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Cost-Effective Optimal Allocation of Electric Vehicle Charging Stations Incorporated with Distributed Generation using HMFO

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***Abstract*— The growing integration of Electric Vehicles (EVs) has posed challenges to conventional distribution networks, including higher energy demand, voltage instability, and feeder overloading. This study demonstrates that coordinated placement of Electric Vehicle Charging Stations (EVCS) with Distributed Generation (DG) units can significantly enhance network reliability and operational efficiency. To allocate the EVCS and DG with proper size and site, a Hybrid Moth-Flame Optimization (HMFO) algorithm was developed, while the Backward/Forward Sweep (BFS) method used for load flow analysis. The multi-objective optimization considered the minimization of active and reactive power losses, enhancement of the voltage profile, and price-effective operation encompassing installation, operation and maintenance (O&M), charging, and energy loss prices, addressing both the Distribution Network Operator (DNO) and Charging Station Owner (CSO) perspectives. A simulation on the IEEE 33-bus system demonstrated that HMFO outperforms Firefly and standard Moth-Flame Optimization in terms of convergence speed, price reduction, and voltage profile improvement, confirming its effectiveness for efficient, resilient, and sustainable smart distribution network planning.**

***Index Terms*— Price optimization, Distributed generation, Electric vehicle charging station, Backward-Forward Sweep method, Hybrid moth flame optimization.**

I. INTRODUCTION

The rapid proliferation of electric vehicles (EVs) is reshaping the landscape of modern power systems, demanding the strategic placement of Electric Vehicle Charging Stations (EVCS) and Distributed Generation (DG) to ensure grid stability, energy efficiency, and environmental sustainability. The incorporation of EVCS into the distribution systems presents both technical and economic challenges that necessitate multi-objective optimization approaches. Existing research can broadly be grouped into four dimensions: EVCS siting and sizing, integrated EVCS–DG planning, price and techno-economic modeling, and optimization algorithms.

Initial efforts emphasized optimal location and sizing to reduce feeder loading and voltage deviation. Zeb et al. [1] formulated a multi-objective function to minimize installation price, transformer loading, and losses in active distribution networks using real and reactive power constraints.

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Sengor et al. [2] to find proper site for different charging types while maintaining grid reliability a mixed-integer linear programming (MILP) model was used. Pal et al. [3] examined the combined allocation of fast-charging stations and PV systems, showing that co-location minimizes power losses and improves renewable utilization. Similarly, Prakobkaew and Wongsaroj [4] proposed a GIS-based optimization model that identifies the least-price EVCS locations considering traffic flow and electrical topology.

Combining EVCS planning with DG allocation improves both energy efficiency and economic feasibility. Velamuri et al. [5] demonstrated that joint EVCS–DG allocation using a hybrid optimization algorithm significantly reduces active power losses and voltage deviations. Astianta et al. [6] integrated network reconfiguration with DG–EVCS siting through Whale Optimization Algorithm (WOA), achieving enhanced voltage stability. Mohanty et al. [7] introduced a hybrid Grey Wolf–PSO method to optimally allocate DGs, capacitors, and charging stations, yielding the lowest total operating price. Golla et al. [8] provided a techno-economic comparison showing that coordinated DG and EVCS placement reduces the price of energy by 14 % compared to uncoordinated planning.

Modern studies increasingly incorporate explicit price terms—installation, O&M, energy loss, and user service prices—within optimization objectives. Nareshkumar [9] proposed a coupled transmission-distribution model that simultaneously minimizes system price and voltage deviations. Poudel et al. [10] conducted a techno-economic analysis of PV-assisted EVCS with distributed storage, identifying optimal configurations that reduce life-cycle prices by 18 %. Wang et al. [11] developed a stochastic carbon-aware planning model that jointly optimizes DGs and EVCS under variable renewable conditions. Rashid et al. [12] presented a comprehensive economic and environmental assessment of PV-fed EV charging stations, identifying O&M price as the dominant economic factor. Das [13] validated that optimized EVCS–DG integration using IEEE-33 and IEEE-69 feeders yields lower real/reactive losses and total operating prices.

