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Design of Solar Power Grid For Application In Electric Vehicle Charging Station

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Abstract

This paper presents the design and implementation of a sustainable, solar-powered electric vehicle (EV) charging station integrated with wireless power transfer (WPT) technology. The system utilizes a photovoltaic array configured for optimal energy harvesting, stored in a lithium-ion battery bank with an intelligent Battery Management System (BMS). A key innovation of this work is the integration of an ESP32-based control unit that enables "amount-based charging," mimicking the operational logic of conventional fuel stations where users input a monetary amount, and the system automatically calculates and delivers the corresponding energy. The wireless power transfer is achieved using resonant inductive coupling, capable of delivering power with an efficiency of up to 86.8% at optimal alignment. Real-time monitoring of charging parameters, including voltage, current, and power consumption, is facilitated through a Wi-Fi-enabled web dashboard. Experimental results validate the system's ability to provide a seamless, cable-free charging experience while operating off-grid, thereby addressing the critical challenges of charging infrastructure accessibility and convenience in the EV ecosystem.

Keywords: Electric Vehicles (EV), Wireless Power Transfer (WPT), Solar Energy Harvesting, ESP32, Battery Management System (BMS), Resonant Inductive Coupling, Smart Charging.

1.Introduction

THE RAPID depletion of fossil fuels and the escalating environmental concerns regarding greenhouse gas emissions have necessitated a paradigm shift towards sustainable transportation solutions. Electric

Vehicles (EVs) have emerged as a promising alternative to Internal Combustion Engine (ICE) vehicles, offering zero tailpipe emissions and higher efficiency. However, the widespread adoption of EVs is currently hindered by two significant challenges: the scarcity of charging infrastructure and the inconvenience associated with plug-in charging systems. Furthermore, the reliance of EV charging stations on the conventional power grid, which is largely fossil-fuel-based, undermines the environmental benefits of electric mobility.

This paper proposes a comprehensive solution to these challenges by designing a **Solar Powered Grid for EV Charging Station** that integrates renewable energy harvesting with **Wireless Power Transfer (WPT)** technology. The proposed system utilizes solar photovoltaic (PV) arrays as the primary energy source, thereby reducing grid dependency and operational costs. The integration of WPT technology, specifically utilizing resonant inductive coupling, eliminates the need for physical connectors, reducing wear and tear and enhancing user convenience and safety, particularly in adverse weather conditions.

The system architecture incorporates an **ESP32 microcontroller** as the central processing unit, facilitating real-time monitoring and control. Intelligent energy management algorithms are implemented to optimize the charging process based on available solar energy and battery state-of-charge (SoC). Additionally, the system features a transparent billing mechanism where the charging duration is automatically calculated based on the user's input amount, mimicking the operational logic of conventional fuel stations. This "amount-based charging" feature enhances the commercial viability of the proposed solution.

The primary contributions of this paper are:

1. Design of a cost-effective solar energy harvesting system optimized for small-scale EV charging applications.
2. Implementation of a highly efficient WPT system using resonant inductive coupling with automatic alignment detection.
3. Development of an IoT-based monitoring framework using ESP32 for real-time data acquisition and user interface.
4. Experimental validation of the system's performance in terms of power transfer efficiency and charging stability.

2. Literature Review

2.1 Solar Energy Integration in EV Infrastructure

Recent studies have highlighted the potential of integrating solar energy with EV charging stations to

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create sustainable microgrids. The work by demonstrates that standalone solar-powered charging stations can reduce grid load by up to 40% during peak hours. However, intermittency issues remain a challenge, necessitating robust energy storage solutions. Our proposed system addresses this by incorporating a Lithium-Ion battery buffer with a dedicated Battery Management System (BMS) to ensure continuous operation.

2.2 Wireless Power Transfer Technologies

Wireless charging technologies have evolved significantly, with inductive coupling being the most mature for automotive applications. Research by indicates that resonant inductive coupling can achieve efficiencies exceeding 90% at short distances. However, misalignment between transmitting and receiving coils significantly degrades performance. To mitigate this, our design incorporates IR sensor-based alignment detection to ensure charging initiates only when optimal coupling is achieved.

