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Design and Implementation of IOT and RFID Payment Solutions for a Solar-Powered Wireless EV Charging Station

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ABSTRACT

This project presents a solar-powered, wireless Electric Vehicle (EV) charging station that integrates IoT connectivity and RFID-based payment solutions to deliver a secure, sustainable, and user-friendly charging experience. The system harnesses solar energy through a photovoltaic panel that charges a 12V battery via a dedicated charging circuit. An Arduino-based control system serves as the central hub, managing energy monitoring, EV charging operations, and communication functionalities. A voltage sensor continuously monitors the solar panel output, enabling real-time energy management and ensuring optimal performance. To maintain uninterrupted operation, an auxiliary power supply automatically engages when solar energy is insufficient. The implementation of RFID technology facilitates secure, contactless payment, where user authentication triggers a relay module that activates a wireless transmitter. This transmitter establishes a secure connection with the EV's receiver, thereby initiating the charging process. Experimental evaluations confirm the system's effectiveness in integrating renewable energy, ensuring operational flexibility, and enhancing security in EV charging applications.

Keywords — Solar-powered EV charging station, wireless charging, IoT integration, RFID payment, Arduino control system, renewable energy, photovoltaic panel, energy monitoring, auxiliary power supply, voltage sensor etc.

I. INTRODUCTION

The rapid evolution of wireless power transfer and renewable energy systems has paved the way for innovative applications across various sectors. Early work by Pawade, Nimje, and Diwase [1] introduced the concept of eliminating physical wires for power transmission, demonstrating the potential for more flexible and adaptable energy systems. Since then, the field has expanded, incorporating energy renewal techniques in sensor networks [2] and optimizing mobile charging paths for rechargeable sensor networks [3]. These advancements have not only contributed to the theoretical understanding of wireless power transmission but have also spurred practical implementations in consumer electronics and electric vehicles (EVs).

Wireless power transfer (WPT) has emerged as a promising technology for overcoming the limitations of conventional wired connections. The pioneering study by Pawade et al. [1] laid the groundwork for eliminating physical constraints, thereby enhancing system flexibility and reducing installation complexity. Complementing this approach, research by Xie et al. [2][3] has focused on the sustainability of sensor networks, proposing mechanisms that enable continuous operation through energy renewal. Other studies have explored the practical aspects of wireless charging, such as the development of compact wireless battery chargers [4] and the implementation of automated mobile charging systems [5]. Moreover, alternative methods like radio frequency energy harvesting [6] and empirical validations of wireless power experiments [7] have enriched the current knowledge base, further expanding the applicability of WPT in real-world scenarios.

Despite these advancements, several challenges persist within the domain of wireless power transmission and renewable energy systems. First, while wireless power transmission has been conceptually proven [1], the efficiency and safety of energy transfer remain critical issues. The experimental methods introduced by Kam and Tsang [7] highlight the difficulties in achieving consistent power delivery under varying environmental conditions. Additionally, sustaining long-term energy supply in sensor networks through wireless power transfer, as investigated by Xie et al. [2][3], reveals challenges related to energy loss and system stability. Further complications arise from integrating these technologies into practical applications; for instance, ensuring secure and seamless payment mechanisms in wireless charging systems requires robust identification and communication protocols, as seen in the RFID-based solutions proposed by Gupta et al. [5]. These issues collectively underscore the need for a comprehensive approach that addresses both the technological and operational challenges inherent in current systems.

The motivation behind this work is to develop a solar-powered, wireless EV charging station that overcomes the aforementioned challenges while leveraging the benefits of renewable energy and modern communication technologies. By integrating IoT connectivity and RFID payment mechanisms, the proposed system aims to offer a user-friendly and secure charging experience. The reliance on solar energy, supplemented by an auxiliary power supply when necessary, ensures operational reliability and sustainability—a critical factor in modern energy systems. This approach is inspired by the need to reduce dependency on non-renewable energy sources while simultaneously enhancing the efficiency and convenience of EV charging infrastructure.