Swarm and evolutionary algorithms have proven efficient in solving nonlinear, multi-constraint EVCS planning problems. Sengor's MILP [2] ensures convexity for small networks, but hybrid metaheuristics scale better. Mahmoud et al. [14] used particle swarm and differential evolution for DG allocation, demonstrating significant loss reduction. Rueda-Medina et al. [15] applied mixed-integer programming to locate DGs in radial networks, setting a foundation for EVCS integration models. Vinod Kumaret al. [16] proposed a hybrid optimization framework that combines reliability assessment with cost-effective placement of EV charging stations and capacitors. Their study demonstrated that incorporating reliability indices along with power loss and cost objectives enhances network stability and ensures an economically optimized configuration for the distribution system. Efthymiou et al. [17] developed a genetic algorithm–based model to identify optimal locations for electric vehicle charging infrastructure. The approach considered travel demand, accessibility, and installation cost, ensuring a balance between user convenience and economic feasibility in planning large-scale EV charging networks. Abdelaziz et al. [18] presented a comprehensive framework that considers the perspectives of both the Charging Station Owner (CSO) and the Distribution Network Operator (DNO) in the optimal allocation of EV charging stations. Their study integrates reliability, operational cost, and investment cost parameters to ensure coordinated decision-making between the CSO and DNO. This dual-perspective optimization enhances economic efficiency, system reliability, and equitable cost-sharing in modern power distribution networks. Velamuri et al. [5] and Mohanty et al. [7] combined swarm intelligence with price modeling, while the Hybrid Moth-Flame Optimization (HMFO) method proposed by B. Mohan et al. [19] highlighted that comprehensive cost analysis is essential for achieving economically efficient and technically reliable operation of EVCS–DG integrated networks. In the proposed HMFO-based framework, both the DNO and the CSO perspectives are incorporated. The DNO focuses on minimizing costs of power loss, energy loss, and voltage stability, while the CSO considers charging, installation, operation, and maintenance costs to maximize revenue. By jointly optimizing these cost components, the model ensures an overall cost-effective and stable distribution network with enhanced voltage performance and reduced power losses and further enhanced convergence with economic performance. B. Mohan et al. [20] emphasized that integrating cost analysis is vital for both economic and operational efficiency in EVCS and DG allocation. In their ALMO-based approach, the DNO framework incorporates cost of power loss, energy loss, and voltage stability within the optimization process. This integration enables the DNO to minimize total operational and maintenance expenses while enhancing voltage stability, reducing power losses, and ensuring reliable network performance.

Despite these advancements, most approaches emphasize either technical or economic objectives rather than both simultaneously. Few models capture the bilevel interaction between the distribution operator and charging station owner, or the comprehensive price components (installation, operation, maintenance, and energy losses). The present research addresses these limitations by applying an HMFO-based framework for simultaneous price and performance optimization in EVCS–DG planning, validated on IEEE test feeders.

The originality of this paper lies in its comprehensive, price-integrated optimization framework and the hybridization of swarm intelligence methods to address multi-objective challenges. The major contributions include:

- Hybrid Moth Flame Optimization (HMFO) Framework: A novel combination of MFO and Firefly Optimization (FFO) is applied to achieve faster convergence and superior exploration–exploitation balance for nonlinear power distribution problems.
- Comprehensive Price Modeling: The formulation simultaneously considers charging price, installation price, operational price, maintenance price, and energy loss price, representing both DNO and CSO perspectives.
- Bi-Level Objective Formulation: A multi-stakeholder optimization framework is proposed, enabling coordination between grid operators and station owners to achieve global price minimization while maintaining network stability.
- Technical and Economic Optimization: The model ensures reduction of active/reactive power losses and enhancement of voltage profile, alongside price-effectiveness and reliability.
- Performance Validation: The algorithm is verified on IEEE 33-bus radial distribution systems, demonstrating substantial reductions in losses and total system price compared to Firefly and standalone MFO algorithms.
- Practical Planning Implications: The approach provides a scalable and adaptable framework for smart grid planning, supporting policy decisions for sustainable EV infrastructure development.

The structure of this paper is organized as follows. Section 1 provides a comprehensive discussion of the existing issues in modern power distribution systems caused by the large-scale integration of EVs, along with a critical review of the benefits and drawbacks of current optimization strategies. Section 2 introduces the proposed framework for identifying the optimal locations and capacities of DG units and EVCS, employing the BFS load flow algorithm. Section 3 formulates the multi-objective, price-sensitive optimization model and explains the implementation details of the HMFO algorithm. Section 4 presents and evaluates the simulation outcomes derived from the IEEE 33-bus benchmark system to validate the performance and robustness of the proposed method. Finally, Section 5 outlines the major findings, conclusions, and prospective areas for future investigation.

