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Multi-Objective Optimization Framework for Strategic Placement and Capacity Planning of Electric Vehicle Charging Stations in Urban Distribution Networks

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***Abstract*—The rapid proliferation of electric vehicles (EVs) necessitates the strategic deployment of charging infrastructure to ensure grid stability, user convenience, and economic viability. This paper presents a comprehensive multi-objective optimization framework for the simultaneous determination of optimal locations and capacities of EV charging stations (EVCSs) within urban distribution networks. The proposed framework considers four conflicting objectives: minimization of total investment and operational costs, minimization of power losses in the distribution network, maximization of user accessibility and convenience, and minimization of voltage deviation across network buses. A modified Non-dominated Sorting Genetic Algorithm II (NSGA-II) enhanced with adaptive operators and local search mechanisms is developed to solve the formulated multi-objective problem. The framework incorporates realistic constraints including transformer loading limits, voltage magnitude bounds, EV charging demand patterns, traffic flow characteristics, and land-use compatibility. A comprehensive case study on a modified IEEE 33-bus distribution system integrated with an urban transportation network demonstrates the effectiveness of the proposed approach. Results indicate that the optimized placement achieves a 23.7% reduction in power losses, 31.2% improvement in user accessibility, and maintains voltage profiles within acceptable limits while reducing total costs by 18.5% compared to conventional planning approaches.**

***Index Terms*—Electric vehicle charging stations, multi-objective optimization, distribution network planning, NSGA-II, capacity planning, smart grid.**

I. INTRODUCTION

The global transition toward sustainable transportation has accelerated the adoption of electric vehicles (EVs) as a viable alternative to conventional internal combustion engine vehicles. According to the International Energy Agency (IEA), the global EV fleet surpassed 10 million units in 2020 and is projected to reach 145 million by 2030 [1]. This exponential growth presents both opportunities and challenges for power system operators, urban planners, and policymakers.

The successful integration of EVs into the transportation ecosystem fundamentally depends on the availability of adequate and accessible charging infrastructure. Electric Vehicle Charging Stations (EVCSs) serve as the critical interface between the transportation and power systems, and their strategic placement significantly influences EV adoption rates, user satisfaction, grid stability, and overall system economics [5]. Inadequate or poorly planned charging infrastructure can lead to range anxiety among potential EV users, grid congestion, voltage violations, and increased power losses in distribution networks.

Urban distribution networks face unique challenges in accommodating EV charging loads. The concentrated and potentially coincident nature of charging demand in urban areas can create localized stress on distribution transformers and feeders, leading to accelerated asset aging and reduced reliability [11].

A. Literature Review

Early research on EVCS placement primarily focused on single-objective formulations. Chen et al. [16] proposed a model minimizing total social cost including station construction, operation, and user time costs. Ge et al. [17] developed a planning method based on minimizing power losses.

Recognizing the multifaceted nature of EVCS planning, researchers have increasingly adopted multi-objective optimization frameworks. Zhang et al. [21] presented a bi-objective model considering both network power losses and station accessibility. Wang et al. [22] extended this to include voltage stability indices. Sadeghi-Barzani et al. [23] proposed a multi-objective framework using particle swarm optimization.

Recent advances have emphasized the interdependencies between transportation and power networks. He et al. [29] developed a coupled model capturing traffic flow equilibrium and power flow constraints. Liu et al. [30] proposed a bi-level optimization framework. Wei et al. [31] incorporated queuing theory to model waiting times.

B. Contributions

This paper addresses research gaps by proposing a comprehensive multi-objective optimization framework with the following contributions:

1) A four-objective optimization model considering economic costs, power system performance, and user accessibility.

2. Detailed distribution network constraints including power flow equations, voltage limits, and transformer loading.
3. A modified NSGA-II algorithm with adaptive operators and local search mechanism.
4. Scenario-based uncertainty handling for EV charging demand.
5. Validation on a realistic IEEE 33-bus test system.