The primary objectives of this work are as follows:

- To design and implement a solar-powered wireless EV charging station that utilizes a photovoltaic panel and a 12V battery system for energy storage.
- To integrate an Arduino-based control system that manages energy monitoring, system operation, and IoT connectivity for real-time data exchange.
- To incorporate an RFID-based payment solution that enables secure, contactless transactions, thereby streamlining the user experience.
- To ensure operational reliability by implementing an auxiliary power supply that automatically activates when solar energy is insufficient.

This paper makes the following key contributions:

- Innovative System Architecture: A comprehensive design that integrates renewable energy with wireless power transfer, IoT communication, and RFID-based secure payment, creating a robust EV charging station.

- Energy Management Strategy: An effective energy monitoring and management system that ensures continuous operation by dynamically switching between solar energy and an auxiliary power supply.
- Enhanced User Interaction: Implementation of a secure RFID payment process that provides a seamless, user-friendly experience while ensuring transaction security.
- Experimental Validation: Detailed experimental evaluation of the system components and overall performance, offering insights into practical challenges and potential areas for further improvement.

The remainder of this paper is organized as follows: Section 2: Related Work provides an in-depth review of prior research in wireless power transmission, renewable energy systems, and wireless charging technologies. Section 3: System Design and Implementation details the architectural design, hardware components, and software integration of the proposed system. Section 4: Experimental Setup and Results presents the testing methodology, performance evaluation, and discussion of experimental findings. Section 5: Discussion and Future Work outlines the implications of the results, potential improvements, and future research directions. Section 6: Conclusion summarizes the key contributions and final thoughts on the work.

Through this structured approach, the paper aims to bridge existing gaps in the literature by presenting a novel solution that combines renewable energy with advanced wireless charging and secure payment technologies

II. RELATED WORKS

The rapid advancement in wireless power transmission and renewable energy systems has spurred extensive research across various domains, as reflected in the following studies:

Pawade, Nimje, and Diwase [1] introduce an innovative approach to wireless power transmission by eliminating traditional wiring. Their work provides foundational insights into the design and challenges of transmitting power wirelessly, laying the groundwork for further exploration in this field.

Xie et al. [2] tackle the issue of energy sustainability in sensor networks through wireless power transfer, proposing a system that prolongs network lifetime by enabling energy renewal. This concept of “immortal” sensor networks underscores the potential of wireless power systems to maintain continuous operation, a principle that can be extended to other applications.

In a related study, Xie et al. [3] address the challenges of mobile stations within rechargeable sensor networks. They explore optimal traveling paths to ensure efficient energy utilization, highlighting strategies that could be adapted for mobile charging solutions and dynamic energy management.

Shilpa et al. [4] focus on designing a wireless battery charger that demonstrates both efficiency and practicality. Their compact design contributes to the body of knowledge on how to integrate wireless charging mechanisms into everyday devices, offering insights that are valuable for portable and stationary applications.

Gupta et al. [5] present an automatic wireless mobile charger that enhances convenience by incorporating automation into the charging process. Their work emphasizes the importance of seamless and user-friendly charging solutions, which is particularly relevant for the growing market of electric vehicles (EVs).

Harrist [6] investigates a wireless battery charging system that leverages radio frequency energy harvesting. This alternative approach to energy capture broadens the scope of wireless power transmission technologies, offering potential methods to harness ambient energy in various settings.

Kam and Tsang [7] contribute with an experimental method that validates the practical aspects of wireless power transfer. Their empirical findings provide crucial data that help refine power transfer techniques, ensuring that theoretical models can be effectively translated into real-world applications.

Farrok et al. [8] explore renewable energy systems by developing a new protection system for linear generators that convert oceanic wave energy into electricity. Their work addresses the reliability and safety of renewable energy conversions, which is critical for integrating such systems into larger power infrastructures.

Habib et al. [9] demonstrate the use of a PID controller in an automatic solar power-driven grass cutting machine. This study showcases the successful integration of solar energy with automated control systems, offering a model for how renewable energy can drive efficient, real-world applications.

