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Solar Energy Integrated Wireless Power Transfer For Electric Vehicle Charging

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Abstract: The increasing adoption of electric vehicles demands innovative charging solutions that are efficient, sustainable, and user-friendly. This project proposes a Solar-Based Wireless Electric Vehicle Charging System that enables contactless energy transfer without requiring physical connections or vehicle stoppage. The system operates by harvesting solar energy and converting it into electrical power, which is then transmitted wirelessly through inductive coils embedded beneath the roadway. A corresponding receiver coil mounted on the vehicle captures this energy and delivers it to the battery through regulated power conditioning circuits. A microcontroller supervises system operation, ensuring controlled power transfer and system safety. By utilizing renewable solar energy, the proposed model reduces dependence on grid electricity and lowers carbon emissions. The elimination of cables and plugs improves convenience, minimizes wear and tear, and supports dynamic charging capability. This approach has the potential to increase vehicle driving range, reduce charging interruptions, and contribute to the development of eco-friendly intelligent transportation systems.

Index Terms - Electric Vehicles (EVs), Solar Energy, Wireless Power Transfer (WPT), Inductive Charging, Dynamic Charging, Renewable Energy, Intelligent Transportation Systems.

I. Introduction

The rapid growth of global energy demand and increasing environmental concerns have intensified the search for cleaner and more sustainable transportation solutions. Conventional internal combustion engine vehicles depend heavily on fossil fuels, which contribute significantly to air pollution, greenhouse gas emissions, and climate change. To address these challenges, electric vehicles (EVs) have emerged as an effective alternative due to their high energy efficiency, low emissions, and reduced operating costs [10]. Governments and industries worldwide are actively promoting EV adoption to achieve sustainable mobility and reduce carbon footprints [14].

Electric vehicles operate using electric motors powered by rechargeable batteries, offering zero tailpipe emissions and quieter operation compared to traditional vehicles. Despite these advantages, the widespread adoption of EVs faces several technical and practical challenges. One of the most critical issues is related to battery charging, including limited driving range, long charging durations, and insufficient charging infrastructure [1]. These limitations create inconvenience for users and restrict the feasibility of EVs for long-distance travel.

Currently, most EVs rely on conductive or wired charging systems, where vehicles must be physically connected to charging stations through cables. While wired charging is effective, it has several disadvantages. Charging often requires vehicles to remain stationary for extended periods, ranging from tens of minutes to several hours depending on charging power levels. This results in increased downtime and reduced user convenience [11]. Additionally, frequent use of charging cables may lead to mechanical wear, safety hazards in wet or dusty environments, and higher maintenance requirements. These concerns have encouraged researchers to explore alternative charging technologies that are safer, more convenient, and efficient.

Wireless power transfer (WPT) technology has gained significant attention as a promising solution to overcome the drawbacks of conventional plug-in charging systems. Wireless charging enables electrical energy to be transmitted from a power source to a load without physical contact, primarily through electromagnetic induction or magnetic resonance coupling [4]. In inductive wireless charging systems, alternating current supplied to a transmitter coil generates a magnetic field, which induces voltage in a receiver coil placed within the magnetic field. This contactless method improves safety, eliminates connector wear, and enhances user convenience [15].

Wireless charging systems for electric vehicles can be broadly categorized into static and dynamic charging methods. Static wireless charging occurs when the vehicle is stationary, such as during parking or at designated charging spots. Dynamic wireless charging, on the other hand, allows vehicles to receive power while in motion through coils embedded in road infrastructure [9]. Dynamic charging has the potential to significantly increase driving range, reduce the need for large onboard batteries, and minimize charging interruptions. However, such systems require reliable energy sources and efficient power transfer mechanisms to ensure consistent performance.

In parallel with advancements in wireless charging, the integration of renewable energy sources into EV charging infrastructure has become an important research focus. Renewable energy sources such as solar power provide clean, sustainable, and widely available energy, making them suitable for supporting electric vehicle charging systems [8]. Solar energy, in particular, offers the advantage of reducing dependence on conventional electrical grids and lowering operational costs. However, traditional solar-based EV charging systems are typically limited to stationary charging and are unable to support continuous energy supply during vehicle operation.

