

Powering EVs in Motion: Dynamic Inductive Charging Technology

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Abstract - Electric Vehicles (EVs) are emerging as a sustainable alternative to conventional vehicles; however, long charging time and limited infrastructure remain major challenges. This paper presents a Dynamic Inductive Charging System that enables EVs to charge wirelessly while in motion using inductive power transfer (IPT). The proposed system consists of road-embedded transmitter coils and vehicle-mounted receiver coils.

A solar-powered energy source is used to enhance sustainability, while an ESP32 microcontroller is used for system control, monitoring, and automation. Sensors such as IR and voltage sensors ensure efficient and safe operation. Experimental results demonstrate the feasibility of continuous power transfer, reduced range anxiety, and improved energy efficiency. The system provides a scalable solution for future smart transportation infrastructure.

Key Words: Electric Vehicles, Wireless Power Transfer, Dynamic Charging, ESP32, Inductive Coupling, Renewable Energy

1. INTRODUCTION

Electric vehicles have become one of the most important technologies in the transition toward clean transportation because they can reduce the direct emissions associated with conventional internal combustion vehicles. However, the convenience of EV ownership depends not only on vehicle performance but also on the availability of efficient and user-friendly charging infrastructure. Long charging times and dependence on fixed plug-in stations remain major concerns for many users, especially in dense urban regions and for vehicles that require frequent operation.

Wireless power transfer has emerged as a useful alternative to conventional wired charging because it enables electrical energy transfer without direct physical contact. In an inductive wireless charging system, an alternating magnetic field is created by a transmitter coil and is captured by a receiver coil placed within the effective magnetic field region. This method improves user convenience, reduces connector wear, and can enhance safety by eliminating exposed conductive charging interfaces.

Dynamic wireless charging extends the same concept further by energizing sections of roadway or a charging path so that power can be delivered while a vehicle is moving or while it is positioned above active charging segments. Such systems are attractive because they may reduce battery size requirements, lower charging downtime, and improve vehicle range utilization. Even though large-scale deployment remains expensive and technically demanding, the concept has strong research relevance for future transportation systems.

The present study focuses on a prototype-level implementation of a solar-assisted dynamic inductive charging system. Instead

of claiming a full-scale commercial charging lane, the work demonstrates the basic operating principle using a low-power model that combines renewable energy support, embedded control, and inductive energy transfer. The use of solar energy is intended to improve sustainability, while the ESP32-based control section adds automation and monitoring capability to the system.

This project aims to demonstrate the feasibility of dynamic inductive charging at a prototype level by analyzing key parameters such as coil design, coupling efficiency, air gap, and power transfer capability. The system also evaluates performance under both static and dynamic conditions, providing insights into real-world implementation challenges.

2. OBJECTIVES

A. To design a wireless power transfer system

Implement inductive coupling between the transmitter coil (TX) and receiver coil (RX) for contactless power transfer.

B. To utilize renewable energy for charging

"Use solar energy as the primary power source and store the generated energy in a battery."

C. To control and monitor the charging process using ESP32

Employ the ESP32 microcontroller to process input signals, control relays, and manage system functions.

D. To monitor voltage levels for safety and efficiency

Use a voltage sensor to measure and send real-time battery or load voltage data to the ESP32 for regulation.

3. LITERATURE SURVEY

Wireless power transfer for EV charging has been studied through both static and dynamic charging approaches. Static wireless charging is typically used when the vehicle is parked, whereas dynamic charging aims to transfer energy while the vehicle is in motion or while it passes over an energized path. Review literature identifies inductive charging as one of the most practical methods for vehicle applications due to its relatively good safety, maturity, and compatibility with short-distance power transfer

Early research in wireless power transfer primarily focused on **Inductive Power Transfer (IPT)** systems for short-range

energy transfer. These systems used electromagnetic induction between two coils to transfer power without physical contact. Studies conducted by Budhia et al. (2011) and Covic & Boys (2013) demonstrated the feasibility of IPT systems for electric vehicle charging with improved efficiency and safety. However, these systems were limited to **static charging applications**, where the vehicle remains stationary during charging.