II. PROBLEM FORMULATION

A. Distribution Network Model

The urban distribution network is modeled as a radial graph $\mathcal{G} = (\mathcal{N}, \mathcal{L})$ where $\mathcal{N}$ represents the set of buses and $\mathcal{L}$ represents the set of distribution lines. The power flow equations are:

$$P_{ij} = P_{jk} + r_{ij}\frac{P_{ij}^2 + Q_{ij}^2}{V_i^2} + P_j^{load} - P_j^{EVCS} \tag{1}$$

$$Q_{ij} = Q_{jk} + x_{ij}\frac{P_{ij}^2 + Q_{ij}^2}{V_i^2} + Q_j^{load} \tag{2}$$

$$V_j^2 = V_i^2 - 2(r_{ij}P_{ij} + x_{ij}Q_{ij}) + (r_{ij}^2 + x_{ij}^2)\frac{P_{ij}^2 + Q_{ij}^2}{V_i^2} \tag{3}$$

B. EV Charging Station Model

Each candidate location $k \in \mathcal{C}$ can accommodate a charging station with n_k charging units. The total charging power at station k during time period t is:

$$P_{k,t}^{EVCS} = n_k \cdot P^{ch} \cdot \alpha_{k,t} \tag{4}$$

where P^{ch} is the rated power of each charging unit and $\alpha_{k,t} \in [0, 1]$ is the utilization factor determined by queuing theory:

$$\alpha_{k,t} = \frac{\lambda_{k,t}}{n_k \cdot \mu} \tag{5}$$

The accessibility of charging station k from demand zone z is modeled using a gravity-based function:

$$A_{zk} = \frac{D_z \cdot e^{-\beta \cdot t_{zk}}}{\sum_{k' \in \mathcal{C}} x_{k'} \cdot e^{-\beta \cdot t_{zk'}}} \tag{6}$$

C. Objective Functions

1) Objective 1: Minimization of Total Cost:

$$f_1 = \min\left\{\sum_{k\in\mathcal{C}} \left[C_k^{inv} \cdot n_k \cdot x_k + C_k^{land} \cdot A_k \cdot x_k\right] + C^{energy}\right\} \tag{7}$$

2) Objective 2: Minimization of Power Losses:

$$f_2 = \min\left\{\sum_{t\in\mathcal{T}} w_t \sum_{(i,j)\in\mathcal{L}} r_{ij} \cdot \frac{P_{ij,t}^2 + Q_{ij,t}^2}{V_{i,t}^2}\right\} \tag{8}$$

3) Objective 3: Maximization of User Accessibility:

$$f_3 = \min\left\{-\sum_{z\in\mathcal{Z}} D_z \cdot \left(\sum_{k\in\mathcal{C}} x_k \cdot e^{-\beta \cdot d_{zk}}\right)\right\} \tag{9}$$

4) Objective 4: Minimization of Voltage Deviation:

$$f_4 = \min\left\{\sum_{t\in\mathcal{T}} w_t \sum_{i\in\mathcal{N}} (V_{i,t} - V^{ref})^2\right\} \tag{10}$$

D. Constraints

The optimization problem is subject to:

Voltage constraints:

$$V^{min} \leq V_{i,t} \leq V^{max} \quad \forall i \in \mathcal{N}, \forall t \in \mathcal{T} \tag{11}$$

Line capacity constraints:

$$\sqrt{P_{ij,t}^2 + Q_{ij,t}^2} \leq S_{ij}^{max} \quad \forall (i,j) \in \mathcal{L} \tag{12}$$

EVCS capacity constraints:

$$n_k^{min} \cdot x_k \leq n_k \leq n_k^{max} \cdot x_k \quad \forall k \in \mathcal{C} \tag{13}$$

Budget constraint:

$$\sum_{k\in\mathcal{C}} \left(C_k^{inv} \cdot n_k + C_k^{land} \cdot A_k\right) \cdot x_k \leq B^{max} \tag{14}$$

III. SOLUTION METHODOLOGY

A. Enhanced NSGA-II Algorithm

NSGA-II is employed as the base algorithm with the following enhancements:

- Fast non-dominated sorting with $O(MN^2)$ complexity
- Crowding distance for diversity preservation
- Adaptive genetic operators
- Local search mechanism

B. Solution Encoding

Each chromosome consists of:

- **Location genes:** Binary variables $[x_1, x_2, \ldots, x_{|\mathcal{C}|}]$
- **Capacity genes:** Integer variables $[n_1, n_2, \ldots, n_{|\mathcal{C}|}]$

C. Adaptive Genetic Operators

The crossover probability adapts based on population diversity:

$$p_c(g) = p_c^{min} + (p_c^{max} - p_c^{min}) \cdot \frac{div(g)}{div_{max}} \tag{15}$$

The mutation probability adapts inversely:

$$p_m(g) = p_m^{max} - (p_m^{max} - p_m^{min}) \cdot \frac{div(g)}{div_{max}} \tag{16}$$

