# Wireless Power Transfer (WPT) using Capacitive Power Transfer Technologies for EV Station

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**Abstract:** The rapid growth in the adoption of Electric Vehicles (EVs) necessitates advancements in charging technologies to enhance convenience, efficiency, and integration with smart grid systems. Wireless Power Transfer (WPT) emerges as a promising solution, offering a seamless charging experience without the need for physical connectors. Among various WPT methods, this paper proposes a novel system for Wireless Power Transfer (WPT) to Electric Vehicle (EV) stations using Capacitive Power Transfer (CPT) technologies. In this system, the grid acts as the primary power source, providing Alternating Current (AC) electricity. A rectifier converts the AC voltage from the grid into Direct Current (DC) voltage, which is stored in a DC bus. The DC bus serves as an intermediate storage and distribution point for electrical energy. An Intermediate Frequency (IF) inverter then converts the DC voltage from the bus into high-frequency AC voltage. This high-frequency AC voltage is fed into a resonant network, comprising capacitors and inductors, which is essential for establishing resonance between the transmitter and receiver coils, thereby facilitating efficient power transfer. On the receiver side, a corresponding resonant network resonates with the transmitter's network, ensuring optimal power transfer. The received AC voltage is subsequently rectified back into DC voltage, which is used to charge the EV battery through a Battery Management System (BMS). The BMS ensures safe and efficient charging by monitoring parameters such as voltage, current, and temperature.

**Keyword:** Wireless Power Transfer (WPT), Capacitive Power Transfer (CPT), Electric Vehicle (EV), Charging Intermediate Frequency (IF) Inverter, Resonant Network

## I. INTRODUCTION

The technology known as Wireless Power Transfer (WPT) has recently garnered a lot of attention due to the fact that it is convenient, safe, and allows for movement while charging a battery. Capacitive Power Transfer (CPT) and Inductive Power Transfer (IPT) are the two nonradiative technologies that are included in the WPT for the purpose of charging the batteries. With its benign characteristics, which include power transfer over a metal barrier, system simplicity, minimal eddy current loss, and less Electromagnetic Interference (EMI), the CPT technology has been the subject of a significant amount of research in recent years. [1] This technique has the potential to be utilized in applications that include low/high power levels as well as small/large air-gaps. The fundamental functioning of a capacitor served as the inspiration for the CPT technology. The conducting plates of a capacitor are separated by an air gap (d), which is often filled with a dielectric substance for the purpose of insulating the capacitor. CPT technology operates on a principle that is analogous to that of a capacitor that is activated by an Alternating Current (AC) power. In Alternating Current (AC) excitation, the direction of the electric field is reversed at the beginning of each half-cycle, and then the charge and discharge are repeated in alternating fashion. According to this method, the capacitor is regarded as being capable of carrying an alternating current [2]. It is possible for the capacitive coupler in a CPT system to be represented by two plates, four plates, or even more plates, as will be detailed in section 4.1. The CPT technique has a wide range of potential applications in the realm of battery charging, including the ability to charge electronic book readers, laptops, digital cameras, and biomedical devices [3]. In addition, the CPT technique has been examined as a potential replacement for slip rings with regard to winding field synchronous machines. It is [4, 5]. In addition, this technology has been utilized in high-power applications, such as the charging of batteries for electric vehicles (EVs) [6, 7]. It is possible to improve the performance of a CPT system by incorporating a compensation circuit that generates an Electric Field in Resonance (EFR). This is done in order to receive a high voltage on the transmitter plate(s), which then becomes capable of producing sufficient electric fields for the capacitive charging [1]. To give an example, Fei L. et al. indicated that the overall performance of a CPT system could be enhanced by utilizing a compensation circuit architecture [1]. Additionally, Kusunoki M. et al. discovered that the transmission distance could be doubled by utilizing a repeater [8]. Both of these findings are quite recent. In most cases, the configuration of the repeater plate(s) is identical to that of the transmission and receiver plates; however, the power supply port is shorted. These are the repeater plates that are positioned in between the reception plates and the transmitter plates [8].

**The need for the CPT technology**

For a considerable amount of time, the IPT technology has been explored for the purpose of charging the batteries of various electronic devices, including Electric Vehicles (EVs) and other similar equipment. Unfortunately, this technique, which is based on electromagnetic induction for a WPT, has a few limitations, such as eddy current losses, Electromagnetic Interference (EMI), and the inability to transfer power across metallic barriers. The electronic component of an electronic device that makes use of this technology is likewise affected by the magnetic field, as stated in paragraph nine. As a result, the CPT technology, which is based on the electric field between the capacitive coupled plates, has been investigated as an alternative to the IPT technology due to the following characteristics: low eddy current losses, low Electromagnetic Interference (EMI), the required components are fewer, and the capability to transfer power through metal objects [5]. As an alternative to an IPT, the CPT technology has also been examined for the purpose of charging biomedical devices [3]. This is done with the intention of reducing the risk of adverse health effects. Not only is the CPT technology utilized in the WPT for the purpose of charging the battery, but it is also utilized in the transmission of data and signals [10]. As an illustration, a capacitive coupler inter-chip experimental system was developed for the purpose of facilitating Wireless Power Transfer (WPT) and bidirectional data transfer between two chips that are stacked in a 3D extremely large-scale integration device. In every pair of capacitive linked plates, there is a single plate located at the top and another plate located at the bottom, which are separated by a length of 10 micrometers. For the purpose of transferring power and data, a power supply with a voltage of 3.3 volts and an operational frequency range of 1 kilohertz to 15 megahertz was utilized [11].

**Capacitive power transfer concept**

Figure 1 is a representation of the usual block diagram of a capacitive charging system. It is clear from looking at Figure 1 that a typical CPT system is made up of both the transmitter and the receiver sides [12-14]. [1] The transmitter side is comprised of filters that prevent unwanted harmonics from being injected back into the utility grid, a half-bridge rectifier for converting AC to DC power, and an inverter that converts DC power into AC power at high frequency before exciting the transmitter plate through a power cable. All of these components are integrated into the transmitter side. When one of the plates on the transmitter side is positively charged (a passive plate), the second plate on the same side have the opposite charge, which is a negative charge (an active plate), and so on. An alternating electric field is created between the capacitive linked plates as a result of this, which results in the generation of phase-altering potentials. After this, the power is transferred from the transmitter plate(s) to the reception plate(s) [14]. To convert the alternating current (AC) electric power that is coming from the receiver plate into Direct Current (DC) electric power that may be supplied to a load, a half-bridge rectifier is required to be installed on the receiver side [1]. To achieve the desired effect of voltage regulation, a DC/DC converter might be utilized before to the inverter. At the time of developing the power stage, careful consideration must be given to the selection of the power cable's material, diameter, length, and weight. By demonstrating its ability to handle large power ratings at high frequencies while minimizing eddy current and skin effect losses, the coaxial cable demonstrates its worthiness [15]. In addition, there are a number of different kinds of inverters that can be utilized, as Section 8 will go into further detail. Parameters that are typically utilized in the process of describing the capacitive coupler are the coupling capacitance (Cm) and the coupling coefficient (k). The capacitance that is apparent between the plates that are capacitive connected is denoted by the symbol Cm. A portion of the electric field that connects the transmitter and receiver plates is denoted by the letter, letter k. As a result of the fact that the k is a geometrical parameter, this parameter is position relative. equation (1) [12] describes the relationship that exists between Cm and k. $C_m = k.\sqrt{C_1}.C2$

