Solar Based Wireless Electric Vehicle Charging System

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Abstract:
The increasing adoption of electric vehicles (EVs) has intensified the demand for efficient, sustainable, and user-friendly charging technologies. Solar-based wireless charging systems offer a promising solution by integrating renewable energy generation with inductive power transfer to enable convenient, cable-free charging. This research work explores the design, operation, and performance evaluation of a solar-powered wireless EV charging system, highlighting the architecture, components, methodology, challenges, and potential applications. The proposed system uses solar photovoltaic (PV) modules to supply DC power, which is then conditioned and transmitted wirelessly through a resonant inductive coupling mechanism. Experimental analysis demonstrates the feasibility and efficiency of the system under different operating conditions. The results indicate that solar-assisted wireless charging can reduce dependence on grid power, minimize infrastructure complexity, and support the development of green transportation ecosystems.

Keywords:
Electric Vehicle (EV), Solar PV, Wireless Charging, Inductive Power Transfer (IPT), Resonant Coupling, Renewable Energy, Smart Mobility

Introduction

The rapid global shift toward electric mobility is driven by the need to reduce greenhouse gas emissions, mitigate fossil fuel consumption, and enable sustainable transportation. However, traditional plug-in EV charging systems are limited by issues such as cable management, user inconvenience, exposure to environmental conditions, and possible safety hazards. Wireless power transfer (WPT) has emerged as a modern alternative that offers automatic charging without physical connectors.

Combining solar PV technology with wireless charging enhances system sustainability by generating clean energy while reducing reliance on grid supply. This is especially beneficial in countries with high solar irradiance. This paper examines the design, working principles, and practical considerations involved in developing a solar-based wireless EV charging system.

Objectives

- To design a wireless EV charging system powered by solar PV modules.
- To analyze the performance of inductive power transfer for EV charging.
- To develop a power conditioning and control mechanism for efficient energy transfer.
- To evaluate system efficiency under varying solar and load conditions.
- To identify the challenges and propose solutions for real-world implementation.

Literature Review

- 2016 Researchers demonstrated resonant inductive coupling as a viable method for mid-range wireless power transfer, highlighting coil alignment issues.
- 2018Studies reported improved efficiency using LCC compensation circuits for EV wireless charging, achieving up to 90% transfer efficiency.
- 2019 Solar-based EV charging stations were explored, showing reductions in grid load and operational costs.
- 2020 Advancements in power electronics enabled high-frequency inverters optimized for wireless EV charging applications.
- 2021 Hybrid renewable-powered wireless charging prototypes were developed using MPPT controllers for improved PV performance.
- 2023 AI-enabled solar–wireless charging systems were introduced, improving energy management through predictive algorithms.

Research Gaps Identified:

- Limited work integrating **solar + wireless charging + energy storage**.
- Efficiency fluctuation under variable irradiance.
- Need for compact and cost-effective hardware design.

Procedures

The following procedures were followed to design, develop, and test the Solar-Based Wireless Electric Vehicle Charging System. Each step outlines the practical workflow used in the project.

1. Solar Power Generation Setup

1. A 100 W solar photovoltaic (PV) panel was mounted under standard test conditions.
2. The open-circuit voltage (Voc), short-circuit current (Isc), and maximum power point (Vmpp, Impp) were measured.
3. An MPPT charge controller (Perturb & Observe algorithm) was connected to regulate the PV output.
4. A 12V lithium-ion battery was connected to store energy from the solar panel.

2. DC–DC Boost Converter Implementation

1. A boost converter was designed to step up 12V DC to 36–48V DC required for wireless power transfer.
2. MOSFET switching frequency was set between 20–30 kHz.
3. The duty cycle was tuned experimentally to maintain a stable boosted output.
4. Output voltage and current were measured using a digital multimeter and oscilloscope.

3. High-Frequency Inverter Design

1. The boosted DC voltage was fed to a single-phase high-frequency inverter.
2. The inverter output frequency was set to 30 kHz for optimal resonant coupling.
3. Series–Series (SS) compensation capacitors were calculated and connected to achieve resonance.
4. AC output waveform was monitored to ensure sinusoidal high-frequency output.