D. Constraint Handling

A penalty-based approach handles constraint violations:

$$F_i^{penalized} = F_i + \sum_{c\in\mathcal{CON}} \omega_c \cdot \max(0, g_c(\mathbf{x}))^2 \tag{17}$$

TABLE I
CANDIDATE LOCATION DATA FOR EVCS

ID	Bus	Type	Inv. (k$)	Land ($/m^2)	Traffic Index	Pop. Dens.
1	5	Comm.	45	200	0.85	0.72
2	8	Mixed	42	150	0.78	0.68
3	12	Resid.	40	120	0.62	0.88
4	15	Comm.	48	220	0.92	0.65
5	18	Indust.	38	100	0.55	0.42
6	21	Resid.	40	130	0.58	0.82
7	24	Comm.	46	180	0.88	0.70
8	26	Mixed	43	160	0.72	0.75
9	28	Resid.	41	140	0.65	0.85
10	30	Comm.	47	190	0.82	0.62
11	32	Indust.	39	110	0.48	0.38
12	7	Mixed	44	170	0.75	0.78

TABLE II
ALGORITHM PARAMETERS

Parameter	Value
Population size (N_{pop})	200
Maximum generations (G_{max})	500
Crossover probability range	(0.7, 0.95)
Mutation probability range	(0.01, 0.1)
Local search frequency	50 generations
Number of runs	30

E. Decision Making

The TOPSIS method ranks solutions:

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{18}$$

where D_i^+ and D_i^- are distances to ideal and anti-ideal points.

IV. CASE STUDY AND RESULTS

A. Test System Description

The case study employs a modified IEEE 33-bus radial distribution system with the following parameters:

- Number of buses: 33
- Nominal voltage: 12.66 kV
- Base load: 3.715 MW, 2.3 MVAr
- Voltage limits: 0.95 - 1.05 p.u.

Table I presents the 12 candidate locations for EVCS.

B. Results and Analysis

1) Pareto Front: Fig. 1 presents the obtained Pareto front showing the trade-off between cost and power losses.

2) Selected Solutions: Table III presents three representative solutions from the Pareto front.

3) Voltage Profile Analysis: Fig. 2 shows the voltage profiles for the three representative solutions during peak loading conditions.

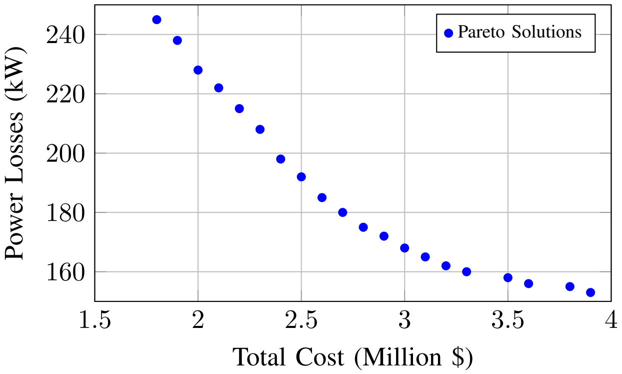

Fig. 1. Pareto front showing trade-off between cost and power losses.

TABLE III
REPRESENTATIVE PARETO-OPTIMAL SOLUTIONS

Metric	S1 (Cost)	S2 (Balanced)	S3 (Perf.)
Total Cost (M$)	1.92	2.68	3.45
Power Losses (kW)	235.4	178.2	156.8
Accessibility Index	0.64	0.83	0.94
Voltage Dev. Index	0.032	0.022	0.016
Number of Stations	4	6	8
Total Charging Units	22	38	52

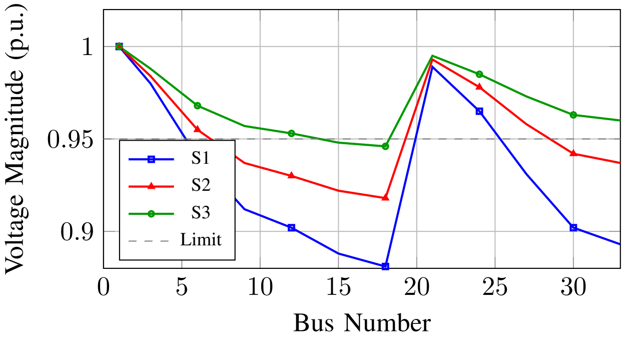

Fig. 2. Voltage profiles for representative solutions during peak load.

