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System Design and Realization of a Wireless Electric Vehicle Charging System

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Abstract - The rising adoption of electric vehicles (EVs), there is a growing demand for sustainable and efficient charging infrastructure. This study presents the design and implementation of a solar-powered, wireless charging system for EVs that addresses two primary challenges in transportation: dependency on fossil fuels and environmental pollution. EVs have already demonstrated reduced operational costs and environmental impact by replacing traditional fuel with electricity.

The proposed charging system introduces a novel solution that eliminates the need for physical cables and external power sources. It utilizes solar energy as the primary input to maintain continuous charging, enabling EVs to recharge even while in motion. The system architecture comprises key components such as solar panels, energy storage batteries, LCD interfaces, charge controllers, AC-to-DC converters, inverters, ATmega microcontrollers, and inductive coils for wireless energy transfer.

Solar panels generate direct current (DC) electricity, which is regulated and stored in batteries. This stored DC power is then converted to alternating current (AC) for wireless transmission via primary coils embedded in the infrastructure. The receiving EV, equipped with secondary coils and an AC-to-DC conversion module, captures and utilizes the transmitted power for battery charging. This dynamic, integrated system illustrates the potential of wireless solar charging to enhance the practicality and sustainability of electric mobility, reducing charging downtime and infrastructure limitations.

***Key Words*:** Electric vehicles; Electromagnetic compatibility; Finite element method; Wireless charging system; Wireless power transfer; Wireless electric vehicle charging system.

1.INTRODUCTION

Wireless Charging Systems (WCS) have been explored for high-power applications, notably in electric vehicles (EVs) and plug-in electric vehicles (PEVs) for stationary charging scenarios. Compared to conventional plug-in systems, WCS offer several benefits, including operational simplicity, enhanced dependability, and improved user convenience. However, a notable limitation of WCS is their applicability predominantly in stationary settings, such as parking lots or traffic stops. Moreover, static wireless charging systems encounter specific technical challenges, including issues related to electromagnetic interference (EMI), constrained power transmission capacity, bulky infrastructure, limited transmission distance, and efficiency constraints.

To address the limitations associated with charging range and onboard battery volume, dynamic wireless charging (DWC) technologies have been investigated. These systems facilitate energy transfer while the vehicle is in motion, potentially reducing the need for large, costly battery packs and thereby extending driving range. Nonetheless, dynamic WCS face critical technical barriers—primarily large air gaps and misalignment of transmitter and receiver coils. The efficiency of power delivery is significantly influenced by the spatial alignment and separation between the primary and secondary coils. In typical passenger vehicles, the air gap ranges from 150 to 300 mm, and may be larger for heavy-duty vehicles.

Accurate alignment with the primary coil can be managed through autonomous vehicle navigation during dynamic operation. Furthermore, various compensation topologies—such as series, parallel, and hybrid configurations—are implemented on both the transmitting and receiving ends to mitigate parasitic effects and enhance overall system efficiency. This review comprehensively examines the core principles underlying WCS in EVs, including different energy transfer techniques. It also presents an overview of innovative wireless transformer designs aimed at optimizing transmission efficiency and summarizes recent advancements in both static and dynamic wireless EV charging systems across academic and industrial domains.

2. PROBLEM STATEMENT

With the increasing adoption of electric vehicles (EVs) and the escalating demand for sustainable and renewable energy solutions, the necessity for efficient, reliable, and eco-friendly charging technologies has become more critical than ever. Although conventional EV charging stations are widely deployed, they typically rely on grid-supplied electricity, which may still be derived from fossil-based or non-renewable energy sources. Additionally, these conventional systems face several infrastructural and logistical constraints, such as fixed installation points, dependence on centralized electrical grids, and the risk of congestion in high-demand areas.

A significant gap exists in the development of an energy-efficient, adaptable, wireless, and solar-powered EV charging infrastructure capable of functioning across diverse environments. This limitation impedes the widespread accessibility and practicality of EV charging, particularly for users without convenient access to stationary charging facilities.

