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Integrated Operation Of PV, DSTATCOM And EV Charging Infrastructure In Distributions Systems For Enhancing Voltage Stability Using Pelican Bird Optimization

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ABSTRACT
Radial Distribution Systems (RDS) play a vital role in electrical power delivery but face several operational challenges such as high power losses, poor voltage profiles, and limited flexibility for integrating distributed energy resources. These issues are further exacerbated by the growing penetration of Photovoltaic (PV) systems, Distributed Static Compensators (DSTATCOM), and particularly Electric Vehicle Charging Stations (EVCS). While EVCS are essential for promoting sustainable transportation, their uncoordinated integration into RDS can lead to voltage instability, increased peak demand, and system congestion, highlighting the need for optimized planning.

This paper presents an integrated planning methodology using the novel Pelican Bird Optimization (PBO) algorithm for optimal placement and sizing of PV, DSTATCOM, and EVCS in the IEEE 69-bus radial distribution system. Inspired by the cooperative hunting behavior of pelicans, the PBO algorithm offers strong global search ability and rapid convergence, making it suitable for solving complex, multi-objective optimization problems in power systems. The optimization aims to minimize real and reactive power losses while improving the system's voltage profile, subject to voltage, capacity, and power balance constraints. Simulation results demonstrate a significant reduction in real and reactive power losses from 224.90 kW and 102.12 kVAr to 6.86 kW and 6.16 kVAr, respectively. The minimum bus voltage is enhanced from 0.909 p.u. to 0.973 p.u. Comparative evaluation with HPO, AVOA, and GWO algorithms confirms the superior performance of PBO in terms of loss minimization, voltage stability, and computational efficiency. The proposed approach provides a robust solution for enhancing the performance of modern RDS under high EVCS penetration

Keywords: *Distribution systems, PV systems, DSTATCOM, Electric Vehicles, Charging Stations, Pelican Optimization Algorithm and Voltage stability.*

1. INTRODUCTION

The increasing adoption of electric vehicles (EVs) is significantly transforming modern power distribution networks, presenting both promising opportunities and notable operational challenges. EVs play a pivotal role in the global transition toward cleaner and more sustainable transportation. However, the growing and often unpredictable charging demands from electric vehicle charging stations (EVCS) are exerting additional pressure on radial distribution systems. These demands can lead to voltage instability, increased power losses, and the potential overloading of existing infrastructure [1].

To mitigate these challenges and minimize system losses, utilities and grid operators are incorporating renewable energy sources (RES) such as photovoltaic (PV) and wind systems. These are often used in conjunction with energy storage systems (ESS) and advanced reactive power compensation technologies. When strategically deployed and properly sized, these technologies can improve the performance of the distribution network by ensuring voltage stability, reducing power losses, accommodating dynamic load variations, and enhancing the overall reliability and resilience of the grid [2].

Researchers have developed various methods to enhance voltage stability in distribution systems with high penetration of RES and EV charging. These include the coordinated operation of PV systems, DSTATCOMs, and EV infrastructure to manage reactive power and maintain voltage levels. Recent studies have explored the use of advanced optimization techniques to efficiently control these integrated systems and improve overall grid performance.

Tang et al. [3] developed an optimization framework using stochastic fuzzy chance-constrained programming to simultaneously control power loss and voltage levels in distribution systems integrated with DGs and EVs. Their method effectively managed the uncertainty in load demand and renewable energy generation, providing a robust strategy for distribution system operation. Chippada and Reddy [4] proposed an optimal planning model for the placement of EV charging stations and multiple DG units. Their approach aimed at minimizing power losses and maintaining voltage stability in radial distribution systems, using conventional optimization methods based on system constraints and network characteristics.

Kannemadugu et al. presented a method for the optimal placement of EVCS, photovoltaic-based DGs and DSTATCOMs in radial distribution systems using the African Vulture Optimization Algorithm [5]. Their approach demonstrated a substantial reduction in real power losses and significant enhancement in voltage stability, confirming that the coordinated deployment of these components improves the operational performance of distribution networks Kumar et al [6] investigated the use of PV-integrated DSTATCOM systems for enhancing voltage stability in weak radial distribution feeders. The study concluded that this combination is particularly effective during periods of high load and variable generation, with noticeable improvements in voltage regulation and reductions in active power losses.

Yuvaraj et al. [7] introduced the Bald Eagle Search Algorithm (BES) for integrating EVCS and DSTATCOMs into Indian distribution systems. The algorithm was used to improve voltage profiles and reduce system losses through efficient resource allocation. The same authors [8] employed a multi-objective optimization approach considering the uncertainty in load for the simultaneous allocation of DGs and DSTATCOMs. Their strategy minimized the negative impact of EVCS on network performance, improving system reliability and stability.