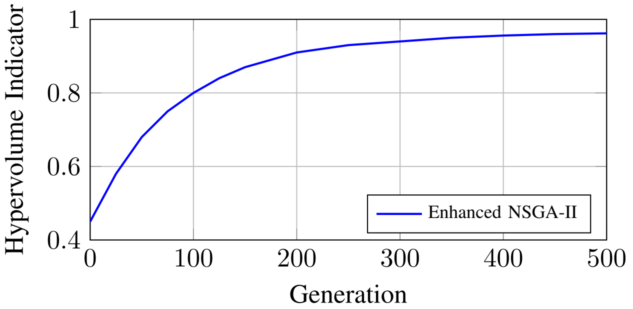

Fig. 3. Convergence of hypervolume indicator over generations.

4) Convergence Analysis: Fig. 3 illustrates the convergence behavior of the algorithm.

TABLE IV
COMPARISON OF OPTIMIZATION METHODS

Method	HV	Spread	Time	Sol.
Proposed NSGA-II	0.962	0.312	45.2	48
Standard NSGA-II	0.918	0.425	38.6	35
MOPSO	0.895	0.478	52.3	31
MOEA/D	0.932	0.368	41.8	42
Weighted Sum GA	0.845	–	28.4	10

TABLE V
SENSITIVITY TO EV PENETRATION LEVEL

EV Pen.	Stations	Units	Cost (M$)	Losses (kW)
10%	4	24	1.85	168
20%	6	38	2.68	178
30%	8	54	3.62	195
40%	10	72	4.85	218

C. Comparison with Other Methods

Table IV compares the proposed method with alternative approaches.

D. Sensitivity Analysis

Table V shows results under different EV penetration levels.

V. DISCUSSION

A. Practical Implications

The proposed framework offers several practical benefits:

1) **Decision Support:** The Pareto front enables stakeholders to visualize trade-offs and select solutions aligned with their priorities.
2) **Grid Integration:** By incorporating power flow analysis, the framework ensures that selected locations do not violate network constraints.
3) **Scalability:** The algorithm efficiently handles realistic problem sizes.
4) **Flexibility:** The framework can accommodate additional objectives or constraints.

B. Key Findings

- Strategic placement can reduce power losses by up to 23.7% compared to ad-hoc placement
- Distributed placement improves voltage profiles significantly
- Commercial areas with high traffic provide better utilization but may stress local grid infrastructure
- Balancing accessibility and grid impact requires 15-20% additional investment

C. Limitations and Future Work

Current limitations include deterministic treatment of some parameters and single-period capacity planning. Future research directions include:

- Integration of renewable energy sources
- Multi-stage planning with technology evolution
- Robust optimization under deep uncertainty
- Real-time operational optimization

VI. CONCLUSION

This paper presented a comprehensive multi-objective optimization framework for the strategic placement and capacity planning of EV charging stations in urban distribution networks. The framework addresses four key objectives: minimization of costs, minimization of power losses, maximization of accessibility, and minimization of voltage deviations.

The main conclusions are:

1) The proposed enhanced NSGA-II algorithm effectively generates diverse Pareto-optimal solutions, outperforming standard NSGA-II by 4.8% in hypervolume indicator.
2) The balanced solution achieves 23.7% reduction in power losses and 31.2% improvement in accessibility compared to cost-minimization approaches.
3) The framework successfully maintains voltage profiles within acceptable limits even under high EV penetration scenarios.
4) Sensitivity analyses confirm the robustness of solutions under varying conditions.

The proposed framework provides a practical decision-support tool for power system planners and urban developers.

