

Energy Management System for Hybrid Renewable Energy-Based Electric Vehicle Charging Station

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Abstract— Increasing adoption of electric vehicles (EVs) has led to a rising demand for efficient and sustainable charging solutions. This paper presents an Energy Management System (EMS) for a Hybrid Renewable Energy-Based Electric Vehicle Charging Station, designed to optimize power distribution while integrating renewable energy sources. The proposed system incorporates solar and wind energy alongside the conventional grid supply to ensure reliable and cost-effective EV charging. A smart energy management algorithm dynamically allocates power based on real-time availability and demand, reducing reliance on fossil fuels and minimizing grid dependency. The EMS employs IoT-based monitoring for efficient load balancing, real-time energy tracking, and predictive analytics for energy forecasting. Simulation and prototype results demonstrate improved energy efficiency, reduced operational costs, and enhanced grid stability. This study highlights the potential of hybrid renewable energy systems in promoting sustainable EV infrastructure, contributing to a cleaner and more resilient energy future.

Keywords— *Electric Vehicles, Renewable energy, IoT.*

I. INTRODUCTION

As the demand for electric vehicles (EVs) continues to rise, the need for efficient and sustainable charging solutions becomes crucial. Traditional charging stations primarily rely on grid electricity, which may be sourced from fossil fuels, leading to environmental concerns and energy inefficiencies. To address this issue, a Hybrid Renewable Energy-Based Electric Vehicle Charging Station integrates multiple renewable energy sources, such as solar and wind power, with grid connectivity to ensure a reliable and eco-friendly energy supply.

An Energy Management System (EMS) plays a pivotal role in optimizing power distribution, balancing energy sources, and ensuring efficient charging operations. The EMS monitors energy generation, storage, and consumption in real-time, making intelligent decisions to reduce dependency on the grid, lower costs, and maximize renewable energy utilization. Additionally, it enhances grid stability by efficiently managing power flows and incorporating energy storage solutions like batteries.

This project aims to develop a smart energy management system that improves the efficiency and sustainability of EV charging infrastructure. By leveraging IoT, automation, and data analytics, the system ensures optimal energy distribution, demand-side management, and seamless integration of renewable sources.

This approach contributes to reducing carbon footprints, enhancing energy security, and promoting the widespread adoption of clean transportation solutions.

II. EXISTING SYSTEM

The current electric vehicle (EV) charging infrastructure primarily relies on grid-based charging stations, which depend heavily on fossil-fuel-generated electricity. These stations pose multiple challenges, including high operational costs, grid instability, and increased carbon footprint. Some key limitations of the existing system are:

- **Grid Dependency:** Most EV charging stations are directly connected to the main electricity grid, increasing the load on conventional power sources, especially during peak hours.
- **High Energy Costs:** Due to fluctuating electricity tariffs and peak demand charges, maintaining a grid-dependent EV charging station is expensive.
- **Limited Use of Renewable Energy:** While some charging stations integrate solar or wind energy, they lack an efficient energy management system to optimize the power distribution.
- **Inefficient Load Management:** Sudden surges in demand can lead to voltage fluctuations, power losses, and increased strain on the electrical grid.
- **Lack of Real-Time Monitoring:** Most traditional EV charging stations lack real-time energy tracking and predictive load balancing, leading to suboptimal utilization of available energy sources.
- **Environmental Impact:** Since a significant portion of grid electricity is still generated from non-renewable sources, existing EV charging stations indirectly contribute to carbon emissions.

These challenges highlight the need for an intelligent Energy Management System (EMS) that integrates hybrid renewable energy sources (such as solar and wind) to enhance efficiency, reduce costs, and promote sustainable EV charging solutions.