3. METHODOLOGY

The development of a solar-powered wireless electric vehicle (EV) charging system involves a multi-phase process extending from initial conceptualization to final testing. A comprehensive overview of this procedure is outlined below.

System Conceptualization and Design Objective: Define the core functionalities and performance requirements of the system.

Key Components:

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- **Photovoltaic Array:** Captures solar energy and converts it into electrical power through photovoltaic conversion.
- **Energy Storage Unit:** Commonly referred to as a battery energy storage system (BESS), this component accumulates surplus electrical energy generated by the solar array for utilization during periods of limited solar irradiance (e.g., overcast conditions).
- **Wireless Power Transfer (WPT) Mechanism:** Facilitates the contactless transmission of power from a stationary transmitter (charging pad) to a vehicle-mounted receiver via resonant inductive coupling.
- **Power Electronics and Control Architecture:** Manages and optimizes the power flow, ensuring safe, stable, and efficient energy transfer throughout the charging cycle.
- **Vehicle Integration Interface:** Ensures compatibility and seamless communication with a range of EV platforms to support universal interoperability.

4. FUTURE PROSPECTS AND POTENTIAL DEVELOPMENTS

1. **Enhanced System Efficiency:** Ongoing advancements in materials engineering and wireless energy transmission technologies are expected to significantly improve the overall efficiency of photovoltaic modules and inductive power transfer mechanisms.
2. **Intelligent Charging Infrastructure:** The incorporation of Internet of Things (IoT) technologies and Artificial Intelligence (AI) enables real-time monitoring, predictive analytics, and optimization of energy consumption, supporting features such as dynamic pricing models and adaptive load distribution.
3. **Expanding Market Viability:** With the exponential growth of the electric vehicle sector, there is increasing commercial interest and demand for next-generation charging infrastructures, creating substantial market potential for solar-powered wireless charging systems.
4. **Innovation through R&D:** Sustained efforts in research and development are essential to uncover novel applications of integrated solar and wireless technologies, including hybrid models that incorporate complementary renewable sources such as wind or bioenergy.
5. **Increased User Safety:** The elimination of physical connectors in wireless systems mitigates the risk of electric shock, enhancing operational safety.
6. **Environmental Robustness:** These systems are designed for resilience, capable of functioning efficiently across diverse climatic conditions, unlike certain conventional charging alternatives that may be sensitive to environmental factors.
7. **Feasibility of Dynamic Power Delivery:** Future systems may support real-time modulation of energy output based on vehicular energy requirements and real-time grid status, facilitating more adaptive and intelligent charging.
8. **Minimized Environmental Impact:** By harnessing solar energy, such systems drastically lower the carbon emissions typically associated with EV charging processes, contributing to broader decarbonization goals.
9. **Enhanced Urban Air Quality:** Reducing reliance on fossil fuel-based transportation contributes to lower particulate and greenhouse gas emissions, promoting improved air quality and public health in urban environments