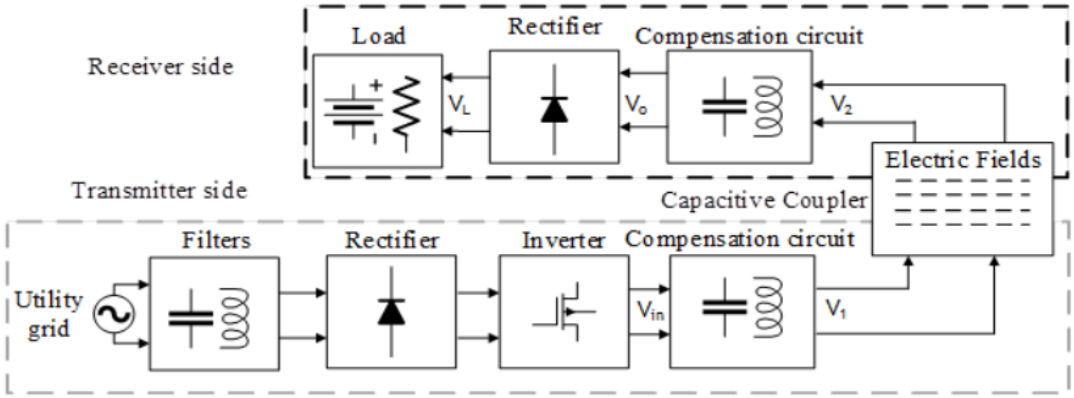


Fig. 1 Typical structure of a CPT system

## II. RELATED WORK

**Nadir Benalia et.al. 2024** Underscoring the necessity of addressing difficulties related with the restricted driving range of Electric Vehicles (EVs), the current market for Electric Vehicles (EVs) is undergoing substantial increase. Within this framework, one of the key focuses is on the enhancement of the process of wireless charging. This work presents a circular spiral coil design that incorporates transceiver coils in order to make a contribution to this research field. To begin, a comprehensive analysis is carried out with the help of the Ansys Maxwell program in order to evaluate the efficiency of the suggested solution by examining the magnetic field distribution, the inductance properties, and the mutual inductance between the receiver and transmitter coils. The subsequent phase involves the implementation of a direct shielding technique, which involves the incorporation of a ferrite core bar, with the purpose of minimizing power leakage and improving the efficiency of power transmission. The magnetic shielding made of ferrite directs magnetic field lines, which leads to a large reduction in flux leakage and an improvement in power transmission. Last but not least, a wireless system that utilizes magnetic resonance series (SS) compensation is created in order to achieve high coupling efficiency and improved performance. Utilizing the Ansys Simplorer software, co-simulation is utilized in order to assess the efficiency of the system. The findings affirm that the proposed solution is effective, demonstrating that it is capable of transmitting 3.6 kilowatts with a success rate that is close to 99%. This work makes a substantial advancement in the development of wireless charging systems for electric vehicles, addressing problems and increasing acceptance on a global scale.

## III. PROPOSED WORK

Capacitive Power Transfer (CPT) leverages electric fields for Wireless Power Transfer (WPT), gaining attention for its low eddy current loss, simplicity, and adaptability. Continuous research has enhanced transfer power, efficiency, and distance. Through the use of soft-switching, this research provides a CPT circuit that makes use of serial resonance to achieve high-frequency, moderate-voltage operation that is both efficient and effective. Analysis predicts efficiency limits and guides component selection. Automatic tuning ensures optimal operation across various conditions. Initially used for low-power transfer with small air-gaps due to voltage concerns, new compensation circuits enable applications across small, medium, and long air-gaps. CPT technology finds applications in mobile phone, laptop, and electric vehicle battery charging. The paper reviews CPT technology, covering operation principles, coupler structures, circuit modeling, resonance topologies, challenges, and limitations. Additionally, it introduces a Hybrid Wireless Power Transfer (HWPT) system combining IPT and CPT technologies to address evolving needs.

In the proposed system, the grid serves as the primary power source, providing Alternating Current (AC) electricity. A rectifier is employed to convert the AC voltage from the grid into Direct Current (DC) voltage, which is then stored in a DC bus. The DC bus serves as an intermediate storage and distribution point for the electrical energy. The Intermediate Frequency (IF) inverter is utilized to convert the DC voltage from the bus into high-frequency AC voltage. This high-frequency AC voltage is then fed into the resonant network, which includes components such as capacitors and inductors. The resonant network is crucial for establishing resonance between the transmitter and receiver coils, facilitating efficient power transfer. On the receiver side, a similar resonant network is employed to resonate with the transmitter's network, ensuring optimal power transfer. The received AC voltage is then rectified back into DC voltage, which charges the battery through a Battery Management System (BMS). The BMS ensures the safe and efficient charging of the battery, monitoring parameters such as voltage, current, and temperature.