The combination of solar energy harvesting with wireless power transfer technology presents a promising solution to address both sustainability and convenience challenges. A solar-assisted wireless electric vehicle charging system integrates photovoltaic power generation with inductive power transfer to enable contactless charging without relying solely on grid electricity [1], [3]. In this approach, solar panels generate electrical energy, which is conditioned and supplied to transmitter coils embedded beneath the roadway. When an electric vehicle equipped with a receiver coil passes over these coils, energy is transferred wirelessly through electromagnetic induction [6].

Recent studies have demonstrated that solar-integrated wireless charging systems can support both stationary and dynamic charging applications, improving charging accessibility and reducing environmental impact [2], [5]. By enabling vehicles to charge while moving, such systems can extend driving range, reduce battery stress, and enhance overall energy efficiency. Furthermore, using solar energy as the primary power source contributes to reduced carbon emissions and supports the development of eco-friendly transportation networks [7].

A typical solar wireless EV charging system consists of solar panels, power conditioning units, transmitter and receiver coils, control circuitry, and energy storage components. Solar panels convert sunlight into electrical energy, which is regulated and processed to meet system requirements. The transmitter coil generates a magnetic field for wireless power transfer, while the receiver coil mounted on the vehicle captures this energy and delivers it to the battery or auxiliary power system. Microcontroller-based control units are commonly employed to manage power flow, ensure system safety, and maintain stable operation [12], [13].

Despite the numerous advantages of solar-assisted wireless charging systems, several challenges remain. Power transfer efficiency, coil alignment, system cost, and infrastructure complexity are major concerns that affect large-scale implementation [8], [9]. Environmental factors such as varying sunlight availability and road conditions also influence system performance. Therefore, comprehensive studies are required to evaluate the feasibility, efficiency, and practical limitations of such systems.

This project focuses on the study of a solar-assisted wireless electric vehicle charging system, emphasizing its working principles, operational characteristics, and potential benefits. The study aims to analyze how the integration of wireless power transfer and solar energy can enhance charging convenience while promoting sustainability. By examining recent developments and research trends, this work highlights the role of solar wireless charging systems in supporting future electric mobility and intelligent transportation infrastructure [14].

In conclusion, the increasing demand for clean energy and efficient transportation solutions necessitates the development of innovative EV charging technologies. Solar wireless electric vehicle charging systems represent a forward-looking approach that combines renewable energy with advanced power transfer techniques. With continued research and technological improvements, these systems have the potential to transform electric mobility by enabling efficient, convenient, and environmentally responsible charging solutions [1], [9], [15].

II. STATEMENT OF THE PROBLEM

Electric vehicles (EVs) play a vital role in reducing environmental pollution, fuel dependency, and greenhouse gas emissions. However, the growing adoption of EVs has increased the demand for charging systems that are safe, efficient, and convenient for users. Presently, most electric vehicles rely on conventional plug-in charging methods that require physical cable connections. These systems often involve manual operation, frequent maintenance, and potential safety risks, particularly in adverse weather conditions. In addition, wired charging requires vehicles to remain stationary for extended periods, leading to inconvenience and limited charging flexibility.

Wireless charging based on inductive power transfer (IPT) provides a potential solution by enabling contactless energy transfer between ground-mounted transmitter coils and vehicle-mounted receiver coils. While this technology eliminates the use of cables and improves user convenience, its effectiveness depends on reliable power availability and system efficiency. The challenge lies in developing a wireless charging approach that is not only convenient but also sustainable and capable of supporting future electric mobility needs. Therefore, there is a need to study and analyze a solar- assisted wireless charging system that can enhance charging accessibility while reducing dependence on conventional power sources.

III. METHODOLOGY

The proposed solar-assisted wireless electric vehicle charging system is implemented using a structured and systematic engineering methodology. The process begins with the identification of system requirements and selection of suitable components to ensure efficient and reliable operation. Key elements such as the solar panel, wireless power transmitter and receiver coils, power conditioning circuits, energy storage unit, and microcontroller are chosen based on voltage ratings, power capacity, and compatibility with the charging system.