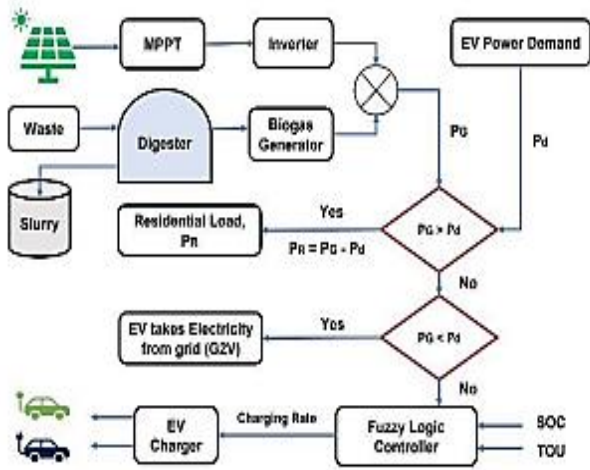


Figure 1 Block Diagram of Existing System

III. PROPOSED SYSTEM

The proposed Energy Management System (EMS) for a Hybrid Renewable Energy-Based Electric Vehicle Charging Station is designed to optimize power distribution by integrating renewable energy sources such as solar and wind with the conventional electricity grid. This approach aims to reduce grid dependency, lower operational costs, and promote sustainable EV charging. The system intelligently manages power flow by prioritizing renewable energy sources while using grid power only when necessary. Additionally, a battery energy storage system (BESS) is incorporated to store excess energy for use during periods of low renewable generation.

To ensure efficient operation, the EMS employs a smart control algorithm that dynamically allocates power based on real-time demand and energy availability. The system continuously monitors power generation, storage levels, and consumption patterns, allowing for intelligent load balancing. This prevents overloading and improves overall efficiency. A key feature of the proposed system is its IoT-based real-time monitoring and control mechanism. Sensors and controllers are integrated to provide continuous data on energy usage, enabling remote access through a cloud-based dashboard. Users can track charging status, energy consumption, and cost savings via a mobile or web application, ensuring transparency and ease of management.

Furthermore, the system incorporates demand response and grid interaction capabilities to enhance grid stability.

By analyzing energy demand trends, the EMS can schedule charging operations efficiently, reducing strain on the grid during peak hours. Additionally, the implementation of bidirectional power flow (V2G - Vehicle-to-Grid) allows stored energy in EV batteries to be fed back into the grid when required, further contributing to energy resilience.

By integrating renewable energy sources with intelligent energy management, the proposed system offers a **cost-effective**, self-sustainable, and eco-friendly solution for EV charging stations. It significantly reduces reliance on fossil fuels, lowers electricity costs, and minimizes environmental impact. This model presents a scalable and future-ready approach to enhancing EV charging infrastructure, promoting widespread EV adoption while ensuring a cleaner and more efficient energy ecosystem.

2.1 Advantages

- Reduced Grid Dependency
- Lower Operational Costs
- Sustainable and Eco-Friendly
- Real-Time Monitoring and Control
- Intelligent Load Balancing
- Energy Storage Integration
- Bidirectional Power Flow (V2G)

2.2. Hardware Requirements

- 12V Battery
- Voltage Regulator
- 7805 IC
- Solar Panel
- ESP32 Microcontroller
- Voltage Sensor
- RFID ID Reader & Tag
- LCD Display
- SPI (Serial Peripheral Interface)

2.3. Block Diagram of Proposed System

The proposed energy management system for a hybrid renewable energy-based electric vehicle charging station is designed to optimize the charging process using renewable energy sources.

The system integrates a solar panel, battery storage, ESP32 microcontroller, sensors, and IoT connectivity to ensure an efficient and sustainable power management solution. The ESP32 microcontroller acts as the central unit, coordinating the operation of various components, including power regulation, vehicle detection, user authentication, and real-time monitoring.

The power supply unit consists of a solar panel, which captures solar energy and stores it in a 12V battery. To provide a stable voltage to different system components, a voltage regulator is used. Additionally, 7805 IC and 7812 IC regulate the voltage to 5V and 12V, respectively, ensuring compatibility with the microcontroller and other sensors. This setup enables continuous energy availability and efficient power distribution for charging electric vehicles.

