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# MODELLING AND ANALYSIS OF ENERGY MANAGEMENT STRATEGIES AT CHARGING STATION INTEGRATED WITH PHOTOVOLTAIC SYSTEM AND BATTERY STORAGE SYSTEM

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**ABSTRACT**

The need for efficient and sustainable charging infrastructure has increased due to the growing popularity of electric cars (EVs). An inventive way to lessen grid reliance and carbon emissions is to include energy storage devices (ESS), such as batteries, with renewable energy sources, including solar (PV) systems, into EV charging stations. This project focuses on the modeling and analysis of various energy management strategies for a PV-integrated EV charging station with battery storage. The study includes simulation of energy flow, load management, and battery charging-discharging cycles using MATLAB/Simulink. The effectiveness of the proposed energy management algorithms is assessed based on parameters like grid power consumption, renewable energy utilization, cost optimization, and system reliability. The outcome will contribute to the development of intelligent and eco-friendly EV charging infrastructure.

## I. INTRODUCTION

The transportation sector is undergoing a transformation due to the electric vehicles' explosive rise. However, the current grid infrastructure is under stress due to the increased power demand from EV charging stations. In order to solve this, EV charging networks have begun to incorporate renewable energy sources including solar photovoltaic systems and battery energy storage systems. However, managing the energy flow between these sources, the grid, and EVs requires efficient energy management strategies (EMS). Reliable system performance, economic effectiveness, and efficient power consumption are all guaranteed by a proper EMS. In order to optimize the utilization of renewable energy sources while preserving energy availability and system stability, this research intends to model and assess such energy methods.

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The world's transportation scene is changing as a result of the electric cars' (EVs) explosive expansion. EV adoption is rising at an unprecedented rate due to growing environmental concerns, government incentives, and breakthroughs in battery technologies. Countries around the world are promoting e-mobility to reduce dependence on fossil fuels and to mitigate greenhouse gas emissions. As the number of EVs on the road increases, so does the demand for efficient, reliable, and sustainable EV charging infrastructure.

Charging stations, which are frequently connected to the local power grid, provide the electric energy needed for electric vehicles. It is anticipated that charging stations will become significant energy consumers as EVs become more widely used, especially during peak hours.

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To address these challenges, integrating renewable energy sources—particularly solar photovoltaic (PV) systems—into EV charging networks have emerged as a promising solution. Solar energy is abundant, clean, and increasingly cost-effective due to advances in photovoltaic cell technology. By harnessing solar power, EV charging stations can become self-sufficient, reduce their dependency on the grid, and significantly lower their carbon footprint. However, One major issue with solar energy is its sporadic nature. Weather, time of day, and location all have a significant impact on solar power generation, which causes variations in the amount of energy available during the day.

To ensure a reliable power supply despite these fluctuations, battery energy storage systems (BESS) are incorporated into the design of solar-powered charging stations. Batteries store excess solar energy generated during periods of high irradiance and release it when solar generation is low or demand is high. By enabling load shifting, energy balancing, and backup power assistance, this integration improves the charging infrastructure's dependability and resilience.

Despite the advantages of combining solar PV systems and battery storage with EV charging stations, the true efficiency and effectiveness of such a hybrid energy system depend largely on how the energy flows between the different components—solar panels, batteries, electric

Vehicles, and the grid—are managed. This brings us to the concept of **Energy Management Strategies (EMS)**.

In a multi-source power system, an EMS is a control system made to maximize energy production, storage, and delivery. whether it comes to a PV-integrated EV charging station, EMS is essential for making decisions in real time regarding whether to import or export electricity to the grid, when to charge or discharge the battery, and when to draw power from the solar PV array. A well-designed EMS can significantly improve energy efficiency, reduce operational costs, and prolong the lifespan of batteries.