II. Mathematical Formulation of the Problem

The principal objective of this research is to simultaneously reduce active and reactive power losses, improve the overall voltage profile, and reduce the average voltage mismatches of the distribution system. In addition optimize the price of the EVCS.

$$\min \left(P_1(y), P_2(y), P_3(y)\right) y \in \lambda \tag{1}$$

$$M_a(y) = 0 a = 1,2,3....N \tag{2}$$

$$K_b(y) = 0 b = 1,2,3,... 0 \tag{3}$$

$$y_v \leq y \leq y_w \tag{4}$$

Where $M_a(y)$ is the equality restrictions, $K_b(y)$ indicates inequality restrictions, y_v represents the below bound y_w defines the upper bound and λ is the space variable, P_1 and P_3 are the generation of powers.

A. Active Power Loss (APL)

The In electrical distribution systems, the majority of total power losses occur within the distribution network, directly impacting the utility's annual energy revenue. Consequently, the reduction of APL is a primary objective in the proper placement of DG integrated EVCS.

$$min\ APL = \sum_{i=1}^{J_{an}} |R_i|^2 * S_i = TPS(S) * |BIBC * I|^2 \tag{5}$$

Here, R_i current flowing in i^{th} branch, S_i resistance of the i^{th} branch, S is the branch resistance matrix which interferes with all resistance branches.

B. Voltage Deviation Index (VDI)

The quality of bus voltages is assessed using the VDI, which quantifies the deviation of bus voltages from their nominal values. Minimizing the VDI is essential to ensure a properly maintained and balanced voltage across radial distribution networks.

$$\min\ E_2 = \sum_{M=1}^{Rbus} \left(V_Q V_{ref}\right)^2 \qquad (6)$$

C. Voltage Stability Index (VSI)

When VDI alone is considered, the distribution system's security level remains insufficient. Therefore, incorporating the VSI as a main objective task is recommended to augment voltage stability and ensure a more secure and reliable voltage profile across the network.

$$VSI_{F+1} = \left|V_F\right|^4 - 4*\left[M_{N+1}X_K - O_{N+1}R_k\right]^2 - 4*\left[M_{N+1}R_k - O_{N+1}X_k\right]\left|V_f\right|^2 \qquad (7)$$

Where, VSI_{F+1} denotes the VSI of $(F+1)^{th}$ bus, R_k and X_k denotes the resistance and reactance of j^{th} branch connecting the $(F)^{th}$ and $(F+1)^{th}$ bus, M_{N+1} represents the active power and O_{N+1} defines the reactive power of the $(F+1)^{th}$ bus.

D. Operational Restrictions

The formulation includes a set of operational and system constraints governing the allocation of EVCS integrated with DG units within radial distribution networks.

Equality restrictions

The balance between the active and reactive power supplied by the substation and DG units must exactly correspond to the total of APL, network active and reactive power demands, and the additional load capacity contributed by EVCS.

The below equation (8) states that the total active power supplied by the **substation** ($P_{substation}$) and the **DG units** (P_{DG}).

$$P_{substation} + P_{DG} = P_{loss} + P_{load} + P_{EVCS} \qquad (8)$$

$$Q_{substation} + Q_{DG} = Q_{loss} + Q_{load} + Q_{EVCS} \qquad (9)$$

The equation (9) represents the **reactive power (Q) balance** in the network. It ensures that the total reactive power supplied by the **substation** ($Q_{substation}$) and **DG units (**Q_{DG}).

Where P_{loss}, Q_{loss} Active and reactive power losses in the distribution network, P_{load} ,Q_{load} Active and reactive power demand of all conventional loads connected to the system, P_{EVCS} and Q_{EVCS} active power consumed and reactive power demand of EVCS.

Inequality restrictions

The voltage magnitude at each bus must be maintained within the permissible range of 0.95 p.u. to 1.0 p.u. to ensure stable and reliable operation of the distribution network.

$$V_{a\min} \le V_j \le V_{\max, j} = 1,2,3,...N_{bus} \qquad (10)$$

Under normal operating conditions, the current passing in every line should not surpass the line's specified extreme current-carrying ability.

$$I_{ai} \le I_{ai}^{\max} i = 1,2,3,...M_{pr} \qquad (11)$$

Here, I_{ai} indicates current flows in i and $I_{ai}^{\max}$ is the maximum limitation of line current.

