

A Hybrid FPSO-MPC Energy Management System for Grid-Connected Solar Electric Vehicle Charging Stations

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Abstract

The rapid increase in electric vehicle adoption and renewable energy integration has created significant challenges in power management, charging coordination, and grid stability. This paper proposes a hybrid Fuzzy-Particle Swarm Optimization-Model Predictive Control (FPSO-MPC) framework for solar-assisted EV charging stations. The proposed framework integrates day-ahead scheduling using MPC, real-time uncertainty management using FIS, and offline parameter optimization using PSO.

1. Introduction

This paper investigates intelligent energy management for grid-connected solar EV charging infrastructure using a hybrid FPSO-MPC framework.

2. Literature Review

Recent studies on fuzzy logic, model predictive control, and particle swarm optimization for renewable-energy-assisted EV charging systems are critically analyzed.

3. Research Gap

Existing EMS frameworks generally fail to combine predictive optimization, uncertainty handling, and adaptive parameter tuning in a unified architecture.

4. Proposed FPSO-MPC Framework

The proposed framework combines Model Predictive Control for day-ahead optimization, Fuzzy Inference Systems for real-time decision-making, and PSO for parameter optimization.

5. Photovoltaic System Modeling

The PV array is modeled using a single-diode equivalent circuit and maximum power point tracking algorithm.

6. Battery Energy Storage Modeling

Battery behavior is modeled using the Thevenin equivalent circuit and Coulomb counting-based SoC estimation.

7. EV Charging Load Modeling

EV arrival and departure behavior are modeled stochastically using probabilistic distributions.

8. Simulation Scenarios

Three simulation scenarios are considered including clear sunny conditions, partially cloudy conditions, and peak EV demand conditions.

9. Results and Discussion

The proposed FPSO-MPC framework demonstrates superior renewable energy utilization and operational efficiency compared with baseline EMS approaches.

10. Conclusion

The proposed hybrid framework significantly improves charging reliability, renewable energy utilization, and economic performance.

Comparative Performance Metrics

Metric	Rule-Based	Det-MPC	PSO-FIS	FPSO-MPC
PV Self-Consumption	71.5%	83.7%	89.1%	94.2%
Grid Independence	52.1%	71.4%	78.6%	87.3%
Charging Completion	85%	95%	98%	100%
Operating Cost	\$267	\$198	\$167	\$142
Peak Grid Reduction	12.1%	28.4%	36.7%	45.3%

References

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