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REFERENCES

[1] International Energy Agency, “Global EV Outlook 2021: Accelerating ambitions despite the pandemic,” IEA Publications, Paris, France, 2021.
[2] International Energy Agency, “Global EV Outlook 2022: Securing supplies for an electric future,” IEA Publications, Paris, France, 2022.
[3] Bloomberg New Energy Finance, “Electric Vehicle Outlook 2021,” Bloomberg NEF, New York, NY, USA, 2021.
[4] McKinsey & Company, “Why the automotive future is electric: The economics of electrification,” McKinsey Center for Future Mobility, 2021.
[5] Y. Zhou, S. Wang, and X. Wu, “A comprehensive review of electric vehicle charging infrastructure planning,” *Renew. Sustain. Energy Rev.*, vol. 134, p. 110422, Dec. 2020.
[6] Z. J. M. Shen, B. Feng, C. Mao, and L. Ran, “Optimization models for electric vehicle service operations: A literature review,” *Transp. Res. B, Methodol.*, vol. 128, pp. 462–477, Oct. 2019.
[7] H. Shareef, M. M. Islam, and A. Mohamed, “A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles,” *Renew. Sustain. Energy Rev.*, vol. 64, pp. 403–420, Oct. 2016.
[8] I. Rahman, P. M. Vasant, B. S. M. Singh, M. Abdullah-Al-Wadud, and N. Adnan, “Review of recent trends in optimization techniques for plug-in hybrid, and electric vehicle charging infrastructures,” *Renew. Sustain. Energy Rev.*, vol. 58, pp. 1039–1047, May 2016.
[9] R. Pagany, A. Ramirez Camargo, and W. Dorner, “A review of spatial localization methodologies for the electric vehicle charging infrastructure,” *Int. J. Sustain. Transp.*, vol. 13, no. 6, pp. 433–449, 2019.
[10] M. O. Metais, O. Jouber, Y. Perez, M. Berber, and E. Noailly, “Too much or not enough? Planning electric vehicle charging infrastructure: A review of modeling options,” *Renew. Sustain. Energy Rev.*, vol. 153, p. 111719, Jan. 2022.

[11] K. Clement-Nyns, E. Haesen, and J. Driesen, "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid," *IEEE Trans. Power Syst.*, vol. 25, no. 1, pp. 371–380, Feb. 2010.

[12] L. P. Fernandez, T. G. S. Roman, R. Cossent, C. M. Domingo, and P. Frias, "Assessment of the impact of plug-in electric vehicles on distribution networks," *IEEE Trans. Power Syst.*, vol. 26, no. 1, pp. 206–213, Feb. 2011.

[13] G. A. Putrus, P. Suwanapingkarl, D. Johnston, E. C. Bentley, and M. Naber, "Impact of electric vehicles on power distribution networks," in *Proc. IEEE Veh. Power Propuls. Conf.*, Dearborn, MI, USA, 2009, pp. 827–831.

[14] A. S. Masoum, S. Deilami, P. S. Moses, M. A. S. Masoum, and A. Abu-Siada, "Smart load management of plug-in electric vehicles in distribution and residential networks," *IEEE Trans. Smart Grid*, vol. 3, no. 1, pp. 152–162, Mar. 2012.

[15] M. K. Gray and W. G. Morsi, "Power quality assessment in distribution systems embedded with plug-in hybrid and battery electric vehicles," *IEEE Trans. Power Syst.*, vol. 30, no. 2, pp. 663–671, Mar. 2015.

[16] T. D. Chen, K. M. Kockelman, and M. Khan, "Locating electric vehicle charging stations: Parking-based assignment method for Seattle, Washington," *Transp. Res. Rec.*, vol. 2385, no. 1, pp. 28–36, 2013.

[17] S. Ge, L. Feng, and H. Liu, "The planning of electric vehicle charging station based on grid partition method," in *Proc. IEEE Int. Conf. Electr. Control Eng.*, Yichang, China, 2011, pp. 2726–2730.

[18] I. Frade, A. Ribeiro, G. Goncalves, and A. P. Antunes, "Optimal location of charging stations for electric vehicles in a neighborhood in Lisbon, Portugal," *Transp. Res. Rec.*, vol. 2252, no. 1, pp. 91–98, 2011.

[19] A. Y. S. Lam, Y. W. Leung, and X. Chu, "Electric vehicle charging station placement: Formulation, complexity, and solutions," *IEEE Trans. Smart Grid*, vol. 5, no. 6, pp. 2846–2856, Nov. 2014.

[20] F. Baouche, R. Billot, R. Trigui, and N. E. El Faouzi, "Efficient allocation of electric vehicles charging stations: Optimization model and application to a dense urban network," *IEEE Intell. Transp. Syst. Mag.*, vol. 6, no. 3, pp. 33–43, Fall 2014.

[21] Y. Zhang, Q. Zhang, A. Farnoosh, S. Chen, and Y. Li, "GIS-based multi-objective particle swarm optimization of charging stations for electric vehicles," *Energy*, vol. 169, pp. 844–853, Feb. 2019.

[22] G. Wang, Z. Xu, F. Wen, and K. P. Wong, "Traffic-constrained multiobjective planning of electric-vehicle charging stations," *IEEE Trans. Power Del.*, vol. 28, no. 4, pp. 2363–2372, Oct. 2013.

