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Integrating Renewable Energy with Wireless EV Charging for Green Mobility

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***Abstract*—The growing demand for electric vehicles (ev's) has increased the need for efficient, sustainable, and accessible charging infrastructure. This project processes an integrated EV charging technology with solar energy to power ev's, especially in remote locations. The System utilizes solar panels to generate electricity, which is stored in battery banks and used to power wireless inductive charging pads embedded in charging stations. This solution eliminates the need for physical charging cables, making the process more convenient and user-friendly useful while also reducing wear and tear on charging equipment. The system is particularly useful for offer grid locations wear conventional power infrastructure is unavailable. By leveraging renewable solar energy, this project aims to reduce dependence on fossil fuels, lower operational costs, and contribute to a greener, more sustainable transportation eco system. The implementation involves designing an efficient solar power management system, optimizing wireless power transfer efficiency, and ensuring safe and reliable charging for different types of evs. The proposed system can be deployed along highways, in rural areas, and in urban parking lots, providing an eco-friendly and futuristic approach to EV charging**

I. Introduction

T As electric vehicles (evs) become increasingly central to sustainable transportation, the demand for more efficient, user-friendly, and environmentally conscious charging solutions grows in parallel. Traditional plug-in charging systems, while effective, pose several challenges including physical cable wear, manual effort, and a heavy reliance on the power grid—most of which still draws energy from non-renewable sources. These limitations call for innovative alternatives that can meet the growing EV infrastructure demands with greater efficiency and sustainability.

Wireless electric vehicle charging systems, particularly those powered by renewable sources like solar energy, represent a forward-thinking solution to these challenges. By integrating wireless inductive power transfer (IPT) with solar-powered energy storage, this project eliminates the need for manual cable connections, enhances safety and convenience, and significantly reduces dependence on grid electricity. The use of RFID-based authentication further ensures secure access to charging, while an automated charging process minimizes human intervention.

Inspired by concepts presented in the IEEE paper "Single Inductor Multi-Port Power Converter for Electric Vehicle Applications," this project implements wireless power transfer using L298 coils, solar energy harvesting, and intelligent control mechanisms to optimize efficiency. The fusion of solar technology and wireless charging in this prototype demonstrates a promising approach to green mobility, particularly for deployment in urban centers, highways, and remote locations lacking grid connectivity.

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Recent advancements in wireless power transfer (WPT) systems have focused on optimizing efficiency and safety, especially for applications in electric vehicle (EV) charging. One critical aspect in WPT design is the choice of compensation topology, which directly impacts system performance and transfer characteristics. Among various options, the Series-Series (SS) compensation topology has been widely adopted due to its superior performance in EV charging environments.

The SS configuration offers several advantages: it minimizes eddy current losses in the vehicle's metallic frame, reduces electric stress on semiconductor components, and operates at a lower frequency—typically around 10 khz—which helps prevent electromagnetic interference with onboard vehicle electronics. These characteristics make it particularly suitable for automotive applications where safety, efficiency, and component longevity are crucial.

Studies have shown that the efficiency of WPT systems is closely linked to coil parameters such as air gap distance and magnetic coupling. Research highlights efficiency rates as high as 96% when these parameters are optimized. Such findings emphasize the importance of careful system design, especially when integrating wireless charging solutions into real-world electric vehicle infrastructures. Additionally, the impact of different charging topologies on the broader electrical grid is a key consideration, guiding the development of sustainable and grid-friendly EV charging networks.

This project aligns with these principles by implementing a wireless EV charging system that uses efficient coil configurations and renewable solar energy. The goal is to reduce grid dependency while ensuring safe, secure, and user-friendly charging in both urban and remote environments.

PHOTOVOLTAICS: SYSTEM DESIGN AND MODELING

Photovoltaic (PV) systems play a crucial role in enabling clean energy generation, particularly for off-grid or hybrid EV charging infrastructures. A well-designed PV system maximizes energy harvest while ensuring cost-effectiveness and operational reliability.

1. **PV System Components:** A standard PV system consists of solar panels, a charge controller, battery storage (if off-grid or hybrid), and an inverter (for AC loads). In this project, the solar panels supply power to charge batteries, which in turn energize the wireless EV charging module.