Initially, electrical energy is harvested from the solar panel and passed through voltage regulation and power conversion circuits to obtain a stable supply suitable for wireless transmission. This regulated power is fed to the transmitter coil, which generates an alternating magnetic field required for inductive power transfer. A receiver coil installed on the electric vehicle captures the magnetic energy and converts it into electrical power, which is then conditioned using rectification and regulation circuits before being supplied to the battery charging unit.

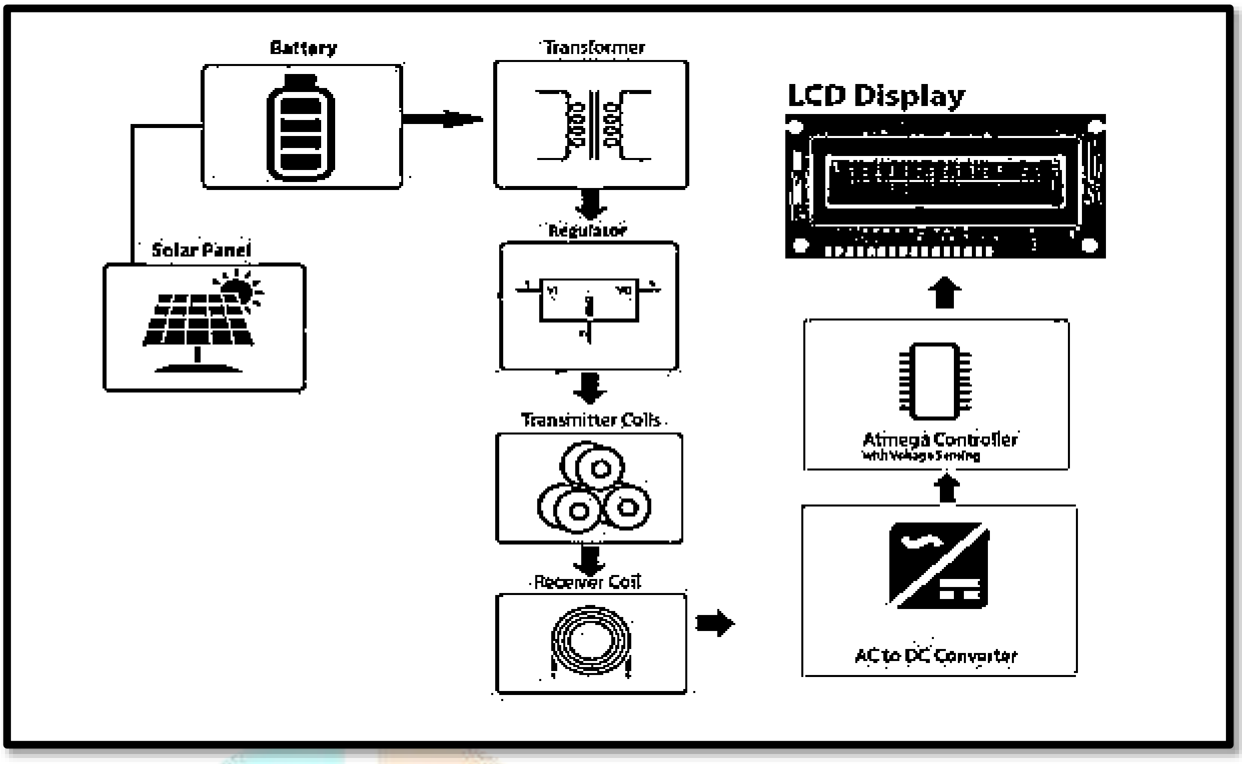

Figure 1: Block diagram of EV charging system

A microcontroller is programmed to supervise the overall system operation, including power flow control, voltage monitoring, and protection against overcharging and abnormal operating conditions. The hardware components are integrated to form a functional prototype, ensuring proper alignment between transmitter and receiver coils for effective power transfer. Experimental testing is conducted under varying conditions such as different solar irradiance levels and load variations to assess system performance. Parameters including output voltage, charging current, power transfer efficiency, and battery charging duration are measured and recorded. The collected data is analyzed to evaluate the feasibility, reliability, and effectiveness of the solar-based wireless electric vehicle charging system.

