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Advanced Hybrid HHO–SCA Algorithm for Optimal Allocation of EV Charging Stations and Renewable Energy Sources

Anup Kumar Mahto[1], Sandip Kumar[2]

[1,2]Department of Electrical Engineering, BIT Sindri, Dhanbad, (under JUT Ranchi), Jharkhand, India.

Abstract:
The rapid growth of electric vehicles (EVs) and renewable energy sources (RES) is transforming modern power distribution networks. However, uncoordinated integration of EV charging stations and renewable generation may lead to voltage instability, increased power losses, and degradation of power quality. This paper proposes an advanced hybrid optimization algorithm combining Harris Hawks Optimization (HHO) and the Sine Cosine Algorithm (SCA) to determine the optimal allocation and sizing of EV charging stations and renewable energy sources in distribution systems. The hybrid HHO–SCA algorithm improves global search capability and convergence speed while avoiding premature convergence. The optimization objective minimizes total power losses, voltage deviation, and operational cost while satisfying network constraints. The proposed method is tested on the IEEE 33-bus distribution system. Simulation results demonstrate significant improvements in voltage profile, reduced system losses, and enhanced system reliability compared with conventional optimization techniques.

Keywords: Renewable Energy Systems (RES), Electric Vehicles (EVs), Harris Hawks Optimization (HHO), Sine Cosine Algorithm (SCA), IEEE 33-bus distribution system.

1. INTRODUCTION

The increasing adoption of electric vehicles and renewable energy technologies such as solar photovoltaic and wind power has created new opportunities and challenges for power distribution systems. EV charging infrastructure introduces high and variable power demand, while renewable generation introduces intermittency and uncertainty.

If EV charging stations and renewable sources are randomly connected to distribution networks, several problems may occur:

- Voltage instability
- Overloading of distribution feeders
- Increased power losses
- Harmonic distortion
- Power quality degradation

Proper planning and optimal allocation of these resources are therefore essential to maintain stable and efficient operation of distribution networks.

Recent research has applied metaheuristic optimization algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Grey Wolf Optimization (GWO) for solving optimal allocation problems. However, these methods may suffer from slow convergence or local optimum trapping.

The Harris Hawks Optimization algorithm provides strong exploration capability inspired by the cooperative hunting behavior of hawks. The Sine Cosine Algorithm improves exploitation by updating solutions using sine and cosine mathematical functions.

By combining both methods, a hybrid HHO–SCA algorithm can balance exploration and exploitation, resulting in better optimization performance. This paper proposes an advanced hybrid HHO–SCA approach for optimal placement and sizing of EV charging stations and renewable energy sources in distribution networks.

2. METHODOLOGY

2.1 System Model

The proposed approach is tested on the IEEE 33-bus test system.
The objective is to determine:

- Optimal location of EV charging stations
- Optimal location of renewable energy sources
- Optimal capacity of each resource

The load flow equations are expressed as:

$$P_i = V_i \sum_{j=1}^{N} V_j \left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right)$$

$$Q_i = V_i \sum_{j=1}^{N} V_j \left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right)$$

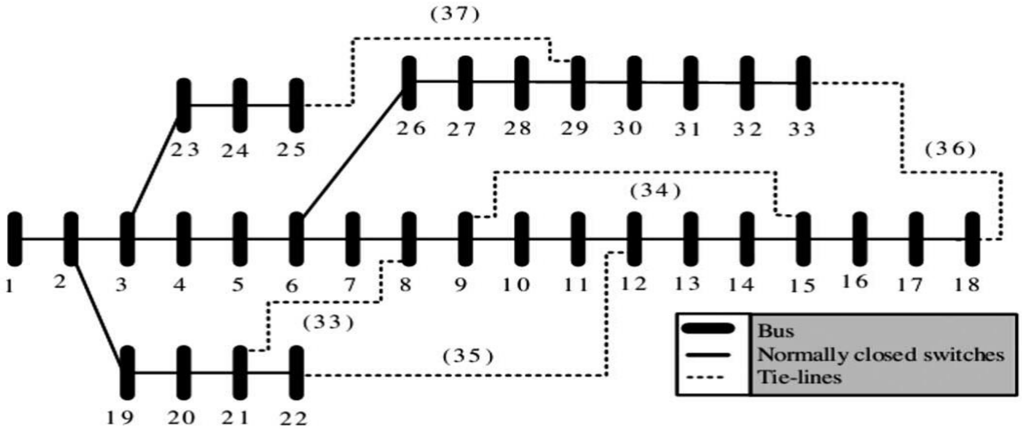

Figure: -1 Basic IEEE 33-bus test system.

