Revolutionizing EV Charging: the Future of Wireless Power Transfer

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Abstract

This paper aims to implement a wireless charging system that transmits power through an electromagnetic field, addressing the pressing need for efficient battery charging in electric vehicles (EVs). As EVs present a sustainable alternative to reduce pollution, enhancing the charging process is essential for greater reliability and user convenience. Wireless Power Transfer (WPT) utilizing resonant inductive coupling has evolved over the past 30 years, resulting in significant advancements in technology, particularly regarding power levels suitable for charging EVs in both stationary and dynamic scenarios. This paper reviews the latest developments in WPT for wireless EV charging, highlighting its potential to simplify the charging process. With battery technology no longer viewed as the sole barrier to widespread EV adoption, this research aims to inspire further innovation in WPT and foster the continued growth of electric vehicles.

Keywords: Wireless Power Transfer (WPT), Electric Vehicles (EVs), Electromagnetic Field, Battery Charging, Inductive Coupling

I. INTRODUCTION

The advent of electric vehicles (EVs) marks a pivotal shift in transportation, aimed at mitigating the adverse environmental impacts associated with internal combustion engines. As the global vehicle population grows, the resultant increase in pollution underscores the urgent need for pollution-free transportation solutions. With escalating greenhouse gas emissions and dwindling petroleum resources, the focus on efficient electric vehicle utilization and portable recharging solutions becomes increasingly critical. Unlike conventional vehicles reliant on petroleum, electric vehicles offer minimal pollution. However, one major challenge remains: the effective charging of EV batteries. Wireless power transfer technology, particularly dynamic charging systems, offers a promising solution by enabling charging while the vehicle is in motion. This technology utilizes inductive power transfer, allowing energy to be transmitted from a stationary source to a vehicle through transformer windings. Implementing such dynamic charging stations along replanted routes, such as at toll gates, traffic signals, and congested areas, could significantly enhance the practicality and efficiency of electric vehicles for longer distances. This paper explores a model for wireless power transfer for electric vehicles, focusing on dynamic charging through emitter coils embedded in roadways and receiving coils installed on vehicles, which collectively aim to increase vehicle range and operational efficiency.

II. OVERALL SYSTEM AND THEORY

A. Magnetic formulation

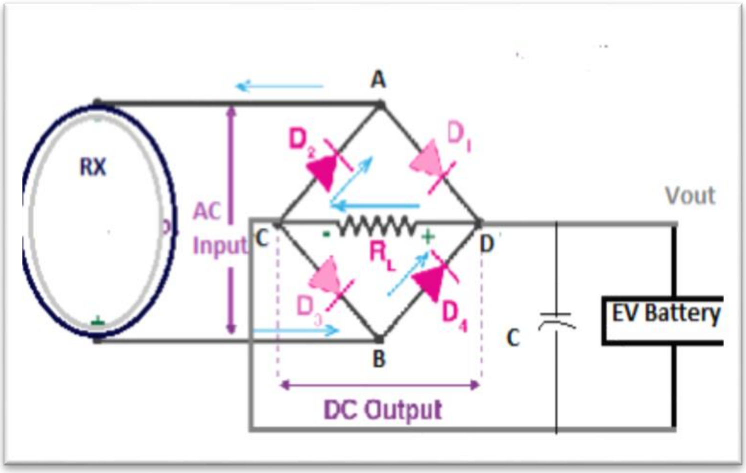

Fig1: Step-down transformer circuit

The Fig1 diagram shows a rectifying bridge shows that when an AC signal is applied, terminal A becomes positive during the positive half-cycle, while terminal B becomes negative. This configuration forward-biases diodes D1 and D3, while diodes D2 and D4 are reverse-biased. Conversely, during the negative half-cycle, terminal B becomes positive and terminal A negative, which forward-biases diodes D2 and D4, while diodes D1 and D3 are reverse-biased. As a result, the current flows through the load resistor in the same direction during both half-cycles. The output DC signal can be entirely positive or negative; in this case, it is entirely positive. If the diodes were reversed, the output would yield a complete negative DC voltage. Thus, a bridge rectifier facilitates electric current flow during both positive and negative half-cycles of the input AC signal.