Chinnaraj et al. utilized the Spotted Hyena Optimization Algorithm [9] to simultaneously allocate renewable DGs, DSTATCOMs, and EVCS in distribution systems. Their findings showed that this integrated planning strategy effectively mitigated the adverse impacts of high EV penetration by reducing energy losses and ensuring voltage levels remained within permissible limits. Muthusamy et al. [10] proposed the use of the Honey Badger Algorithm to optimize EVCS integration into smart grids. This metaheuristic technique improved voltage stability and reduced energy losses by effectively managing charging demands.

Aljafari et al. [11] introduced a novel Spotted Hyena Optimization algorithm to optimize the placement of DGs and EVCS in radial distribution systems. Their method enhanced system performance by reducing power losses and managing voltage constraints under varying load conditions. Goutham et al focused on optimal EVCS placement using Grey Wolf Optimization [12] in order to address voltage stability issues caused by uncoordinated EV charging. Their model successfully minimized total system power losses while maintaining acceptable voltage profiles across the distribution network.

Zhang et al. developed a multi-objective optimization framework [13] for the placement of EVCS integrated with PV systems, considering stochastic uncertainties in EV charging demands. Their simulation results validated the effectiveness of renewable-EV coordination in minimizing energy losses and stabilizing voltage levels throughout the network under various load conditions. Several studies have explored the coordinated integration of renewable energy sources, electric vehicles (EVs), and DSTATCOMs to enhance voltage stability and energy efficiency in distribution networks. Abdelaziz et al. proposed the Hippopotamus Optimization Algorithm [14] for optimal placement and sizing of these components, demonstrating significant improvements in voltage profiles and loss reduction in distribution systems.

Sahoo et al. [15] applied an Improved Snow Ablation Optimizer (ISAO) for optimal integration of D-STATCOMs in grid-tied micro grids with renewable DGs and EVCS. Their optimization model significantly enhanced voltage regulation and reduced power losses in renewable-integrated distribution systems.

In this paper, propose an integrated control strategy for enhancing voltage stability in distribution systems by optimally coordinating Photovoltaic (PV) generation, Distribution Static Compensators (DSTATCOMs) and Electric Vehicle (EV) charging infrastructure. The growing adoption of renewable energy and EVs presents new challenges in maintaining voltage profiles and minimizing losses in radial distribution networks. To address this, employ the Pelican Bird Optimization (PBO) algorithm to determine the optimal placement and sizing of PV units, DSTATCOMs, and EV charging stations. The proposed approach is implemented in MATLAB 2021.0 and evaluated on the IEEE-69-bus distribution test systems. A comparative study is conducted against other well-established optimization techniques to assess the performance of the PBO algorithm. Simulation results demonstrate significant improvements in voltage stability and power loss reduction, validating the effectiveness of the proposed method.

2. MATHEMATICAL MODELLING AND PROBLEM FORMULATION

2.1 EVCS Modeling

The integration of Electric Vehicle Charging Stations (EVCS) into a power distribution system affects power flow and voltage stability. To accurately represent this impact, mathematical models are used. The two equations provided describe the active power drawn by the EVCS and the updated total load at a bus

$$P_{EVCS} = \frac{V_s \times V_e \sin\delta}{\omega L_c} \quad (1)$$

The charging station adds to the existing power demand at the node where it is installed. This updated load must be considered in power flow and stability analysis

$$P_{i(new)} = P_{i(base)} + P_{i(EVCS)} \quad (2)$$

2.2 Solar Modeling

The integration of solar photovoltaic (PV) systems into a distribution network helps reduce the net load at buses and supports voltage stability. The modeling captures the variation in PV output with respect to temperature and its impact on bus power demand

$$P_{PV} = P_{PV(base)}\left[1 + \alpha_{PV(T-T_{ref})}\right]\frac{\delta_{PV}}{100} \quad (3)$$

The PV generation offsets part of the base load, reducing the total power that must be supplied from the grid. This helps reduce stress on the distribution system and improves voltage profiles

$$P_{i(new)} = P_{i(base)} - P_{i(PV)} \quad (4)$$

2.3 DSTATCOM Modeling

DSTATCOM is a power electronic device used in distribution systems to provide reactive power support, regulate voltage, and improve power quality. The following equations model its reactive power injection and the effect on the system's reactive load

$$Q_D = -|V_D|^2 B_D + |V_D||V_D|B_D \quad (5)$$

The reactive power provided by the DSTATCOM reduces the net reactive load at the bus. This compensation improves the voltage profile, reduces reactive power losses, and enhances system voltage stability. The Updated Reactive Power at the Bus is represented below.

$$Q_{i(new)} = Q_{i(base)} - Q_{i(D)} \quad (6)$$

2.4 OBJECTIVE FUNCTION

The goal of this optimization model is to improve the voltage stability and minimize active power losses in a power distribution system that integrates EVCS, PV systems, and DSTATCOM. This is achieved through the objective function defined in Equation (7), supported by the loss and voltage stability calculations in Equations (8) and (9).

