

SOLAR-POWERED CHARGING STATION WITH ENERGY STABILIZATION FOR ELECTRIC SCOOTER (AI)

¹Gudusaba Peerasaba Sasabala, ²Dr.Malatesh S H, ³Kushal Kumar KC, ⁴Janardhan Reddy

¹UG Student, ²Head of Department, ³UG Student, ⁴UG Student

¹Computer Science and Engineering,

¹M S Engineering College, Bengaluru, India

Abstract: The increasing adoption of electric scooters calls for sustainable and automated charging solutions. This project proposes a smart solar-powered charging system using the ESP32 microcontroller to efficiently manage energy sources for scooter charging. The system utilizes an IR sensor to detect the presence of a scooter and automatically determines the availability of solar power. If solar energy is sufficient, the system charges the scooter using solar power via a relay-controlled circuit. In the absence of adequate solar energy, it seamlessly switches to mains power to continue charging. An LCD display provides real-time feedback on the charging status and power source in use. This intelligent dual-source charging setup minimizes dependency on the grid, promotes renewable energy usage, and ensures uninterrupted scooter charging with minimal human intervention.

Index Terms – Solar powered charging station, Hybrid Energy system, Renewable Energy, Automatic Power Switching

I. INTRODUCTION

Electric scooters have emerged as an eco-friendly alternative to traditional fuel-based vehicles, significantly contributing to the reduction of carbon emissions and dependence on fossil fuels. However, with the rise in electric vehicle (EV) usage, the demand for efficient and sustainable charging systems has also increased. Traditional charging methods primarily rely on electricity from the grid, which may not always be eco-friendly or cost-effective.

This project introduces an intelligent and automated solar-powered charging system for electric scooters using the ESP32 microcontroller. The system is designed to automatically detect the presence of a scooter using an IR sensor and choose the most suitable power source between solar energy and mains electricity. The availability of solar power is continuously monitored, and a relay module is used to switch the charging source accordingly. If solar energy is available, the scooter is charged from the solar panel; otherwise, the system switches to the mains source. An LCD display shows the charging status and power source in real time, enhancing user awareness.

By prioritizing renewable energy and providing automation, the proposed system not only promotes green technology but also ensures convenience, reliability, and efficient energy usage in urban mobility infrastructure.

Problem Statement.

The rapid growth of electric scooter usage has created an increasing demand for efficient and sustainable charging solutions. Traditional charging infrastructures predominantly rely on grid electricity, which not only increases dependency on non-renewable power sources but also contributes to peak-time load stress on the electrical grid. As adoption expands, there is a pressing need for charging systems that can alleviate grid burden while supporting large-scale EV charging requirements.

Additionally, many existing charging setups require manual intervention — plugging, mode selection, and power source management — leading to inefficiencies and inconvenience for users. Without smart automation, charging stations cannot dynamically adapt to varying environmental and power conditions, particularly concerning intermittent renewable energy availability such as solar power.

Therefore, there is a need for a smart, automated charging solution that can intelligently determine the optimal power source, adapt to energy availability, and ensure reliable charging with minimal human supervision. A hybrid solar–mains power architecture managed by a microcontroller is essential to enable efficient energy utilization and support sustainable electric mobility.

Literature Review

1. Pavan, Vijayendra, Shashikala (2015) present a proposed charging station microgrid model for off-grid EV charging station with the integration of renewable energies such as solar photovoltaic, wind, Fuel Cell with provision for storage with mainly battery and optional storage with ultra-capacitors has been presented.

2. Vishal, Vaidya, Kaiwalya, Kulkarni (2015) have done the team's research indicated a benefit to the campus for such a structure and also room for improvement on other existing charging stations. Other stations the team found were quite expensive to build. Additionally, solar designs and innovations are rapidly advancing which could contribute to a more efficient charging station.

3. Simon Steinschaden and José Baptista (2015) discuss about the tool has been developed to help find solutions for each combination of charging station properties, most efficient combination. It emerges that solar charging stations for private and commercial use can be design. In summary, due to the ease of management and simplicity of the tool compared to alternative computing software, this tool is suitable to suit a wide range of audience groups including professionals and non-professionals. However, all the necessary parameters for the design of a solar charging station are taken into account. The results are comparable with solar power design, self-sufficiency rate, self-expenditure and payback period.