IV. BLOCK DIAGRAM DESCRIPTION

The block diagram represents the functional layout of the solar-powered wireless electric vehicle (EV) charging system, illustrating how solar energy is harvested, processed, and transmitted wirelessly to the vehicle. It also highlights monitoring and control mechanisms for safe and efficient operation. Solar Panel: The system starts with the solar panel, which captures sunlight and converts it into electrical energy through photovoltaic action. This renewable energy source serves as the primary power supply for the entire system, promoting sustainability and reducing dependency on the conventional grid. Battery: The electrical energy generated by the solar panel is stored in a rechargeable battery. The battery ensures a steady and uninterrupted power supply, enabling the system to operate even during periods of low sunlight or temporary shading. Transformer:The stored DC power is passed through a transformer to adjust voltage levels as required. The transformer ensures that the voltage delivered to the transmitter coils is optimal for efficient inductive wireless power transfer. Voltage Regulator:A voltage regulator maintains a stable and constant output voltage. This protects sensitive electronic components, ensures safe operation, and prevents voltage fluctuations that could reduce the efficiency of wireless charging. Transmitter Coils: The regulated electrical power is supplied to the transmitter coil array, which generates a high-frequency alternating magnetic field. This magnetic field is the core mechanism for wireless energy transfer via inductive coupling. Receiver Coi: The receiver coil, mounted on the electric vehicle, captures the magnetic flux generated by the transmitter coils. The magnetic energy is converted back into electrical power, which is then routed toward the EV's battery charging circuit. AC to DC Converter: The energy captured by the receiver coil is initially in AC form. An AC–DC converter is used to transform this alternating current into direct current, making it suitable for charging the vehicle's DC-operated battery system. Atmega Microcontroller (with Voltage Sensing): An Atmega microcontroller equipped with voltage sensing monitors critical system parameters such as input/output voltage, charging progress, and coil alignment performance. It serves as the central control unit, managing power flow, safety protocols, and operational stability. LCD Display: Finally, an LCD display is integrated to provide real-time feedback on system operation, including voltage levels, charging status, and overall performance. This ensures transparency and allows the user to monitor the system easily.

Component	Rating	Description
Solar Panel	50W/12V	Converts sunlight to electricity
Charger Controller	12V/10A	Regulates battery charging
Battery	12V/7Ah	Stores solar power
Inverter	12v to 230V AC	Converts DC to AC
Transmitting Coil	Copper,10-20 turns	Generates magnetic field
Receiving Coil	Copper,10-20 turns	Receives power
Rectifier	5A bridge	AC to DC conversion