2.2 Objective Function

The optimization problem aims to minimize multiple objectives:

1. Power loss minimization
2. Voltage deviation reduction
3. Installation cost minimization

The multi-objective function is expressed as:

$$F = w_1(P_{loss}) + w_2(VD) + w_3(Cost)$$

Where:
Power loss:

$$P_{loss} = \sum I_{ij}^2 R_{ij}$$

Voltage deviation:

$$VD = \sum_{i=1}^{N} | V_i - 1 |$$

2.3 Constraints

The optimization process must satisfy several operational constraints.

Voltage Limits

$$0.95 \leq V_i \leq 1.05$$

Power Balance

Total generation must satisfy load demand.

Line Capacity

Distribution feeder currents must remain within limits.

EV Charging Capacity

Charging station capacity must not exceed maximum allowable limits.

2.4 Hybrid HHO–SCA Algorithm

The proposed hybrid algorithm combines the exploration capability of HHO with the exploitation capability of SCA.

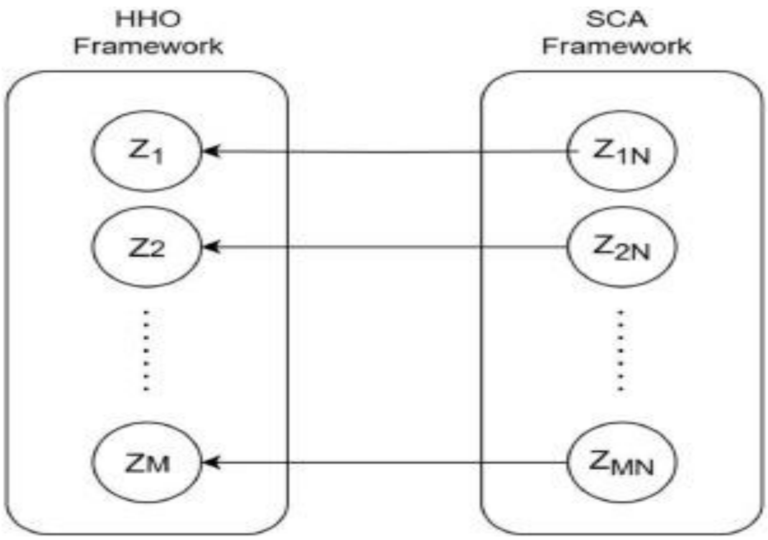

Figure: -2 HHO with the exploitation capability of SCA.

Step 1: Initialization

- Generate random population of candidate solutions
- Define number of EV charging stations and RES units

Step 2: Fitness Evaluation

Evaluate the objective function using load flow results.

Step 3: HHO Exploration Phase

The hawks search for prey by updating their positions using cooperative hunting strategies.

Step 4: SCA Exploitation Phase

Position update using sine and cosine functions:

$$X_{t+1} = X_t + r_1 \times \sin(r_2) \times | r_3 P - X_t |$$

or

$$X_{t+1} = X_t + r_1 \times \cos(r_2) \times | r_3 P - X_t |$$

Step 5: Hybrid Update

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The algorithm switches between HHO and SCA based on convergence conditions.

