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SMART CHARGING STATION (PCB + IoT) WITH LOAD BALANCING & PREPAID BILLING

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Abstract The rapid growth of electric and electronic devices has increased the demand for efficient, safe, and intelligent charging solutions. Conventional wired charging systems suffer from limitations such as cable degradation, energy losses, and lack of user authentication, leading to inefficient power utilization. To overcome these challenges, this paper presents the design and implementation of a Smart Wireless Charging Station integrated with RFID-based prepaid billing, load balancing, and IoT-enabled monitoring.

The proposed system utilizes an Arduino Uno as the main controller and a NodeMCU module for real-time data communication with cloud platforms. Wireless power transfer is achieved using inductive coupling between transmitter and receiver coils, enabling contactless energy transfer. An RFID module ensures secure user authentication and controlled access based on prepaid balance. Additionally, an IR sensor detects device presence to prevent idle power consumption, while a voltage sensor continuously monitors system conditions to enable efficient load balancing and protection.

The system also incorporates IoT technology to provide real-time monitoring of parameters such as voltage levels, charging duration, and user activity through platforms like ThingSpeak. Experimental results demonstrate reliable authentication, efficient wireless power transfer, effective load management, and accurate data logging.

The proposed Smart Charging Station offers enhanced safety, improved energy efficiency, and user convenience, making it a suitable solution for applications in smart cities, public charging stations, and IoT-based energy management systems.

Keywords: RFID, Arduino uno Microcontroller, LCD Display, PCB, Node MCU, Wireless charging station, power transmission coils.

I. INTRODUCTION

The rapid growth of electric and electronic devices has increased the demand for safe, efficient, and user-friendly charging solutions. Conventional wired charging systems often suffer from cable wear, power losses, and limited user authentication, leading to inefficient energy usage.

To address these limitations, smart charging stations integrated with wireless power transfer and Internet of Things (IoT) technologies are gaining significant attention. This project presents the design and implementation of a Smart Wireless Charging Station that combines RFID-based user authentication, real-time voltage monitoring, and IoT-enabled data logging.

The system allows only authorized users with sufficient credit to access charging services, ensuring controlled and fair energy distribution. Wireless power transfer enhances safety and convenience by eliminating physical connectors, while sensors prevent idle or unauthorized charging.

II. LITERATURE SURVEY

The development of smart charging systems has gained significant attention due to the increasing demand for efficient energy management, especially in the fields of electric vehicles and portable electronic devices. Several researchers have contributed to wireless power transfer, RFID-based authentication, and IoT-enabled monitoring systems.

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2.1 Wireless Power Transfer Systems

Wireless power transfer (WPT) technology has been extensively studied as an alternative to conventional wired charging systems. Zhen Bi et al. (2016) presented a comprehensive review of WPT technologies for electric vehicles. Their study highlighted inductive coupling and magnetic resonance as the most widely used methods for efficient energy transfer. The research also discussed challenges such as energy loss, coil misalignment, and electromagnetic interference.

Similarly, Andre Kurs et al. demonstrated resonant inductive coupling for mid-range wireless energy transfer, achieving improved efficiency compared to traditional methods. However, the system required precise alignment and complex design considerations.

These studies confirm that while WPT provides convenience and safety, efficiency optimization remains a key challenge.

2.2 RFID-Based Authentication Systems

Radio Frequency Identification (RFID) technology has been widely used for secure access control and prepaid billing systems. Klaus Finkenzeller discussed the fundamentals of RFID systems, including tags, readers, and communication protocols.

In addition, Jong-Hoon Lee et al. developed RFID-based smart energy systems that allow user authentication and controlled energy usage. Their system improved security but lacked real-time monitoring and remote access features.

RFID-based systems are reliable for authentication; however, their integration with modern IoT platforms is necessary for enhanced functionality.

2.3 IoT-Based Monitoring Systems

The integration of IoT in energy systems has revolutionized real-time monitoring and control. Al-Fuqaha Ala et al. presented an overview of IoT architecture, highlighting its role in data communication, cloud storage, and remote monitoring.

IoT-based smart energy systems enable users to monitor parameters such as voltage, current, and power consumption in real time. Platforms like ThingSpeak allow data visualization and analysis.