Table 1: Components ratings of system

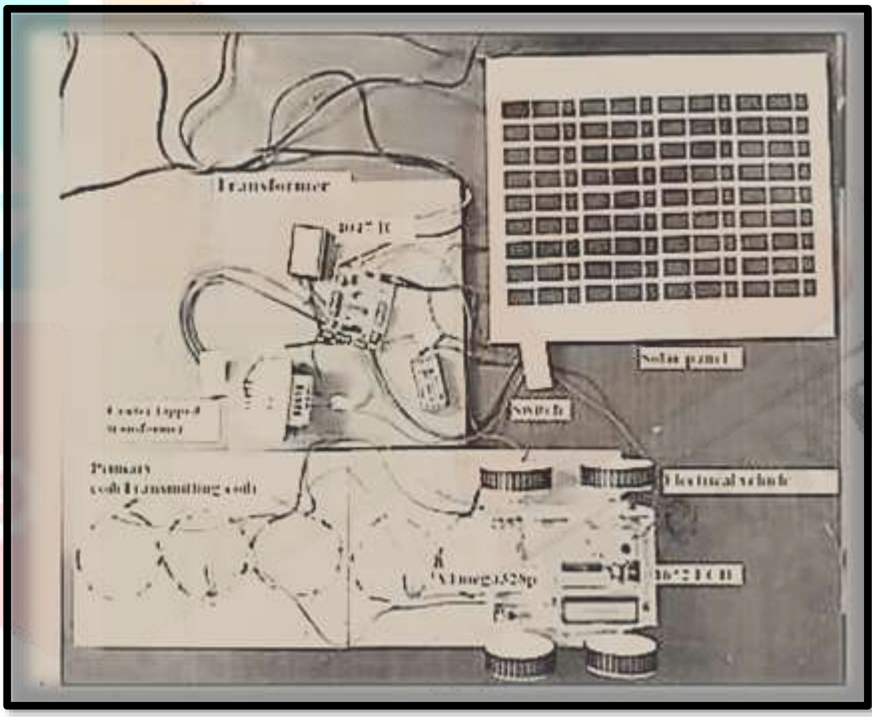

Figure 2: Hardware model of the solar wireless charging system

V. WORKING PRINCIPLE

The solar wireless electric vehicle (EV) charging system operates based on the principle of Inductive Power Transfer (IPT). In this system, solar energy is harnessed to provide clean, renewable power for wireless charging. The solar panels convert sunlight into electrical energy, which is then regulated and supplied to the transmitter coil embedded in the charging platform. When alternating current flows through this coil, it produces a time-varying magnetic field.

A receiver coil installed on the electric vehicle passes through this magnetic field, inducing an AC voltage through electromagnetic induction. This induced voltage is rectified and regulated to charge the EV battery. The process allows contactless charging without physical connections, promoting safety, convenience, and continuous energy supply. Additionally, the system is capable of dynamic charging, enabling an electric vehicle to receive power while in motion, reducing dependence on grid electricity and eliminating the need for conventional plug-in methods.

The detailed working process can be explained in the following steps:

1. Solar Power Generation

The system begins with a solar panel array that captures sunlight and converts it into DC electrical energy. A charge controller ensures efficient power conversion and prevents overcharging of the battery. The generated DC energy is stored in a battery bank, which provides a stable and reliable power source for the wireless charging system even during periods of low sunlight or cloud cover.

2. Power Conversion

The stored DC energy from the battery is converted into alternating current (AC) using an inverter. This is essential because inductive wireless charging relies on an alternating magnetic field to transfer energy efficiently. The AC voltage and frequency are further adjusted, often using a transformer, to match the specifications required by the transmitter coils.

3. Wireless Power Transfer (Inductive Coupling)

The transmitter coils embedded in the charging platform or roadway are energized with AC current, producing an oscillating magnetic field. The EV is equipped with a receiver coil beneath the chassis, which captures this magnetic flux. When the vehicle is within the proximity of the transmitter coils, the oscillating magnetic field induces an AC voltage in the receiver coil through electromagnetic induction. This process enables energy transfer without any physical contact between the vehicle and the charging infrastructure.

4. AC–DC Rectification and Battery Charging

The AC voltage induced in the receiver coil is then converted back to DC voltage using a rectifier circuit. The rectified DC power is suitable for charging the EV battery or powering its onboard electrical systems. In dynamic charging setups, the vehicle continues to charge as long as it remains over the transmitter coils, allowing uninterrupted energy supply while driving.

5. Control and Monitoring

A microcontroller, such as an Atmega or Arduino, supervises the charging process by:

- ✓ Monitoring input and output voltage, current, and overall power flow.
- ✓ Controlling charging indicators, including LEDs and LCD displays, to show battery level, charging progress, and system status.
- ✓ Ensuring safe operation by preventing overcharging, under-voltage, and other abnormal conditions.

Through these steps, the solar wireless EV charging system provides a safe, efficient, and environmentally friendly solution for powering electric vehicles, combining renewable energy utilization with the convenience of contactless power transfer.

VI. RESULTS

The implemented Solar-Powered Wireless Electric Vehicle (EV) Charging System successfully demonstrated efficient transfer of energy from the transmitter coil to the vehicle's receiver coil. The solar panel provided a stable DC supply, which was regulated and transmitted through the inductive coil arrangement. During testing, the EV battery consistently showed an increase in charge level, confirming the functionality of wireless charging. The system maintained smooth voltage and current flow under adequate sunlight, indicating reliable operation. The prototype validated that continuous, contactless charging is feasible without physical connectors, making it suitable for both stationary and on-road applications. Overall, the results confirm that the proposed system is technically feasible, environmentally sustainable, and capable of supporting EV charging using renewable solar energy.

