

Review on Efficient Wireless Power Transfer Technologies for Electric Vehicle Charging Applications

Swati Ramesh Sugandhe¹, Dr .A. V. Nikalje²

¹ PG scholar Department of Electronics and communication Engineering (VLSI Design), People's Education Society College of Engineering, Nagsenvana, Chhatrapati Sambhajanagar, India

²Associate professor Department of Electronics and communication Engineering (VLSI Design), People's Education Society College of Engineering, Nagsenvana, Chhatrapati Sambhajanagar, India

Abstract –

The rapid growth of electric vehicles (EVs) has increased the demand for efficient, reliable, and intelligent charging infrastructures. Wireless Power Transfer (WPT) technology has emerged as a promising solution for enhancing user convenience, reducing mechanical wear, and enabling automated charging systems. This review paper presents a comprehensive analysis of efficient wireless power transfer technologies for electric vehicle charging applications integrated with smart grid architectures. The study focuses on a hybrid smart grid system that combines conventional utility power supply (MSEB), solar photovoltaic energy, and wind energy sources to provide sustainable and uninterrupted power for EV charging.

The proposed system utilizes an ESP32 microcontroller as the central monitoring and control unit, enabling real-time acquisition of electrical parameters through DC voltage sensors connected to multiple energy sources. The wireless power transfer module consists of transmitter and receiver coils that facilitate contactless energy transfer to the electric vehicle battery. Relay-based switching is employed for intelligent source selection and load management based on the availability of renewable energy and grid power. Furthermore, a GSM communication module is incorporated to provide instant notifications and alerts regarding source status, charging conditions, voltage fluctuations, and system faults. A local display unit continuously presents real-time voltage measurements, source selection information, and charging status for user monitoring.

Key Words: Wireless Power Transfer, Electric Vehicle Charging, Smart Grid, ESP32, Solar Energy, Wind Energy, GSM Communication, IoT Monitoring, Renewable Energy Integration, DC Voltage Sensor, Inductive Power Transfer.

1. INTRODUCTION

The rapid growth of electric vehicles (EVs) has created a significant demand for efficient, reliable, and sustainable charging infrastructure. Conventional plug-in charging systems, although widely adopted, suffer from limitations such as cable wear, safety concerns, user inconvenience, and maintenance requirements. Wireless Power Transfer (WPT) technology has emerged as a promising alternative that enables contactless energy transmission between a transmitter and receiver coil, thereby improving charging convenience, safety, and system reliability. Recent advancements in inductive and resonant wireless power transfer techniques have demonstrated high power transfer efficiency, making WPT a viable solution for future EV charging applications.

Simultaneously, the integration of renewable energy resources into EV charging infrastructure has become an important research area due to increasing concerns regarding environmental sustainability and grid stability. Smart grid technologies facilitate the efficient management of multiple energy sources, including utility grid supply, solar photovoltaic systems, and wind energy systems, ensuring continuous power availability while reducing dependence on fossil-fuel-based electricity generation. The combination of wireless charging technology with renewable energy-powered smart grids can significantly enhance the efficiency, flexibility, and sustainability of EV charging stations.

This review paper presents a comprehensive analysis of efficient wireless power transfer technologies for electric vehicle charging applications and discusses their integration within smart grid environments. The proposed smart charging architecture utilizes an ESP32-based monitoring and control system capable of managing multiple energy sources, including Maharashtra State Electricity Board (MSEB) supply, solar energy, and wind energy. A DC voltage sensing

mechanism continuously measures real-time voltage levels from each energy source and transmits the data to the control unit for intelligent energy management.