With advancements in technology, researchers began exploring **dynamic wireless power transfer (DWPT)** systems, where energy can be transferred while the vehicle is in motion. Stamati and Bauer (2013) proposed a **capacitive power transfer (CPT)**-based dynamic charging system, which showed the possibility of continuous charging on roads. However, CPT systems faced challenges such as lower efficiency and higher sensitivity to environmental conditions compared to inductive systems.

Later, Zaheer et al. (2017) introduced a **high-power IPT system** capable of delivering up to 15 kW for electric vehicles in motion. This system used a **Double-D coil structure** and segmented track energization to improve efficiency and safety. Their work significantly contributed to the practical implementation of dynamic charging systems but highlighted the issue of **high installation cost and infrastructure complexity**.

Research by Zhao et al. (2017) focused on **misalignment-tolerant resonant topologies**, such as LCC compensation networks. These systems were designed to maintain stable power transfer even when the alignment between transmitter and receiver coils is not perfect. Misalignment is one of the major challenges in real-world applications, and this research improved system reliability under dynamic conditions.

Further studies by Heebl et al. (2014) compared **frequency tuning and impedance tuning techniques** in wireless power systems. The results showed that impedance tuning provides better adaptability to varying distances and load conditions, making it more suitable for dynamic environments. Similarly, Li et al. (2015) introduced the **Maximum Efficiency Point Tracking (MEPT)** algorithm, which dynamically adjusts system parameters to maintain high efficiency under changing conditions.

Recent research (2021–2025) has focused on improving system performance using **simulation tools, artificial intelligence, and IoT technologies**. Razu et al. (2021) used ANSYS Maxwell simulations to optimize coil design and achieved efficiency levels of up to 92% under ideal conditions. Modern systems also incorporate **AI-based alignment correction**, real-time monitoring, and smart control to enhance efficiency and safety.

In addition, researchers have explored the integration of **renewable energy sources**, such as solar power, into wireless charging systems. Solar-powered charging infrastructure

reduces dependency on grid electricity and supports sustainable energy utilization. Studies show that combining solar energy with wireless power transfer can significantly reduce environmental impact and operational costs.

Sr. No.	Author / Year	Work	Key Features	Limitations
1	Stamati (2013)	Capacitive Power Transfer (CPT) Charging	Contactless charging	Low efficiency
2	Zaheer (2017)	Inductive Power Transfer (IPT) System	High power transfer	Costly
3	Razu (2021)	Coil Simulation	92% efficiency	Simulation only
4	Zhao (2017)	Resonant Topology	Misalignment tolerant	Complex design
5	Recent (2025)	AI-based DWPT	Smart monitoring	High cost

Table -1: Literature Survey

4. KEY FINDINGS

The key findings of the proposed Solar-Integrated Wireless EV Charging System are derived from the analysis, design, and implementation of the prototype. These findings highlight the effectiveness, performance, and improvements achieved by integrating solar energy, wireless power transfer, and ESP32-based control into a single platform.

A. Renewable Energy Utilization

The system effectively uses solar energy as the primary power source, reducing dependence on the electrical grid. The solar panel charges the 12V battery, which stores energy for continuous operation and makes the system suitable for off-grid charging applications. This improves sustainability and lowers operating cost.

B. Efficient Wireless Power Transfer

The prototype successfully transfers power wirelessly from the transmitter coil to the receiver coil through electromagnetic induction. The use of a pulse generator and copper coils enables contactless charging, eliminating the need for physical connectors. This makes the system convenient, safe, and practical for EV charging applications.

C. Automated Control Using ESP32

The ESP32 microcontroller plays a major role in controlling and monitoring the system. It receives input from the IR sensor,

operates the relay module, and displays system status on the 16×2 LCD

D. Stable Receiver-Side Charging

At the receiver end, the induced AC voltage is converted into DC using a bridge rectifier, filter capacitor, and voltage regulator. This ensures a smooth and regulated output suitable for battery charging. The circuit provides stable charging performance and protects the battery from voltage fluctuations.