$$F_0 = min(P_l) + max(VSI) \quad (7)$$

Where, $P_l$are the system active losses and give by, $P_l = \sum_{K=1}^{N} |I|^2 \times r_k$ (8)

$$VSI(k+1) = V_k^4 - 4(P_{k+1}X_k - Q_{k+1}R_k)^2 - 4(P_{K+1}Q_k + Q_{k+1}X_k)V_k^2 \quad (8)$$

2.5 CONSTRAINTS

In any power system optimization problem, constraints are necessary to ensure that the solution adheres to physical limits and operational requirements. The following constraints ensure that voltages, power generation, and device limits remain within acceptable and safe ranges.

a. Voltage Limits Constraint

The voltage at every bus stays within a safe operating range—typically between 0.95 to 1.05 per unit (p.u). It prevents over-voltage or under-voltage conditions, which can damage equipment or degrade performance.

$$V_{min} \leq V_k \leq V_{max} \quad (10)$$

b. Active Power Balance Constraint

This is the active power balance condition. It ensures that the total active power supplied by conventional generators and PV systems is at least equal to the total system losses, the base load demand, and the additional load from EV charging stations. This maintains power balance and avoids shortages.

$$P_{generated} + P_{PV} \geq P_{loss} + P_{demand} + P_{EVCS} \quad (11)$$

c. Reactive Power Balance Constraint

This constraint ensures that reactive power supplied by generators and the DSTATCOM is sufficient to meet the reactive power demand and losses in the system. Adequate reactive power support is crucial for voltage stability and regulation.

$$Q_{generated} + Q_D \geq Q_{loss} + Q_{demand} \quad (12)$$

d. PV Power Output Limits

This constraint ensures the PV output remains within its rated capacity. Due to changing solar irradiance and temperature, PV power generation varies, and this range reflects the minimum and maximum feasible generation from PV panels.

$$P_{PV\,min} \leq P_{PV} \leq P_{PV\,max} \quad (13)$$

e. DSTATCOM Reactive Power Limits

This defines the operational range of the DSTATCOM. It cannot supply or absorb unlimited reactive power. The limits depend on the device's design and ratings**,** ensuring it operate safely within technical boundaries.

$$Q_{D\,min} \leq Q_D \leq Q_{D\,max} \quad (14)$$

3. PROPOSED METHODOLOGY

3.1 Proposed Pelican Bird Optimization (PBO) Algorithm for Voltage Stability Enhancement

The Pelican Bird Optimization (PBO) algorithm is a population-based, nature-inspired metaheuristic developed by Pavel Trojovský and Mohammad Dehghani in 2022 [16–18]. It simulates the hunting behavior of pelicans, focusing on two key phases: moving toward prey and winging on the water surface. These phases allow the algorithm to efficiently explore and exploit the search space to find optimal solutions for constrained optimization problems. In this work, PBO is employed to identify the optimal placement and sizing of PV-based DGs, DSTATCOMs, and EV Charging Stations (EVCSs) to improve voltage stability in radial distribution systems. The mathematical modeling of population initialization, search agent updates, and position calculations is presented in the following sections

Initialization of Populations

The lower and upper boundaries of POA randomly generate the initial population by the following equation with help of random number.

$$x_{i,j} = l_j + rand.\left(u_j - l_j\right), i = 1,2,3, \ldots\ldots, N, j = 1,2,3, \ldots\ldots, m, \quad (19)$$

The randomly generated populations are reprinted in the matrix form. The size of the matrix $N \times m$ is represented in the below equation:

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_i \\ \vdots \\ X_N \end{bmatrix}_{N\times m} = \begin{bmatrix} X_{1,1} & \cdots & X_{1,j} & \cdots & X_{1,m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ X_{i,1} & \cdots & X_{i,j} & \cdots & X_{i,m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ X_{N,1} & \cdots & X_{N,j} & \cdots & X_{N,m} \end{bmatrix}_{N\times m} \quad (20)$$

The above initial populations are used to determine the objective functions of the projected work and are represented in the vector form as shown in equation (21):

$$F = \begin{bmatrix} F_1 \\ \vdots \\ F_i \\ \vdots \\ F_N \end{bmatrix}_{N\times 1} = \begin{bmatrix} F(X_1) \\ \vdots \\ F(X_i) \\ \vdots \\ F(X_N) \end{bmatrix}_{N\times 1} \tag{21}$$

The POA methodology is illustrated through two distinct phases that mimic the hunting behaviour of pelicans.