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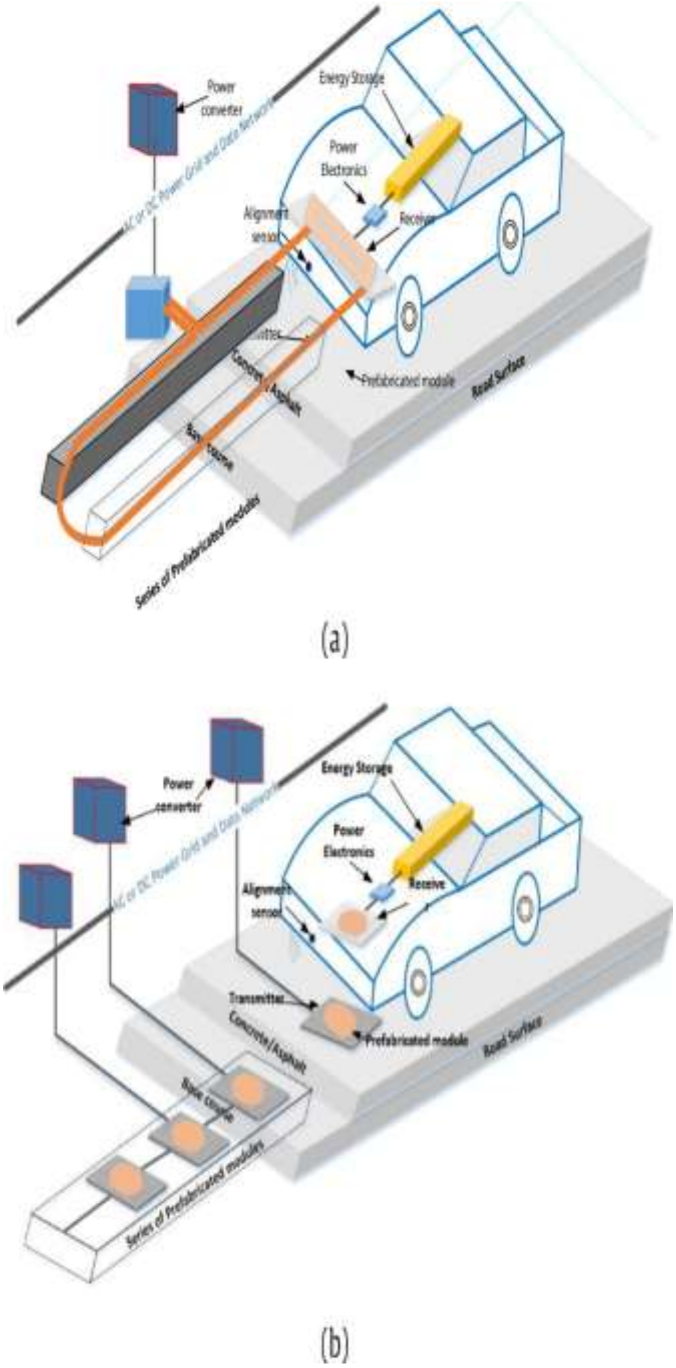
5. BLOCK DIAGRAM:

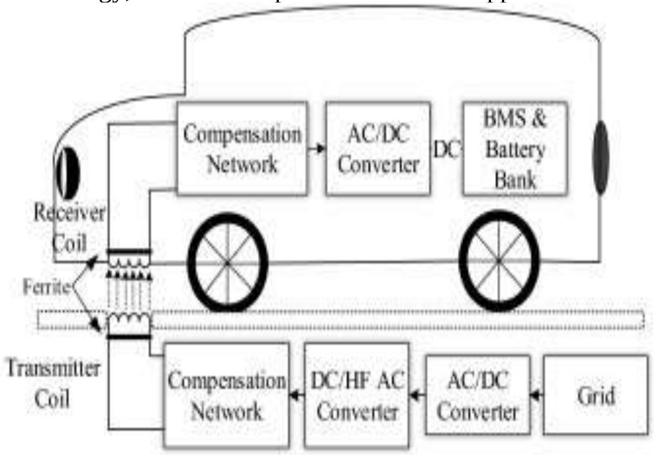


Dia.-1: Diagram of wireless EV charging system

6. WIRELESS CHARGING SYSTEM FOR EVS:

Fundamental Operating Principle: The fundamental block diagram of a static Wireless Charging System (WCS) for Electric Vehicles (EVs) is presented. For efficient energy transmission from the primary (transmitting) coil to the secondary (receiving) coil, the alternating current (AC) input from the power grid is first rectified to direct current (DC) and then inverted back to high-frequency (HF) AC using AC-DC and DC-AC converters. To enhance the efficiency of the power transfer, compensation networks based on series and parallel configurations are incorporated on both the transmitter and receiver ends. The receiving coil—typically installed beneath the EV—captures the oscillating magnetic flux and converts it back into HF AC. This HF AC is subsequently rectified and regulated into DC to recharge the onboard battery pack. Additional subsystems, such as power electronics control, data communication modules, and a Battery Management System (BMS), are integrated to maintain operational safety and system stability. Magnetic ferrite plates are utilized on both sides of the inductive link to suppress stray magnetic flux and to improve the alignment and efficiency of magnetic coupling.