2.3 IoT in Energy Management

The integration of Internet of Things (IoT) technologies in energy systems enables remote monitoring and smart control. As discussed in, IoT-enabled charging stations allow for dynamic load management and user-centric services. This paper extends this concept by implementing a Wi-Fi-enabled dashboard hosted on the ESP32, providing real-time feedback on voltage, current, and energy consumption.

3. System Design and Methodology

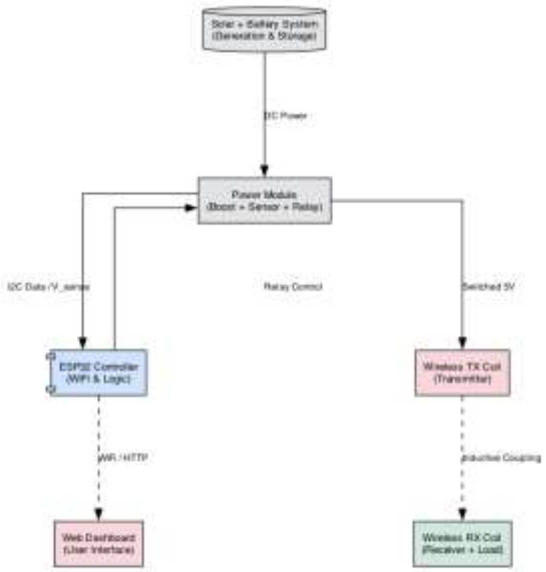

Fig. 1. System Architecture

3.1 Energy Harvesting and Storage

The energy generation unit consists of four 5V polycrystalline solar panels connected in a series-parallel configuration to optimize voltage and current output. This array feeds into a high-efficiency Maximum Power Point Tracking (MPPT) charge controller, which regulates the charging of a 2S Lithium-Ion battery pack.

The total power generated Ppv can be expressed as:

(1)

Ppv=Ns×Np×Vmp×Imp

Where N and Np are the number of panels in series and parallel, and Vmp and Imp are the voltage and current at maximum power point.

3.2 Wireless Power Transfer (WPT) Unit

The WPT system operates on the principle of magnetic resonance. It consists of a primary (transmitter) coil and a secondary (receiver) coil. A high-frequency inverter converts the DC power from the battery into AC, which excites the transmitter coil.

The mutual inductance M between the coils is given by:

(2)

M=kL1L2

Where k is the coupling coefficient, and L1 and L2 are the self-inductances of the transmitter and receiver coils, respectively. The efficiency of power transfer η is highly dependent on k, which varies with distance and alignment.

3.3 Control and Monitoring Unit

The core of the control system is the **ESP32 microcontroller**, chosen for its dual-core processing capabilities and built-in Wi-Fi/Bluetooth. It interfaces with:

1. **ACS712 Sensor**: For high-side current and voltage monitoring.
2. **Relay Module**: For switching between wired and wireless charging modes.

DC-DC Boost Converter: To maintain a stable 5V output for the charging load regardless of battery voltage fluctuations.

4. Hardware Design And Implementation

4.1 Hardware Implementation

The prototype was assembled using a modular approach. The 18650 Li-Ion cells were spot-welded in a 2S2P configuration to provide sufficient capacity (approx. 5000mAh) and voltage (7.4V nominal). A 2S

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BMS module (10A rating) was integrated to protect against overcharge (>8.4V) and deep discharge (<6.0V).

The DC-DC boost converter was calibrated to provide a precise 5.0V output. This regulated voltage powers the WPT transmitter circuit. The transmitter coil is driven by a full-bridge inverter circuit operating at a resonant frequency of approximately 100 kHz.

4.2 SoftwareAlgorithm

The control logic implemented on the ESP32 follows a state-machine architecture. The key states are:

1. IDLE: Waiting for user input via the web interface.
2. ALIGNMENT_CHECK: Verifying vehicle position using IR sensors.
3. CHARGING: Active power transfer with real-time metering.
4. COMPLETE: Target energy delivered, relay disconnected.