Phase 1: Moving towards Prey
The movement of pelican towards the prey is mathematically represented by the following equations:

$$X_{i,j}^{p_1} = \begin{cases} X_{i,j}, + rand\,.(P_j - I\,.\,X_{i,j}). & F_p < F_i; \\ X_{i,j}, + rand\,.(X_{i,j} - P_j), & else, \end{cases} \tag{22}$$

The position of the POA is updated using the below equation:

$$X_i = \begin{cases} X_i^{P_1}, & F_i^{P_1} < F_i; \\ X_i, & else, \end{cases} \tag{23}$$

Phase 2: Winging on the Water Surface
This behaviour of pelicans during hunting in the water surface is mathematically defined as follows:

$$X_{i,j}^{P_2} = X_{i,j} + R\,.(1 - \frac{t}{T}).(2\,.\,rand - 1).X_{i,j}, \tag{24}$$

The position of the phase 2 is updated using the following equation:

$$X_i = \begin{cases} X_i^{P_2}, & F_i^{P_2} < F_i; \\ X_i, & else, \end{cases} \tag{25}$$

3.2 Implementation of Integrated Operation Strategy for PV, DSTATCOM, and EVCS Using Pelican Bird Optimization
The proposed method applies Pelican Bird Optimization (PBO) to enhance voltage stability in radial distribution systems by optimally locating and sizing PV-based Distributed Generators (DGs), DSTATCOMs, and EV Charging Stations (EVCSs). The objective is to reduce real and reactive power losses and improve voltage stability indices while satisfying operational constraints under EV-integrated loading.

1. Load input data for 33-bus and 69-bus radial distribution systems, including line, bus, load data, and characteristics of EVs, charging stations, PV-DGs, and DSTATCOMs.
2. Perform base case power flow without DER or EVCS integration; calculate base power loss, Voltage Deviation Index (VDI), Voltage Stability Index (VSI), and bus voltages.
3. Define the number and ratings of PV-DGs, DSTATCOMs, and EVCSs (charging points) as decision variables.
4. Initialize PBO parameters: population size, problem dimension, max iterations, and variable bounds.
5. Generate initial population of pelicans representing candidate solutions with component placements and sizes.
6. Evaluate each pelican using power flow to compute Power Loss Index (PLI) and VSI.
7. Store global best and personal best solutions.

8. Phase 1: Moving towards Prey (Exploration) - Update pelican positions simulating long-range search behavior toward or away from the global best solution.
9. Apply boundary checks to ensure feasibility of updated positions.
10. Recalculate fitness; update personal bests if improvement occurs.
11. Phase 2: Winging on the Water Surface (Exploitation) - Refine pelican positions through local search simulating hunting attack behavior.
12. Enforce variable bounds and recalculate fitness; update personal and global bests.
13. Check system constraints (voltage, line loading, capacity); penalize or discard infeasible solutions.
14. Store updated global best and monitor convergence.
15. If maximum iterations are unmet, increment iteration count and repeat from Step 8.
16. Upon convergence, output the optimal locations and sizes of PV-DGs, DSTATCOMs, and EVCSs, along with improved power loss reduction and voltage stability metrics. Terminate the algorithm.

4. RESULTS AND DISCUSSION

In this study, the integrated operation of Photovoltaic (PV) systems, Distribution Static Compensators (DSTATCOM) and Electric Vehicle Charging Stations (EVCS) within distribution networks is investigated to enhance voltage stability and minimize power losses. The optimization of component placement and sizing is achieved using the Pelican Bird Optimization (PBO) algorithm, a recent metaheuristic inspired by pelican hunting behavior. MATLAB R2021a is utilized as the simulation platform, running on a dual-core processor with 8 GB of RAM. The performance of the proposed methodology is evaluated on standard IEEE 69-bus radial distribution systems and one line diagram shown in fig. 1.