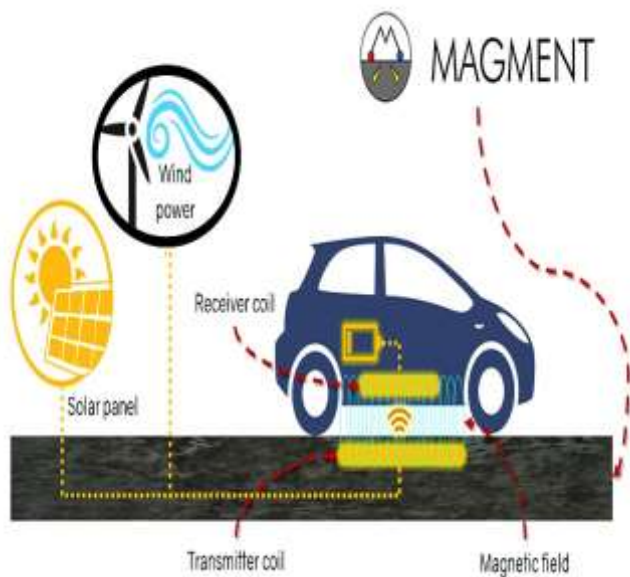


Fig1:- Introduction To Wireless Electric Vehicle Charging System

In the proposed system, wireless transmitter and receiver coils serve as the primary charging interface for EV battery charging. Relay-based switching is employed to select the most suitable power source based on availability and operating conditions. Furthermore, a GSM communication module provides instant notifications regarding charging status, source selection, system faults, and power availability. An LCD display offers real-time visualization of system parameters, including source voltage, charging status, and wireless power transfer operation.

The review explores various wireless power transfer methods, including inductive coupling, magnetic resonance coupling, capacitive power transfer, and hybrid techniques, highlighting their operating principles, efficiencies, advantages, challenges, and suitability for EV charging. Additionally, the paper discusses recent developments in smart grid integration, renewable energy utilization, IoT-based monitoring, and intelligent energy management systems. The findings provide valuable insights into the development of next-generation wireless EV charging stations that are energy-efficient, environmentally sustainable, and capable of supporting future smart transportation ecosystems.

This review evaluates various inductive and resonant wireless charging techniques, their efficiency, power transfer capabilities, alignment challenges, and integration with renewable energy-based smart grids. The analysis highlights the role of IoT-enabled monitoring, GSM-based communication, and intelligent energy management in improving system reliability and operational efficiency. The findings indicate that the integration of wireless EV charging with renewable energy resources and smart grid technologies can significantly enhance energy utilization, reduce carbon emissions, and support the development of sustainable transportation infrastructure. Future research directions involving artificial intelligence, predictive energy management, and vehicle-to-grid (V2G) communication are also discussed.

2. LITERATURE SURVEY

1. Xiaolin Mou, Daniel T. Gladwin, and Rui Zhao (2019)

Mou et al. presented a comprehensive survey on magnetic resonant coupling-based wireless power transfer (WPT) for electric vehicle charging. The authors analyzed coil structures, compensation topologies, power electronics interfaces, and efficiency optimization techniques. Their study highlighted resonant inductive coupling as one of the most promising methods for high-efficiency EV charging over moderate air gaps.

2. Alicia Triviño, José M. González-González, and José A. Aguado (2021)

The authors reviewed various wireless power transfer technologies applied to electric vehicles, including inductive power transfer (IPT), capacitive power transfer (CPT), and magnetic resonance coupling. They discussed system architectures, charging standards, and technical challenges such as coil misalignment and electromagnetic compatibility.

3. Emrullah Aydin, Mehmet Timur Aydemir, Ahmet Aksoz, Mohamed El Baghdadi, and Omar Hegazy (2022)

Aydin et al. reviewed inductive power transfer systems for EV charging applications. Their work focused on compensation networks, inverter topologies, coil design methods, and control techniques for improving efficiency and power transfer capability. The study

concluded that resonant inductive charging provides high reliability and user convenience for future EV infrastructure.

4. Vivian Sultan, Arun Aryal, Hao Chang, and Jiri Kral (2022)

The researchers conducted a systematic review on integrating electric vehicles into smart grids. Their work examined bidirectional energy flow, renewable energy integration, vehicle-to-grid (V2G) technology, demand response management, and intelligent energy scheduling for sustainable power systems.

5. Benitto Albert Rayan, Umashankar Subramaniam, and S. Balamurugan (2023)

The authors investigated wireless power transfer technologies for EVs with emphasis on coil structures, compensation topologies, safety issues, and renewable energy integration. They demonstrated that optimized coil geometry and resonance compensation significantly improve charging efficiency and system reliability.

6. Venkatesan Ramakrishnan, Dominic Savio, Chakravarthy Balaji, and Narayanamoorthi Rajamanickam (2024)

This study reviewed efficiency enhancement techniques in wireless EV charging systems. The authors evaluated resonant frequency tuning, advanced compensation circuits, power electronic converters, and alignment mechanisms. Their findings showed that optimized resonance and converter design can substantially improve charging efficiency.

7. Mohammad Rabih, Maen Takruri, Mohammad Al-Hattab, Amal A. Alnuaimi, and Mouza R. Bin Thaleth (2024)

The researchers presented a comprehensive survey of wireless charging technologies for electric vehicles. Their work analyzed the evolution of wireless charging systems, power transfer methods, standardization efforts, and future trends toward smart and automated charging infrastructures.