E. Practical and Scalable Design

The overall system is compact, low-cost, and suitable for small-scale EV charging demonstrations. The integration of solar power and wireless charging makes it a promising solution for future sustainable transportation infrastructure. With further improvements in power capacity and efficiency, the system can be scaled for larger EV applications.

F. Improved Safety Features

The system enhances safety by using an IR sensor and relay-based control to activate the transmitter coil only when an object is detected. This reduces unnecessary power loss and helps prevent overheating or accidental operation. As a result, the charging process becomes safer and more reliable.

G. Real-Time Monitoring Capability

The inclusion of the LCD display and WiFi-enabled ESP32 allows real-time monitoring of system parameters. Important information such as system status, charging condition, and activation state can be displayed or transmitted wirelessly. This makes the system more user-friendly and suitable for smart charging applications.

H. Reduced Manual Intervention

The charging process operates automatically once the vehicle is positioned properly. Users do not need to plug or unplug cables, which simplifies the charging experience. This improves convenience and supports the development of contactless charging infrastructure.

I. Environmentally Friendly Operation

Since the system is powered by solar energy, it reduces reliance on fossil-fuel-based electricity. This lowers the carbon footprint of EV charging and supports clean energy usage. The project therefore contributes to sustainable and eco-friendly transportation.

5. SYSTEM ARCHITECTURE

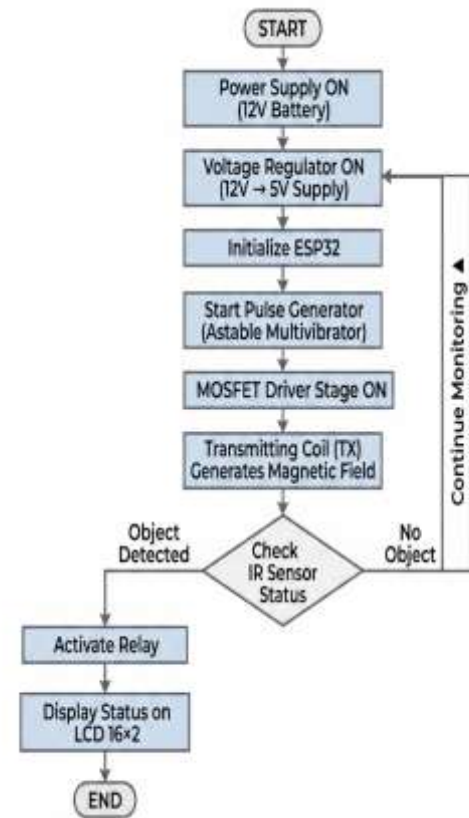
The system design of the proposed Solar-Integrated Wireless EV Charging System is based on the integration of renewable energy generation, energy storage, wireless power transfer, and intelligent control. The complete setup is designed to charge an EV battery without physical contact while maintaining safe, automated, and efficient operation. The system is divided into two main sections: the transmitter side and the receiver side.

A. Power Generation Unit

The system starts with a solar panel that acts as the primary power source. The solar panel converts sunlight into electrical energy, which is used to charge a 12V rechargeable battery. This battery stores energy and supplies power to the entire setup when sunlight is unavailable. The use of solar energy makes the system independent of the grid and environmentally friendly.

B. Energy Storage Unit

A 12V rechargeable battery is used as the main energy storage component of the system. It stores the generated solar power and provides a stable supply to the pulse generator and control circuit. This ensures continuous operation of the charging system even during low solar radiation or nighttime conditions. The battery also helps maintain consistent performance during testing.



C. Pulse Generation Unit

The stored DC power is fed to the pulse generator module, which produces high-frequency pulses required for wireless energy transfer. These pulses are converted into an alternating signal that drives the transmitter coil. The high-frequency operation improves the efficiency of magnetic coupling between the transmitting and receiving coils.