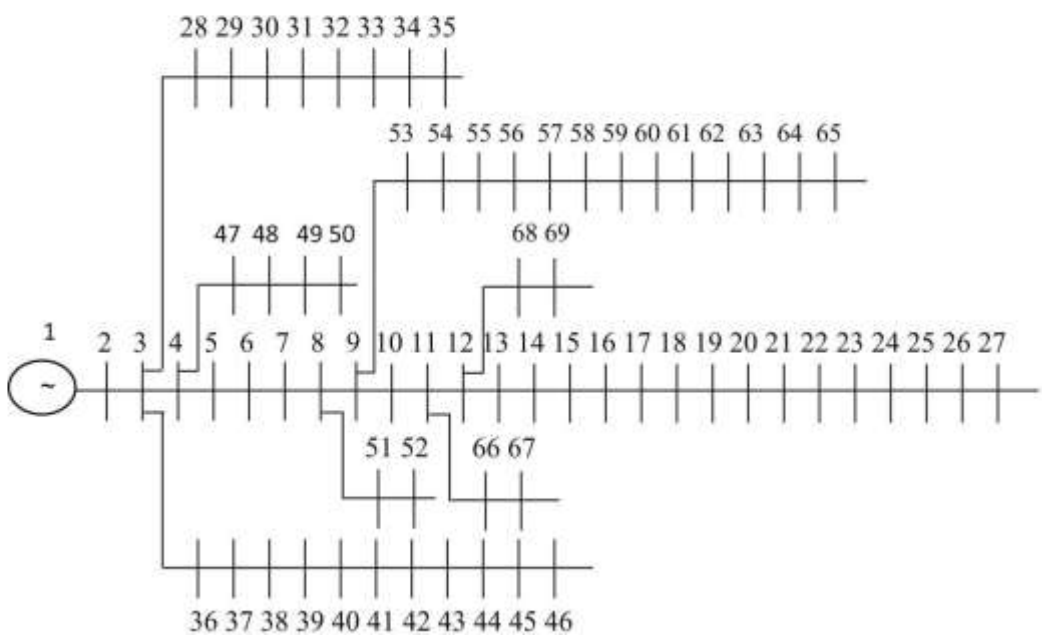

Fig. 1 One-line diagram of 69-node distribution test system

Five scenarios were analyzed to assess the impact of integrating PV, DSTATCOM, and EVCS on voltage stability and power loss:

- Base Case: Original system without any integration.

- Only EVCS: Integration of EV charging stations.
- EVCS and DSTATCOM: Integration of EV charging stations and DSTATCOM.
- EVCS and PV: Integration of EV charging stations and photovoltaic systems.
- EVCS, PV and DSTATCOM: Full integration of EV charging stations, photovoltaic systems, and DSTATCOM

Results demonstrate that the full integration scenario significantly improves voltage profiles and minimizes both active and reactive power losses. The PBO algorithm effectively identifies optimal configurations, ensuring efficient coordination among distributed resources. These findings underscore the potential of advanced metaheuristic algorithms for enhancing the reliability and efficiency of modern distribution networks with increasing renewable energy and EV penetration

The IEEE 69-node radial distribution test system is a standard benchmark network operating at 12.66 kV with a base power of 100 MVA. It consists of 69 buses and 68 branches in a radial configuration, with Node 1 as the substation (source) and Nodes 61–69 as far-end buses. The system has a total active power load of 3.802 MW and a reactive power load of 2.694 MVAR, distributed unevenly across the network. Fig. 2 shows the voltage profile of the 69-node system under three scenarios: Base Case, Only EVCS, and EVCS with PV and DSTATCOM. In the Base Case, voltage drops are seen especially at distant buses (e.g., Bus 65 at 0.909 p.u.). With only EVCS, voltage further deteriorates due to added load. However, when PV and DSTATCOM are optimally integrated using Pelican Bird Optimization (PBO), voltage levels improve significantly across all buses, with most voltages close to or above 0.998 p.u.