Operational Principle: This wireless charging methodology adheres to the Qi standard, which was initially developed for low-power applications such as mobile devices. The same principle can be extended to EVs. The system functions on the concept of electromagnetic induction, wherein the transmitting coil embedded in the ground (primary side) generates a magnetic field when energized. This varying magnetic field induces a current in the nearby receiving coil (secondary side) without any physical contact. When this induced current is directed into a charging circuit, wireless energy transfer is realized. Although wireless EV charging remains in the developmental stage due to challenges related to safety, infrastructure, and cost, this paper aims to outline a prototype of a dynamic wireless charging system powered by solar energy, which holds promise for future applications.

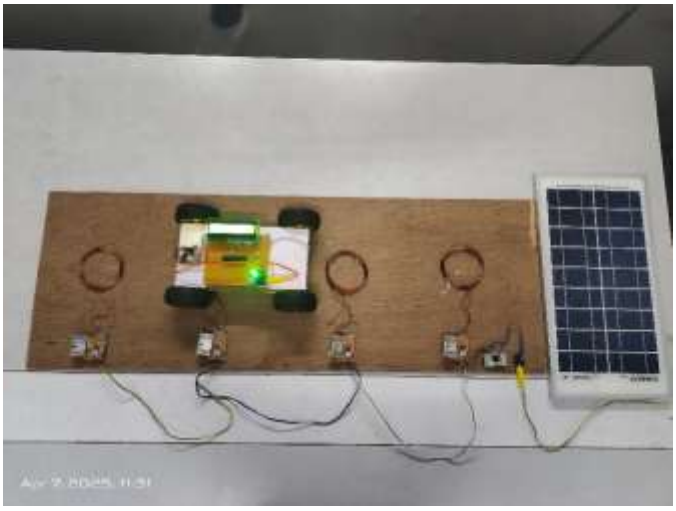


Dia.-2: Block diagram of wireless EV charging system

7. PROBLEM STATEMENT

1. **Energy Efficiency:** Achieving optimal energy conversion from photovoltaic panels to the charging platform while reducing energy losses during the wireless transmission process.
2. **System Scalability:** Developing a solution that can be easily adapted and expanded to suit a variety of settings, including urban, rural, and diverse environmental conditions.
3. **Economic Viability:** Striking a balance between the initial capital investment required for solar infrastructure and wireless charging systems and the long-term operational savings and ecological advantages.
4. **Compliance and Safety Standards:** Adhering to relevant regulations and safety protocols for both solar power systems and wireless charging technologies, ensuring the safety of users and vehicles.
5. **Environmental Sustainability:** Evaluating and mitigating the ecological footprint of the materials used in the production of solar panels, charging stations, and the entire system throughout its operational lifespan.

8. Hardware Model:



9.Components:

1. Solar Panel System

The solar panel subsystem comprises photovoltaic (PV) modules that harness solar radiation and convert it into direct current (DC) electricity. The panels are typically rated between 300W to 400W depending on the configuration and energy requirements. To ensure uninterrupted power availability during low irradiance periods (e.g., nighttime or cloudy conditions), a battery energy storage system (BESS) is employed. This battery bank stores surplus solar energy for later use, ensuring a consistent power supply for the EV charging process.

2. Power Conditioning Unit (PCU)

The PCU primarily consists of a DC-AC inverter, which converts the DC power output from the solar panels or battery storage into alternating current (AC). This AC power is necessary to drive the wireless power transfer mechanism, particularly the transmitter coil. The inverter also ensures that the output voltage and frequency are regulated, stable, and within the specified operating range suitable for the downstream components.