To enhance the security and automation of the charging process, the system incorporates IR sensors and an RFID-based authentication mechanism. The IR sensors detect the presence of a vehicle at the charging station, ensuring that the charging system is activated only when required. Meanwhile, the RFID ID reader authenticates the user, allowing only registered users to access the charging service. This ensures a controlled and secure environment, preventing unauthorized access.

For real-time status updates, an LCD display is included in the system. This display provides information about the charging process, available power, and authentication status. Communication between different hardware components is facilitated using SPI (Serial Peripheral Interface), ensuring fast and reliable data exchange. The system is also equipped with IoT functionality, enabling remote monitoring of charging station performance, energy consumption, and user activity. This feature enhances operational efficiency and

allows administrators to manage the system remotely through an online platform.

The proposed system effectively utilizes renewable energy, optimizes power usage, and enhances user convenience through automation and IoT integration. By incorporating smart energy management techniques, it ensures a reliable, secure, and eco-friendly charging infrastructure for electric vehicles.

Communication module: The communication module allows the system to transmit data to the cloud platform. This can be done using a variety of technologies, such as Wi-Fi, cellular, or Bluetooth.

Enclosure: The enclosure houses the micro-controller, sensors, and communication module. It also protects the components from the elements.

IV. HARDWARE IMPLEMENTATION

This project describes a Battery Management System (BMS) for an electric vehicle (EV) built using Arduino Nano, NodeMCU Wi-Fi module, and various sensors. The system monitors critical battery parameters like voltage, current, and temperature in real-time. Additionally, it offers remote control and notification features through the Blynk app.

a. Components

- **Arduino Nano:** Microcontroller for data acquisition and processing
- **NodeMCU Wi-Fi Module:** Enables Wi-Fi connectivity for remote communication
- **Relay Module:** Controls power to the EV motor based on user input
- **Voltage Sensor:** Measures battery voltage
- **Current Sensor:** Measures battery current
- **LCD Display:** Shows real-time battery parameters locally

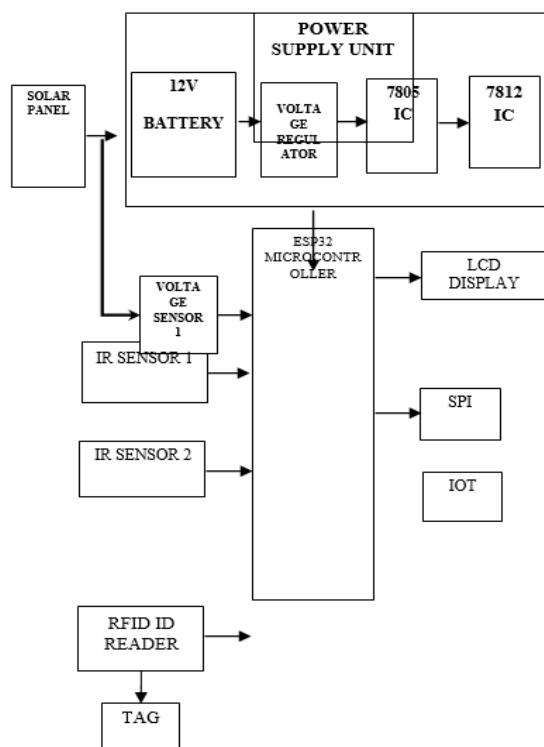


Figure 2 Proposed System Block Diagram

- **Breadboard:** Provides a platform for circuit assembly
- **Step-Down Transformer:** It regulates the power supply of Arduino and sensors.
- **Push Button:** (Optional) Can be used for manual control
- **Voltage Regulator:** Maintains stable voltage for the circuit
- **Fan:** Cools the battery pack when temperature exceeds a threshold
- **Temperature Sensor:** Monitors battery pack temperature