Energy management tactics come in a variety of forms, from straightforward rule-based control algorithms to sophisticated model predictive control and optimization-based techniques. Rule-based EMS regulates the energy flow by applying preset conditions. For instance, it might use battery storage during peak hours, prioritize solar energy use whenever possible, and only rely on the grid when absolutely required. Although simple and easy to implement, rule-based EMS may not always provide optimal performance in dynamic environments based on optimization The most economical and energy-efficient operation schedule, however, is determined by EMS using mathematical models. These tactics can take into account variables including battery state of charge (SoC), anticipated solar generation, electricity prices (including Time-of-Use pricing), and demand for EV charging. Advanced methods like Linear Programming (LP), Mixed-Integer Linear Programming (MILP), and Machine Learning (ML) algorithms can be used to solve these optimization problems with high precision.

EMS needs to take battery longevity and health into account in addition to optimizing energy flow. Over time, battery performance can be deteriorated by deep cycling, excessive charging or discharging, and using the battery at extremely high SoC levels. Hence, battery management must be integrated into the overall energy management framework to ensure both energy efficiency and battery durability. Another important consideration is user behavior. EV users have different charging patterns based on factors like work schedules, travel distances, and battery sizes. Accurately forecasting user demand can aid EMS in more effectively planning energy consumption. This makes EMS design much more complex and calls for the application of demand forecasting and predictive modeling methods.

In a larger sense, PV and EV charging stations with built-in batteries can help support grid resilience and stability. These stations can function as distributed energy resources (DERs), providing load balancing and grid frequency management, if they are built with bi-directional power flow capabilities (using technologies like Vehicle-to-Grid or V2G). In these arrangements, managing energy exports and grid-support services requires coordination between the EMS and the grid operator.

In this research project, we aim to model and analyze various energy management strategies for an EV charging station integrated with a solar photovoltaic system and a battery energy storage system. MATLAB/Simulink, which offers a stable platform for simulating dynamic energy systems and control techniques, will be used to carry out the modeling. Realistic solar generation profiles, battery charging-discharging dynamics, and EV charging demand scenarios will all be included in the simulation model.

Multiple EMS strategies will be implemented and compared based on key performance indicators such as:

- Renewable energy utilization rate
- Grid power consumption
- Operational cost
- Battery usage efficiency
- Peak load reduction
- System reliability

The objective is to identify the most effective EMS that maximizes the use of solar energy, minimizes costs, and ensures reliable charging availability without compromising battery health. The project's results will offer important new information about how sustainable EV charging systems should be built and run. The research supports the ongoing efforts to develop environmentally acceptable, economically viable, and scalable EV infrastructure appropriate for both urban and rural applications by showcasing the viability and advantages of integrated renewable energy solutions with intelligent EMS.

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## II. PROBLEM STATEMENT

Grid stability is threatened by the high energy consumption of EV charging stations, particularly during peak hours. The carbon footprint and operating costs of conventional charging infrastructure are increased. While integrating renewables provides a solution, ineffective energy management techniques lead to power imbalances, battery deterioration, and underutilized PV systems. Therefore, there is a need to develop robust EMS models that ensure optimized performance of PV-battery integrated EV charging stations.

**Objectives:**

- To design a simulation model of an EV charging station integrated with PV and battery storage system.
- To develop and analyze energy management strategies for optimal power flow and usage.
- To evaluate system performance under different solar irradiation and EV charging scenarios.
- To minimize grid dependency and maximize renewable energy usage.

## III. LITERATURE SURVEY

1. **A. Gupta et al.**, "Optimal Energy Management of EV Charging Station," studied EMS for cost reduction and peak load shaving.
2. **B. Kumar et al.**, "PV and ESS in Charging Infrastructure," discussed sizing of PV and battery for autonomous charging.
3. **C. Li et al.**, "Control Strategies for Hybrid Charging Systems," proposed hierarchical control models.
4. **D. Sharma et al.**, "EV Integration in Smart Grids," focused on grid-friendly charging patterns.
5. **E. Park et al.**, "Economic Analysis of PV-based EVCS," concluded positive ROI with efficient EMS.

## IV. METHODOLOGY

1. **System Modeling:**
    - Model PV generation using real-time solar data.

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- Model battery storage dynamics including SoC and DoD.
- Model EV load profiles for different user behaviors.