3. Wireless Power Transfer (WPT) System

The WPT subsystem facilitates contactless energy transfer using inductive coupling. It includes:

- Transmitter Coil (Primary Coil): Installed on the ground or within a charging pad, this coil generates an alternating magnetic field when energized by the AC power from the inverter.
- Receiver Coil (Secondary Coil): Mounted beneath the EV, this coil captures the alternating magnetic field and induces a corresponding voltage. The output may be AC or DC based on the specific system configuration.
- Rectifier and Voltage Regulator: If the output from the receiver coil is AC, a rectification stage is required to convert it back to DC. A voltage regulator ensures the output is within the suitable range for battery charging.

4. EV Battery Charging System
Following wireless energy transfer, the rectified DC power is passed through a DC-DC converter to match the charging voltage of the EV's battery pack (typically 400V or 800V). This converter adjusts the voltage level to meet the battery's specific requirements. Additionally, a Battery Management System (BMS) is integrated to monitor and control the charging process, preventing issues such as overcharging, overheating, or deep discharging. The BMS ensures optimal battery health and enhances the safety and lifespan of the EV battery.

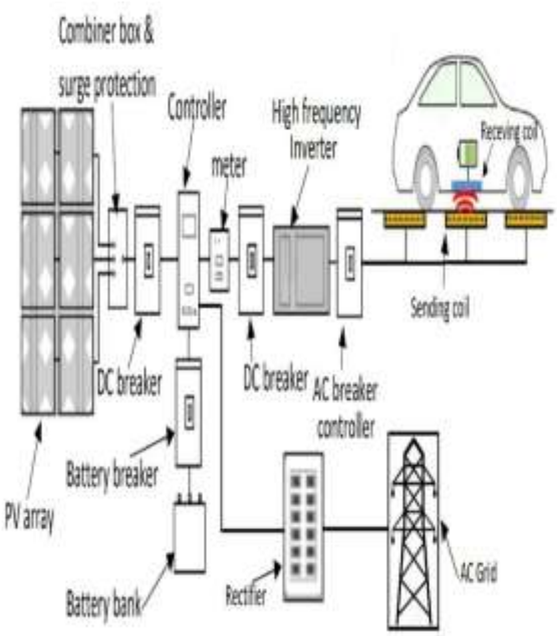
5. Control and Communication System
An intelligent control and communication module facilitates seamless interaction between the EV and the charging infrastructure. Communication protocols such as Wi-Fi, Bluetooth, or Power Line Communication (PLC) are implemented to exchange data related to system status, charging parameters, and fault diagnostics. This communication ensures that the charging session is initiated, monitored, and terminated safely and efficiently.

8. CHALLENGES

Despite the numerous advantages, there remain several challenges associated with wireless EV charging systems that require resolution. A significant barrier is the installation cost. The higher initial setup expenses of wireless charging infrastructure, when compared to traditional charging systems, could hinder widespread adoption. Another challenge is interoperability. Due to the absence of universal standards for wireless EV charging, it may be difficult for electric vehicle owners to identify compatible charging stations. The alignment between the charging and receiving pads, as well as their relative positioning, plays a critical role in the efficiency of the wireless power transfer process.

1. **Power Transfer Efficiency**
   • **Obstacle:** Wireless power transmission (WPT) generally suffers from lower efficiency in comparison to wired alternatives, leading to prolonged charging times or energy losses.
2. **Energy Storage and Regulation**
   • **Obstacle:** The variability of solar energy—directly linked to the availability of sunlight—poses a challenge in ensuring that an adequate amount of energy is consistently stored for reliable charging. This issue becomes particularly pronounced in areas with limited sunlight or during cloudy weather conditions.
3. **ChargingRate**
   • **Obstacle:** Wireless charging systems tend to have slower charging speeds relative to wired systems, primarily due to lower power transmission efficiency and the current limitations of wireless technologies.