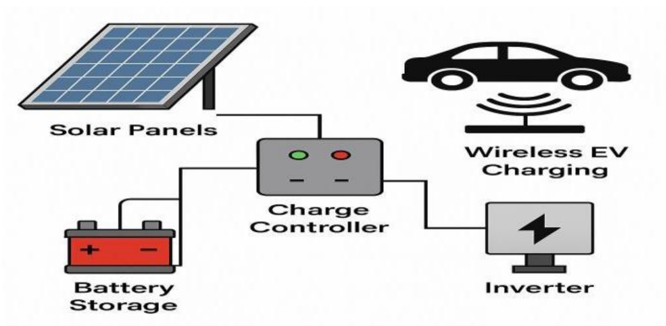

Fig1 shows: PV system components

A. MODELING OF PHOTOVOLTAIC PANELS

Location and Solar Irradiance: Site-specific factors like average sun hours and shading impact energy generation However, to accurately simulate the real-life performance of PV arrays, which comprise multiple interconnected cells, additional parameters need to be considered Owing to its accuracy and simplicity, this practical model is extensively utilized. Accordingly, the model presented by

The parameters of the PV panel, according to the equivalent circuit shown in and the models given by and are listed in Table

Symbol	Value	Symbol	Value
G_n^*	1000 W/m^2	V_{oc}	31.4 V
q	1.602 e-19 C	k_{sc}	1.7e-3
a	1.3	T_n	25°C
k	1.38e-23	W_{kg}	16
r_{pv}^{se}	0.22 Ω	P_{max}	230 W
r_{pv}^{p}	415.4 Ω	V_{MPP}	29.7 V
I_{sc}^{n}	9.76 A	I_{MPP}	9.18 A

PRINCIPLE OF THE MPPT-BASED TECHNIQUE

To increase the efficiency of PV systems, it is typically necessary to monitor and adjust the MP of a PV array. The MPPT enables harvesting of the maximum output power P_{max} under specific temperature and irradiance conditions to determine the optimal voltage V_m and current I_m at which the PV system operates most efficiently. Focusing on

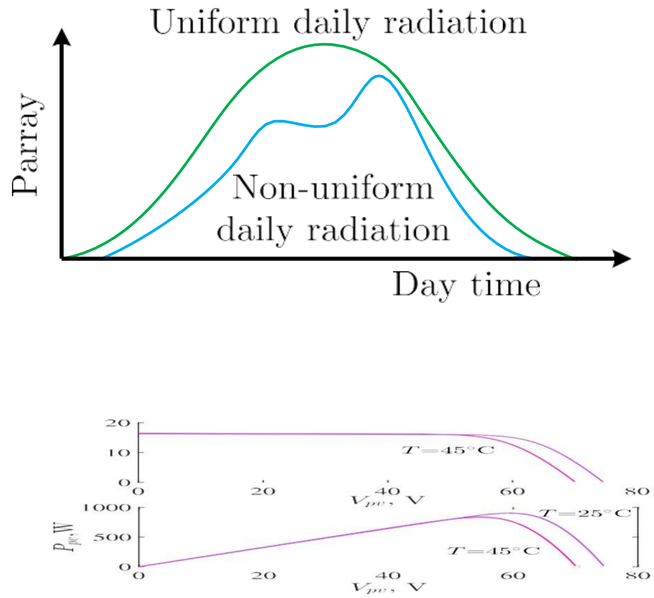

FIGURE 2. (a) PV output power under daily solar irradiance: uniform and nonuniform, (b) PV output current and power versus PV voltage under different temperatures.

PV power maximization, a cross-correlation (CC) algorithm is implemented to obtain the MP from the PV arrays as introduced in . The CC plays a crucial role in signal processing to gauge the likeness between two signals or the degree of self-resemblance when one signal is shifted in relation to another

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2. Design Considerations:

- **Panel Orientation and Tilt:** Optimal tilt angle (based on latitude) ensures maximum solar exposure.
- **System Size:** Panel wattage and quantity are selected based on EV energy demand, daily usage, and autonomy days.
- **Battery Sizing:** Must match solar input and output load demands to avoid overcharging or deep discharge.

3. Modeling and Simulation: Mathematical modeling of a PV system helps in understanding performance under varying environmental conditions. Tools like MATLAB/Simulink or PV*SOL can simulate real-world operation, allowing:

- Estimation of energy output under irradiance and temperature variation
- Sizing validation for batteries and panels
- Analysis of power losses across system components

4. Integration with EV Charging:

The PV array charges a battery bank via a charge controller. When an EV is parked and authenticated, energy flows from the battery through the wireless power transfer (WPT) system. The system uses MPPT (Maximum Power Point Tracking) algorithms to optimize solar output and ensure stable voltage for charging.