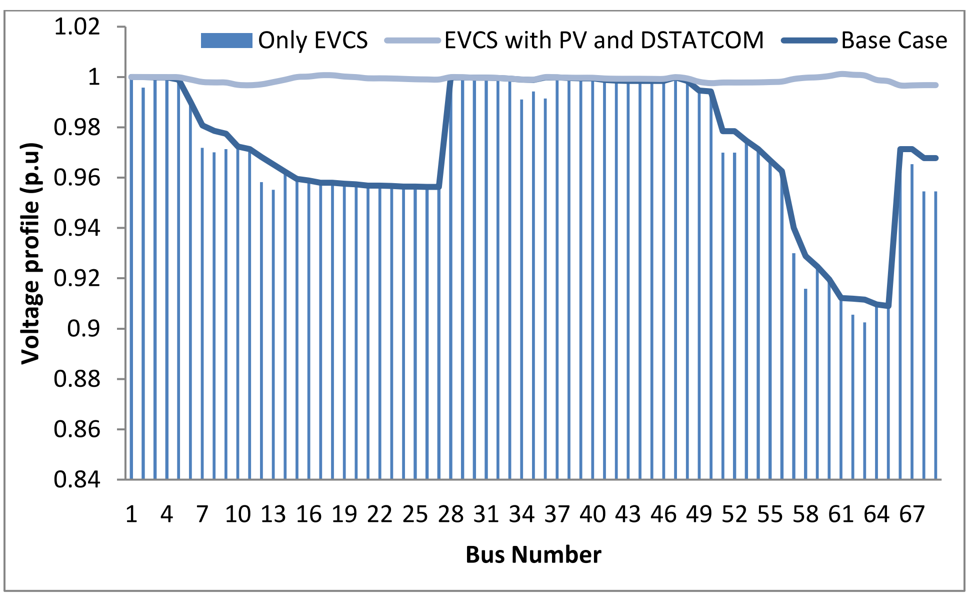

Fig 2 Voltage Profile for 69 node test system

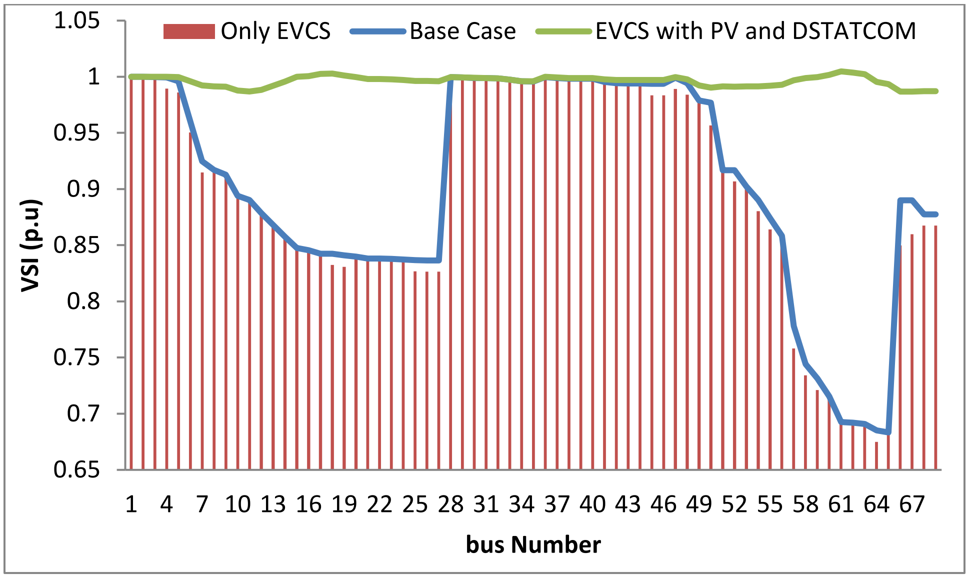

Fig 3 VSI for 69 node test system

Fig . 3 provide the Voltage Stability Index (VSI) values for each bus. The VSI decreases noticeably when only EVCS are integrated, reflecting a decline in voltage stability—for example, Bus 61 drops to 0.6925. However, with the inclusion of PV and DSTATCOM optimized using the Pelican Bird Optimization algorithm, the VSI values improve substantially, with many buses reaching values close to or exceeding 1.0, indicating enhanced overall system stability. It confirms that stability is lowest in the EVCS-only case and highest in the EVCS + PV + DSTATCOM case, validating the effectiveness of the PBO approach.

Table 1 Simulation results of 69-node system for different cases

69 – node system Different cases	Active power loss (KW)	Reactive power loss (KVAr)	EV CS location and size	PV location and size	DSTATCOME Location and size
Base case	225.00	102.16			
Only EVCS	225.17	102.65	2(996) 10(996) 48(996)		
EVCS and DSTATCOM	82.75	40.86	2(996) 30(996) 48(996)		11(570) 28(510) 62(1245)
EVCS and PV	69.27	34.99	2(996) 36(996) 61(996)	12(530) 48(1092) 61(1780)	
EVCS with PV and DSTATCOM	6.86	6.16	18(996) 28(996) 45(996)	45(1089) 18(1571) 61(1756)	61(1214) 12(591) 49(565)

Table 1 presents the simulation results of the 69-node distribution system under five different scenarios, highlighting the impact on active and reactive power losses as well as the optimal placement and sizing of EVCS, PV systems, and DSTATCOMs using the PBO algorithm. In the base case, without any additional components, the system experiences high losses - 225.00 kW of active power and 102.16 kVAr of reactive power. When only EVCS are integrated at buses 2, 10, and 48 (each 996 kW), the losses slightly increase to 225.17 kW and 102.65 kVAr, showing the added stress from EVCS. The inclusion of DSTATCOMs at buses 11, 28, and 62 significantly reduces losses to 82.75 kW and 40.86 kVAr, highlighting the benefits of reactive power compensation. Further improvement is seen when PV systems are added at buses 12, 48, and 61 along with EVCS, resulting in losses of 69.27 kW and 34.99 kVAr due to the contribution of local generation.