B. Step-down transformer circuit

In a bridge rectifier circuit, the application of an alternating current (AC) signal leads to the conversion of AC to direct current (DC) through a diode arrangement where diodes D1 and D3 conduct during the positive half-cycle, and diodes D2 and D4 conduct during the negative half-cycle. This ensures a unidirectional current flow through the load resistor, thus generating a pulsating DC output. To improve the quality of this rectified DC voltage, a capacitor is often connected at the output. The capacitor plays a critical role in smoothing the rectified DC voltage by charging during the peaks of the waveform and discharging when the voltage falls, thereby reducing ripple and stabilizing the output. This smoothing action significantly enhances the DC output by minimizing voltage fluctuations that could otherwise affect the performance of sensitive electronic circuits. Although current flow through conductors in the rectifier circuit does create a small magnetic field, the impact of capacitors on magnetic effects is minimal and negligible. Capacitors primarily function to maintain a more consistent DC voltage across the load, thereby optimizing performance and reliability without substantial magnetic interference. Thus, the addition of a capacitor to a bridge rectifier circuit effectively improves the stability of the DC output, ensuring a cleaner and more consistent voltage supply for electronic applications.

III. ANALYSIS

A. Magnetic Field Formulation

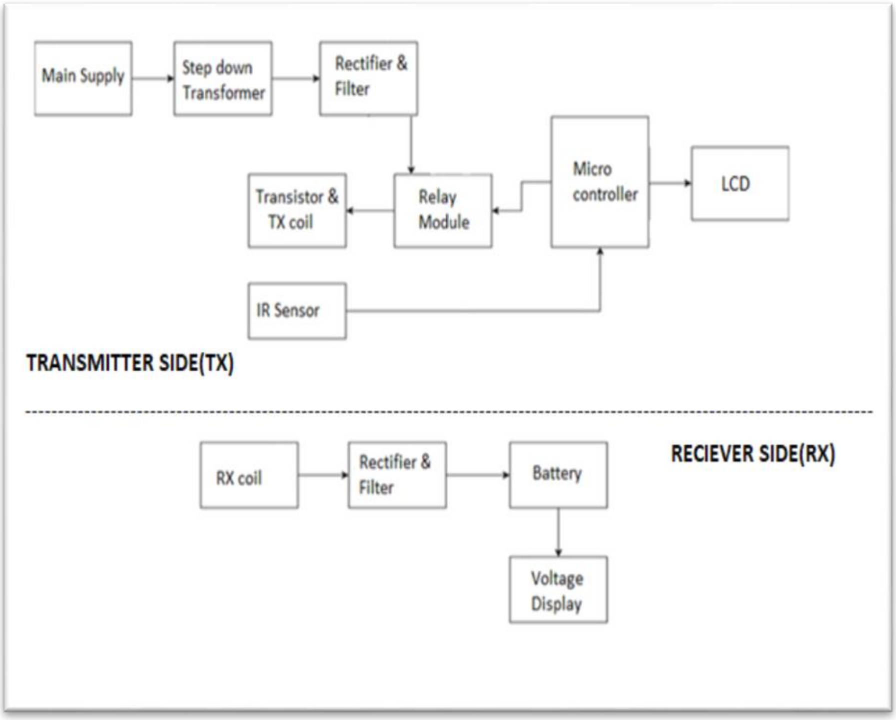

Fig2: Magnetic field formulation

The schematic diagram of the overall system in fig2 illustrates the key components involved in the Wireless Power Transfer (WPT) setup. The system consists of a primary side that includes a power supply and stepdown transformer, as well as a secondary side featuring a filter and rectifier. The power inverter is responsible for converting low-frequency 60 Hz AC voltage into high-frequency current. This high-frequency current generates a magnetic field through the high-frequency coil integrated into the power line. On the secondary side, the pickup module captures this high-frequency magnetic field, while the rectifier transforms it into direct current (DC) voltage, facilitating efficient power transfer to the electric vehicle's battery.

B. Controller Logic

The system utilizes the ATmega328 microcontroller, implemented through the Arduino Uno, an open-source board based on the Microchip ATmega328P. The LCD is interfaced with the Arduino through digital pins (D4 to D7), with the Enable pin connected to pin 2 and the RS pin to pin 1. The R/W pin is grounded, and the Vo pin is linked to the potentiometer for contrast adjustment. An integrated IR sensor monitors the charging status; when a vehicle is detected, the microcontroller activates a relay to initiate charging. If no vehicle is present, the system halts the charging process, thereby optimizing energy management and enhancing system sustainability.