This integration supports a green mobility ecosystem by reducing fossil fuel reliance and enabling sustainable, decentralized energy systems. Through intelligent system design and accurate modeling, photovoltaic technology significantly enhances the effectiveness and reliability of wireless EV charging infrastructures.

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Wireless Charging

The rapid growth of electric vehicles (evs) has highlighted the limitations of conventional plug-in charging methods, especially in terms of convenience, safety, and infrastructure scalability. Wireless charging, also known as inductive charging, offers a transformative approach that addresses several key challenges in current EV charging systems.

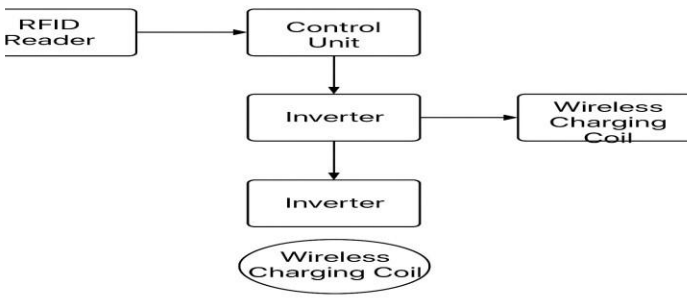

Fig3 shows: wireless charging mode

1. Convenience and Automation:

Wireless charging eliminates the need for physical connectors, allowing evs to charge automatically when parked over a charging pad. This hands-free process is particularly beneficial in public and commercial settings, reducing user effort and improving accessibility for individuals with mobility limitations.

2. Safety Enhancements:

Plug-in connectors are exposed to wear and environmental factors such as moisture and dust, which can lead to mechanical failure or electrical hazards. Wireless charging systems are sealed and operate without exposed contacts, reducing the risk of electric shock, fire, or short circuits.

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Wireless EV charging systems are inherently safer than traditional plug-in alternatives due to their contactless design. Here are the key safety advantages:

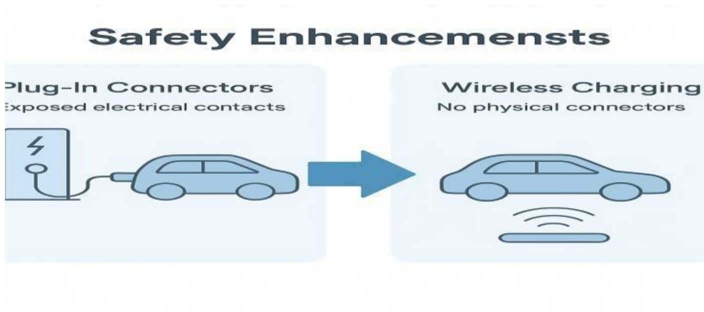

Fig4 shows : safety enhancements

- **No Exposed Electrical Contacts:** Since wireless systems transfer power inductively through air gaps, there are no physical connectors that can be damaged, corroded, or tampered with. This makes the system safe in all weather conditions—rain, snow, dust, or extreme heat.
- **Reduced Risk of Electrical Hazards:** In plug-in systems, damaged cables and connectors can result in arcing, short circuits, or electric shocks. Wireless systems prevent such risks by enclosing the transmitter and receiver coils in protective housings.
- **Automatic Shutoff and Misalignment Detection:** Many wireless charging systems incorporate safety protocols such as automatic shutoff when an object or obstruction (e.g., a metallic object or an animal) is detected between coils. Misalignment or overheating triggers system alerts or halts the charging process, further enhancing safety.
- **Electromagnetic Field (EMF) Shielding:** Properly designed systems use shielding and frequency control to ensure EMF exposure remains well within international safety standards, protecting both humans and animals in the vicinity.

3. Reduction in Mechanical Wear:

Frequent plugging and unplugging can degrade connectors over time. Wireless systems significantly extend the lifespan of charging equipment by eliminating physical contact, making them ideal for high-use environments like fleets, public transit, or autonomous vehicles.

4. Seamless Integration with Renewable Energy:

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Wireless charging is well-suited for integration with solar and other renewable sources, enabling fully off-grid or hybrid EV charging solutions. This supports sustainable transportation goals and reduces reliance on fossil-fuel-based grid power.