Table 2 Comparison of simulation results of proposed with existing methods

Different Cases	Algorithms	APL(kW)	V_{min} (P.u)(@bus)	VSI
Only EVCS	HPO	225.35	0.909(65)	0.68
	AVOA	225.24	0.909(65)	0.68
	GWO	225.24	0.909(65)	0.68
	PBO (Proposed)	**225.17**	**0.9092(61)**	**0.68327**
EVCS and DSTATCOM	HPO	84	0.96(65)	0.76
	AVOA	145.66	0.93(65)	0.75
	GWO	147.06	0.93(65)	0.75
	PBO (Proposed)	**82.75**	**0.9712(31)**	**0.76125**
EVCS and PV	HPO	71.08	0.982(65)	0.9
	AVOA	71.14	0.982(65)	0.93
	GWO	74.78	0.978(27)	0.91
	PBO (Proposed)	**69.27**	**0.9899(60)**	**0.9465**
EVCS with PV and DSTATCOM	HPO	7.61	0.994(50)	0.97
	AVOA	7.8	0.994(50)	0.97
	GWO	8.88	0.990(27)	0.96
	PBO (Proposed)	**6.86**	**0.9971(15)**	**0.98679**

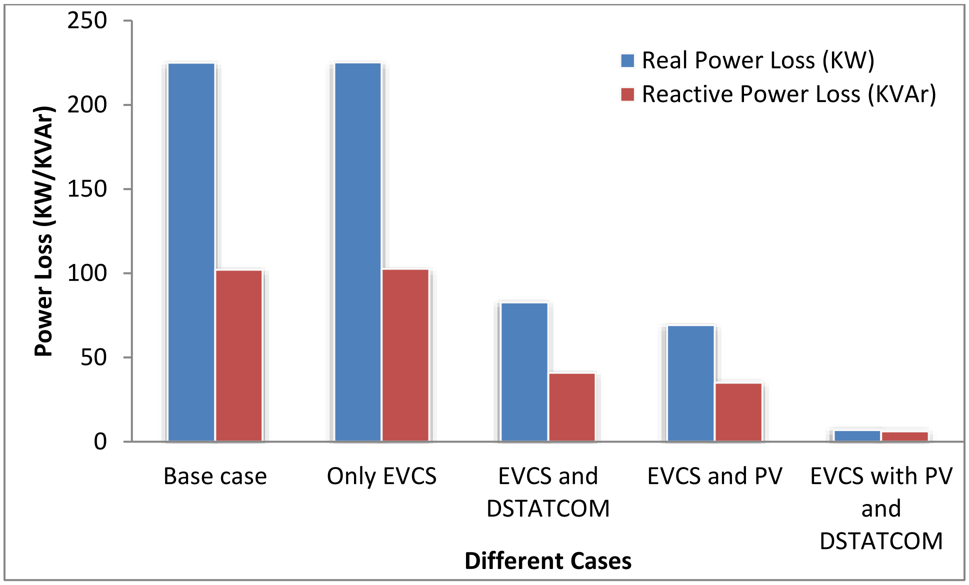

Fig 4 Comparison of Real and Reactive power loss of 69- node test system with different cases

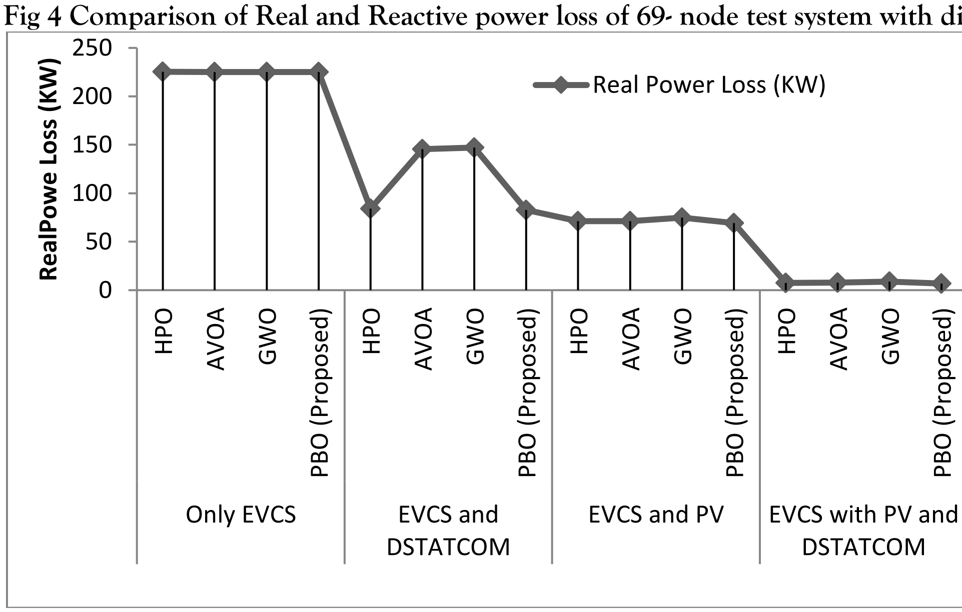

Fig 5 Comparison of Real power loss of proposed method with existing methods for different cases

The best performance is achieved in the final case, where EVCS, PV, and DSTATCOM are optimally integrated at various buses—resulting in the lowest losses of just 6.86 kW (real) and 6.16 kVAr (reactive), confirming the effectiveness of the PBO algorithm. Fig 4 compares the real and reactive power losses of the 69-node system under different scenarios. The base case and EVCS-only cases show the highest losses due to increased load and lack of support. Adding DSTATCOM and PV reduces losses significantly by providing reactive power compensation and local generation. The lowest losses occur when EVCS, PV, and DSTATCOM are optimally combined using Pelican Bird Optimization, demonstrating the effectiveness of coordinated integration in improving system efficiency and stability.