9.CIRCUIT DIAGRAM



10. COIL STRUCTURE DESIGN

When an alternating current flows through the transmitter coil, also referred to as the primary coil, it generates a time-varying magnetic field. This magnetic field propagates outward and enables contactless energy transmission to the receiving coil. The receiver coil, or secondary coil, captures this magnetic field and, through the principle of electromagnetic induction, induces an alternating current within itself. This induced current is subsequently rectified and regulated to produce a stable direct current (DC) voltage, which is then used to recharge the electric vehicle's battery system. By eliminating physical cables and connectors, this wireless energy transfer mechanism enhances safety, convenience, and user accessibility for both the vehicle and the charging infrastructure.
The electrical power is initially transformed into alternating current (AC) using a transformer and subsequently stabilized via voltage regulation circuits. This controlled power is directed to the transmitter-side copper coils, which facilitate the wireless transmission of energy. A corresponding copper coil is mounted beneath the electric vehicle. When the vehicle aligns above the charging pad, energy is transmitted from the ground-based transmitter coil to the vehicle-mounted receiver coil. Although the induced energy is still in the form of AC, it is then converted back into DC to effectively charge the EV's battery pack. In solar-powered wireless charging systems, the transmitter coil embedded in the charging pad creates a magnetic flux upon energization, which induces current in the receiver coil installed in the vehicle, thereby enabling wireless charging through electromagnetic coupling.

Result Table

Sr. No.	Parameter	Input	Output
1.	Solar Panel Output Voltage (V)	Solar PV Panel	18–20 V DC (depending on sunlight)
2.	Battery Storage Voltage (V)	Li-ion Battery Bank	12V DC
3.	Inverter Output Voltage (V)	From Battery / Solar Panel	230 V AC
4.	Transmitter Coil Frequency (kHz)	Inverter AC Output	40–60 kHz
5.	Distance Between Coils (cm)	Physical Setup	10 cm
6.	Receiver Coil Output Voltage (V)	EV-side Coil	~11 V AC
7.	Rectified Voltage (V)	After Receiver Rectifier	10 V DC
8.	DC-DC Converter Output Voltage (V)	To EV Battery	12 V
9.	EV Battery Charging Current (A)	BMS-controlled	4.2 A
10	Efficiency of Wireless Power Transfer (%)	Calculated	~65–75%

11.CONCLUSIONS

The wireless charging mechanism utilized for replenishing electric vehicle (EV) batteries operates based on the principle of Inductive Power Transfer (IPT). A driver circuit is incorporated between the transmitting and receiving coils, employing a MOSFET switch and a microcontroller to regulate energy flow. To mitigate energy loss and minimize electromagnetic radiation, the system activates the transmitter circuit only when the vehicle is correctly positioned and deactivates it in the absence of the vehicle. The power delivery is managed through an AC switch integrated within the excitation circuit design. Experimental validation using an EV battery charger demonstrated the feasibility of the inductive power transfer approach. A functional prototype was developed, achieving an energy transfer efficiency of approximately 67%, thereby confirming system performance. The proposed setup offers enhanced reliability, operational safety, and durability.

The dynamic solar-powered wireless EV charging system marks a major innovation in electric vehicle charging infrastructure, allowing vehicles to be recharged while in motion. This significantly reduces idle charging periods and extends the operational driving range. By integrating photovoltaic energy generation with wireless power transfer (WPT) technology embedded within road surfaces, the system utilizes sustainable energy sources to deliver continuous charging—particularly advantageous for long-haul transport and commercial fleet services.

In summary, the dynamic solar wireless charging solution has the potential to transform the EV ecosystem by enabling real-time, renewable energy-based charging. However, for widespread implementation, critical technological, economic, and regulatory challenges must be effectively addressed.

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