C. Transmitter (TX) Part

The transmitter section of fig3 of the setup commences with a step-down transformer, which reduces the 230V AC mains voltage to a safer 0-12V AC output, providing either 0V (ground) or 12V AC depending on its configuration. This AC output is subsequently rectified using a bridge rectifier composed of four diodes, enabling full-wave rectification to convert AC to DC. The rectified DC voltage is then filtered to remove any residual AC ripple, ensuring a stable DC signal for further processing. Within the transmitter circuit, a transistor is employed to generate high-frequency alternating current across a center-tapped coil. This coil, driven by the alternating current, creates a magnetic field around it. The configuration involves one side of the coil connected to a resistor and the other side linked to the collector terminal of an NPN transistor. During operation, current through the base resistor activates the transistor, leading to the inductor (coil) charging with energy. When the transistor switches off, the inductor discharges, producing high-frequency oscillations. These oscillations are transmitted as a magnetic field, facilitating efficient wireless power transfer to the receiver unit and minimizing energy losses.

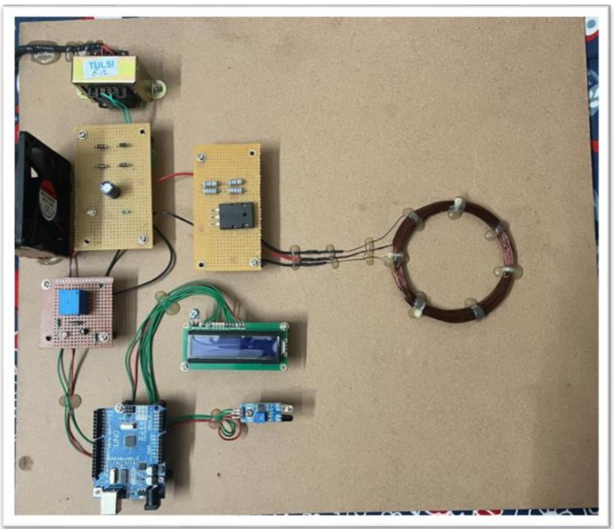

Fig3: Transmitter side circuit

The system utilizes an infrared (IR) transmitter to emit continuous IR light, with an IR receiver monitoring for reflected light. When an object obstructs the path between the transmitter and receiver, the reflected IR light is detected by the receiver, signaling the presence of an object. This IR-based detection is commonly employed in object detection applications, such as vehicle detection at charging stations. Upon detecting an object, the IR sensor sends a signal to a microcontroller, such as the ATmega328 used in the Arduino Uno. The microcontroller processes this input and activates a relay, which is an electrically operated switch with control input terminals and high-power switching output terminals. In this context, the relay connects the transmitter circuit's coil, enabling wireless power generation through the oscillating magnetic field produced by the transistor-driven coil.

Arduino Uno, featuring the Microchip ATmega328P microcontroller, acts as the central control unit, interfacing with various components including the IR sensor, relay, and potentially an LCD display. The Arduino Uno board offers digital and analog input/output pins, including PWM-capable pins, for interfacing with a broad range of sensors, actuators, and display devices. For visual feedback or user interaction, an LCD (Liquid Crystal Display) module can be connected to the Arduino Uno. This module typically interfaces through digital pins (D4 to D7), an Enable pin (pin 2), and an RS (Register Select) pin (pin 1), with additional connections such as the R/W (Read/Write) pin grounded and the Vo (Voltage for Contrast Adjustment) pin connected to a potentiometer, enabling control over the display's functions.

D. Receiver Part (RX)

In the receiver section fig4 of the wireless charging system, the magnetic field generated by the transmitter coil induces an electromotive force (EMF) in the receiving coil, in accordance with Faraday's law of electromagnetic induction. This induced EMF is directly utilized to charge a connected battery. The receiver unit incorporates a bridge rectifier to convert the induced alternating current (AC) voltage into a stable direct current (DC) voltage suitable for battery storage. The rectified voltage is then processed through a filtering stage to eliminate any residual ripples, ensuring a stable DC output.