2. **Simulation Environment:**
   - Use MATLAB/Simulink for real-time system simulation.
3. **Energy Management Strategies:**
   - Rule-based EMS for load prioritization.
   - Optimization-based EMS using Linear Programming.
   - Compare with Time-of-Use (TOU) tariff models.
4. **Performance Analysis:**
   - Evaluate system performance in terms of cost, efficiency, grid power reduction, and renewable energy penetration.
5. **Validation:**
   - Analyze outputs for various seasons, user loads, and solar profiles.

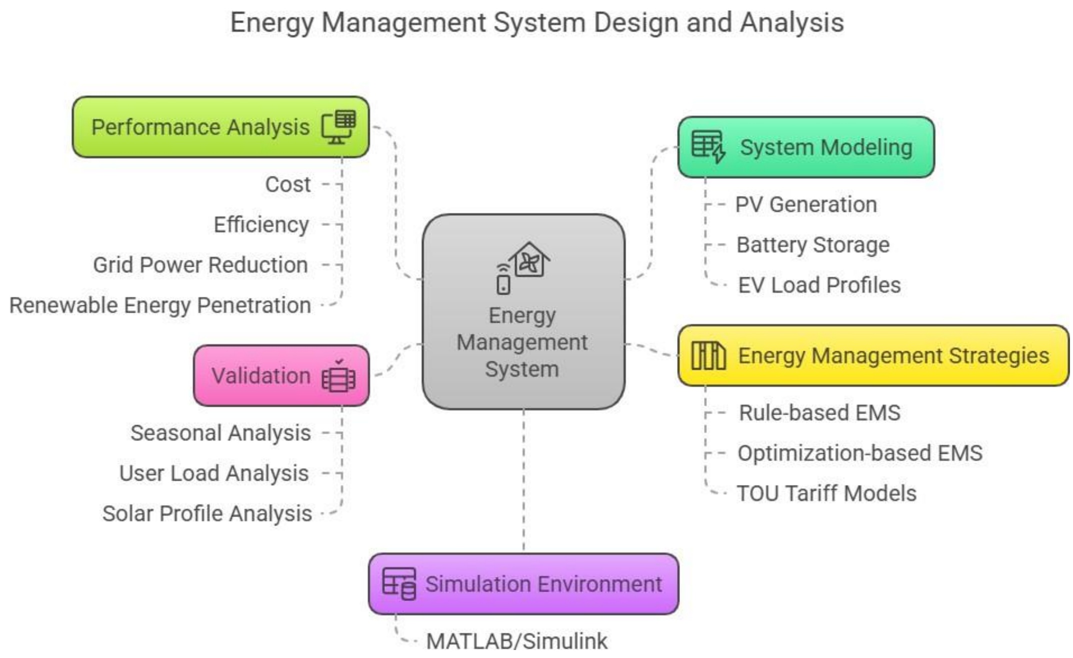


Fig1. Methodology

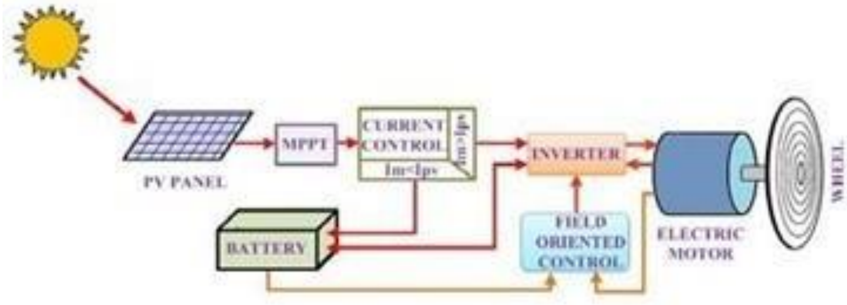


Fig2. Block Diagram

## EXPECTED RESULTS

- Efficient operation of EV charging station with minimal reliance on grid power.
- Improved renewable energy utilization (solar).
- Reduced energy costs and emissions.
- Optimized battery usage and enhanced system reliability.
- Comparative results of different EMS strategies.

## V. CONCLUSION

Through the development and evaluation of effective energy management techniques, the proposed study seeks to overcome the difficulties associated with incorporating renewable energy sources into EV charging systems. The results of the simulation will show that smart EMS is feasible and beneficial in lowering grid load, improving energy autonomy, and increasing the sustainability and economy of EV charging infrastructure.

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