ADVANTAGES

- ✓ Contactless Charging: Eliminates cables and physical connectors, reducing wear and enhancing convenience.
- ✓ Environmentally Friendly: Utilizes solar energy, lowering carbon emissions and dependence on the electrical grid.
- ✓ Reduced Maintenance: Fewer moving parts and no frequent cable handling reduce maintenance requirements.
- ✓ Dynamic Charging Capability: Vehicles can receive power while in motion, extending driving range and reducing downtime.
- ✓ Safety: Reduced risk of electric shock due to the absence of exposed conductors.

DISADVANTAGES

- ✓ Dependence on Sunlight: Performance drops during cloudy or nighttime conditions.
- ✓ Lower Efficiency: Power losses occur due to coil misalignment, air gaps, and electromagnetic leakage.
- ✓ High Initial Cost: Installation of coils, inverters, solar panels, and electronics is expensive.
- ✓ Alignment Sensitivity: Misalignment between transmitter and receiver coils reduces efficiency.
- ✓ Limited Charging Speed: Wireless charging is generally slower than fast DC chargers.
- ✓ System Complexity: Multiple electronic components such as inverters, rectifiers, MPPT controllers, and resonant circuits increase system complexity.
- ✓ Space Requirements: Adequate area is needed for solar panel installation to generate sufficient power.

APPLICATIONS

- ✓ Electric Vehicles (EVs): Wireless charging for cars, bikes, and scooters without physical connectors.
- ✓ Public Charging Stations: Can be installed in parking lots, malls, offices, and bus terminals.
- ✓ Smart Roads / Highways: Supports dynamic charging as EVs move over embedded coils.
- ✓ Residential Charging: Home driveways or garages can implement clean, contactless charging.
- ✓ Industrial and Commercial Fleets: Automated charging for delivery vehicles, trolleys, and service fleets.

VII. FUTURE SCOPE

- ✓ Integration with Smart Roads and Infrastructure: Embedding dynamic wireless power transfer (DWPT) coils in highways and urban roads can enable continuous EV charging at higher power levels.
- ✓ Improved Wireless Power Transfer Efficiency: Advanced coil designs, resonance tuning, and alignment optimization can reduce losses and increase efficiency, even at higher vehicle speeds.
- ✓ Standardization and Commercial Adoption: Following emerging standards like SAE J2954 ensures interoperability, safety, and widespread deployment.
- ✓ Hybrid Energy Integration: Combining solar power with grid support or battery-to-grid (B2G) technologies can improve reliability and manage peak demand.
- ✓ Cost-Benefit and Environmental Analysis: Lifecycle assessments can guide policymakers and investors regarding installation cost, energy efficiency, and reduction in carbon emissions.
- ✓ Safety and Electromagnetic Compatibility (EMC): Ensuring human safety and compliance with EMC standards is essential before large-scale deployment.

✓ AI-Assisted Optimization and Control: Machine learning can dynamically optimize power transfer, vehicle alignment, and energy distribution to improve system performance and reduce losses.

VIII. CONCLUSION

The Solar Wireless Electric Vehicle Charging System offers a transformative solution for electric vehicle charging by enabling continuous, contactless energy transfer, eliminating the need for vehicles to stop. By combining solar energy harvesting with inductive wireless power transfer, the system facilitates efficient charging in both stationary and dynamic modes, improving overall usability for EV owners. This approach not only enhances user convenience but also supports sustainable energy utilization and reduces reliance on fossil fuels. Implementing such systems can effectively address critical challenges in electric mobility, including range anxiety and the limitations of existing charging infrastructure, while promoting the development of green and intelligent transportation networks. In summary, the project confirms that solar wireless EV charging is a practical, environmentally friendly, and scalable solution for meeting the growing energy demands of the electric vehicle market.

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