However, many IoT-based systems focus only on monitoring and lack integration with control and billing mechanisms.

2.4 Smart Charging and Energy Management Systems

Recent research focuses on combining multiple technologies to develop intelligent charging systems. Shyam Sundar et al. proposed a smart charging system with load management features. The system improved energy efficiency but did not include wireless charging.

Other studies have explored prepaid energy meters integrated with IoT for remote billing and monitoring. These systems provide better control over energy consumption but lack user-friendly wireless charging capabilities.

2.5 Research Gap

From the above literature, the following gaps are identified:

- Lack of integration between **wireless charging and RFID billing**
- Limited implementation of **IoT-based real-time monitoring with control**
- Absence of **load balancing mechanisms** in many systems
- Need for a **compact, PCB-based smart charging solution**

III. PROPOSED SYSTEM METHODOLOGY AND DISCUSSION

3.1 System Design Overview

The proposed Smart Charging Station is designed as an integrated system that combines wireless power transfer, RFID-based prepaid billing, load balancing, and IoT-enabled monitoring. The architecture consists of both hardware and software modules working in coordination to ensure efficient, secure, and intelligent charging.

The hardware components include an Arduino Uno microcontroller for system control, a NodeMCU module for IoT communication, an RFID reader for user authentication, inductive coils for wireless power transfer, and sensors for realtime monitoring of system parameters. The software layer manages authentication, billing, data acquisition, and cloud communication.

A modular design approach is adopted, where each subsystem performs a dedicated function. This enhances system flexibility, simplifies troubleshooting, and allows future scalability.

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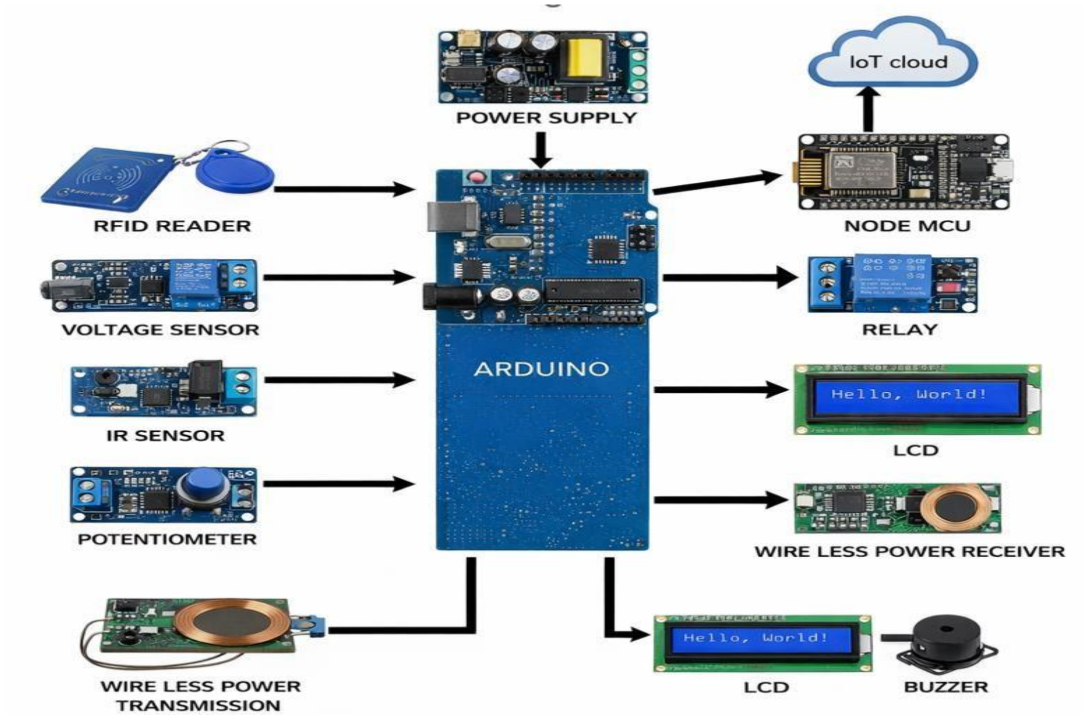