5. Enhanced Urban and Highway Infrastructure:

In cities, wireless pads embedded in parking lots or roadside stations can support large-scale EV adoption. On highways, dynamic wireless charging (where vehicles charge while moving) holds future potential to extend driving range and reduce battery size requirements.

6. Future-Readiness for Autonomous Vehicles:

As autonomous vehicles become more prevalent, the ability to charge without human intervention becomes critical. Wireless charging offers a viable solution for continuous operation without manual input.

Wireless Power Transfer (WPT) using L298 Coil

Wireless Power Transfer (WPT) is a method of transmitting electrical energy without physical connections, typically using magnetic resonance or inductive coupling. In this project, the L298 coil is used as a key component to achieve inductive coupling between the transmitter and receiver coils for wireless EV charging.

System Overview:

The WPT system consists of a transmitter side that is powered by a solar-charged battery and a receiver side embedded within the electric vehicle. The L298 driver module is used to switch current through the transmitter coil, generating a time-varying magnetic field. This magnetic field induces a voltage in the receiver coil, which is then rectified and regulated to charge the EV battery.

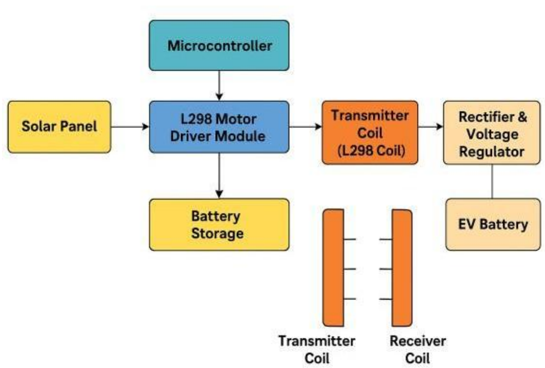

Fig 5 RFID-based Secure Authentication System

ensures reliable, fast, and secure access control for sensitive areas such as offices, homes, and laboratories.

To design an RFID-based authentication system.

To implement real-time access control based on RFID tags.

To store and verify unique ids of users.

To enhance security in restricted areas.

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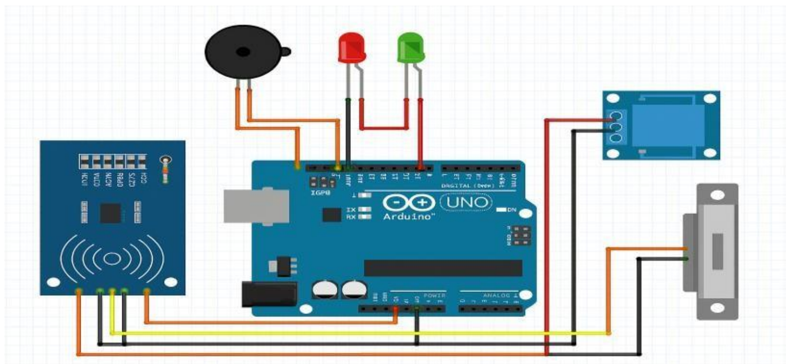

FIG 6 SHOWS: RFID-based Secure Authentication System

Working Principle of RFID System:

1. RFID Tag Transmission:
   - Each RFID card/tag contains a unique identification number (UID).
   - When the tag is brought near the RFID reader (typically within 2–5 cm), it emits a radio signal with the UID using electromagnetic waves.
2. RFID Reader Reception:
   - The RFID reader generates an electromagnetic field using its antenna.
   - The reader detects the signal from the tag and captures the UID sent by it.
3. Data Transfer to Controller:
   - The RFID reader sends the captured UID to a microcontroller (e.g., Arduino) using communication protocols like SPI, UART, or I2C.
4. Authentication Process:
   - The microcontroller compares the received UID with a predefined list of authorized uids

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stored in memory (EEPROM, database, or code).

- If the UID is matched, the system grants access by:
  - Activating a relay to open a lock.
  - Turning on a green LED.
  - Sounding a short buzzer beep.
- If the UID is not matched, the system:
  - Turns on a red LED.
  - Sounds a warning beep (long or double).
  - Displays "Access Denied" if an LCD is used.

5. Optional Logging:
   - The system can log entry attempts with date/time using an RTC (Real-Time Clock) module or transmit data to a PC via serial/USB.