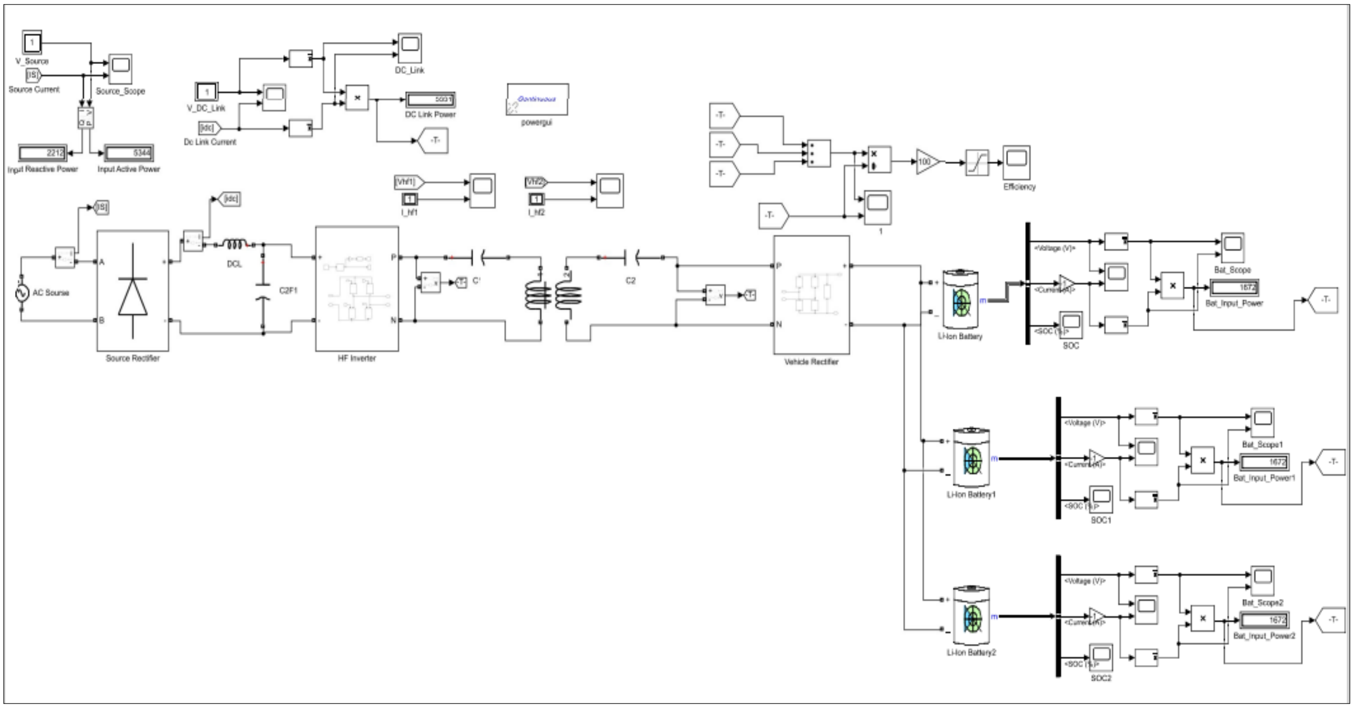


Fig.2 Simulink model

**Modules**

1. Grid:
2. Rectifier
3. DC-bus
4. Inverter
5. IIF inverter
6. Resonant network
7. Battery BMS
8. Capacitive coupler

**Grid:** The electrical grid, also known as the power grid, is the interconnected network that delivers electricity from power plants to consumers. It consists of transmission lines, substations, and distribution lines.
The grid can be represented by its voltage $\mathbf{V_{grid}}$ and impedance $\mathbf{Z_{grid}}$. The power delivered by the grid can be calculated using the formula

$$\mathbf{P_{grid}} = \frac{\mathbf{V_{grid}^2}}{\mathbf{Z_{grid}}}$$

**Rectifier:** Changing alternating current (AC) into direct current (DC) is the function of a rectifier, which is a type of electrical equipment. It is common practice to make use of diodes in order to restrict the flow of electricity to a single direction. DC-bus: The DC bus refers to the direct current (DC) electrical distribution system within a device or system. It serves as a common electrical pathway for connecting various components powered by DC.
The rectifier converts alternating current (AC) to direct current (DC). It can be represented using mathematical models such as the diode bridge rectifier or the Graetz bridge rectifier. The output DC voltage VDCcan be calculated as $V_{DC}=V_{AC}-V$ diode drop, Where $V_{AC}$ is the input AC voltage and $V_{diode}$ drop is the voltage drop across the diodes.
**Inverter**: An inverter is a piece of electrical equipment that is capable of converting Direct Current (DC) to Alternating Current (AC). In situations where, Alternating Current (AC) electricity is necessary, such as in grid-connected solar photovoltaic systems or electric vehicle propulsion systems, it is frequently utilized. The inverter converts DC power from the DC-bus into AC power. It can be represented using mathematical models such as

the Voltage-Source Inverter (VSI) or the Current-Source Inverter (CSI). The output AC voltage $V_{AC}$and frequency Fac can be controlled using Pulse Width Modulation (PWM) techniques**.**

**IIF inverter:** It seems there might be a typo here. Perhaps you meant "IGBT inverter," which refers to an inverter that uses Insulated-Gate Bipolar Transistors (IGBTs) as switching devices. **IGBT** inverters are commonly used in high-power applications such as motor drives and renewable energy systems.

**DC-bus:** The DC-bus represents the intermediate DC voltage between the rectifier and the inverter. It can be modeled using a capacitor. The voltage across the capacitor $V_{DC}$-bus can be calculated using the formula $V_{DC}$-bus=$Q/C$, where Q is the charge stored in the capacitor and C is the capacitance.

**Resonant network:** A resonant network is a circuit that utilizes the phenomenon of resonance to achieve specific electrical characteristics, such as frequency tuning or impedance matching. In the context of power electronics, resonant networks are often used in resonant converters or inverters to improve efficiency and reduce switching losses. The resonant network consists of inductive and capacitive components designed to create resonance at a specific frequency. Its mathematical expression depends on the resonance frequency, the inductance L, and the capacitance C of the network.

**Battery BMS:** In the context of rechargeable batteries, a Battery Management System (BMS) refers to an electrical system that is responsible for monitoring and controlling the charging and discharging processes. The performance of the battery is improved as a result. Protect against overcharging and over discharging, and ensure safe operation.

**Capacitive coupler:** A capacitive coupler is a device used to transfer electrical energy wirelessly through capacitance coupling. It typically consists of two conductive plates separated by a dielectric material, which allows for the transfer of electrical energy without the need for physical contact. The capacitive coupler transfers power wirelessly through capacitive coupling. Its mathematical expression depends on the capacitance $C$C of the coupler, the voltage $V$V across the coupler, and the frequency f of the AC signal. The power transferred P can be calculated as P=CV $^2$f.