Fig3.1a BLOCK DIAGRAM

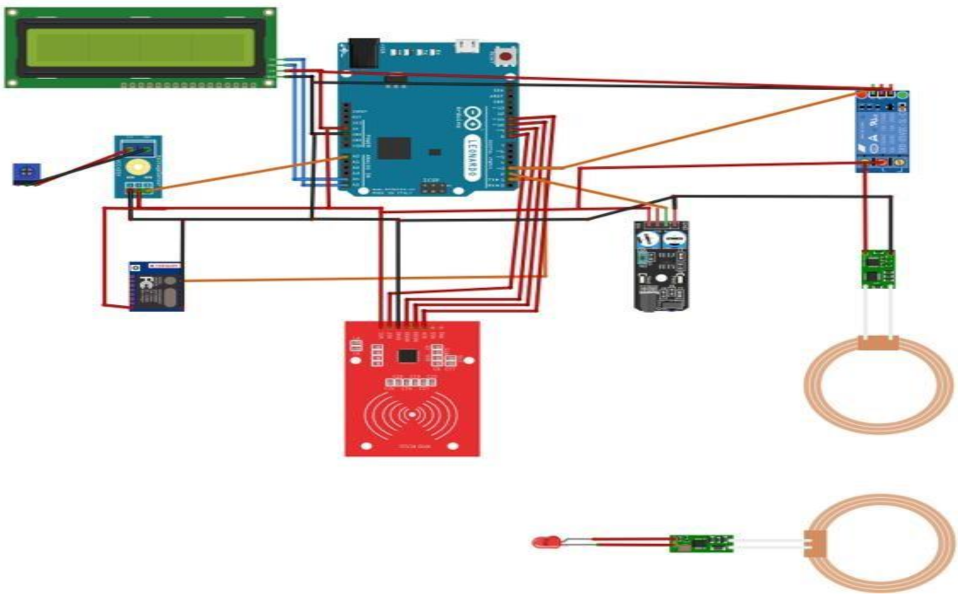

Fig 3.1b CIRCUIT DIAGRAM

3.2 Working Methodology

The operation of the system follows a sequential and automated process:

- **Step 1: User Authentication**

The process begins when a user scans an RFID card on the reader. Each card contains a unique identification number associated with a prepaid account.

- **Step 2: Verification and Authorization**

The Arduino Uno verifies the RFID credentials against the stored database. If sufficient balance is available, access is granted; otherwise, the system denies operation.

- **Step 3: Charging System Activation**

Upon successful authentication, a relay module is triggered to initiate the charging process. The relay provides electrical isolation and ensures safe switching.

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- **Step 4: Wireless Power Transfer**

Wireless energy transfer is achieved using inductive coupling. The transmitter coil generates an alternating magnetic field, which induces current in the receiver coil. The received AC signal is then rectified and regulated into DC for charging.

- **Step 5: Device Detection**

An infrared (IR) sensor detects the presence of a device on the charging pad. If no device is detected, the system automatically disables charging to minimize energy loss.

- **Step 6: Voltage Monitoring and Load Balancing**

A voltage sensor continuously monitors output conditions. In the event of abnormal parameters such as voltage fluctuations or overload, the system dynamically adjusts or terminates charging to maintain safety and efficiency.

- **Step 7: IoT Data Transmission**

The NodeMCU module transmits real-time operational data, including voltage levels, charging duration, and usage statistics, to a cloud platform such as ThingSpeak for remote monitoring.

- **Step 8: Billing Mechanism**

The system deducts the charging cost from the user's prepaid balance based on usage time or energy consumption, ensuring an automated billing process.