Power added by DGs to the EVCS

The added active and reactive powers of DG units should be maintained within given range.

$$P_{min}^{DG} \le P_{DG} \le P_{max}^{DG} \qquad (12)$$

$$Q_{min}^{DG} \leq Q_{DG} \leq Q_{max}^{DG} \quad (13)$$

Here, P_{DG} and Q_{DG} are the active and reactive power added by the DG unit, P_{min}^{DG}, P_{max}^{DG} are the lowest and highest active power limits, Q_{min}^{DG}, Q_{max}^{DG} are the lowest and highest reactive power limits.

DG unit's penetration

A common way to express DG unit penetration mathematically is:

$$\text{DG Penetration (\%)} = \sum_{i=1}^{NDG} \text{PDG,i} \,/\, P_{\text{total load}} * 100 \quad (14)$$

Here, N_{DG} is number of DG units installed, $P_{DG,i}$ active power rating of the i^{th} DG unit and $P_{\text{total load}}$ total active power demand of the distribution system.

III. HMFO ALGORITHM

In EVCS distribution lines, proper allocation of EVCS and DGs faces encounters related to location, power loss, equipment price and size, as well as vehicle scheduling and charging time. To address these issues, the IEEE bus system is coupled with an HMFO algorithm, which effectively finds the proper site and size of EVCS and DGs. HMFO combines Firefly Optimization (FFO) and Moth-Flame Optimization (MFO), where FFO explores local regions with a limited range, and MFO guides the search to avoid premature convergence, enhancing overall optimization performance.

A. Mathematical model of Hybrid Moth flame optimization

Initialization

Initialize the algorithm settings, to set the parameters of hybrid Moth flame optimization from the available numbers of DGs and EVs with the site and capacity of the EVCS. Then the initial level of the parameters was obtained from the loss of power, price and site of the DGs and EVCS.

Here, K_{pl} denotes power loss, K_l represents the location, K_c denotes the price, K_s indicates the size, K_{AVDI} represents the average voltage deviation index K_{VSI} represents the average voltage stability index K_{DGEV} indicates the DGs and EVs units of EVCS.

$$K_{DGEV} = \begin{bmatrix} K_{pl} \\ K_l \\ K_c \\ K_{VDI} \\ K_{VSI} \\ K_s \end{bmatrix} \quad (15)$$

Determine the fitness function

$$Fit_{K_{DGEV}} = Fit \begin{bmatrix} K_{pl} \\ K_l \\ K_c \\ K_{VDI} \\ K_{VSI} \\ K_s \end{bmatrix} \quad (16)$$

Then the fitness solution of the equation (16) could be expressed, every solution of the fitness function is developed from the candidate solution for a given set of values in HMFO through the objective function and objective values in scheduling time with an hour for the EVs charging station. Moreover, the best solution with the iteration in power loss, price and location.

$$Sum\ of\ fitness\ value = Voltage\ stability + \frac{1}{power\ loss} + \frac{1}{voltage\ deviation} \quad (17)$$

B. Distribution network operator approach (DNO)

Efficient distribution networks ensure reliable power supply to commercial, household and industrial consumers, for the added load locations affecting network performance. The DNO seeks proper EVCS placement to reduce real and reactive power loss prices, voltage deviation, and to enhance the reliability and stability of the system.

$$Min\sum A(DNO) = power\ loss\ \ price + Energy\ loss\ \ price + Voltage\ \ stability\ \ price \qquad (18)$$

C. Charging stations owner approach (CSO)

The CSO bears the full price of establishing an EVCS and aims to increase income from EV charging. To identify the most profitable locations, the CSO considers investment, installation, operating, maintenance, road construction, and land prices, seeking sites that provide high revenue with minimal expenditure.

$$Min\sum B(CSO) = Ch\arg ing\ \ price + Operation\ \ \ price + Installati\ on\ \ price + Ma\operatorname{int} anencepric\ e \qquad (19)$$

IV. Results and Discussion

Load flow study is done on the IEEE 33-bus RDS, a medium-voltage network with 37 lines, including 32 active branches and 5 sectionalizing/tie switches. The 100 MVA substation operates at 12.66 kV and has a total load of 3715 kW real and 2300 kVar reactive power. Prior to the integration of DGs and EVCS, the network experienced 202.68 kW of active power loss (APL) and 134.7 kVar of reactive power loss (RPL).