III.PROPOSED METHOD

The proposed method leverages a hybrid energy management system that primarily uses a solar panel to charge a 12V battery, which in turn powers an Arduino-based control unit. The control system continuously monitors energy levels through an integrated voltage sensor to ensure optimal performance of the photovoltaic input. When solar energy is insufficient, the system automatically switches to an auxiliary power source to maintain uninterrupted operation. In parallel, an RFID reader is employed to authenticate user credentials, ensuring secure, contactless payment. Once a valid payment is detected, the Arduino activates a relay module that triggers a wireless transmitter, establishing a secure connection with the EV's receiver to commence the charging process. Additionally, IoT connectivity is incorporated to enable real-time monitoring, data logging, and remote management, enhancing the overall efficiency and reliability of the charging station

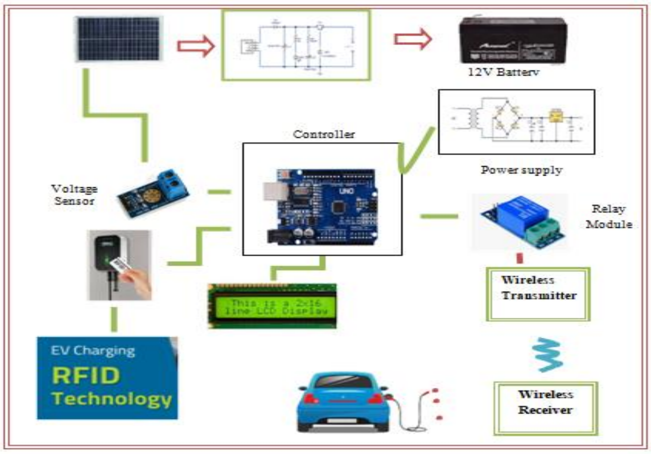

Fig. 1. Architecture of the proposed method

A. Hardware Setup

1) Photovoltaic (PV) Solar Panels

The system employs a photovoltaic (PV) solar panel as the primary energy source, responsible for harnessing solar energy and converting it into electrical power. The solar panel is selected based on its efficiency and power output to ensure sufficient energy generation for charging the EV. The output from the solar panel is regulated and stored in a 12V battery, which acts as the main energy reservoir for the charging station..

Fig. 2. Solar Panel

2) RFID Module

The RFID module is responsible for enabling secure and contactless user authentication. Each user is issued an RFID card, which, when scanned by the RFID reader, sends a unique identification code to the Arduino for verification. If the user is authorized, the system initiates the charging process. This module enhances security and ensures seamless access to the charging station.

3) 12V Battery

A 12V rechargeable battery is used to store energy collected from the solar panel. The charging circuit, consisting of a charge controller, ensures safe and efficient energy transfer from the solar panel to the battery. The charge controller prevents overcharging and deep discharging, thereby enhancing the battery's lifespan and maintaining stable voltage levels for powering the system.

4) Arduino UNO Microcontroller

The Arduino microcontroller serves as the central control unit, coordinating all system operations, including energy monitoring, authentication, and wireless power transfer. It processes data from voltage sensors, communicates with the RFID module, controls the relay module, and interfaces with the IoT platform for real-time monitoring. The Arduino is programmed to make intelligent decisions, such as switching between power sources and activating the charging process upon successful user authentication.

Fig. 3. Arduino

5) Voltage Sensors

The voltage sensor is used to monitor the output of the solar panel and battery. It provides real-time data to the Arduino, allowing the system to assess energy availability and make decisions regarding power source selection. If the battery voltage falls below a threshold, the system automatically switches to an auxiliary power source to maintain uninterrupted charging.

Fig. 4. Voltage sensor

6) Relay Module

The relay module acts as an electronic switch that controls the activation of the wireless power transmitter. When a user is authenticated via the RFID system, the Arduino triggers the relay, allowing power to flow from the transmitter to the EV's receiver. The relay ensures that charging is only initiated upon successful authentication, preventing unauthorized usage.

7) Wireless Power Transmitter and Receiver

The wireless power transfer system consists of a transmitter coil integrated into the charging station and a receiver coil located in the EV. When the relay is activated, power is transferred inductively from the transmitter to the receiver, enabling cable-free EV charging. This system eliminates the need for physical connectors, improving durability and ease of use.

