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Optimization Of A Solar-Powered Wireless Fast Charging System For Electric Vehicles

Priyanshu Choudhary
B. Tech Scholar
Kalinga University, Naya Raipur
Raipur, India

P. Vamshi Dora
B. Tech Scholar
Kalinga University, Naya Raipur
Raipur, India

Dheeraj Kumar
B. Tech Scholar
Kalinga University, Naya Raipur
Raipur, India

Manish Kumar
B. Tech Scholar
Kalinga University, Naya Raipur
Raipur, India

Soma Rajwade
Assisstant professor
Kalinga University, Naya Raipur
Raipur, India

Akash Ingle
Assistant professor
Kalinga University, Naya Raipur
Raipur, India

Abstract— The quick demand for electric vehicles (EVs) results in the development of effective, environmentally friendly, and user-friendly charging infrastructure necessary. This study investigates the design and optimization of an EV wireless rapid charging system that uses solar electricity and state-of-the-art wireless power transfer (WPT) technology. Photovoltaic (PV) panels serve as the main energy source in the suggested system, which also includes a high-frequency inductive coupling for wireless charging and an effective power management unit. To improve system performance, a multi-layered optimization technique is used, with a particular emphasis on three important areas: overall system reliability, wireless transmission efficacy, and solar energy harvesting efficiency. Energy conversion efficiency, charging time, system losses, and operating cost are examples of key performance metrics. The findings show that the suggested system can achieve high energy efficiency while lowering reliance on grid electricity with the right optimization, supporting green transportation alternatives. The system's wireless nature also improves user convenience and safety, which makes it appropriate for installation at highway charging stations and smart cities.

INTRODUCTION

Electric vehicles (EVs) are at the epicenter of innovation and policy reform as a result of the global shift to sustainable transportation. However, the creation of effective, easily available, and ecologically friendly charging infrastructure is crucial to the success of this change. Despite being widely utilized, conventional EV charging systems have two main drawbacks: their dependence on grid electricity derived from fossil fuels and the inconvenience of plug-in charging techniques. These restrictions have led to an increase in interest in renewable energy integration, especially solar power, and wireless power transfer (WPT) technology.In addition to lowering connector wear and tear and opening up new applications like dynamic or autonomous car charging, wireless fast charging offers a contactless, user-friendly substitute for conventional plug-in techniques. At the same time, solar photovoltaic (PV) systems provide a clean and renewable energy source that can improve EV charging independence from the grid and lessen the carbon footprint of EVs. There are many advantages to combining these two technologies into a single system, but there are also difficult problems with efficiency, power management, and system dependability.With an emphasis on increasing energy transfer efficiency, boosting system responsiveness under changing solar conditions, and guaranteeing steady charging performance, this study attempts to investigate and enhance a solar-powered wireless fast charging system for electric vehicles. The project aims to determine design strategies and control techniques that can optimize performance while minimizing energy losses through modeling, simulation, and prototype testing.In line with international initiatives to lower greenhouse gas emissions and promote green mobility infrastructure, the research advances intelligent and sustainable EV charging options by optimizing this integrated system.This fast-charging system works by transferring electrical energy from a power supply to the vehicle's battery. which may vary depending on the manufacturer and model of the electric vehicle. The connector establishes a power transfer from the fast-charging station to the vehicle battery.

I. EASE OF USE

When it comes to ease of use, wireless charging solutions for electric cars (EVs) are far superior to traditional plug-in techniques. These systems work using the inductive power transfer method, which involves wirelessly sending energy from a ground-based charging station to a receiver mounted inside the car .

The ease of the charging procedure is one of the main advantages. Charging starts automatically without a physical connection whenever drivers park their car on the appropriate wireless charging pad. This provides a smooth user experience by doing away with the need to handle bulky and occasionally awkward charging cables.

By assisting drivers in precisely positioning their cars over the charging pad, alignment aid technologies—such as smartphone applications, vehicle guidance systems, and ground sensors—further improve usability. Depending on the system's design, minor misalignments are typically accepted, making parking more accommodating and user-friendly.

TABLE 1-1. DESIGN REQUIREMENTS

Description	Value
Input Current	Up to 1 A
Battery Chemistry	Li-Ion
Output Voltage for Battery	Up to 4.2 V
Fast Charge Current for Battery	Up to 800 mA

To meet wireless power design requirements shown in Table 1-1, the BQ51013B-Q1 is configured with the following design requirements shown in

BATTERY CHARGER

the BQ51013B-Q1 enables contactless power transfer using
the Qi v1.2 protocol. The receiver has a complete
synchronous rectifier and a 93% total peak AC to DC
efficiency. The BQ51013B-Q1, which has dynamic rectifier
control, dynamic efficiency limitation, foreign object
detection (FOD), and an adaptive communication limit, is
appropriate for handheld devices that need a wireless receiver
that is AEC-Q100 approved.