D. Transmitter Coil Section

The copper transmitter coil generates an alternating magnetic field when energized by the pulse generator. This magnetic field carries power across a short distance to the receiver coil. The coil arrangement is a key part of the wireless charging process and is designed to maximize power transfer while minimizing energy loss.

E. Control and Monitoring Unit

The ESP32 microcontroller acts as the central control unit of the system. It receives input from the IR sensor, controls the relay module, and manages system operation automatically. The 16×2 LCD displays the working status of the system, while the WiFi module enables remote communication and monitoring. A voltage regulator supplies a stable 3.3V to the ESP32 for proper functioning.

F. Receiver Coil Section

The receiver coil is placed near the transmitter coil to capture the alternating magnetic field. Due to electromagnetic

induction, an AC voltage is induced in the receiver coil. This induced voltage forms the input for the receiver-side power conversion circuit.

G. Rectification and Filtering Unit

The induced AC output from the receiver coil is first passed through a bridge rectifier, which converts it into pulsating DC. A filter capacitor is then used to smooth the output by reducing ripple voltage. This step is important for producing stable DC power suitable for charging the battery.

H. Voltage Regulation and Charging Unit

After filtering, the DC voltage is passed through a voltage regulator to obtain a constant output voltage. This regulated DC is then supplied to the battery for safe charging. The charging unit ensures that the battery receives a stable and suitable voltage level, protecting it from overvoltage and fluctuations.

5. RESULT & DISCUSSIONS

The implementation of the proposed Solar-Integrated Wireless EV Charging System produced satisfactory results during testing. The system was able to capture solar energy, store it in the battery, generate high-frequency pulses, and transfer power wirelessly to the receiver side. The results confirm that the designed prototype is functional, automated, and suitable for small-scale EV charging applications.

A. Successful Solar Energy Conversion

The solar panel successfully converted sunlight into electrical energy and charged the 12V battery. This proves that the system can operate using renewable energy without depending on the grid. The battery storage also ensured that the system could continue working when solar input was reduced.

B. Effective Wireless Power Transfer

The transmitter coil generated an alternating magnetic field that was successfully received by the receiver coil. The received output confirmed that electromagnetic induction was achieved effectively over a short distance. This demonstrates that wireless charging is possible with the designed coil arrangement and pulse generator.

C. Stable Output at Receiver Side

The bridge rectifier, filter capacitor, and voltage regulator successfully converted the induced AC voltage into a stable DC output. The output was suitable for battery charging and showed that the receiver-side power conditioning circuit worked properly. This improved the reliability of the charging process.

D. Automatic System Operation

The IR sensor and relay module allowed automatic switching of the transmitter coil based on object detection. When the vehicle or target object was placed in the charging zone, the system activated without manual control. This made the charging process more efficient and user-friendly.

E. ESP32-Based Monitoring

The ESP32 microcontroller successfully controlled the overall system and displayed information on the LCD. The WiFi capability also made the system suitable for remote monitoring and smart charging applications. This added intelligence and flexibility to the prototype.

F. Discussion of Performance

The results show that the combination of solar energy, wireless charging, and automation is practical for prototype-level EV charging. However, the system performance depends on sunlight availability, coil alignment, and distance between transmitter and receiver coils. Any misalignment or increase in gap may reduce efficiency and output voltage.

G. Limitations Observed

Although the prototype worked properly, the output power is limited by the size of the solar panel, battery capacity, and coil design. The system is more suitable for small-scale demonstrations rather than full-size EV charging at present. Future improvements in coil design, converter efficiency, and energy storage can help increase performance.

H. Overall Conclusion from Results

Overall, the experimental results confirm that the proposed system is feasible, sustainable, and effective for wireless EV charging using solar energy. The integration of renewable power and automated control makes it a promising solution for future green transportation systems.