A. Placement of 2-DGs in RDS using CSO Approach

Table 1 represents the proposed technique generated a very high efficient performance values with less number of losses into the real and reactive power as 63.96kW and 43.90kVAR, AVDI generated as 0.02p.u, AVSI segregated as 0.86p.u under the levels of DGs units position is 6,14 and best power production from DGs is 2352.9073,619.09274 kW.

TABLE I. 2-DGS IEEE33 BUS SYSTEM WITH PRICE ANALYSIS

Algorithms	APL (kW)	RPL (kVAR)	VDI (p.u)	VSI (p.u)	DGs Site	DGs Rating (kW)	Charging Price ($)	Operation Price ($)	Installation Price ($)	Maintenance Price ($)
Base case	201.89	134.64	0.35	0.74	0,0	0,0	0.00	371500.00	1500.00	1500.00
Firefly	75.38	54.30	0.03	0.86	14, 6	619.0936 2352.906	0.00	310456.36	1253.66	1213.28
Moth flame	74.94	54.13	0.03	0.86	6, 14	2298.263 673.7366	0.00	310034.20	1242.32	1212.89
HMFO	63.96	43.90	0.02	0.86	6,14	2352.907 619.0927	0.00	301615.85	1227.95	1207.68

Table 1 also presents the price details of two DG units integrated with EVCS, including charging, operation, installation, and maintenance prices. The charging price for the DGs is assumed to be zero, while the remaining prices are comparatively lower than other systems. The station incurs an operating price of $301,615.85, an installation price of $1,227.95, and a maintenance price of $1,207.68.

B. Placement of 2-EVCS in RDS using CSO Approach

Table 2 presents the price details of two EV units integrated with EVCS, including charging, operation, installation, and maintenance prices. The charging price is comparatively low at $601.03, while the other prices are also lower than in alternative systems. The station incurs an operating price of $602,847.85, an installation price of $1,204.30, and a maintenance price of $1,204.12.

TABLE II. 2-EVCS IEEE 33 BUS SYSTEM WITH PRICE ANALYSIS

Algorithms	APL (kW)	RPL (kVA)	VDI (p.u)	VSI (p.u)	EVCS Site	DGs Rating (kW)	Charging Price ($)	Operation Price ($)	Installation Price ($)	Maintenance Price ($)
Base case	201.89	134.64	0.35	0.74	0,0	0,0	750.00	371500.00	1500.00	1500.00
Firefly	203.94	212.09	0.36	0.74	2,1	337.7272 3377.272	615.94	619024.73	1231.22	1219.12
Moth flame	203.75	208.05	0.35	0.74	1,2	3343.937 371.0621	606.99	612995.63	1227.14	1205.15
HMFO	203.57	206.96	0.35	0.74	4,26	3377.272 337.7272	601.03	602847.85	1204.30	1204.12

Table 2 also represents the proposed technique generated a very high efficient performance values with less number of losses into the real and reactive power as 203.57 kW and 206.96 kVAR, AVDI generated as 0.35 p.u, AVSI segregated as 0.74 p.u under the levels of EVs units position is 4,26 and best power production from EVs is 3377.2727,337.72727 kW.

C. Simultaneous Placement of 3-DGs and 2-EVCS in RDS using CSO Approach

Table 3 demonstrates the proposed technique's effectiveness, achieving low real and reactive power losses of 74.04 kW and 49.52 kVAR, respectively. The system records an AVDI of 0.04 p.u. and an AVSI of 0.89 p.u. DG units are optimally placed at buses 1, 27, and 12 with maximum outputs of 2083.87 kW, 208.39 kW, and 679.74 kW, while EVs are optimally located at buses 6 and 5 with peak powers of 2592.89 kW and 1122.11 kW. Table 4 presents the price details for a system with 3 DGs and 2 EVs integrated with EVCS, covering charging, operation, installation, and maintenance prices.

The EVs' charging price is notably low at $590.47, while other prices remain price-effective compared to alternative systems. The station incurs an operating price of $334,693.62, an installation price of $1,202.16, and a maintenance price of $1,203.19. Also the site of EVCS 6, 5 and the powers of EVs 2592.8902 kW, 1122.1098kW.