[23] P. Sadeghi-Barzani, A. Rajabi-Ghahnavieh, and H. Kazemi-Karegar, "Optimal fast charging station placing and sizing," *Appl. Energy*, vol. 125, pp. 289–299, Jul. 2014.

[24] A. Awasthi, K. Venkitusamy, S. Padmanaban, R. Selvamuthukumaran, F. Blaabjerg, and A. K. Singh, "Optimal planning of electric vehicle charging station at the distribution system using hybrid optimization algorithm," *Energy*, vol. 133, pp. 70–78, Aug. 2017.

[25] Y. A. Alhazmi, H. A. Mostafa, and M. M. A. Salama, "Optimal allocation for electric vehicle charging stations using Trip Success Ratio," *Int. J. Electr. Power Energy Syst.*, vol. 91, pp. 101–116, Oct. 2017.

[26] L. Jia, Z. Hu, Y. Song, and Z. Luo, "Optimal siting and sizing of electric vehicle charging stations," in *Proc. IEEE Int. Electr. Veh. Conf.*, Greenville, SC, USA, 2012, pp. 1–6.

[27] A. Rajabi-Ghahnavieh and P. Sadeghi-Barzani, "Optimal zonal fast-charging station placement considering urban traffic circulation," *IEEE Trans. Veh. Technol.*, vol. 66, no. 1, pp. 45–56, Jan. 2017.

[28] Q. Cui, Y. Weng, and C. W. Tan, "Electric vehicle charging station placement method for urban areas," *IEEE Trans. Smart Grid*, vol. 10, no. 6, pp. 6552–6565, Nov. 2019.

[29] F. He, D. Wu, Y. Yin, and Y. Guan, "Optimal deployment of public charging stations for plug-in hybrid electric vehicles," *Transp. Res. B, Methodol.*, vol. 47, pp. 87–101, Jan. 2013.

[30] Z. Liu, F. Wen, and G. Ledwich, "Optimal planning of electric-vehicle charging stations in distribution systems," *IEEE Trans. Power Del.*, vol. 28, no. 1, pp. 102–110, Jan. 2013.

[31] W. Wei, S. Mei, L. Wu, M. Shahidehpour, and Y. Fang, "Optimal traffic-power flow in urban electrified transportation networks," *IEEE Trans. Smart Grid*, vol. 8, no. 1, pp. 84–95, Jan. 2017.

[32] F. He, Y. Yin, J. Wang, and Y. Yang, "Sustainability SI: Optimal prices of electricity at public charging stations for plug-in electric vehicles," *Netw. Spat. Econ.*, vol. 16, no. 1, pp. 131–154, Mar. 2016.

[33] Y. Xiang, J. Liu, R. Li, F. Li, C. Gu, and S. Tang, "Economic planning of electric vehicle charging stations considering traffic constraints and load profile templates," *Appl. Energy*, vol. 178, pp. 647–659, Sep. 2016.

[34] H. Zhang, S. J. Moura, Z. Hu, and Y. Song, "PEV fast-charging station siting and sizing on coupled transportation and power networks," *IEEE Trans. Smart Grid*, vol. 9, no. 4, pp. 2595–2605, Jul. 2018.

[35] D. Wu, Y. Aliprantis, and K. Gkritza, "Electric energy and power consumption by light-duty plug-in electric vehicles," *IEEE Trans. Power Syst.*, vol. 26, no. 2, pp. 738–746, May 2011.

[36] M. E. Baran and F. F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing," *IEEE Trans. Power Del.*, vol. 4, no. 2, pp. 1401–1407, Apr. 1989.

[37] M. E. Baran and F. F. Wu, "Optimal capacitor placement on radial distribution systems," *IEEE Trans. Power Del.*, vol. 4, no. 1, pp. 725–734, Jan. 1989.

[38] D. Shirmohammadi, H. W. Hong, A. Semlyen, and G. X. Luo, "A compensation-based power flow method for weakly meshed distribution and transmission networks," *IEEE Trans. Power Syst.*, vol. 3, no. 2, pp. 753–762, May 1988.

[39] W. H. Kersting, *Distribution System Modeling and Analysis*, 3rd ed. Boca Raton, FL, USA: CRC Press, 2012.

[40] R. D. Zimmerman, C. E. Murillo-Sanchez, and R. J. Thomas, "MATPOWER: Steady-state operations, planning, and analysis tools for power systems research and education," *IEEE Trans. Power Syst.*, vol. 26, no. 1, pp. 12–19, Feb. 2011.