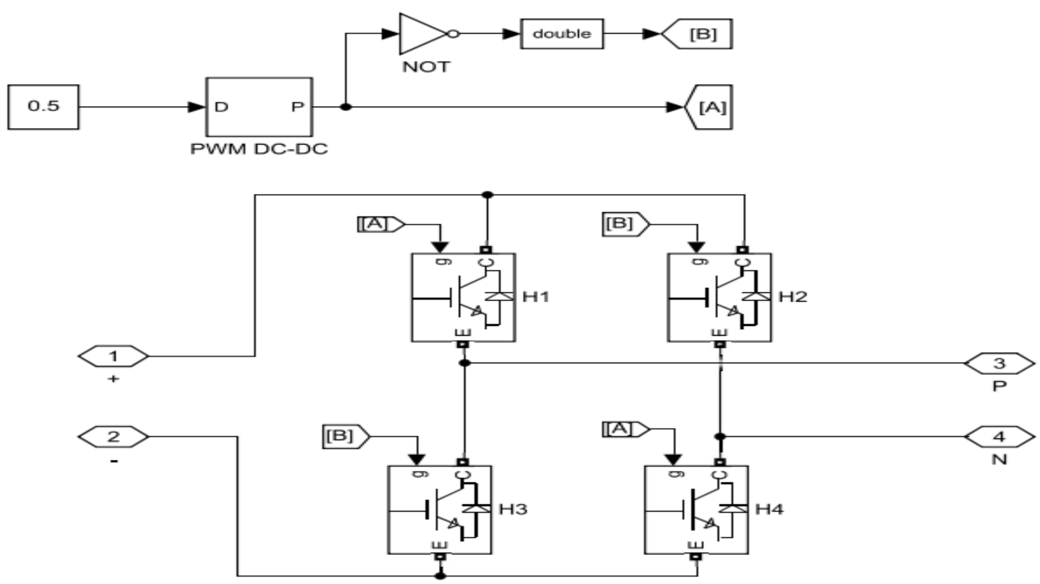


Fig. 3 HF inverter

High-frequency (HF) inverters are commonly used in power electronics applications, including Capacitive Power Transfer (CPT) systems, where high-frequency switching is essential for efficient power conversion. The mathematical expression for an HF inverter can be described using various modulation techniques such as Pulse Width Modulation (PWM). Here's a general mathematical expression for an HF inverter using PWM: a single-phase HF inverter topology with a DC input voltage $V_{DC}$$V_{DC}$ and an output AC voltage $V_{AC}$ at a given frequency $f_{AC}$. The modulation index (m) represents the ratio of the peak amplitude of the modulating signal to the peak amplitude of the carrier signal.

The output voltage $V_{AC}(t)$ of the HF inverter can be expressed as:

$V_{AC}(t) = m \cdot V\text{carrier} \cdot \text{PWM}(t)$

Where:

- Vcarrier is the peak amplitude of the carrier signal.
- PWM(t) is the pulse-width modulation function, which determines the duty cycle of the inverter switches over time.

The PWM function PWM(t) can take different forms based on the modulation technique used, such as sinusoidal PWM, space vector PWM, or third-harmonic injection PWM. For example, in sinusoidal PWM, the PWM function PWM(t) generates a pulse train with varying pulse widths to approximate a sinusoidal waveform. The duty cycle of the PWM signal is adjusted to control the magnitude of the output voltage. In space vector PWM, the PWM function generates a set of voltage vectors that represent different output voltage levels. By appropriately selecting and switching between these voltage vectors, the desired output voltage waveform can be synthesized. In third-harmonic injection PWM, a high-frequency triangular carrier signal is modulated with a low-frequency sinusoidal reference signal, and the third harmonic component is injected to improve the quality of the output voltage waveform.

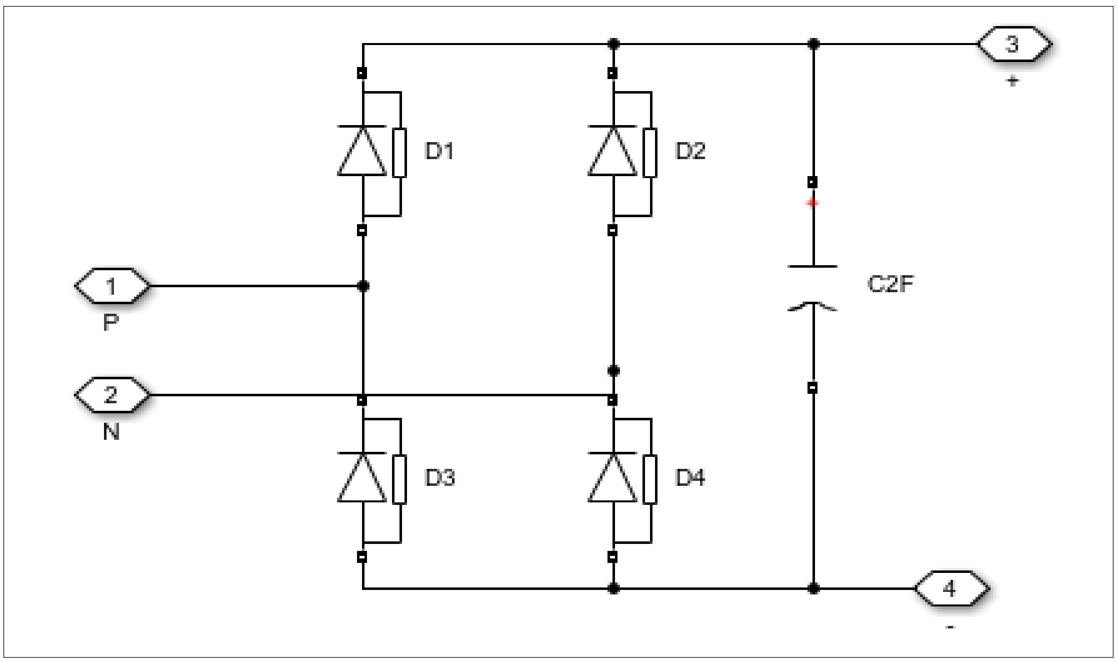


Fig.4 Vehicle rectifier

## IV SIMULATION RESULTS

The simulation results of Capacitive Power Transfer (CPT) in MATLAB reveal promising advancements in wireless power transfer technology, particularly in the context of electric vehicle (EV) charging. Through rigorous modeling and analysis, the CPT system demonstrates efficient power transfer capabilities, achieving high levels of power transmission efficiency while minimizing losses. The simulation highlights the effectiveness of capacitive couplers and resonant networks in facilitating wireless energy transfer over various distances, showcasing their adaptability and scalability for different charging scenarios., the MATLAB simulation provides insights into the optimal design parameters and operating conditions for maximizing power transfer efficiency and ensuring reliable charging performance. These simulation results underscore the potential of CPT as a viable solution for enhancing EV charging infrastructure, offering fast, efficient, and convenient charging solutions for electric vehicles in the future.