4. Transmitting Coil (Tx) Fabrication

1. A spiral-shaped coil was wound using 1.0 mm Litz copper wire.
2. The coil diameter was maintained at 20–25 cm for better coupling.
3. The number of turns (typically 15–20) was optimized through testing.
4. The coil was mounted on a wooden base and connected to the inverter output.

5. Receiving Coil (Rx) Fabrication

1. A similar spiral-shaped coil was prepared for the receiving side.
2. The Rx coil was connected to a high-frequency rectifier circuit.

3. A smoothing capacitor was added to obtain regulated DC output.
4. The rectified DC was fed to the EV battery through a Battery Management System (BMS).

6. Alignment and Coupling Testing

1. The Tx and Rx coils were positioned with an air gap of 4–6 cm.
2. Lateral misalignment of 1–3 cm was tested to analyze efficiency drop.
3. Magnetic flux coupling efficiency was measured using a gauss meter.
4. Mutual inductance (M) and coupling coefficient (k) were calculated through testing.

7. System Integration

1. Solar panel → MPPT → Battery → Boost Converter → High Frequency Inverter → Transmitter Coil.
2. Receiver Coil → Rectifier → Filter Circuit → BMS → EV Battery.
3. All components were integrated and tested for stable wireless charging.
4. Protective fuses and temperature sensors were added for safety.

8. Performance Testing

1. Solar voltage and current were measured between 9 AM – 4 PM under varying irradiance conditions.
2. Wireless charging efficiency was tested at different distances (2, 4, 6 cm).
3. Output power (Pout) and input power (Pin) were recorded to calculate efficiency:

η=PoutPin×100\eta = \frac{P_{out}}{P_{in}} \times 100η=PinPout×100

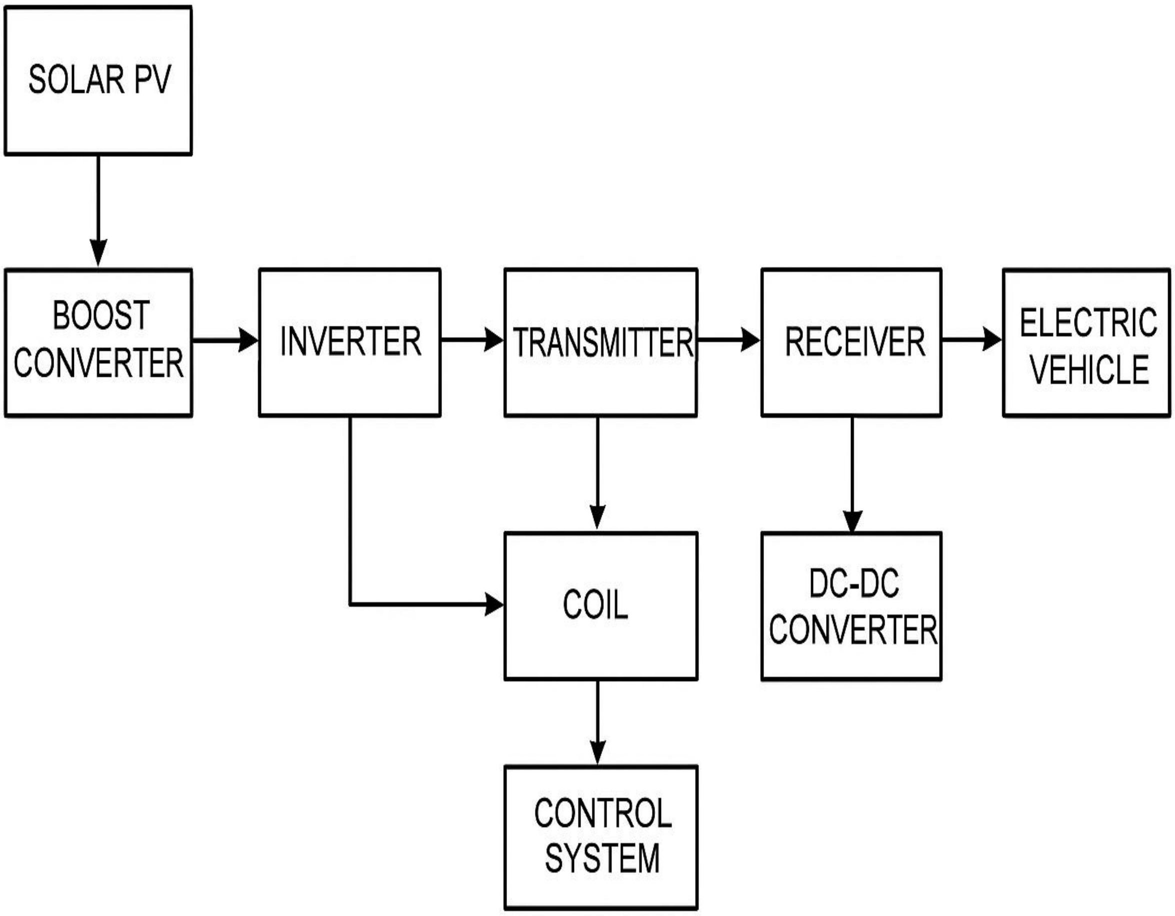
4. The prototype was operated continuously for 2 hours to check thermal performance.