I. Performance Analysis

The transmitter coil was supplied with 12 V and 200 mA. Wireless power transfer produced an output of 6 V and 140 mA at the transmitter side and 6 V and 50 mA at the receiver side. The input power was calculated as 2.4 W, while the received power was 0.3 W, resulting in an overall efficiency of approximately 12.5%.

The battery capacity used in the prototype was 1000 mAh. With a charging current of 140 mA, the estimated charging time was 7.14 hours. During vehicle operation, the wireless charging system provided an additional 280 mAh charge over 2 hours, increasing the effective battery capacity to 1280 mAh. As a result, the vehicle operating time improved from 2 hours to 2.56 hours, representing an increase of approximately 28%.

Sr. No.	Parameter	Value
1.	Input Power	2.4W
2.	Received Power	0.3W
3.	Overall Efficiency	12.5%
4.	Battery Capacity	1000 mAh
5.	Charging Time	7.14 Hours
6.	Vehicle Runtime	2 Hours
7.	Runtime with Charging	2.56 Hours
8.	Runtime Improvement	28%

6. FUTURE SCOPE

A. Advanced Coil Design and Efficiency Improvement

Future work can focus on improving the design of transmitter and receiver coils to enhance coupling efficiency. Techniques such as multi-layer coils, optimized coil geometry can be used to reduce power losses. Additionally, resonance-based

compensation methods (LCC, Series-Series, etc.) can be implemented to achieve higher efficiency over larger distances.

B. High-Power Dynamic Charging Systems

The current prototype operates at a low power level. Future systems can be scaled to support high-power applications (in kW range) suitable for real electric vehicles. This includes the development of robust inverter circuits, high-power semiconductor devices, and advanced thermal management systems.

C. AI-Based Alignment and Control

One of the major challenges in wireless charging is coil misalignment. Artificial Intelligence (AI) and machine learning algorithms can be used to predict and correct misalignment in real time. Smart control systems can dynamically adjust frequency, voltage, and current to maintain optimal power transfer.

D. IoT-Based Monitoring and Smart Control

The system can be integrated with Internet of Things (IoT) platforms for remote monitoring and control. Data such as voltage, current, temperature, and efficiency can be transmitted to cloud servers, enabling real-time analysis, predictive maintenance, and user notifications via mobile applications.

E. Smart Road Infrastructure

Future implementation can involve embedding transmitter coils beneath highways and urban roads to create dedicated dynamic charging lanes. These smart roads can automatically activate only when a vehicle is detected, improving energy efficiency and reducing operational costs.

F. Integration with Smart Grid Systems

The system can be connected to smart grids for efficient energy distribution and load management. Renewable energy sources such as solar and wind can be integrated into the grid, enabling sustainable and decentralized energy systems for EV charging.

G. Cost Reduction and Commercial Feasibility

One of the key challenges is the high installation cost of dynamic charging infrastructure. Future work can focus on developing low-cost materials, simplified circuit designs, and scalable manufacturing techniques to make the system economically viable.

7. CONCLUSION

The Solar-Powered Wireless Charging System using ESP32 successfully demonstrates the integration of renewable energy and wireless power transfer technology. The system efficiently converts solar energy into electrical power, which is stored in a battery and used to charge electronic devices wirelessly. By incorporating sensors such as the IR sensor and voltage sensor, the system ensures intelligent operation by detecting the presence of a device and monitoring the voltage levels to maintain safe and efficient charging. The ESP32 microcontroller plays a key role in processing sensor data and controlling various modules like the relay and LCD display.

The experimental results confirm that the proposed design is capable of achieving stable wireless charging within a limited

range while utilizing clean and renewable solar energy. This makes the project an eco-friendly and innovative solution that reduces dependency on conventional wired chargers and fossil fuels. Although there are challenges such as alignment accuracy, energy losses, and environmental dependence, the system shows great potential for improvement through enhanced coil design, IoT integration, and energy optimization.

In conclusion, this project represents a step forward toward sustainable, efficient, and user-friendly charging technology. With further development, it can be implemented in smart cities, remote areas, and public charging infrastructures, contributing to a greener and more connected future.

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