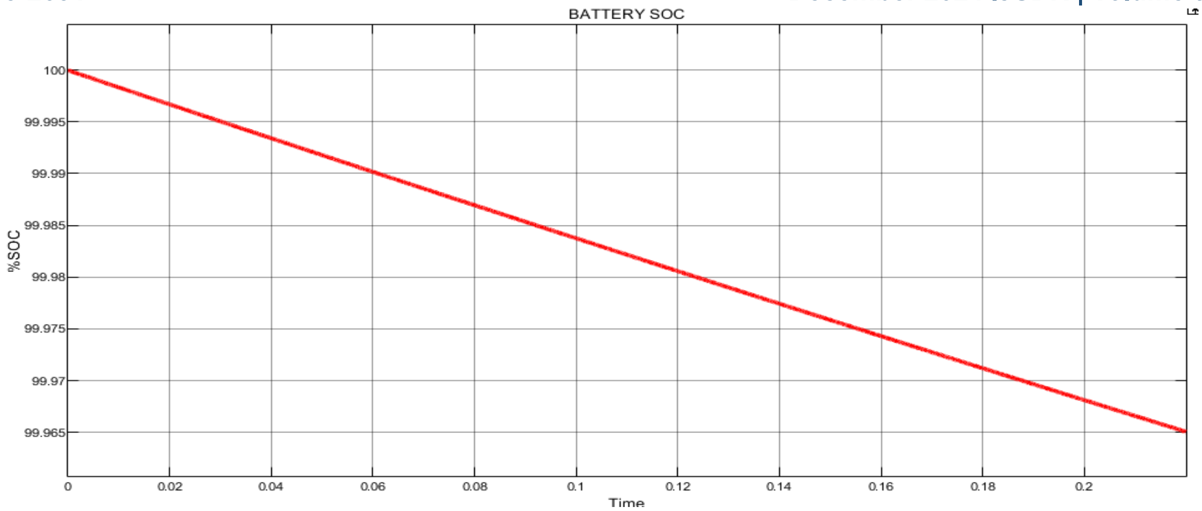


Fig. 5 Battery SoC

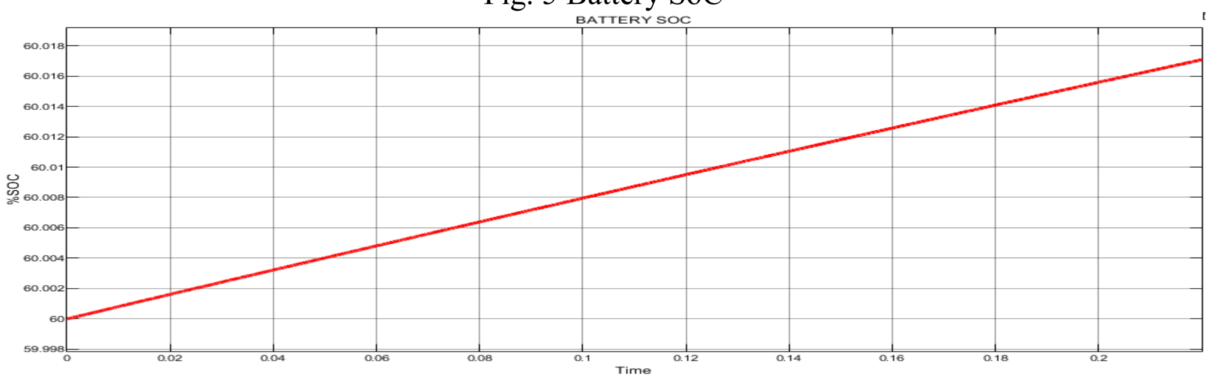


Fig.6 Battery SoC

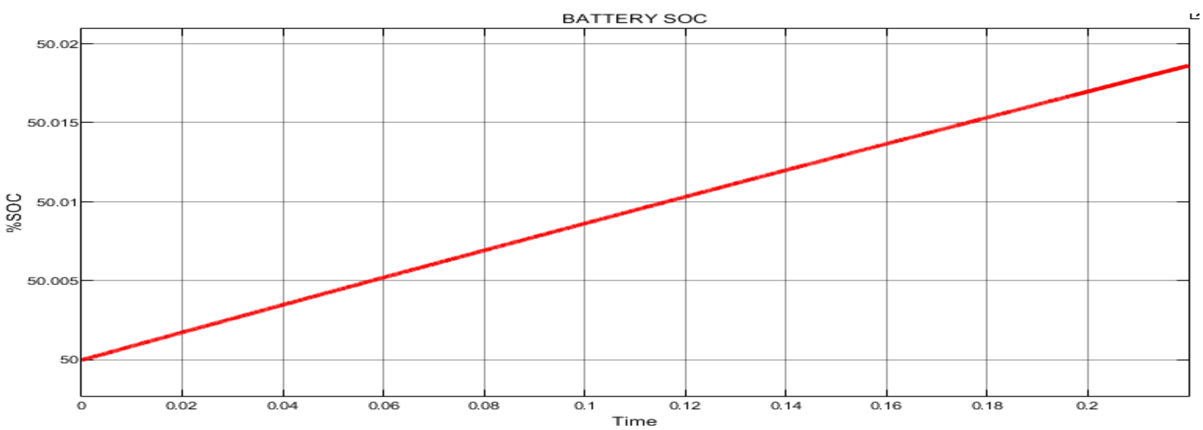


Fig.7 Battery SoC

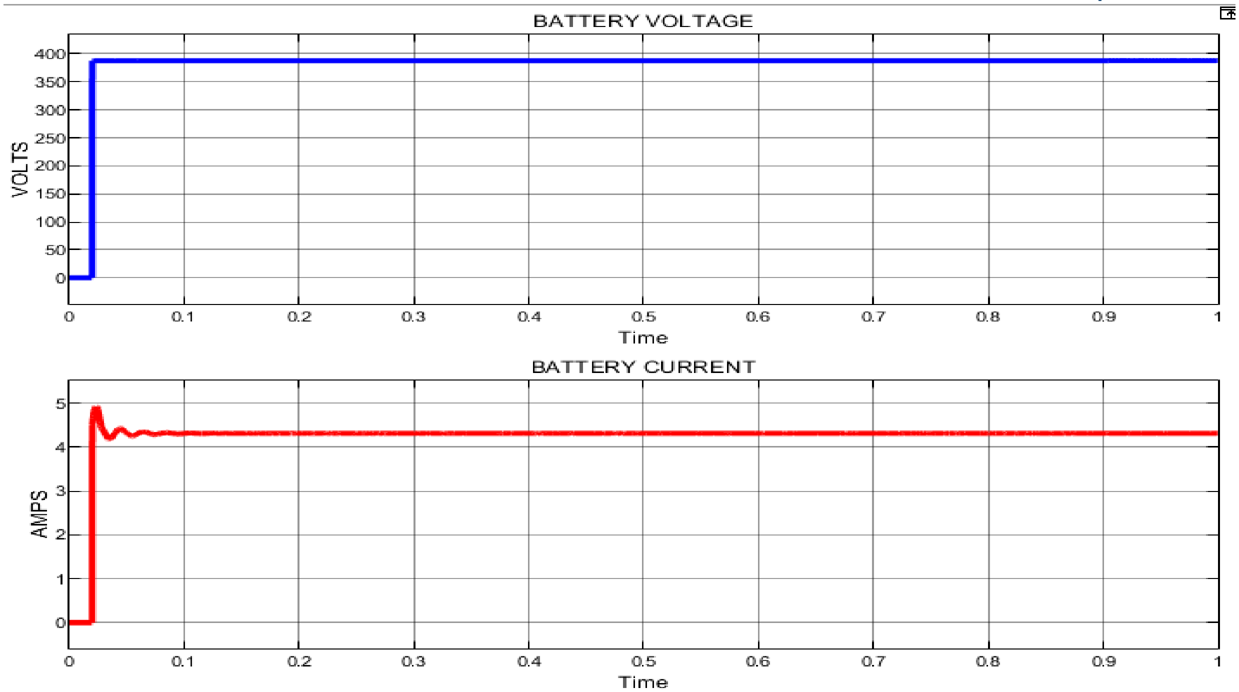


Fig. 8 Battery voltage and battery current

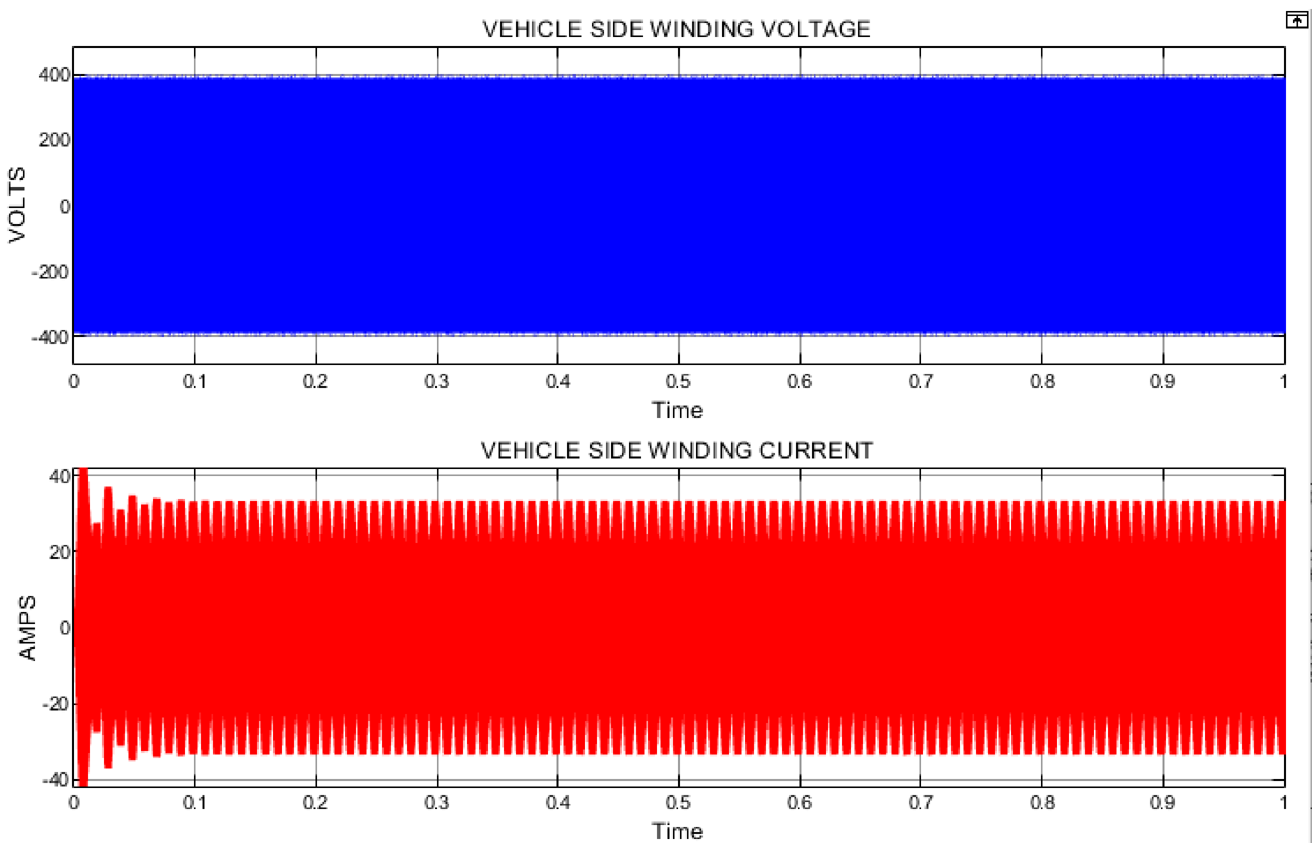


Fig.9 Vehicle side winding voltage current

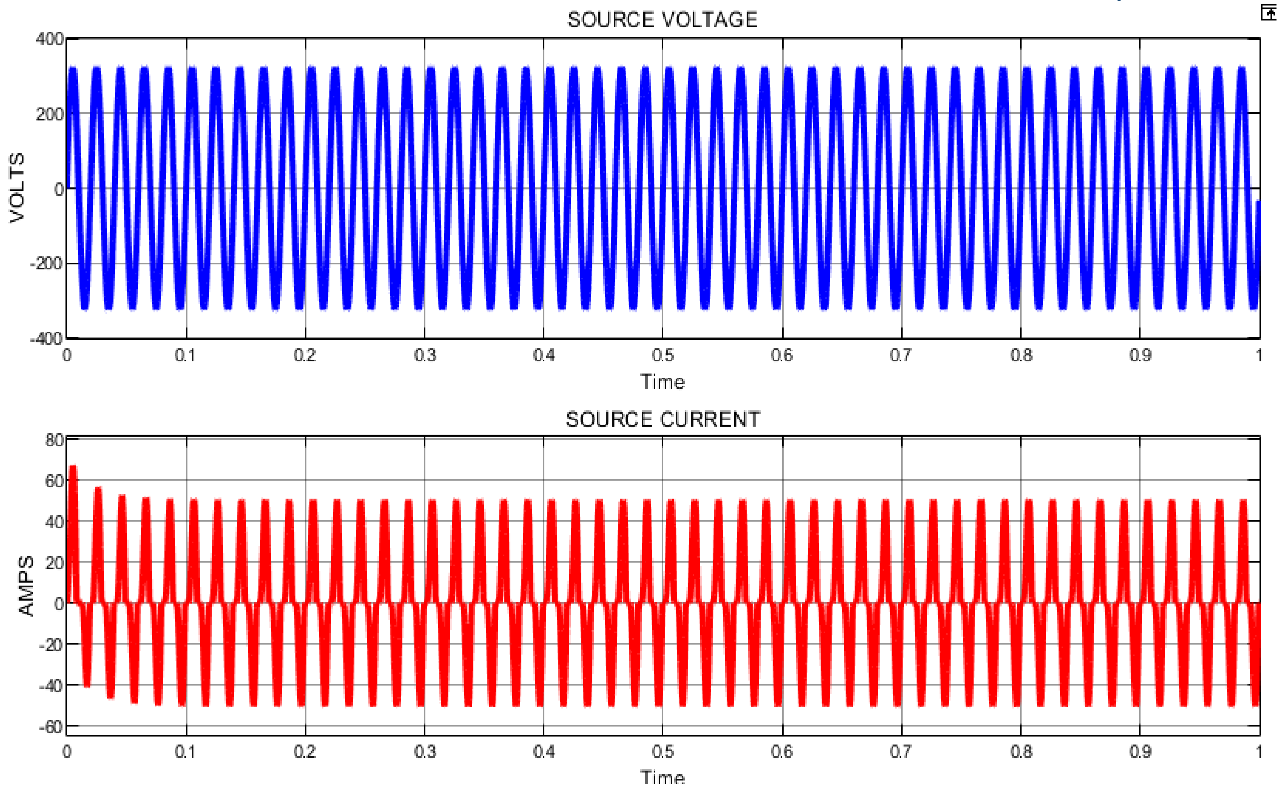


Fig.10 Source voltage and source current

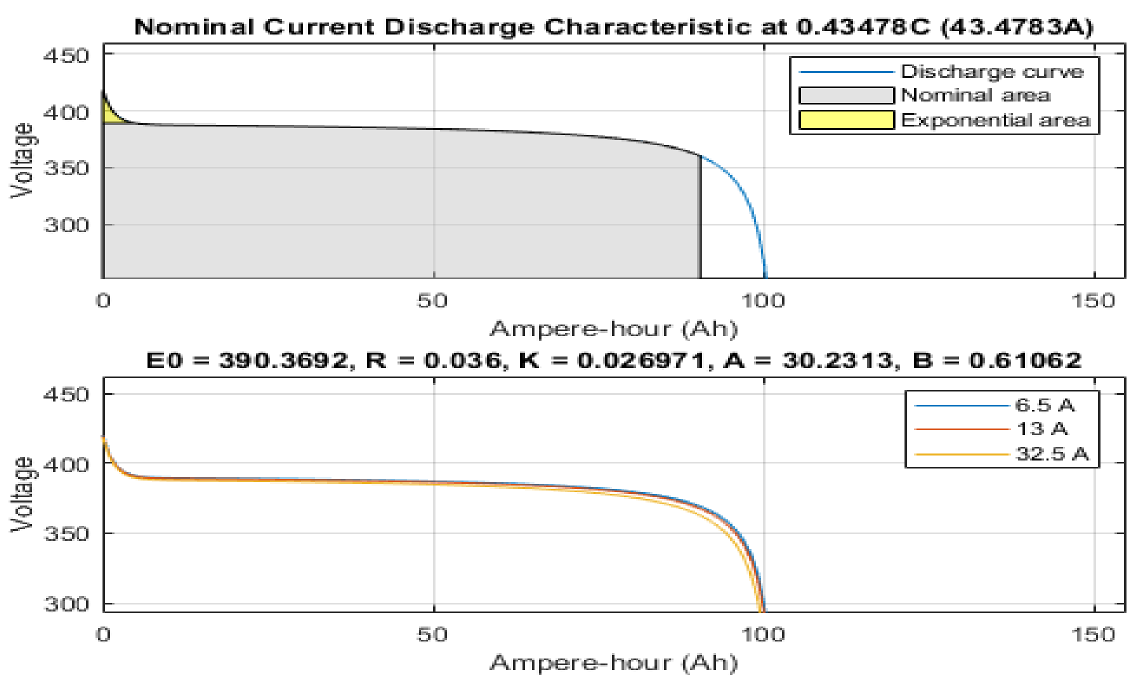


Fig.11 Source voltage and source current

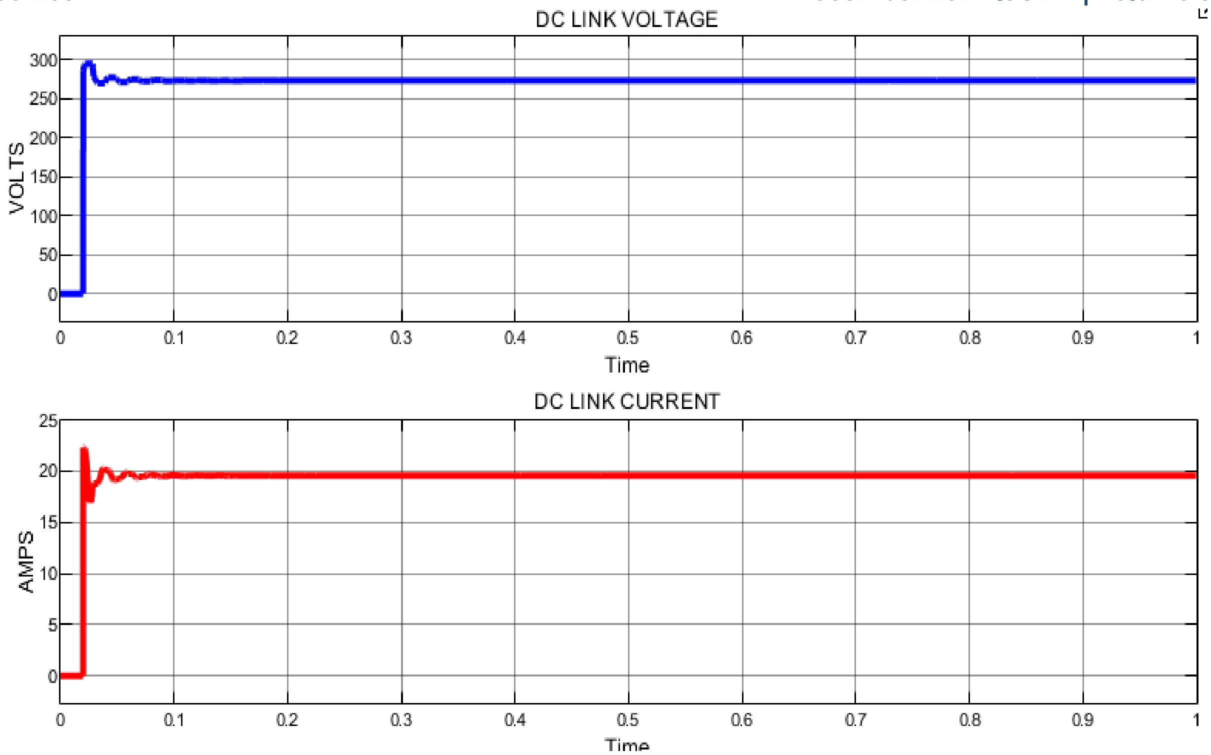


Fig.12 Source voltage and source current