3.3 Flowchart Description

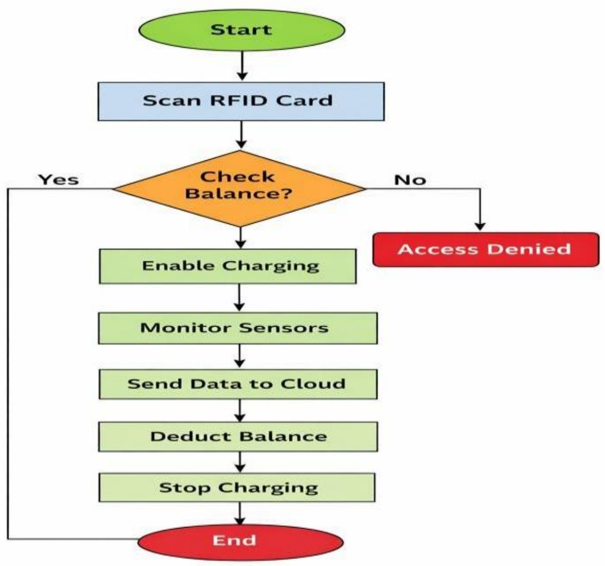

FIG. 3.3 FLOW CHART DIAGRAM

3.4 Key Features of the Proposed System

- Contactless wireless charging mechanism
- Secure RFID-based prepaid authentication
- Automatic load balancing and protection
- Real-time IoT-based monitoring
- Energy-efficient and user-friendly operation

3.5 System Performance Evaluation

The developed prototype was experimentally tested under various operating conditions to evaluate its functionality and reliability.

- **RFID Authentication Performance**

The RFID module demonstrated high accuracy in identifying authorized users. Unauthorized access attempts were successfully blocked, ensuring secure system operation.

- **Wireless Charging Efficiency**

The wireless power transfer mechanism operated effectively over short distances. Proper alignment between transmitter and receiver coils significantly improved efficiency and ensured stable energy transfer with minimal losses.

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3.6 Sensor-Based Monitoring

- **IR Sensor Performance**

The IR sensor accurately detected the presence or absence of a device on the charging platform. Automatic shutdown in the absence of a load helped reduce unnecessary power consumption.

- **Voltage Monitoring**

The voltage sensor provided continuous feedback on system conditions. It played a critical role in:

- Preventing overload conditions
- Maintaining stable output voltage
- Supporting dynamic load balancing

3.7 IoT Monitoring and Data Logging

The NodeMCU module successfully enabled real-time data transmission to the cloud platform. The monitored parameters included:

- Charging duration
- Voltage levels
- User activity

This capability enhances system transparency and enables remote supervision and analysis.

3.8 Load Balancing Analysis

The implemented load balancing mechanism ensured efficient power distribution across the system. It effectively prevented overloading and maintained safe operating limits, thereby improving system reliability and extending component lifespan.

3.9 Comparative Analysis

Feature	Conventional System	Proposed System
Charging Method	Wired	Wireless
Authentication	Not Available	RFID-based
Monitoring	Manual	IoT-based
Energy Efficiency	Low	High
Safety	Moderate	High

TABLE FOR COMPARITIVE ANALYSIS

3.10 Discussion Summary

The proposed Smart Charging Station demonstrates an effective integration of wireless power transfer, RFID authentication, and IoT monitoring into a unified system. Compared to conventional charging methods, it provides improved efficiency, enhanced safety, and better user control. The inclusion of prepaid billing and real-time monitoring makes it a promising solution for future smart energy management systems.

IV. EXPERIMENTAL RESULTS

4.1 Project view

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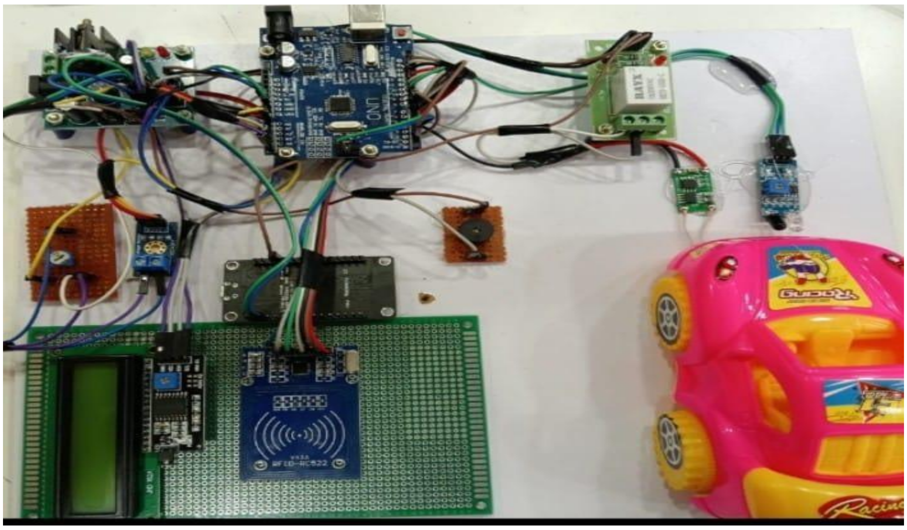