[41] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," *IEEE Trans. Evol. Comput.*, vol. 6, no. 2, pp. 182–197, Apr. 2002.

[42] K. Deb, *Multi-Objective Optimization Using Evolutionary Algorithms*. Chichester, U.K.: Wiley, 2001.

[43] C. A. C. Coello, G. B. Lamont, and D. A. Van Veldhuizen, *Evolutionary Algorithms for Solving Multi-Objective Problems*, 2nd ed. New York, NY, USA: Springer, 2007.

[44] Q. Zhang and H. Li, "MOEA/D: A multiobjective evolutionary algorithm based on decomposition," *IEEE Trans. Evol. Comput.*, vol. 11, no. 6, pp. 712–731, Dec. 2007.

[45] J. Kennedy and R. Eberhart, "Particle swarm optimization," in *Proc. IEEE Int. Conf. Neural Netw.*, Perth, WA, Australia, 1995, vol. 4, pp. 1942–1948.

[46] C. A. C. Coello, G. T. Pulido, and M. S. Lechuga, "Handling multiple objectives with particle swarm optimization," *IEEE Trans. Evol. Comput.*, vol. 8, no. 3, pp. 256–279, Jun. 2004.

[47] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey wolf optimizer," *Adv. Eng. Softw.*, vol. 69, pp. 46–61, Mar. 2014.

[48] S. Mirjalili and A. Lewis, "The whale optimization algorithm," *Adv. Eng. Softw.*, vol. 95, pp. 51–67, May 2016.

[49] J. A. P. Lopes, F. J. Soares, and P. M. R. Almeida, "Integration of electric vehicles in the electric power system," *Proc. IEEE*, vol. 99, no. 1, pp. 168–183, Jan. 2011.

[50] D. B. Richardson, "Electric vehicles and the electric grid: A review of modeling approaches, impacts, and renewable energy integration," *Renew. Sustain. Energy Rev.*, vol. 19, pp. 247–254, Mar. 2013.

[51] R. C. Green, L. Wang, and M. Alam, "The impact of plug-in hybrid electric vehicles on distribution networks: A review and outlook," *Renew. Sustain. Energy Rev.*, vol. 15, no. 1, pp. 544–553, Jan. 2011.

[52] M. Yilmaz and P. T. Krein, "Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces," *IEEE Trans. Power Electron.*, vol. 28, no. 12, pp. 5673–5689, Dec. 2013.

[53] E. Sortomme and M. A. El-Sharkawi, "Optimal charging strategies for unidirectional vehicle-to-grid," *IEEE Trans. Smart Grid*, vol. 2, no. 1, pp. 131–138, Mar. 2011.

[54] I. S. Bayram, G. Michailidis, M. Devetsikiotis, S. Bhattacharya, A. Chakrabortty, and F. Granelli, "Local energy storage sizing in plug-in hybrid electric vehicle charging stations under blocking probability constraints," in *Proc. IEEE Int. Conf. Smart Grid Commun.*, 2011, pp. 78–83.

[55] D. Said and H. T. Mouftah, "A novel electric vehicles charging/discharging management protocol based on queuing model," in *Proc. IEEE Electr. Power Energy Conf.*, Calgary, AB, Canada, 2014, pp. 1–6.

[56] D. Tang and P. Wang, "Nodal impact assessment and alleviation of moving electric vehicle loads: From traffic flow to power flow," *IEEE Trans. Power Syst.*, vol. 31, no. 6, pp. 4231–4242, Nov. 2016.

[57] T. Zhang, W. Chen, Z. Han, and Z. Cao, "Charging scheduling of electric vehicles with local renewable energy under uncertain electric vehicle

arrival and grid power price," *IEEE Trans. Veh. Technol.*, vol. 63, no. 6, pp. 2600–2612, Jul. 2014.

[58] C. L. Hwang and K. Yoon, *Multiple Attribute Decision Making: Methods and Applications*. New York, NY, USA: Springer-Verlag, 1981.

[59] T. L. Saaty, *The Analytic Hierarchy Process*. New York, NY, USA: McGraw-Hill, 1980.

[60] R. E. Bellman and L. A. Zadeh, "Decision-making in a fuzzy environment," *Manage. Sci.*, vol. 17, no. 4, pp. 141–164, Dec. 1970.

[61] M. Zeleny, *Multiple Criteria Decision Making*. New York, NY, USA: McGraw-Hill, 1982.