📚 Summary:

The RFID system works on wireless identification through radio waves. When a tag is presented near a reader, the system reads its unique ID and decides whether to grant or deny access based on stored credentials.

Solar-Powered RFID-Based Secure Authentication System

This project presents an enhanced RFID-based secure authentication system integrated with solar power. The use of solar energy ensures continuous operation even in remote or power-scarce areas, promoting sustainable and eco-friendly security solutions. The system authenticates users via RFID cards and grants access if the credentials match the stored data. Powering the system with a solar panel and battery backup ensures uninterrupted security operations.

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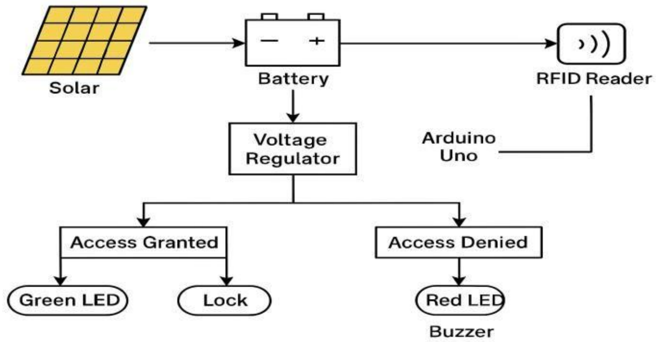

FIG7 SHOWS: Solar-Powered RFID-Based Secure Authentication System

The Solar-Powered RFID-Based Secure Authentication System is an eco-friendly security solution that combines renewable energy with modern access control technology. It operates by using RFID (Radio Frequency Identification) to authenticate individuals through unique RFID tags or cards. When a user presents their RFID tag to the reader, the system verifies the tag's unique ID against a list of authorized ids stored in the microcontroller. If the tag is recognized, access is granted by activating a door lock mechanism, and a green LED or buzzer indicates successful authentication. If unauthorized, access is denied with a warning alert.

What sets this system apart is its integration with solar power, which allows it to function independently of the traditional electrical grid. A solar panel charges a battery during the day, and this battery powers the entire system through a voltage regulator that provides a stable 5V supply. This makes the system ideal for remote or off-grid locations, such as agricultural fields, military zones, or rural buildings where consistent power supply is a challenge. By combining sustainability with security, this system ensures reliable, 24/7 access control while reducing dependency on conventional energy sources.

The Automated Charging Process

The Automated Charging Process is a smart and efficient system designed to manage the charging of batteries or electronic devices without the need for manual intervention. This system uses sensors and microcontrollers to monitor the battery voltage and automatically control the charging cycle. When the battery voltage drops below a predefined threshold, the system activates the charger, allowing current to flow into the battery. Once the battery reaches full charge, the system automatically disconnects the power supply to prevent overcharging, which helps in extending battery life and enhancing safety.

This process is widely used in solar power systems, electric vehicles, and portable electronic devices where reliable and safe battery management is critical. In solar applications, for example, the automated charging circuit includes components like a solar panel, charge controller, voltage regulator, and battery, all working together to ensure efficient energy storage from sunlight. By automating the charging and discharging cycles, the system not only improves energy efficiency but also reduces the risk of damage due to human error, making it ideal for both residential and industrial

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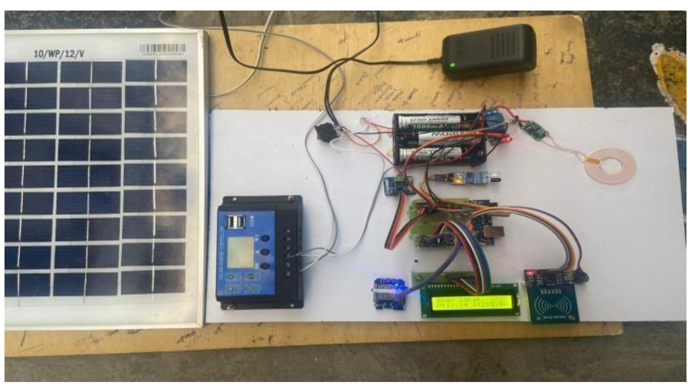
applications.

Working Solar-Powered RFID-Based Secure Authentication System:

The working principle of the smart EV wireless charging system is clearly illustrated through a step-by-step process. The operation begins when the user taps an RFID card, which is verified by the system for authentication. Once the RFID credentials are validated, the IR sensor checks if the electric vehicle (EV) is properly parked in the charging zone. This is a critical step to ensure correct alignment for effective wireless power transfer.