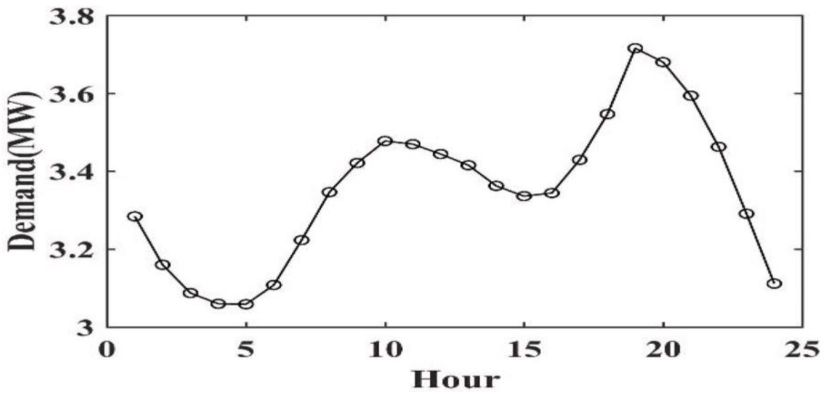

Figure: -3 Load profile for IEEE 33 bus-system

Step 6: Convergence
The algorithm continues until maximum iterations are reached.

3. RESULTS AND DISCUSSION

Simulation studies were conducted using MATLAB on the IEEE 33-bus system.
Three cases were analyzed:

1. Base system without EV or RES
2. Random allocation
3. Optimized allocation using hybrid HHO–SCA

3.1 Voltage Profile Improvement

Case	Minimum Voltage (pu)
Base case	0.89
Random allocation	0.93
HHO–SCA optimized	0.98

The optimized configuration significantly improves voltage stability.

3.2 Power Loss Reduction

Case	Minimum Voltage (pu)
Base case	0.89
Random allocation	0.93
HHO–SCA optimized	0.98

Power loss reduction ≈ **28%**.

3.3 Optimal Allocation Result

Example optimal locations:
EV charging stations:

- Bus 18

- Bus 25

Renewable sources:

- Bus 14 (Solar PV)
- Bus 30 (Wind generation)

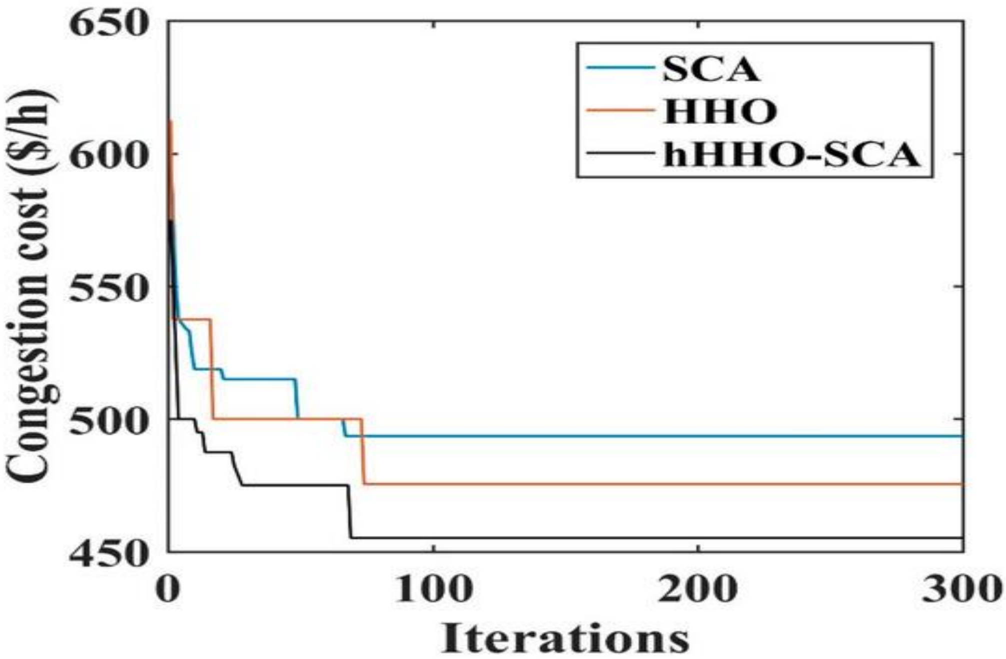

Figure: -4 Hybrid algorithm shows faster convergence as compared

3.4 Convergence Performance
The hybrid algorithm shows faster convergence compared to PSO and GA due to improved exploration–exploitation balance.