[62] P. Nunes, T. Farias, and M. C. Brito, "Day charging electric vehicles with excess solar electricity for a sustainable energy system," *Energy*, vol. 80, pp. 263–274, Feb. 2015.

[63] P. J. Tulpule, V. Marano, S. Yurkovich, and G. Rizzoni, "Economic and environmental impacts of a PV powered workplace parking garage charging station," *Appl. Energy*, vol. 108, pp. 323–332, Aug. 2013.

[64] L. Liu, F. Kong, X. Liu, Y. Peng, and Q. Wang, "A review on electric vehicles interacting with renewable energy in smart grid," *Renew. Sustain. Energy Rev.*, vol. 51, pp. 648–661, Nov. 2015.

[65] H. Chen, Z. Hu, H. Luo, J. Qin, R. Rajagopal, and H. Zhang, "Design and planning of a multiple-charger multiple-port charging system for PEV charging station," *IEEE Trans. Smart Grid*, vol. 10, no. 1, pp. 173–183, Jan. 2019.

[66] J. Dong, C. Liu, and Z. Lin, "Charging infrastructure planning for promoting battery electric vehicles: An activity-based approach using multiday travel data," *Transp. Res. C, Emerg. Technol.*, vol. 38, pp. 44–55, Jan. 2014.

[67] D. Vazquez-Canteli and Z. Nagy, "Reinforcement learning for demand response: A review of algorithms and modeling techniques," *Appl. Energy*, vol. 235, pp. 1072–1089, Feb. 2019.

[68] S. Guo and H. Zhao, "Optimal site selection of electric vehicle charging station by using fuzzy TOPSIS based on sustainability perspective," *Appl. Energy*, vol. 158, pp. 390–402, Nov. 2015.

[69] F. Wu and R. Sioshansi, "A stochastic flow-capturing model to optimize the location of fast-charging stations with uncertain electric vehicle flows," *Transp. Res. D, Transp. Environ.*, vol. 53, pp. 354–376, Jun. 2017.

[70] J. Y. Yong, V. K. Ramachandaramurthy, K. M. Tan, and N. Mithulananthan, "A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects," *Renew. Sustain. Energy Rev.*, vol. 49, pp. 365–385, Sep. 2015.

[71] X. H. Sun, T. Yamamoto, and T. Morikawa, "Fast-charging station choice behavior among battery electric vehicle users," *Transp. Res. D, Transp. Environ.*, vol. 46, pp. 26–39, Jul. 2016.

[72] J. Neubauer and E. Wood, "The impact of range anxiety and home, workplace, and public charging infrastructure on simulated battery electric vehicle lifetime utility," *J. Power Sources*, vol. 257, pp. 12–20, Jul. 2014.

[73] J. R. Birge and F. Louveaux, *Introduction to Stochastic Programming*, 2nd ed. New York, NY, USA: Springer, 2011.

[74] A. Ben-Tal, L. El Ghaoui, and A. Nemirovski, *Robust Optimization*. Princeton, NJ, USA: Princeton Univ. Press, 2009.

[75] S. Huang, L. He, Y. Gu, K. Wood, and S. Benjaafar, "Design of a mobile charging service for electric vehicles in an urban environment," *IEEE Trans. Intell. Transp. Syst.*, vol. 16, no. 2, pp. 787–798, Apr. 2015.

[76] F. Ahmad, A. Iqbal, I. Ashraf, and M. Marzband, "Optimal location of electric vehicle charging stations," *Sustain. Cities Soc.*, vol. 83, p. 103921, Aug. 2022.

[77] X. Li, C. Wang, and Y. Huang, "Two-stage stochastic programming for the optimal placement of charging stations for electric vehicles," *Energies*, vol. 15, no. 5, p. 1842, 2022.

[78] S. S. Amiri, M. Jadid, and H. Saboori, "Multi-objective optimum charging management of electric vehicles through battery swapping stations," *Energy*, vol. 262, p. 125443, Jan. 2023.

[79] T. Unterluggauer, J. Rich, P. B. Andersen, and S. Hashemi, "Electric vehicle charging infrastructure planning for integrated transportation and power distribution networks: A review," *eTransportation*, vol. 12, p. 100163, May 2022.

[80] S. Deb, X. Z. Gao, K. Tammi, K. Kalita, and P. Mahanta, "A comprehensive survey on AI and ML-based approaches for EV charging management and infrastructure development," *IEEE Access*, vol. 10, pp. 35212–35239, 2022.