After successful validation and vehicle detection, the solar panel takes over to power the entire system, including charging the onboard battery and energizing the wireless charging coil. Once the system is sufficiently powered, the wireless charging coil activates, and energy is transmitted wirelessly from the transmitter coil to the receiver coil embedded in the EV.

During the charging process, an LCD screen displays real-time updates, such as voltage levels and charging status, allowing users to monitor the progress. Additionally, an LED indicator blinks as a visual cue, providing a charging status notification. Finally, when the EV's battery reaches full capacity, the system is designed to automatically stop charging, ensuring energy efficiency and battery protection. This automated, user-friendly approach highlights the integration of renewable energy, secure access, and wireless technology in modern EV charging solutions.



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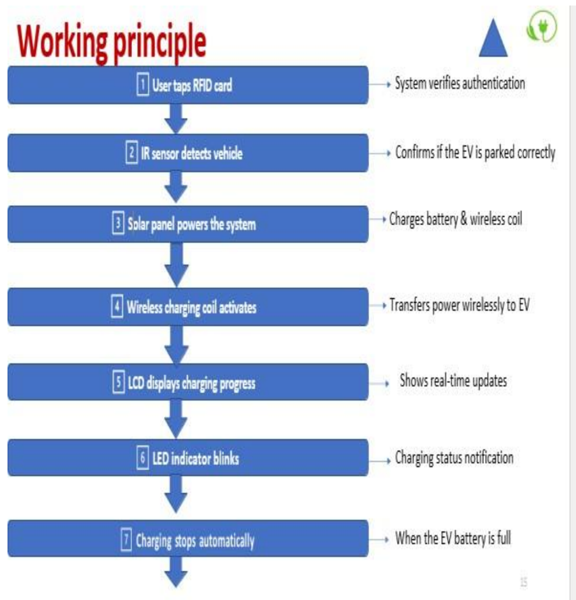

FIG 8 SHOWS WORKING PRINCIPLE Working Solar-Powered RFID-Based Secure Authentication System

SIMULATION & PROTOTYPE RESULTS :

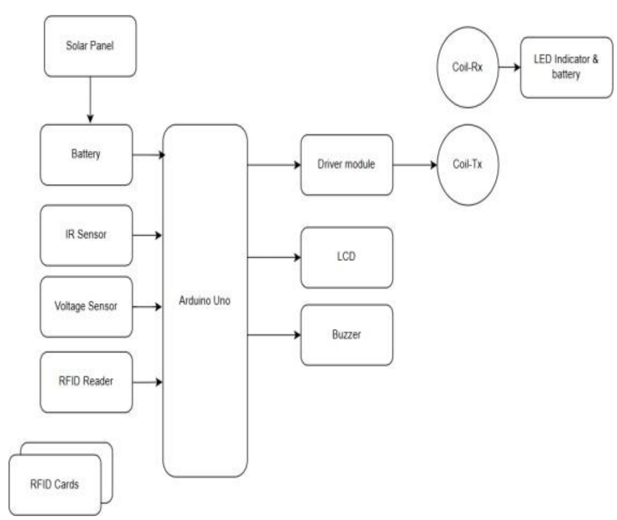

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Fig 9shows: block diagram of Integrating Renewable Energy with Wireless EV Charging Systems

The given block diagram illustrates a smart charging system powered by renewable energy and controlled by an Arduino Uno. At the heart of the system lies the Arduino Uno, which coordinates inputs from various sensors and modules. A solar panel is used to charge a battery, which in turn powers the Arduino and the entire circuit. The system utilizes an IR sensor for proximity detection and a voltage sensor to monitor the battery voltage. An RFID reader is used to identify users through RFID cards, enabling access control and secure charging. Once a valid RFID card is detected, the Arduino processes the input and activates the driver module, which powers a Coil-Tx (transmitter coil). This coil wirelessly transfers energy to a Coil-Rx (receiver coil), which is connected to an LED indicator and a secondary battery for charging. Meanwhile, an LCD displays relevant information, such as charging status or user identification, and a buzzer provides auditory feedback for events like successful authentication or errors. Overall, this system represents an integration of solar energy, wireless power transmission, and RFID-based access control for a smart and sustainable charging solution.

bottom of each column. Large figures and tables may span both columns. Place figure captions below the figures; place table titles above the tables. If your figure has two parts, include the labels “(a)” and “(b)” as part of the artwork. Please verify that the figures and tables you mention in the text actually exist.