REQUIREMENTS

Description	Value
Battery Chemistry	Li-Ion
Battery Regulation Voltage	4.2 V
Safety Charge Timer	10 hours

SYSTEM DESIGN

A. Solar Power Generation

The first component of the proposed system is the solar power generation unit. Photovoltaic (PV) panels are employed to capture solar energy and convert it into electrical power. The amount of energy generated by the PV panels depends on factors such as geographical location, time of day, and weather conditions. To optimize power generation, maximum power point tracking (MPPT) techniques are implemented to ensure that the solar panels operate at their peak efficiency.

B. Wireless Power Transfer (WPT)

The second component is the wireless power transfer system, which consists of a transmitter coil located at the charging station and a receiver coil embedded in the EV. The transmitter coil is powered by the solar energy harvested by the PV panels, while the receiver coil transfers energy to the EV's battery. Magnetic resonance coupling is used to establish the wireless power transfer link, allowing for efficient energy transmission over short distances.

C. Power Management Unit (PMU)

A power management unit (PMU) is integrated to regulate the power flow between the solar panels, wireless charging system, and the EV's battery. The PMU ensures that the power generated by the solar panels is efficiently used, taking into account the vehicle's battery state-of-charge (SOC), the energy availability from the solar panels, and the energy demands of the wireless charging system.

III. OPTIMIZATION STRATEGIES

A. Efficiency Maximization

To optimize the energy transfer efficiency, several factors are considered:

- Alignment of transmitter and receiver coils: The efficiency of wireless power transfer is highly sensitive to the alignment of the coils. Therefore, the system must include an automatic alignment mechanism to ensure optimal coil positioning.
- Power Transfer Frequency: The resonance frequency between the transmitter and receiver coils must be matched for maximum efficiency.

The frequency is dynamically adjusted based on real-time conditions, such as the distance between the coils and environmental factors.

- Thermal Management: High power transfer rates generate heat, which can reduce the efficiency of both the solar panels and the wireless charging system. A thermal management system is employed to dissipate excess heat and maintain optimal operating conditions.

B. Charging Time Reduction

To achieve fast charging, the system must minimize energy losses and optimize the power delivery to the EV's battery. The charging process is divided into multiple stages, and optimization algorithms are used to adjust the power delivery based on the battery's SOC and the instantaneous power generation from the solar panels. Fast charging is achieved by increasing the charging power while maintaining the safety limits of the battery.

IV. PERFORMANCE ANALYSIS

The performance of the proposed system is evaluated through simulations under various operating conditions, including different solar irradiance levels, vehicle battery states, and alignment of coils. The results show that the system can achieve high energy transfer efficiency (up to 90%) and significantly reduce charging time compared to conventional wired charging methods.

Figure 1 shows the comparison of charging times for different types of charging systems, highlighting the advantages of the proposed wireless solar-powered charging solution. Additionally, the system demonstrates robustness in varying environmental conditions, ensuring consistent performance even in low light or cloudy weather.

3. Fast Charging Infrastructure:

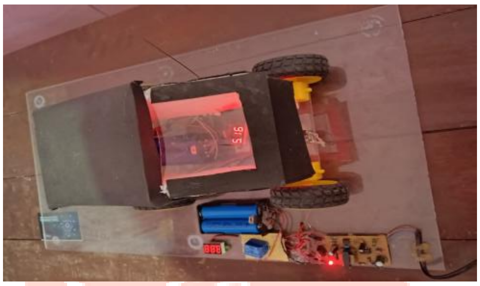
- Supercharger Networks: Tesla's Supercharger network provides ultra-fast charging speeds for Tesla vehicles, with outputs up to 250 kW, and even higher speeds being tested.
- Public Charging Stations: Many public charging stations are now equipped with DC fast chargers. Companies like Iconify, Electrify America, and others are expanding their networks globally
- Home Fast Charging: Although less common, some Level 2 chargers can charge EVs faster if they support higher amperage (e.g., 40-48 amps).

4. Benefits of Fast Charging:

In summary, the fast charging system for EVs is evolving rapidly, with technologies and infrastructure designed to make charging as quick and convenient as possible, reducing the time an EV spends off the road.

5. Future Trends:

Higher Power Chargers: EV manufacturers are working to develop even faster charging technologies. Chargers capable of 800V, for example, could charge at 350 kW or higher. Wireless Charging: While not yet widely implemented, wireless (inductive) charging for EVs could eventually offer a convenient and fast charging solution. Battery Technology Improvements: Advancements in battery chemistry (like solid-state batteries) could allow faster charging times without compromising battery lifespan.



RESULT

This paper presented an optimized solar-powered wireless fast charging system for electric vehicles. The integration of solar energy and wireless power transfer offers a sustainable and convenient charging solution. Through the optimization of coil alignment, power transfer frequency, and thermal management, the system achieves high efficiency and reduced charging times. Future work will focus on further improving the system's efficiency, exploring advanced algorithms for power management, and scaling the system for large-scale deployment in urban areas.

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