4. Gheorghe Badea, Raluca-Andreea, Felseghi (2015) examines the possibility of charging electric vehicle batteries with clean energy using solar autochthonous renewable resources. At the charging station of a photovoltaic module and battery-based electric vehicle, an island system was designed, sized, and simulated in operation. The optimal configuration of the photovoltaic system was supplemented with Hybrid Optimization software enhanced by Genetic Algorithm (iHOGA) version 2.4 and we simulated its operation. The solar power system should be designed so that the charging station always has enough electricity to power multiple electric vehicles 24 hours a day.

Existing System

Currently, most electric scooter charging setups depend solely on conventional grid-based power sources. Charging must often be initiated manually by plugging in the charger, and users are responsible for ensuring the power supply and charging conditions. These systems do not intelligently manage energy sources or automatically detect connected devices.

There is generally no integration of renewable sources in traditional chargers, and no automated switching capability between power inputs based on availability or efficiency. Existing approaches are passive and lack real-time monitoring, making them energy-inefficient and unsuitable for smart, adaptive charging environments.

Demerits of Existing System

- Complete dependency on grid power.
- No automatic detection of scooters for charging initiation.
- Absence of renewable energy utilization.
- Manual operation required.
- No real-time status monitoring or display interface.
- Inefficient energy usage and higher operational cost.

Proposed System

The proposed system introduces a solar-powered smart charging mechanism controlled by an ESP32 microcontroller that intelligently manages energy sources. Using an IR sensor, the system detects when a scooter is present and automatically initiates the charging process. If sufficient solar energy is available, charging is performed using solar power through a relay-controlled circuit. In cases of reduced solar output, the system seamlessly switches to mains power without interrupting charging.

An LCD interface continuously displays the charging progress and current power source, enabling transparency and ease of monitoring. By integrating intelligent control logic and renewable energy prioritization, the system reduces reliance on grid power, ensures uninterrupted charging, and promotes environmentally friendly transportation infrastructure.

Software Requirements:

1. Arduino IDE
2. ESP32 Board Libraries
3. I2C & LCD Libraries
4. Relay Control & Power Logic Code

Hardware Requirements:

1. ESP32 Microcontroller
2. IR Sensor
3. Relay Module
4. Solar Panel
5. LCD Display

ESP32 Microcontroller

The ESP32 is the central processing unit of the charging system and is responsible for executing the decision-making logic of the project. It coordinates signals from input sensors, executes the switching conditions, and controls output relays. Its dual-core architecture and fast processing speed make it ideal for real-time control applications such as this automated charging system.

With built-in Wi-Fi and Bluetooth capabilities, the ESP32 provides future-ready options for remote monitoring, IoT connectivity, and mobile app integration. Although the current system focuses on local operation, the microcontroller's capabilities allow extensions toward cloud-based reporting or centralized charging-station management.

The ESP32 also offers numerous GPIO pins, ADC channels, and protocol support including I2C, SPI, and UART. This flexibility allows seamless communication between the microcontroller and peripherals like the IR sensor and LCD module. Its low power consumption is an added advantage for energy-efficient embedded systems.

IR Sensor

The IR (Infrared) sensor serves as the scooter presence detector. It identifies whether an electric scooter is docked in the charging bay by sensing reflected infrared radiation. This ensures that the system knows when to initiate charging automatically.

Deploying an IR sensor eliminates the need for manual charging activation buttons or human input, reducing operational effort and minimizing human error. The sensor's functionality is stable, affordable, and highly reliable for short-range detection. Its digital output interface makes it easy to interface with the ESP32 controller. When the scooter is detected, the output pin signals the microcontroller to trigger the charging logic sequence. When the scooter is absent, the charging circuit remains inactive to prevent idle energy drain. False triggers are avoided by fine-tuning the sensitivity and threshold level of the sensor. In addition, simple signal filtering software logic ensures noise is ignored, guaranteeing accurate detection under various lighting conditions.