8) IoT Module (Wi-Fi Connectivity)

An IoT module, typically using ESP8266 or ESP32, is incorporated into the system to enable remote monitoring and data logging. It allows users to track charging sessions, energy consumption, and payment history via a cloud-based platform. This feature enhances user experience and provides station operators with real-time insights into system performance.

9) LCD Display

An LCD display is used to provide real-time feedback to users regarding system status, authentication confirmation, charging progress, and energy availability. The display improves user interaction by offering clear and immediate information

B. Implementation

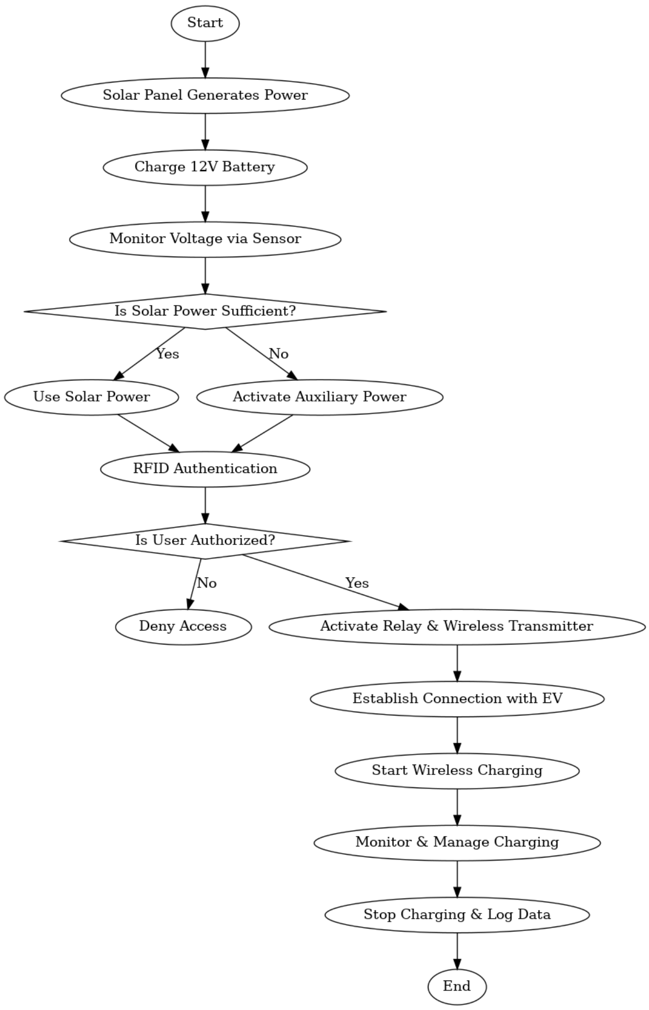

Fig. 5. Implemetnation Fow chart

IV. EXPERIMENTAL RESULTS

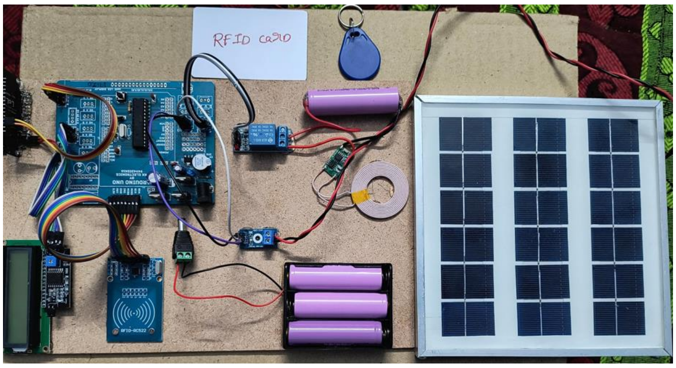

Fig. 6. Hardware Setup Model

The hardware setup model represents the complete implementation of a solar-powered, wireless EV charging station integrated with IoT and RFID-based payment solutions. The system consists of multiple components working together to enable efficient energy harvesting, secure authentication, and wireless power transmission.