fig.4.1 project view

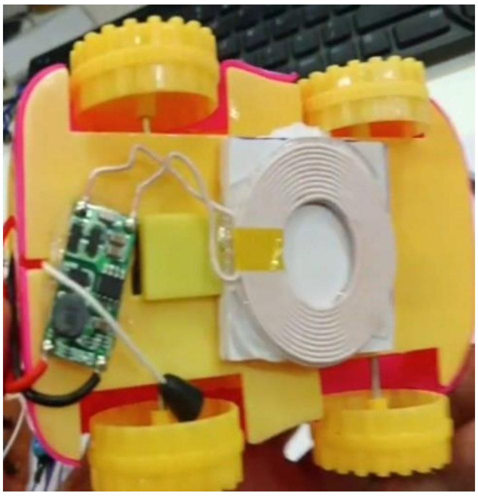

fig :4.1a receiver coil image

4.2 Results of display

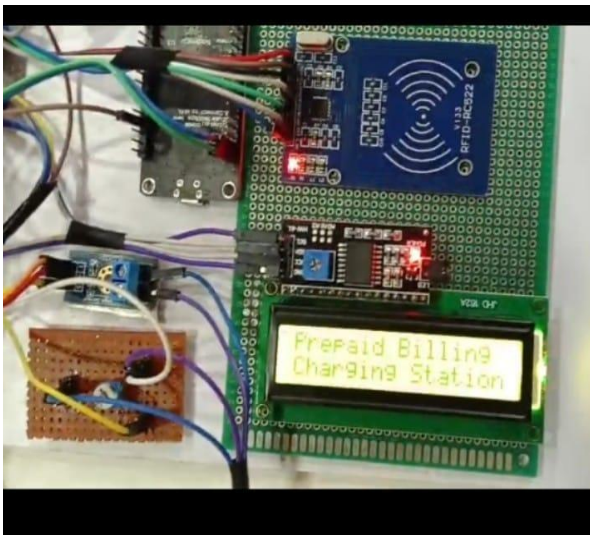

Fig4.2a

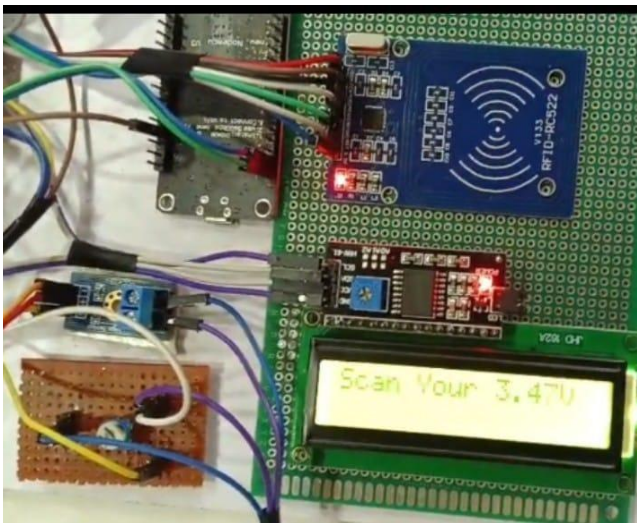

fig.4.2b

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The above and the below display images shows the results of the display. on the display we are getting the messages like prepaid billing charging station, scan your card, payment done,balance and also the place device, low voltage.

Theses all messages are displayed by the instruction given by the Arduino uno based the information from the RFID card ,relay, ir sensor.