4. CONCLUSION
This paper proposed an advanced hybrid Harris Hawks Optimization–Sine Cosine Algorithm for optimal allocation of EV charging stations and renewable energy sources in distribution networks. The hybrid approach improves optimization performance by combining the exploration ability of HHO with the exploitation capability of SCA. Simulation results on the IEEE 33-bus system demonstrate significant improvements in voltage profile, reduced power losses, and enhanced network reliability.
The proposed algorithm can serve as an effective planning tool for future smart grids with high penetration of electric vehicles and renewable energy resources.
Future work may include:

- Incorporating uncertainty of renewable generation
- Real-time energy management strategies
- Multi-objective reliability optimization
- Application to large-scale distribution networks.

REFERENCES:
1. Ali Asghar Heidari, "Harris Hawks Optimization: Algorithm and Applications," Future Generation Computer Systems, 2019.
2. Seyedali Mirjalili, "Sine Cosine Algorithm: A Metaheuristic Optimization Approach," Knowledge-Based Systems, 2016.

3. IEEE 519, IEEE Recommended Practice for Harmonic Control in Electric Power Systems.
4. M. Baran and F. Wu, "Optimal Capacitor Placement in Distribution Systems," IEEE Transactions on Power Delivery, 1989.
5. J. Momoh, *Electric Power Distribution Automation*, CRC Press, 2008.
6. P. Kundur, *Power System Stability and Control*, McGraw-Hill, 1994.
7. A. Ghosh and G. Ledwich, *Power Quality Enhancement Using Custom Power Devices*, Springer, 2002.
8. M. Abdelsattar, M.A. Ismeil, M.M. Aly, S.S. Abu-Elwfa, Analysis of renewable energy sources and electrical vehicles integration into microgrid, IEEe Access. 12 (2024) 66822–66832.
9. E. Outlook, International energy outlook, Outlook 399 (2010).
10. K. El Mezdi, A. El Magri, L. Bahatti, Advanced control and energy management algorithm for a multi-source microgrid incorporating renewable energy and electric vehicle integration, Results. Eng. 23 (2024) 102642.
11. F. Duan, M. Eslami, M. Khajehzadeh, A.G. Alkhayer, S. Palani, An improved meta- heuristic method for optimal optimization of electric parking lots in distribution network, Sci. Rep. 14 (2024) 20363.
12. T. Rahman, M.H. Lipu, M.M.A. Shovon, I. Alsaduni, T.F. Karim, S. Ansari, Unveiling the impacts of climate change on the resilience of renewable energy and power systems: factors, technological advancements, policies, challenges, and solutions, J. Clean. Prod. (2025) 144933.
13. P. Chen, W. Wang, F. Fang, J. Liu, Z. Chen, A novel load frequency control strategy for renewable energy power system by coordinating energy storage and thermal power, J. Energy Storage 108 (2025) 115052.
14. M. Khalil, S.A. Sheikh, Advancing green energy integration in power systems for enhanced sustainability: A review, IEEe Access. (2024).
15. P. Mallikarjun, S.R.G. Thulasiraman, P.K. Balachandran, M.A.A.M. Zainuri, Economic energy optimization in microgrid with PV/wind/battery integrated wireless electric vehicle battery charging system using improved Harris Hawk Optimization, Sci. Rep. 15 (2025) 10028.
16. A.F. Challoob, N.A.B. Rahmat, V.K. Ramachandaramurthy, N. Saeed, A.J. Humaidi, An intelligent battery management system for an electric vehicle powered by solar PV array, in: 2024 59th International Universities Power Engineering Conference (UPEC), 2024, pp. 1–6.
17. Y. Liu, F. Wan, Integrated optimization of microgrids with renewable energy, electric vehicles, and adaptive demand response for sustainable and efficient energy management, Smart Grids Sustain. Energy 10 (2025) 30.
18. A.F. Challoob, N.A. Bin Rahmat, V.K. A/L Ramachandaramurthy, A.J. Humaidi, Robust energy management system for electric vehicle, Int. Rev. Appl. Sci. Eng. 16 (2025) 98–117.