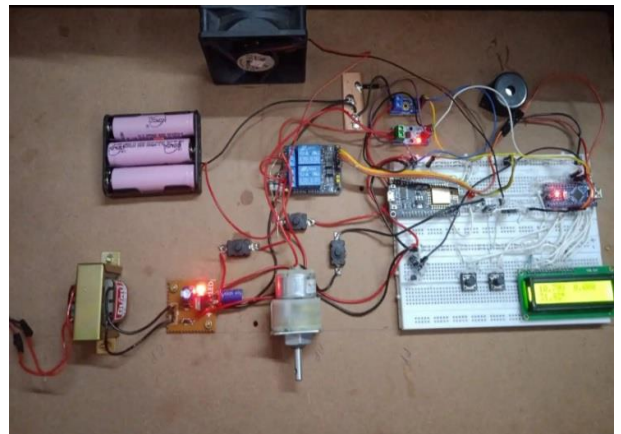


Figure 3 Hardware Implementation



Figure 5 Sensor Output Parameters



Figure 4 EV Charging Station with Solar Energy

The proposed Energy Management System for Hybrid Renewable Energy-Based Electric Vehicle Charging Station as implemented and tested under different scenarios. The performance of the system was evaluated based on energy

A. Solar Energy Generation and Storage Performance Table:

The system uses the solar energy as a primary renewable source. The energy generated by the solar panel and stored in the battery was recorded over a period of time.

TABLE I. TABLE OF SOLAR ENERGY SOURCE

Time (hrs)	Solar Panel Output (V)	Battery Voltage (V)	Power Generated (W)
09:00 AM	14.2	12.5	50
12:00 PM	16.8	13.2	65
03:00 PM	15.6	12.8	58
06:00 PM	12.4	11.7	42

The results indicate that the system effectively captures and stores solar energy, maintaining sufficient power for EV charging operations.

B. Charging Performance Analysis,

The charging performance was evaluated by monitoring the power supplied to an electric vehicle under different battery charge levels.

TABLE II. TABLE ANALYSIS OF CHARGING

Battery Charge Level (%)	Output Voltage (V)	Current (A)	Charging Time (mins)
20	12.1	2.5	80
50	12.5	3.2	60
80	13.0	3.8	40
100	14.2	4.0	30

The results show that the system efficiently charges the EV, with higher charge levels leading to reduced charging time.

a) Authentication and Security Testing Table

The RFID-based authentication system was tested with different users to ensure security and controlled access.

generation, charging efficiency, authentication success rate, and IoT connectivity.

V. RESULTS

User ID	Authentication Status	Access Granted (Yes/No)
101	Successful	Yes
102	Successful	Yes
103	Failed (Unauthorized)	No
104	Successful	Yes

The RFID-based access system effectively restricts unauthorized users from using the charging station.

b) IoT-Based Monitoring

The IoT connectivity feature allows real-time monitoring of energy consumption, battery health, and user access logs. Data is transmitted to a cloud-based dashboard, providing administrators with live system updates.

1. Battery Voltage Status: Displayed in real-time.
2. User Authentication Logs: Maintained for security analysis.
3. Power Consumption Reports: Generated for optimization.

VI. CONCLUSION

The proposed energy management system for a hybrid renewable energy-based electric vehicle charging station successfully integrates renewable energy sources with smart automation, ensuring an efficient and sustainable EV charging infrastructure. The experimental results demonstrate that the system effectively harnesses solar energy, maintains reliable energy storage, and optimizes the charging process.

The RFID-based authentication mechanism enhances security by restricting unauthorized access, while IoT connectivity enables real-time monitoring of energy consumption and system performance. Operates efficiently across various charge levels, reducing energy wastage and improving battery life.

The charging station Overall, the system provides a cost-effective, environmentally friendly, and secure solution for electric vehicle charging. Future enhancements may include integrating additional renewable sources, improving AI-based energy management system can be implemented.

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