The low voltage is shown when the voltage was dropped manually by the potentiometer

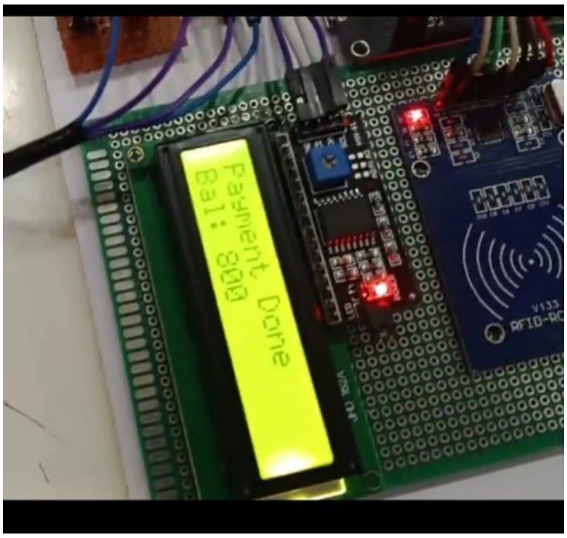

Fig 4.2c

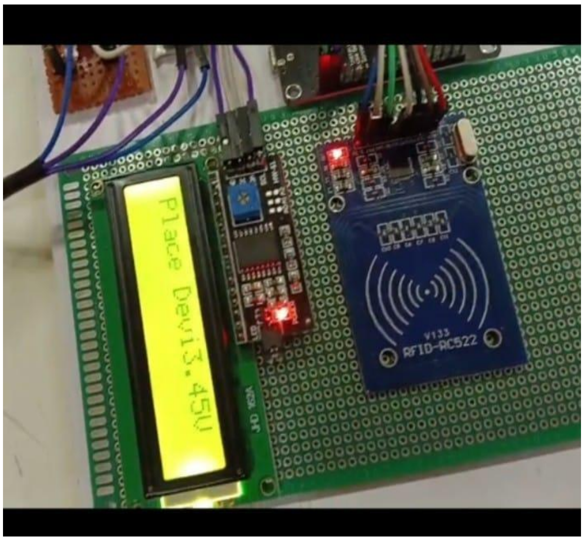

Fig 4.2d

Fig.4.2.e

Wire less charging was showed by the help of toy car as shown in the above and the toy car has the receiver coil inside it and led is placed on the above the toy car which is turn on when the payment is done.

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4.3 Things Speak Results

FIG.4.3 ThingsSpeak results

4.4 csv file of Prepaid billing

created_at	entry_id	field1	field2
2026-02-05	52	4.86	1
2026-02-05	53	4.84	0
2026-02-05	54	4.86	1
2026-02-05	55	4.86	0
2026-02-05	56	4.84	0
2026-02-05	57	4.86	1
2026-02-05	58	4.89	1
2026-02-05	59	4.86	1
2026-02-05	60	4.86	1
2026-02-05	61	4.86	1
2026-02-05	62	4.89	1
2026-02-05	63	4.89	1
2026-02-13	76	3.59	0
2026-02-13	77	3.59	0
2026-02-13	78	3.62	0
2026-02-13	79	3.59	0
2026-02-13	80	3.59	0
2026-02-13	81	3.59	1
2026-02-13	82	3.62	1
2026-02-13	83	3.59	0
2026-02-13	84	3.59	1

Table4.4 csv file of prepaid billing

4.5 Advantages:

- Wireless and cable-free charging improves safety
- RFID authentication prevents unauthorized usage
- Credit-based charging enables fair energy distribution
- IoT monitoring allows remote supervision
- Voltage sensing protects the circuit from overload
- Compact and portable prototype design
- Low maintenance due to fewer physical connectors
- Scalable for multiple users and devices

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4.6 APPLICATIONS:

- Electric vehicle charging stations
- Public charging kiosks
- Smart parking areas
- Educational laboratories
- Shopping malls
- Offices and campuses
- Smart cities
- Industrial charging zones

V. CONCLUSION

The Smart Wireless Charging Station presented in this project demonstrates an intelligent and secure approach to modern charging systems by integrating wireless power transfer, RFID-based user authentication, real-time voltage monitoring, and IoT connectivity. The prototype ensures authorized access, efficient power management, and continuous monitoring through cloud platforms. By eliminating physical connectors and incorporating smart control features, the system enhances safety, convenience, and energy efficiency. The proposed design is cost-effective, portable, and scalable, making it suitable for future public charging infrastructures and smart city applications.

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