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Cost Optimization of an Office EV-Charging Parking Lot with Integrated PV and Grid

Raimundo Cassinda Domingos
Department of Electrical Engineering
Malaviya National Institute of Technology Jaipur
Jaipur, India

***Abstract* - The rapid growth of electric vehicles has significantly increased the energy demand at workplace charging facilities. Uncoordinated charging leads to high grid dependency, increased operational cost, and stress on distribution systems. This paper presents a cost-optimization framework for an office EV-charging parking lot integrated with a rooftop photovoltaic system. A mathematical model is developed to represent EV charging demand, PV generation, grid interaction, and economic factors including capital and operational costs. Particle Swarm Optimization is employed to jointly determine the optimal PV capacity and EV charging schedule while satisfying user constraints. Simulation results demonstrate that coordinated charging aligned with PV generation significantly reduces grid import, improves PV utilization, and lowers annual operating costs. The proposed approach provides a scalable and economically viable solution for EV-ready commercial infrastructures.**

Keywords - Electric Vehicle Charging, Photovoltaic System, Cost Optimization, Particle Swarm Optimization, Smart Charging

INTRODUCTION

The electrification of transportation is a key strategy for reducing greenhouse gas emissions and urban pollution. As electric vehicle adoption increases, the demand for charging infrastructure in commercial and institutional environments is rising rapidly. Office parking lots are particularly suitable for EV charging due to long parking durations during daytime hours. However, uncontrolled charging can result in new peak loads, higher electricity bills, and increased stress on the distribution network.

Rooftop photovoltaic systems offer an effective solution by supplying clean energy during office hours when EVs are parked. Nevertheless, the benefits of PV integration depend strongly on appropriate PV sizing and intelligent coordination between EV charging demand and PV generation. Therefore, an optimized energy management strategy is required to minimize operational costs while ensuring user satisfaction.

This paper proposes a joint optimization framework for PV sizing and EV charging scheduling using Particle Swarm Optimization to achieve cost-effective and grid-friendly operation.

I. SYSTEM DESCRIPTION AND MODELLING

1) A. EV Charging Model

The system under study consists of an office parking lot with

100 EVs connected to identical 7 kW chargers. The daily scheduling horizon is divided into 48 time slots of 30 minutes each. Each EV is characterized by battery capacity, arrival and departure time, initial state of charge, and required final state of charge. A binary decision variable determines whether a vehicle is charging during a given time slot.

The aggregated EV load at each time interval is computed as the sum of individual charging powers of active vehicles.

1) B. Photovoltaic Generation Model

The rooftop PV system consists of multiple identical PV modules operating under standard test conditions. The PV output is modeled using a normalized irradiance profile with peak generation at midday, representing clear-sky conditions. The total PV output at each time slot depends on the number of installed panels and the irradiance level.

1) C. Grid Interaction and Cost Model

PV generation is prioritized to supply EV charging demand. Any deficit is met by grid import, while surplus PV power is exported to the grid at a fixed tariff. The total annual cost includes grid electricity charges, revenue from exported energy, and annualized PV investment cost.

II. PROBLEM FORMULATION

A. Objective Function

The objective is to minimize the total yearly cost of operating the EV charging facility. The cost function includes grid import cost, PV investment cost, and export revenue. Penalty terms are added to encourage smooth charging profiles, high PV utilization, and strict satisfaction of EV energy requirements.

B. Constraints

- Charging is allowed only within each EV’s arrival and departure window
- Each EV must receive its required charging energy
- Charging power is limited by charger ratings
- PV size is constrained by available rooftop capacity

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III. PARTICLE SWARM OPTIMIZATION APPROACH

Particle Swarm Optimization is employed to solve the nonlinear and mixed-variable optimization problem. Each particle encodes a candidate EV charging schedule along with a PV sizing variable. During each iteration, particles update their positions based on individual and global best solutions. A repair mechanism ensures feasibility by adjusting charging schedules to meet energy requirements.

The algorithm iteratively converges toward the optimal PV size and charging pattern that minimize total annual cost.

IV. RESULTS AND DISCUSSION

A. Simulation Setup

Simulations are conducted in MATLAB for a representative office-day scenario. Economic parameters are selected based on prevailing Indian electricity tariffs and PV costs.

The simulation is performed for an office parking lot consisting of 100 electric vehicles connected to identical chargers. The main system parameters used in the simulation are summarized in Table I

TABLE I - EV SYSTEM PARAMETERS

Parameter	Value
Number of EVs	100
Charger Rating	7 kW
Battery Capacity	50 kWh
Time Slots per Day	48
Slot Duration	30 minutes

The photovoltaic system parameters considered in the simulation, including module rating, cost, and lifetime, are summarized in Table II.

TABLE II: PV SYSTEM PARAMETERS

Parameter	Value
PV Module Rating	0.30 kW
PV Installation Cost	₹45,000 / kW
PV Lifetime	25 Years
Total Installed PV	270 KW

B. Performance Analysis

The optimized system achieves high PV utilization exceeding 90 percent, with minimal grid import. Coordinated charging significantly reduces peak demand and operational costs compared to a grid-only charging scenario. Annual savings demonstrate the economic feasibility of the proposed framework, with a substantially reduced per-unit EV charging cost.

The results confirm that intelligent scheduling aligned with PV availability enhances system efficiency and financial performance.