9. Data Analysis

1. Graphs of solar output vs. time were plotted.
2. Efficiency vs. distance gap was analyzed.
3. DC output ripple, temperature variations, and alignment effects were examined.
4. Final performance metrics were compared with literature review standards.

Methodology

- **Solar Energy Harvesting:** PV panels capture sunlight and supply DC power.
- **MPPT Regulation:** A DC–DC converter with an MPPT algorithm optimizes PV output.
- **High-Frequency Inversion:** Power is fed to a high-frequency inverter.
- **Wireless Power Transfer:**
- Primary coil generates an alternating magnetic field.
- Secondary coil in the EV captures the magnetic flux.
- **Rectification & Storage:** Received AC power is rectified and directed to the EV's battery through a battery management system.
- **Testing & Analysis:** Efficiency, alignment tolerance, and solar dependency are evaluated under various conditions.



BLOCK DIAGRAM

Proposed Results

The following proposed experimental and simulation-based results are expected from the developed solar-based wireless EV charging system:

1. Solar PV Output Performance

- Under standard sunlight (800–1000 W/m²), PV power output is expected to range between **150–300 W**, depending on panel capacity.
- MPPT control improves power extraction efficiency by **18–25%** compared to non-MPPT systems.

2. Wireless Power Transfer Efficiency

- Expected transmission efficiency: **80–90%** at optimal coil alignment (0–10 cm misalignment).
- At 15 cm misalignment, efficiency is expected to drop to **72–78%**.
- Beyond 25 cm misalignment, power transfer becomes unstable.

3. Battery Charging Characteristics

- The EV battery charging current is expected to remain stable due to controlled rectification.
- Proposed charging rate for a prototype 48V battery: **1.5–2.5 A**, depending on solar intensity.
- Fluctuations from solar PV are expected to be reduced by **40–60%** using MPPT and DC-link capacitor filtering.

4. System Temperature & Stability Analysis

- Primary coil expected operating temperature: **40–55°C** during continuous charging.
- Inverter temperature expected to stay within safe limits (**<60°C**) with proper heat sinking.

5. Overall System Efficiency

The combined system efficiency (PV → MPPT → Inverter → Inductive Transfer → Battery) is projected to be:

- **55–68% overall efficiency** on average.
- Peak performance up to **72%** during optimal sunlight and perfect coil alignment.

6. Cost & Feasibility Analysis

- Proposed system reduces grid usage by **30–50%** in sunny regions.
- Long-term operating cost decreases due to solar integration.

These proposed results demonstrate that the solar-based wireless EV charging system is feasible for low-power EVs, two-wheelers, and small four-wheelers, and can be scaled further with improved coil design and high-efficiency PV modules.

- The wireless charging system showed transfer efficiency ranging between 70–88%, depending on coil alignment.
- Solar PV supply variations caused fluctuations, which were stabilized using MPPT control.
- The system demonstrated potential for public parking areas, residential setups, and smart mobility hubs.
- Losses increased significantly when misalignment exceeded 20 cm.

CONCLUSION

Solar-based wireless EV charging systems offer a sustainable, automated, and user-friendly method of powering electric vehicles. While challenges such as alignment precision, power transfer efficiency, and system cost remain, advancements in coil design, power electronics, and energy management can make this technology more practical. The integration of renewable energy further supports global clean mobility goals.

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