Fig 10shows: prototype model hardware kit

The image depicts a practical implementation of the smart charging system previously discussed in the block diagram. On the left, we can clearly see a solar panel rated at 10W/12V, which serves as the primary power source. This solar panel is connected to a solar charge controller, which regulates the charging process and protects the rechargeable lithium-ion batteries (18650 cells) mounted on the board. These batteries supply power to the rest of the circuit, ensuring a consistent power flow even in the absence of sunlight.

In the center of the setup, various modules and sensors are interconnected, with an Arduino Uno acting as the main controller. The image shows an IR sensor, voltage sensor, RFID reader (RC522), and a 16x2 LCD display, all wired to the Arduino. The LCD is currently active, displaying the prompt "Scan Card" along with voltage and time data, indicating that the system is ready for RFID-based authentication.

On the right side, a wireless power transmission coil (Coil-Tx) is visible, connected through a driver module. This coil will wirelessly transfer energy to a receiving coil (Coil-Rx), typically placed in a compatible charging device. The setup also includes a buzzer and an ESP8266 wifi module, suggesting the potential for iot integration, such as remote monitoring or logging of charging sessions.

Overall, this real-world prototype effectively translates the conceptual block diagram into a functioning model. It demonstrates the integration of renewable energy, wireless charging, and secure user access through RFID—all controlled and monitored by a microcontroller platform.

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Fig 11 solar powered ev

The voltage graph presented shows the performance of the solar-powered EV wireless charging system over a 24-hour period. According to the chart, the voltage began at a minimum value of 4.28V on 01 March at 16:12, which indicates either the battery was nearly depleted or minimal sunlight was available for charging at that time. As the day progressed, the voltage quickly rose, reaching its maximum value of 11.33V by 18:41 on the same day, suggesting effective solar charging and energy accumulation.

Following the peak, the voltage remained consistently stable around 11.17V throughout the night and into the next day, demonstrating the system's ability to maintain and regulate stored energy over extended periods without significant losses. This plateau also reflects a healthy battery capacity and efficient energy management by the Arduino-controlled system.

The current (CUR) graph provides insights into the operational behavior of the solar-powered wireless EV charging system over a specified period. At the start, the current was 0.0 on 01 March at 16:12, which is

Fig11 shows output graph of voltage

expected as the system was likely idle or just initializing. Shortly thereafter, there's a sharp rise to around 217 m a, with some noticeable fluctuations, indicating the system began drawing current, likely for initial charging or system activation. By 18:43 on 01 March, the system reached its maximum current draw of 302.8 ma, which suggests the peak operational point—potentially when the EV was wirelessly charging at its highest demand. These fluctuations in current early in the timeline can also be associated with dynamic environmental conditions such as varying solar irradiance or load switching behavior during charging. Following the peak, the current stabilized around 217.3 ma, maintaining this level through the night and into the following day. This steady current implies efficient energy regulation and a sustained charging or idle maintenance mode by the system. A slight drop is seen again at 14:25 on 02 March, which could either represent the end of a charging session or a dip in solar input . Overall, the graph reflects a responsive and adaptive charging system that reacts effectively to energy demands while maintaining steady operation during extended use, highlighting its reliability and sustainability in real-world conditions

Fig 12,output waveforms

CONCLUSION:

The project demonstrates a smart and sustainable solution for wireless electric vehicle (EV) charging using solar energy. The system effectively integrates RFID-based user authentication, IR-based vehicle detection, and solar-powered wireless charging with real-time feedback through LCD displays and LED indicators. The automated process, from initiating charging to safely terminating it when the battery is full, ensures a user-friendly and efficient experience.

The voltage and current analysis further validate the system's functionality. The voltage graph shows a steady increase and stabilization around 11.17V, indicating consistent energy availability from the solar source. Meanwhile, the current graph reflects responsive energy usage with a peak of 302.8 ma during active charging, followed by a stable current flow, demonstrating reliable energy management.

In conclusion, the project successfully delivers a contactless, eco-friendly EV charging mechanism that aligns with the growing need for renewable energy integration and autonomous systems. It holds promising potential for real-world deployment in smart cities and sustainable transportation networks.

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