The key outcomes obtained from the PSO-based optimization, including energy balance, grid interaction, and PV utilization, are summarized in Table III

TABLE III – Optimization Results

Parameter	Value
Daily EV Energy Demand	1000 kWh
Daily PV Energy Generated	1082.86 kWh
Grid Import	43.22 kWh
Grid Export	76.09 kWh
PV.Utilization Efficiency	93%
Net Daily Cost	₹240.96

The arrival and departure pattern of electric vehicles during office hours plays a crucial role in charging flexibility. The distribution of EV availability throughout the day is illustrated in Fig. 1

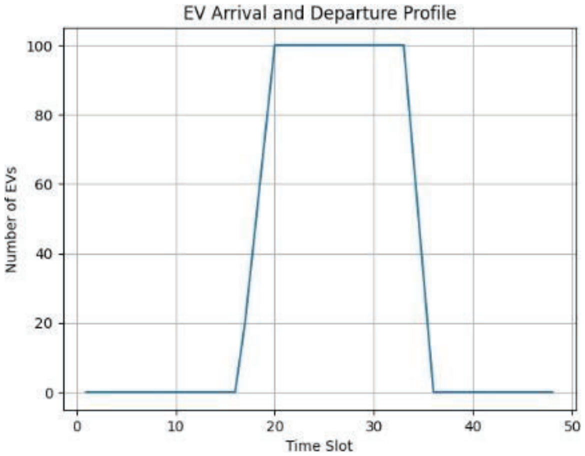

Fig. 1. EV arrival and departure profile during office hours

The coordination between photovoltaic generation and EV charging demand is a key objective of the proposed optimization framework. Fig. 2 compares the PV power output with the aggregated EV charging demand over the daily time horizon

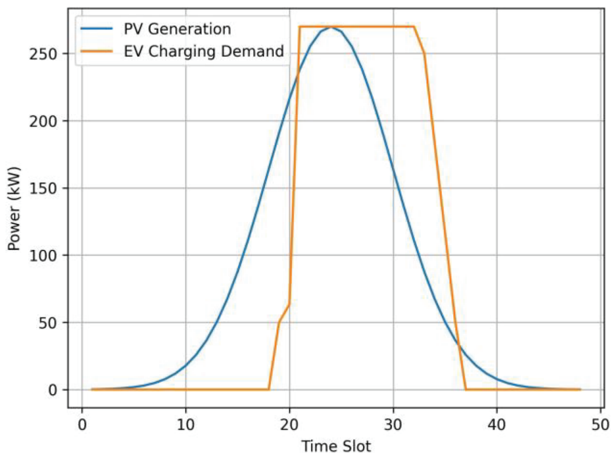

Fig. 2. Comparison of photovoltaic generation and aggregated EV charging demand.

To evaluate the economic feasibility of the proposed framework, a yearly cost comparison is performed considering grid-only operation and PV-assisted charging. The detailed annual cost breakdown is presented in Table IV.

TABLE IV – Yearly Economic Analysis

Description	**Value**
PV Installation Cost	₹31,755,000
Annual PV Cost (CAPEX + OPEX)	₹2,018,149
Grid-only Annual Cost	₹4,380,000
Annual Savings	₹2,361,850
Effective EV Charging Cost	₹5.53 / kWh

The optimized charging behavior obtained using the PSO algorithm results in a coordinated and smooth charging profile throughout the day. The number of EVs charging in each time slot is illustrated in Fig. 3.

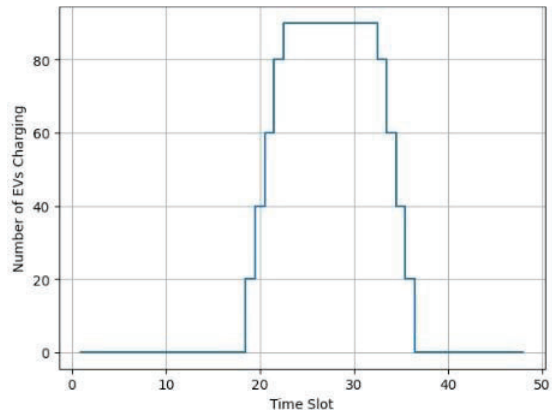

FIG. 3 – Optimized EV Charging Schedule

V CONCLUSION

This paper presented a cost-optimization framework for an office electric vehicle charging parking lot integrated with a rooftop photovoltaic system. A comprehensive mathematical model was developed to represent EV charging demand, PV generation, and grid interaction while incorporating economic considerations. Particle Swarm Optimization was employed to jointly determine the optimal PV capacity and EV charging schedule under realistic operational constraints. Simulation results demonstrated that coordinated charging aligned with PV availability significantly reduced grid energy import and improved solar energy utilization. The optimized system achieved high PV utilization efficiency while maintaining smooth charging profiles and satisfying all EV state-of-charge requirements. A detailed economic assessment confirmed substantial annual cost savings and a reduced effective charging cost compared to a grid-only charging scenario.

Overall, the proposed approach provides a practical and scalable solution for deploying economically viable EV charging infrastructure in commercial and institutional environments. Future work may extend this framework by incorporating battery energy storage systems, time-varying electricity tariffs, and uncertainty-aware optimization techniques to further enhance system performance and robustness.

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