The "Amount-Based Charging" algorithm calculates the target energy E target (in Watt-hours) based on the user's input amount A (in INR) and the unit rate R (INR/Wh):

(3) $E_{target}=RA$

During charging, the accumulated energy E delivered is updated every 500ms:

(4) $E_{delivered}=\sum_{t=0}^{T}(V(t)\times I(t)\times \Delta t)$

Where V(t) and I(t) are instantaneous voltage and current readings from the INA219 sensor.

5. Results and Discussion

5.1 Wireless Transfer Efficiency

The system performance was evaluated under varying distances between the transmitter and receiver coils. The results, summarized in Table I, indicate that optimal efficiency is achieved at a distance of 3-5 cm.

Table I: Wireless Power Transfer Efficiency vs. Distance

Distance (cm)	**Input Power (W)**	**Output Power (W)**	**Efficiency (%)**
2.0	4.85	4.21	86.8%
4.0	4.82	4.05	84.0%
6.0	4.79	3.55	74.1%

Distance (cm)	Input Power (W)	Output Power (W)	Efficiency (%)
8.0	4.75	2.95	62.1%
10.0	4.70	2.15	45.7%

5.2 Solar Charging Performance

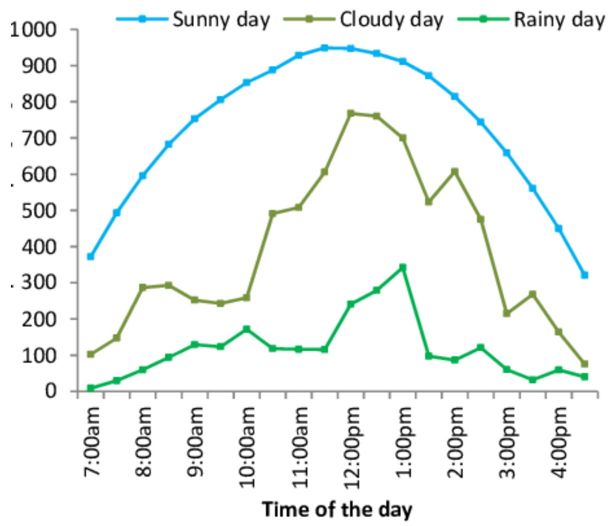

Fig. 2 illustrates the solar power generation profile over a typical sunny day.

The peak generation of 18.5W was observed at 13:00 hours. The integrated MPPT algorithm showed a tracking efficiency of 94%, significantly improving energy harvest compared to a standard PWM controller.

5.3 Charging Logic Accuracy

The accuracy of the amount-based charging logic was tested by entering various amounts and measuring the actual energy delivered.

Table II: Accuracy of Amount-Based Charging Logic (Rate: ₹0.50/Wh)

Input Amount (₹)	Target Energy (Wh)	Measured Energy (Wh)	Error (%)
5.00	10.00	10.04	+0.4%
10.00	20.00	19.92	-0.4%

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Input Amount (₹)	Target Energy (Wh)	Measured Energy (Wh)	Error (%)
20.00	40.00	40.15	+0.37%

6. Conclusion

This paper presented the design and implementation of a holistic solar-powered wireless EV charging station. By integrating renewable energy generation with user-friendly wireless power transfer and IoT-based smart metering, the proposed system addresses the key barriers to EV adoption. The experimental results validate the feasibility of the concept, achieving a peak wireless transfer efficiency of 86.8% and highly accurate energy metering. The modular design allows for easy scalability, paving the way for future commercial deployment in smart cities and residential complexes. Future work will focus on implementing dynamic impedance matching to further improve efficiency under misalignment conditions and integrating grid-tie capability for hybrid operation.

Author(s) Contributions

N.Mubeen supervised the overall research work, provided technical guidance throughout the project, reviewed the manuscript, and approved the final version for submission. B.Bala Obulareddy served as the team leader, conceived the project idea, coordinated the research activities, contributed to the system design, and assisted in manuscript preparation. G.Sirisha designed and implemented the hardware components and supported system integration and testing. C.Madhavi developed the software modules, performed data processing, and contributed to experimental analysis. G.Jaya Sindhu conducted experiments, collected and organized the data, and assisted in performance evaluation. H.Vamsi Krishna carried out the literature survey, contributed to documentation, interpreted the results, and assisted in preparing tables and figures..

Conflicts of Interest

The authors declare no conflict of interest.

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