TABLE III. 3-DGS AND 2-EVCS IN IEEE33 BUS SYSTEM

Algorithms	APL (kW)	RPL (kVA)	VDI (p.u)	VSI (p.u)	DGs Site	DGs Rating (kW)	EVCS Site	EVCS Rating (kW)
Base case	201.89	134.64	0.35	0.74	0,0,0	0,0,0	0,0	0,0
Firefly	86.36	61.26	0.08	0.83	1,16,11	224.771 1385.8489 1361.3801	6,33	2592.8922 1122.1078
Moth flame	84.70	60.26	0.07	0.83	1,33,20	863.0034 732.14172 1376.8548	6,24	2746.4871 968.5129
HMFO	74.04	49.52	0.04	0.89	1,27,12	2083.8694 208.38694 679.7437	6,5	2592.8902 1122.1098

TABLE IV. 3-DGS AND 2-EVCS PRICE ANALYSIS

Algorithms	Charging Price ($)	Operation Price ($)	Installation Price ($)	Maintenance Price ($)
Base case	750.00	371500.00	1500.00	1500.00
Firefly	610.66	354630.74	1235.38	1218.63
Moth flame	601.36	353098.84	1230.91	1214.99
HMFO	590.47	334693.62	1202.16	1203.19

D. Price Analysis of 2-DGs in RDS using DNO Approach

Table 5 presents the price analysis for two DG units integrated with EVCS, including power loss, energy loss, and voltage stability prices.

The power loss price is notably low at $7,354.87, while other prices are also favorable compared to alternative systems.

Specifically, the station's energy loss price is $179.49, and the voltage stability price is $69.16.

TABLE V. 2-DGS WITH PRICE ANALYSIS

Algorithms	Power Loss Price ($)	Energy Loss Price ($)	Voltage Stability Price ($)
Base case	20189.25	484.54	73.84
Firefly	7506.21	180.04	71.55
Moth flame	7391.39	179.80	70.37
HMFO	7354.87	179.49	69.16

E. Placement of 2-EVCS in RDS using DNO Approach

Table 6 presents the price analysis for two EV units integrated with EVCS, including power loss, energy loss, and voltage stability prices.

The power loss price is notably low at $16,445.79, while the other prices are also more price-effective than in alternative systems. Specifically, the station's energy loss price is $392.29, and the voltage stability price is $52.98.

TABLE VI. 2-EVCS WITH PRICE ANALYSIS

Algorithms	Power Loss Price ($)	Energy Loss Price ($)	Voltage Stability Price ($)
Base case	20189.25	484.54	73.84
Firefly	16925.63	406.96	59.26
Moth flame	16842.41	394.48	57.45
HMFO	16445.79	392.29	52.98

F. Simultaneous Placement of 3-DGs and 2-EVCS in RDS using DNO Approach

Table 7 presents the price analysis for a system with 3 DGs and 2 EVs integrated with EVCS, covering power loss, energy loss, and voltage stability prices. The power loss price is notably low at $8,342.86, while the other prices also remain more price-effective than alternative systems. Specifically, the station's energy loss price is $189.77, and the voltage stability price is $56.45.

TABLE VII. 3-DGS AND 2-EVCS WITH PRICE ANALYSIS

Algorithms	Power Loss Price ($)	Energy Loss Price ($)	Voltage Stability Price ($)
Base case	20189.25	484.54	73.84
Firefly	8664.52	205.89	67.19
Moth flame	8597.54	202.16	66.94
HMFO	8342.86	189.77	56.45

V. CONCLUSIONS

In this paper, a comprehensive price-aware optimization framework was successfully developed for the simultaneous placement and sizing of EVCS and DG units in a radial distribution network. The BFS method provided accurate load flow analysis, while the proposed HMFO algorithm effectively solved the multi-objective problem, accounting for installation, operation & maintenance, energy loss, and charging prices. Application of the HMFO–BFS framework on the IEEE 33-bus system demonstrated significant reductions in real and reactive power losses, improved voltage profiles, and minimized overall system prices. Comparative analysis with Firefly and standard MFO algorithms confirmed the superior convergence, efficiency, and techno-economic performance of HMFO, validating its effectiveness for planning smart, reliable, and sustainable power distribution networks. Further work can be enhanced by taking the solar PV and large test systems.

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