Fig4: Receiver side coiling

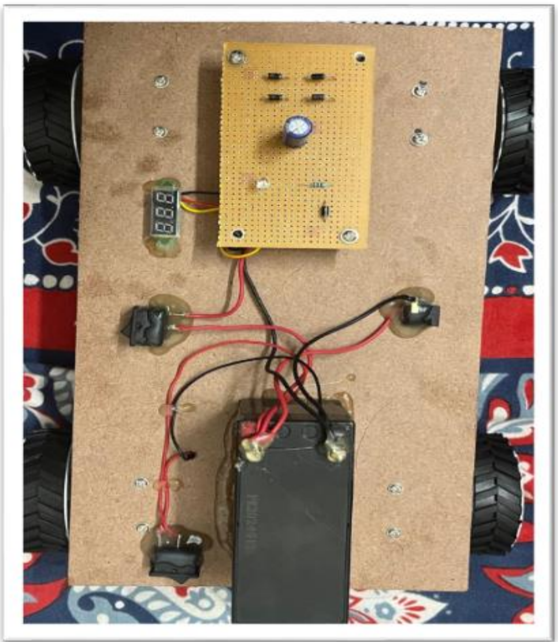

Fig5: Receiver side circuit

A pivotal component of the system is the infrared (IR) sensor, which is interfaced with a microcontroller. The IR sensor detects the presence of a vehicle at the charging station by emitting and receiving infrared light. Upon detecting reflected IR light from a vehicle, the IR sensor transmits a signal to the microcontroller. In response to this signal, the microcontroller actuates a relay switch that regulates the connection between the receiver coil and the rectifier/filtering circuit. When a vehicle is detected, the relay switch permits the transfer of induced energy from the receiver coil to be converted into DC voltage for battery charging. Conversely, in the absence of a vehicle, the relay switch disconnects the charging circuit, thereby preventing unnecessary energy consumption and ensuring safe operation. This automated control mechanism facilitates the initiation of the charging process exclusively when a vehicle is present at the charging point, thus optimizing energy efficiency and improving the overall reliability of the system.

IV. RESULTS

The transmitter section of the wireless charging system begins with a step-down transformer that effectively reduces the 230V AC mains voltage to a 0-12V AC output. This AC voltage is then rectified into direct current (DC) using a bridge rectifier and subsequently filtered to ensure a stable DC signal. In the transmitter circuit, a transistor generates high-frequency AC across a center-tapped coil, producing a magnetic field that facilitates wireless power transfer. The effective operation of the transformer, rectifier, and transistor circuit demonstrates the system's capability to provide the necessary high-frequency AC for efficient wireless power transmission.

On the receiver side, the magnetic field generated by the transmitter induces an electromotive force (EMF) in the receiving coil, in accordance with Faraday's law of electromagnetic induction. This induced EMF is rectified by a bridge rectifier, converting the alternating current (AC) signal into a stable direct current (DC) voltage suitable for battery charging. The system integrates an LED indicator to enhance user interaction. When the parking slot is unoccupied, the LED displays messages such as "Welcome" and "Slot Empty" (Fig. 6 and Fig. 7).

Fig6: Welcome display

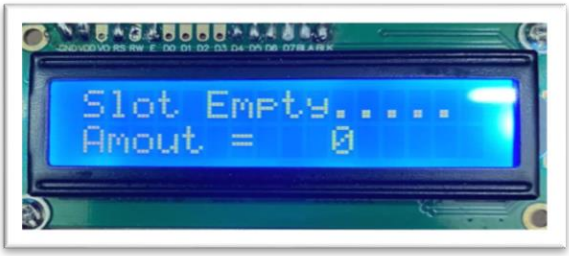

Fig7: Slot empty display

Fig8: Slot Charging and Amount display

Upon detecting a vehicle, the LED updates to show the charging amount and associated costs (Fig. 8). The receiver system's voltage displays transitions from 0V to 13V, indicating effective charging with 1V discharged and 12V added to the battery (Fig. 9 and Fig. 10). This real-time voltage feedback ensures transparency, allowing users to monitor battery charge levels and system efficiency. Such capabilities are particularly beneficial for applications like electric vehicle charging stations and portable electronic devices, where reliable and visible charging status is crucial for optimal operation.

Fig9: Voltage display 0V

Fig10: Voltage display 13V

V. CONCLUSION

The development and deployment of wireless charging technology for electric vehicles (EVs) signify a major advancement in automotive electrification, addressing essential aspects such as user convenience, operational efficiency, and environmental sustainability. By eliminating physical charging cables, the wireless system simplifies the charging process, mitigates range anxiety, and enhances the practicality of EVs. The system's high charging accuracy is evidenced by real-time voltage displays, showing a clear increase from 0V to 13V during operation, with 1V discharged and 12V effectively charged into the battery. Additionally, the ability to perform dynamic charging while vehicles are in motion is particularly advantageous for public transportation and logistics, promoting continuous operation and extended vehicle range. Integrating wireless charging into smart city infrastructures supports cleaner urban environments and reduces fossil fuel dependence.

Technological advancements such as resonant charging and multi-coil configurations are critical for optimizing system efficiency and alignment tolerance. Ensuring safety through the mitigation of electromagnetic interference (EMI) and compliance with safety standards is paramount. Future advancements in battery technologies, such as solid-state batteries, and the standardization of wireless charging protocols are essential for broader adoption and seamless integration across various EV manufacturers and infrastructure providers. Addressing these technological and regulatory challenges will not only enhance user experience with high charging accuracy but also transform transportation infrastructure, making electric mobility more accessible and sustainable.

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