1) Solar Energy Harvesting and Power Management

The system uses a solar panel as the primary energy source. The power generated is stored in a 12V battery, which ensures continuous operation. A voltage sensor monitors the energy levels and sends real-time data to the microcontroller.

Table I : Power Management

Component	Specification	Function
Solar Panel	50W, 12V	Converts sunlight into electrical energy
Battery	12V, 7Ah	Stores energy for continuous operation
Voltage Sensor	0-25V input	Monitors solar panel and battery voltage

2) Control System (Arduino-Based)

The Arduino microcontroller serves as the system's control hub, managing energy distribution, authentication, and wireless charging. It receives input from the sensors and controls various actuators based on real-time conditions..

Table II : Control System

Component	Specification	Function
Arduino Uno	ATmega328P	Controls system operations
Relay Module	5V, Single Channel	Switches power between different components
IoT Module	ESP8266 / GSM Module	Enables remote monitoring

3) RFID-Based Authentication and Payment

An RFID module enables secure, contactless user authentication. Users scan their RFID card, and the system verifies their credentials before granting access to the charging system.

Table III : Authentication and payment

Component	Specification	Function
RFID Module	MFRC522	Reads RFID cards for authentication
RFID Card	13.56 MHz	Stores user data for authentication

4) Wireless Power Transfer System

The system employs wireless power transmission to charge EVs. Upon successful authentication, the relay module triggers the wireless power transmitter, which sends power to the vehicle's wireless receiver coil.

Table IV : Wireless Power Transfer system

Component	Specification	Function
Wireless Power Transmitter	12V, 5A	Sends energy wirelessly to EV
Wireless Power Receiver	12V, 5A	Receives power and charges the EV

5) IoT-Based Monitoring and Communication

An IoT module enables remote monitoring of charging status, power usage, and transaction details. The data is displayed on a cloud-based dashboard for users and administrators.

Table V : IoT Based Monitoring

Component	Specification	Function
IoT Module	ESP8266 / GSM	Sends real-time data to cloud
LCD Display	16x2 / OLED	Displays charging status

6) Safety Mechanisms

To ensure safe and reliable operation, the system includes protection circuits and alerts for detecting overcharging, overheating, or power fluctuations.

Table VI : Safety System

Component	Specification	Function
Buzzer	5V	Provides alerts for authentication & errors
Protection Circuit	Overvoltage & Overcurrent	Prevents electrical damage

The hardware setup model (Fig. 6) successfully integrates solar energy harvesting, RFID authentication, wireless power transfer, and IoT monitoring into a smart EV charging station. This approach ensures efficient power utilization, secure user access, and real-time monitoring, making it an ideal solution for sustainable and contactless EV charging.

V. CONCLUSION AND FUTURE SCOPE

The proposed solar-powered, wireless EV charging station with IoT and RFID-based payment solutions successfully integrates renewable energy, wireless power transfer, and smart monitoring for efficient and sustainable EV charging. The system ensures uninterrupted power supply by utilizing solar energy and an auxiliary power source when needed. The RFID-based authentication mechanism enhances security by allowing only authorized users to access charging services. Real-time monitoring through IoT provides insights into energy consumption and user transactions, improving system reliability and efficiency. By eliminating physical connectors, the system reduces wear and tear, enhancing durability and ease of use. This innovative approach contributes to the advancement of smart and sustainable EV infrastructure.

VI. FUTURE SCOPE

Future developments in this system can include higher power transmission efficiency to support fast charging for a wider range of EVs. Integration with machine learning algorithms can optimize power distribution based on user demand and solar availability. Additionally, implementing blockchain-based payment systems can enhance security and transparency in transactions. Expanding IoT capabilities with mobile app integration can provide users with remote control and scheduling options. Further, incorporating bidirectional wireless power transfer can enable vehicle-to-grid (V2G) technology, allowing EVs to supply power back to the grid. These advancements will contribute to the widespread adoption of wireless EV charging as a key component of future smart cities.

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