Table 2 presents a comparative analysis of various optimization algorithms such as HPO, AVOA, GWO, and the proposed Pelican Bird Optimization for voltage stability enhancement in a 69-bus distribution system. The analysis is conducted under different scenarios: EVCS alone, EVCS with DSTATCOM, EVCS with PV, and EVCS with both PV and DSTATCOM. The novelty of the PBO algorithm lies in its nature-inspired exploration–exploitation balance, which enables more accurate and globally optimal solutions. This allows it to efficiently coordinate distributed resources, minimize power losses and improve voltage stability. As shown in the results, PBO consistently outperforms other methods by achieving the lowest active power loss, highest minimum voltage, and the most favorable Voltage Stability Index in all cases.

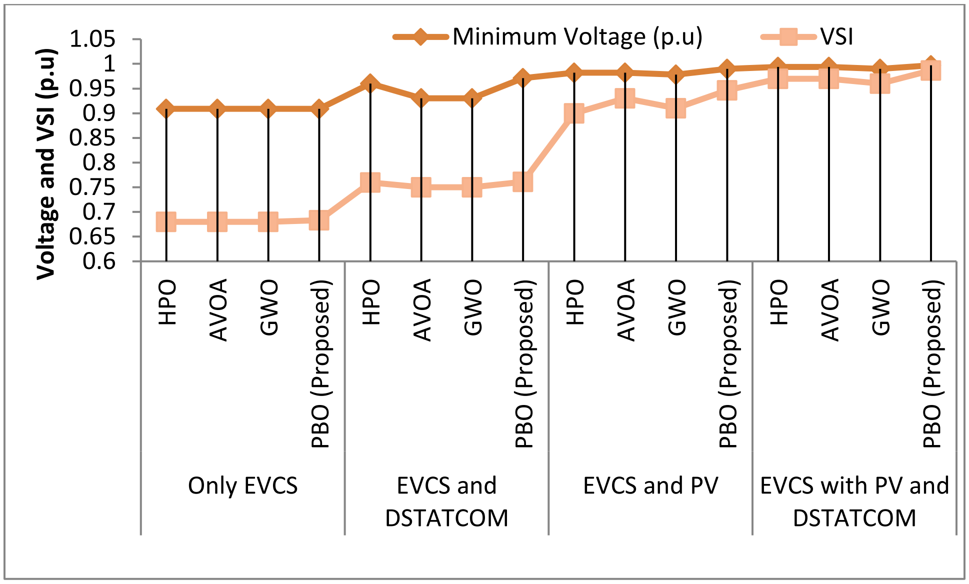

Fig 6 Comparison of voltage profile and VSI of proposed method with existing methods for different cases

This fig 5 shows real power losses across different methods. The PBO method has the lowest power losses in all cases, especially when both PV and DSTATCOM are used, proving its effectiveness in reducing system losses. Fig 6 compares voltage profiles and VSI. The PBO algorithm maintains better voltage levels across the network and provides higher voltage stability than the other methods, indicating improved system performance and reliability

5. CONCLUSION

This study presented an effective optimization framework for the optimal allocation and sizing of PV systems, DSTATCOM, and Electric Vehicle Charging Stations (EVCS) in radial distribution systems using the Pelican Bird Optimization (PBO) algorithm. The proposed method was applied to the IEEE 69-bus test system, with objectives centered on minimizing power losses and enhancing voltage stability. The PBO algorithm, inspired by the cooperative hunting behavior of pelicans, effectively balanced exploration and exploitation, enabling it to navigate the complex multi-dimensional solution space with high efficiency.Simulation results on the 69-bus system demonstrated the effectiveness of the proposed approach, with real and reactive power losses significantly reduced to 6.86 kW and 6.16 kVAr, respectively. Furthermore, the minimum bus voltage was improved from 0.909 p.u. to 0.973 p.u., indicating enhanced voltage stability throughout the network. Comparative analysis with other metaheuristic algorithms such as HPO, AVOA, and GWO revealed the superior performance of PBO in terms of solution quality, convergence speed, and robustness.

Overall, the PBO-based planning strategy proves to be a reliable and effective tool for optimizing the operation of modern radial distribution systems with high penetration of distributed energy resources and

EVCS. Future research will focus on extending the framework to incorporate economic considerations, such as cost-benefit analysis and profit maximization, particularly within deregulated electricity market environments.

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