	28	200	75	48
28	28	29	0.4	0.524	0.09	29	200	75	48
29	29	30	0.5	0.524	0.09	30	200	75	48
30	10	31	0.3	0.524	0.09	31	100	57	34.5
31	31	32	0.4	0.524	0.09	32	200	57	34.5
32	32	33	0.2	0.524	0.09	33	200	57	34.5
33	33	34	0.3	0.524	0.09	34	200	57	34.5

Appendix 2: Data of IEEE's 33-bus distribution system

Table 2: IEEE's line and bus data

LINE DATA					BUS DATA		
No	**Sending node**	**Receiving node**	**Resistance**	**Reactance**	**Bus No**	**Pload (KW)**	**Qload (KVAr)**
1	1	2	0.092	0.047	2	100	60
2	2	3	0.493	0.251	3	90	40
3	3	4	0.366	0.186	4	120	80
4	4	5	0.381	0.194	5	60	30
5	5	6	0.819	0.707	6	60	20
6	6	7	0.187	0.619	7	200	100
7	7	8	0.711	0.235	8	200	100
8	8	9	1.03	0.74	9	60	20
9	9	10	1.044	0.74	10	60	20
10	10	11	0.197	0.065	11	45	30
11	11	12	0.374	0.124	12	60	35
12	12	13	1.468	1.155	13	60	35
13	13	14	0.542	0.713	14	120	80
14	14	15	0.591	0.526	15	60	10
15	15	16	0.746	0.545	16	60	20
16	16	17	1.289	1.721	17	60	20
17	17	18	0.732	0.574	18	90	40
18	2	19	0.164	0.157	19	90	40
19	19	20	0.504	1.355	20	90	40
20	20	21	0.4095	0.478	21	90	40
21	21	22	0.709	0.937	22	90	40
22	3	23	0.451	0.308	23	90	50
23	23	24	0.898	0.709	24	420	200
24	24	25	0.896	0.701	25	420	200
25	6	26	0.203	0.103	26	60	25
26	26	27	0.284	0.145	27	60	25
27	27	28	1.059	0.934	28	60	20
28	28	29	0.804	0.701	29	120	70
29	29	30	0.508	0.259	30	200	600
30	30	31	0.974	0.963	31	150	70
31	31	32	0.311	0.362	32	210	100
32	32	33	0.341	0.53	33	60	40