8. Avishek Munsii, Sushan Pradhan, and Kunwar Aditya (2024)

The authors reviewed control strategies for resonant inductive power transfer systems focusing on constant-current and constant-voltage charging. Their research highlighted the importance of advanced control algorithms for maintaining stable and efficient wireless charging under varying operating conditions.

9. Oghenevwaire Akpeghagha, C. M. Nwosu, and E. C. Ejiogu (2024)

The researchers studied the effect of resonance circuits on inductive EV charging systems. Their work demonstrated that resonance circuit design significantly affects power transfer efficiency, transmission distance, and voltage/current stresses in wireless charging systems.

10. Bachhati Latha, Mohammed Mujahid Irfan, Butukuri Koti Reddy, and C. H. Hussaian Basha (2025)

The authors presented an updated analysis of compensation topologies used in wireless EV charging systems. Their review compared series-series, series-parallel, parallel-series, and LCC compensation networks, concluding that proper topology selection enhances charging efficiency and system robustness.

Research Gap

Most existing studies focus on wireless power transfer efficiency, compensation topologies, coil structures, and charging control strategies. However, limited work has been reported on integrating:

- ESP32-based IoT monitoring
- Smart grid operation with MSEB utility supply
- Hybrid renewable energy sources (Solar + Wind)
- Real-time DC voltage monitoring
- GSM-based notification systems
- Automatic relay-based source selection
- Display-based user notification

Therefore, the proposed system aims to develop a **Smart Grid-Based Wireless EV Charging System** using ESP32, solar energy, wind energy, MSEB supply, GSM

communication, and IoT monitoring for efficient and intelligent power management.

3. METHODOLOGY

A. Proposed System Overview

The proposed system presents a smart-grid-enabled wireless power transfer (WPT) platform for electric vehicle charging by integrating multiple energy sources, including utility grid supply (MSEB), solar photovoltaic generation, and wind energy systems. An ESP32 microcontroller acts as the central control unit to monitor, manage, and optimize energy flow from available sources to the wireless charging station.

The system continuously measures real-time voltage levels from renewable and grid sources using DC voltage sensors. Based on source availability and voltage conditions, the ESP32 selects the most suitable energy source and controls the charging operation through relay-based switching. The wireless power transfer section consists of a transmitter coil connected to the selected power source and a receiver coil connected to the EV battery load.

Additionally, a GSM module is integrated to provide remote notifications regarding charging status, source availability, and fault conditions. An LCD display provides local monitoring of system parameters and charging information.

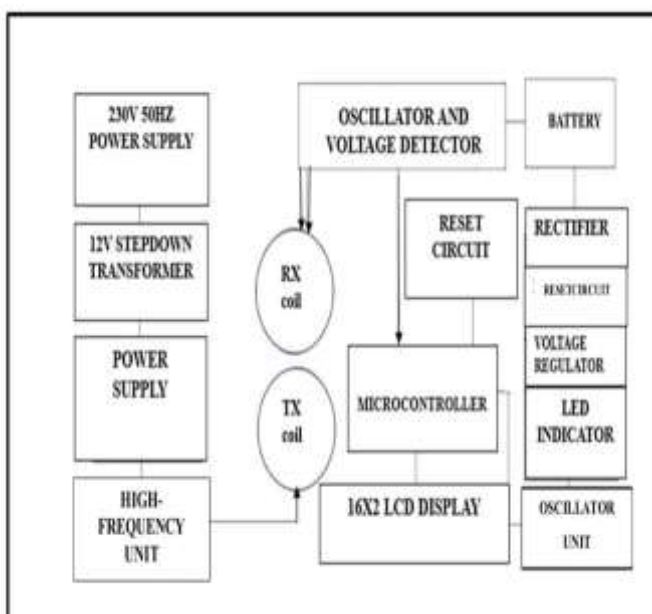


Fig -2: Proposed Block Diagram

B. System Architecture

The proposed smart charging system consists of the following major subsystems:

1. Utility Grid Supply (MSEB)
2. Solar Photovoltaic Source
3. Wind Energy Source
4. ESP32-Based Energy Management Controller
5. DC Voltage Monitoring Unit
6. Relay-Based Source Selection Circuit
7. Wireless Power Transfer Transmitter Coil
8. Wireless Power Transfer Receiver Coil
9. GSM Communication Module
10. LCD Display Unit

The ESP32 receives voltage data from each source and executes an energy management algorithm to determine the optimal charging source.