Relay Module

The relay module acts as the electrical interface between the charging system and the two power sources—solar and mains. It switches high-power electrical circuits based on low-voltage input signals from the ESP32.

Using a relay ensures complete electrical isolation between the microcontroller and high-voltage circuitry, providing operational safety. The module supports switching up to 220V AC while being controlled safely by a 3.3V or 5V logic signal.

When solar power is determined sufficient, the relay connects the charging circuit to the solar panel output. If solar voltage drops below the threshold, the relay seamlessly switches to mains supply without interrupting charging.

The relay's ability to perform mechanical switching with predictable response time makes it a dependable component. Its durability and life-cycle rating further ensure long-term reliability of the system in real-world conditions.

Solar Panel

The solar panel is the primary energy source, converting sunlight into electrical power for charging the scooter. Designed for sustainable energy generation, it reduces reliance on grid-based electricity.

The panel delivers DC voltage to the charging circuit, which is regulated through a solar charge controller or voltage regulator to ensure a stable output suitable for charging batteries.

Environmental factors such as sunlight intensity, shading, and temperature affect solar output. Therefore, the system constantly monitors panel voltage to determine whether it can sustain charging.

Using renewable power not only reduces carbon footprint but also enables low-cost charging infrastructure deployment, especially for residential or public solar charging stations.

LCD Display

The LCD display is the user-interface component, responsible for showing the charging state and selected power source. It provides real-time feedback such as “Solar Charging,” “Mains Charging,” or “No Vehicle Detected.”

By using I2C protocol, wiring complexity is reduced and communication with the ESP32 is simplified. The display operates with low energy consumption and can output text clearly even in daylight environments.

LCD feedback ensures transparency of system status, enabling even non-technical users to understand charging progress. It acts as an operational diagnostic tool during both development and real-world deployment.

If system faults occur—such as IR sensor failure or no power source—the LCD can issue warnings, making troubleshooting faster and safer.

Methodology

The methodology began with defining the functional and operational requirements of the smart charging system. The core conceptual idea was to develop a hybrid power-source charging model capable of using solar energy as the primary input and conventional grid power as the fallback backup. To achieve autonomous operation, the system needed to determine scooter presence, detect solar availability, perform power source selection, and communicate charging status to the user. During the initial planning phase, the behavioral workflow of the system was charted, including scooter detection, solar evaluation, relay switching logic, and microcontroller-based control. This conceptual mapping ensured that all functional modules—sensing, switching, power routing, and feedback—were integrated logically and efficiently.

Limitations

- Solar dependency restricts maximum autonomy — during prolonged periods of low sunlight, the system relies fully on mains.
- The system does not yet monitor scooter battery charge level; thus, charging continues until the battery's own BMS terminates charging.
- Energy data is not logged or stored; no long-term statistics are maintained.
- Physical environmental conditions such as dust, IR interference, or sensor misalignment can impact detection accuracy.

APPLICATIONS

- Public EV Charging Stations
- Residential Scooter Charging
- Smart City Infrastructure
- Battery Swapping Stations

Result

The implemented smart charging system successfully demonstrated autonomous recognition of scooter presence, dynamic selection of power source based on real-time solar availability, and user feedback through the LCD interface. Across multiple test cycles and

environmental conditions, the system consistently functioned without human input. The integration of ESP32 with IR sensing and voltage evaluation proved efficient in achieving the intended charging automation.

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CONCLUSION

This project successfully achieved the development of an intelligent EV charging system that prioritizes solar power while providing mains fallback automatically. Using the ESP32 controller, the system processes real-time sensor data to autonomously manage energy routing. The inclusion of IR-based scooter presence detection and LCD user feedback enhances autonomy and user-friendliness.

The results affirm that the proposed dual-power charging framework is effective, stable, and adaptable to varied environmental conditions. The automatic relay switching mechanism proved reliable in ensuring uninterrupted charging. The project contributes to the development of future green infrastructure and demonstrates the practical application of embedded systems in sustainable engineering.

FUTURE ENHANCEMENTS

- IOT Connectivity
- Battery Level Monitoring
- Multi-Port Charging Design
- AI-Enhanced Power Forecasting
- Payment & Authentication System
- Compact Enclosure & Product Prototype

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