C. Energy Source Monitoring

Voltage sensors are connected to the output of the solar panel, wind turbine rectifier, and MSEB DC conversion unit. The measured voltages are continuously sampled by the ESP32 analog input channels.

The controller compares the available voltage levels with predefined threshold values to identify:

- Active energy source
- Available charging power
- Renewable energy contribution
- Source failure conditions

This real-time monitoring enables intelligent source selection and efficient energy utilization.

D. Smart Grid Energy Management Strategy

The smart grid controller follows a priority-based energy allocation algorithm:

Priority 1: Solar Energy

When sufficient solar power is available, the charging system utilizes solar energy as the primary source.

Priority 2: Wind Energy

If solar energy is unavailable or insufficient, wind energy is selected.

Priority 3: Utility Grid (MSEB)

When renewable energy generation falls below the required charging demand, the utility grid acts as a backup source.

The ESP32 automatically switches between energy sources using relays while ensuring uninterrupted charging operation.

E. Wireless Power Transfer Implementation

The wireless charging unit consists of:

- High-frequency transmitter coil
- Compensation network
- Air gap coupling section
- Receiver coil
- Rectifier and battery charging circuit

The selected energy source energizes the transmitter coil through an inverter stage. Magnetic coupling transfers energy wirelessly to the receiver coil mounted on the EV charging side. The receiver converts the induced AC power into DC power suitable for battery charging.

F. Relay-Based Load Management

Electromechanical relays are used to:

- Connect the selected energy source
- Enable or disable wireless charging
- Isolate faulty energy sources
- Protect the charging system during abnormal conditions

The relay operation is controlled by ESP32 GPIO outputs according to source availability and charging requirements.

G. IoT Monitoring and Communication

The ESP32 transmits system parameters to an IoT platform through Wi-Fi connectivity. The monitored parameters include:

- Solar voltage
- Wind voltage
- Grid voltage
- Charging voltage
- Charging status
- Source selection status

The cloud platform provides real-time visualization and historical analysis of charging performance.

H. GSM-Based Notification System

A GSM module is employed to provide remote alerts to users and operators. Notifications include:

- Charging started
- Charging completed
- Solar source active
- Wind source active
- Grid source active
- Low voltage warning
- Source failure detection

SMS-based communication ensures reliable monitoring even in the absence of internet connectivity.

I. LCD-Based Local Monitoring

A 16×2 or 20×4 LCD display is used to display real-time system information such as:

- Solar Voltage
- Wind Voltage
- Grid Voltage
- Selected Energy Source
- Charging Status
- Wireless Power Transfer Status

This enables local supervision of system operation without requiring cloud access.

J. Performance Evaluation Parameters

The performance of the proposed system is evaluated using the following metrics:

- Wireless Power Transfer Efficiency (%)
- Source Utilization Ratio
- Renewable Energy Contribution (%)
- Charging Time
- Relay Switching Response
- Voltage Stability
- IoT Communication Reliability
- GSM Alert Response Time

These parameters provide a comprehensive assessment of the effectiveness of smart-grid-assisted wireless EV charging using renewable energy resources.

4. CONCLUSIONS

Furthermore, this study proposes a smart grid-based wireless EV charging framework that integrates conventional utility power supply (MSEB) with renewable energy sources such as solar and wind energy. The proposed system utilizes an ESP32 microcontroller for intelligent monitoring and control, while DC voltage sensors continuously measure real-time voltage levels from multiple energy sources. Based on source availability and voltage conditions, relay-based switching enables optimal energy management and efficient power delivery to the wireless transmitter coil. The receiver coil acts as the charging load, demonstrating contactless energy transfer for EV charging applications.

The integration of GSM communication and display modules enhances system reliability by providing real-time notifications, operational status updates, and fault alerts to users. The smart grid architecture improves energy utilization, reduces dependency on conventional power sources, and supports sustainable transportation infrastructure. The combination of renewable energy integration, IoT-enabled monitoring, wireless charging technology, and intelligent source management offers a practical solution for future smart EV charging stations.

Future research can focus on improving wireless power transfer efficiency, implementing artificial intelligence-based energy management algorithms, vehicle-to-grid (V2G) integration, and developing adaptive charging strategies to further enhance the performance and scalability of smart wireless EV charging systems. Such advancements will play a crucial role in achieving energy-efficient, environmentally friendly, and intelligent transportation ecosystems.

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