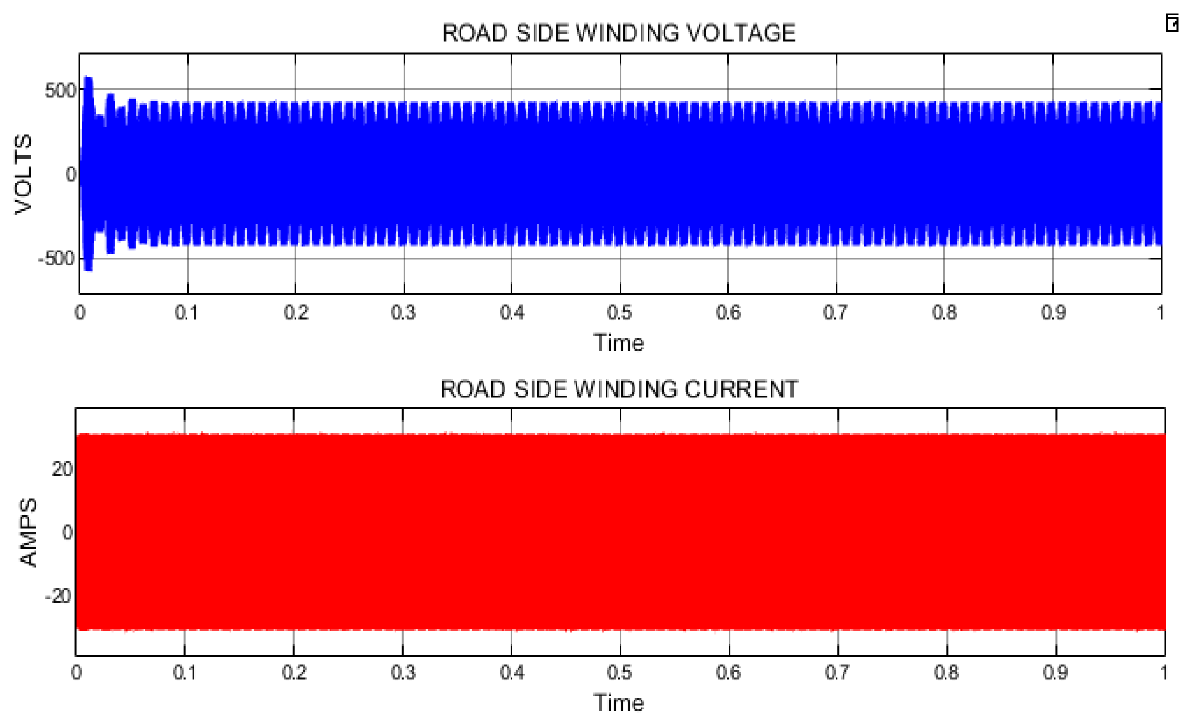


Fig.13 Source voltage and source current

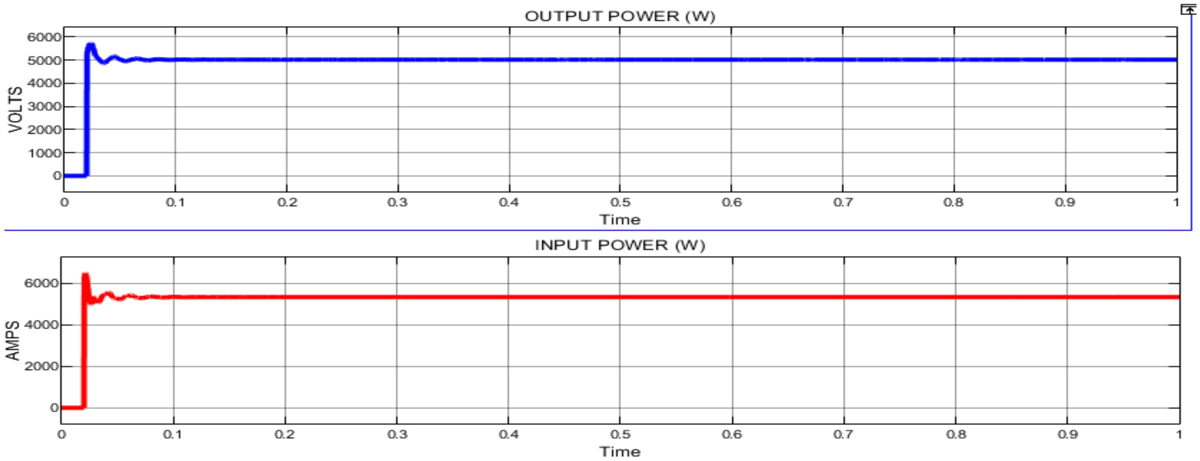


Fig.14 Source voltage and source current

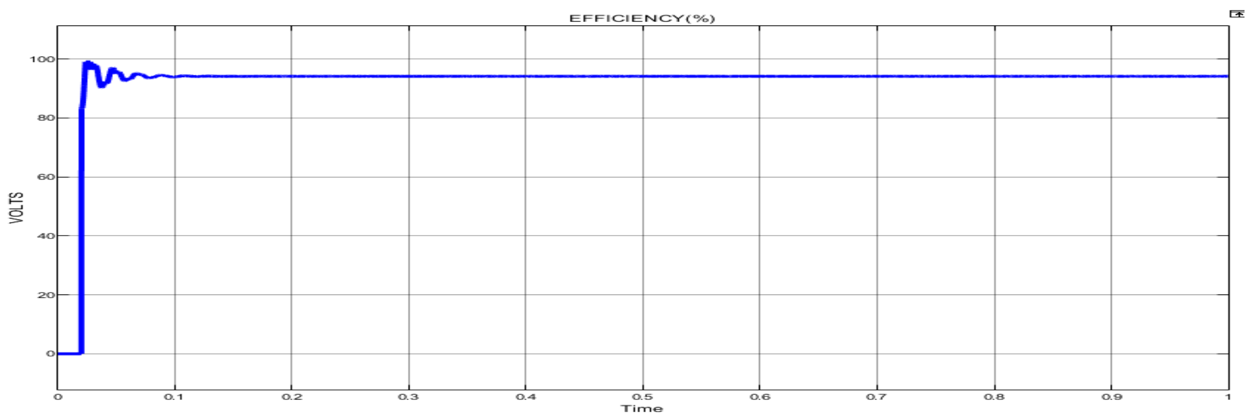


Fig.15 Source voltage and source current

## CONCLUSION

The exploration of Capacitive Power Transfer (CPT) technologies for Electric Vehicles (EVs) presents a compelling avenue for revolutionizing the landscape of electric vehicle charging infrastructure. Throughout this study, we have delved into the principles, advancements, challenges, and potential applications of CPT technologies in the context of EV charging.

Investigation has underscored the significant advantages offered by CPT over traditional inductive charging methods. The inherent benefits of CPT, including reduced eddy current losses, enhanced efficiency, and adaptability to varying air-gap distances, position it as a promising solution for addressing the limitations and inefficiencies of current EV charging systems.

Furthermore, the integration of CPT technologies has the potential to unlock new possibilities for electric vehicle charging infrastructure. By leveraging capacitive couplers, resonant networks, and advanced control algorithms, EV charging stations can offer faster, more efficient, and more convenient charging experiences for consumers.

Moreover, the scalability and flexibility of CPT technologies make them well-suited for deployment in various environments, ranging from public charging stations to residential and commercial settings. The ability to accommodate different air-gap distances and charging scenarios further enhances the versatility and accessibility of EV charging infrastructure.

As we look to the future, continued research and development in CPT technologies will be critical for realizing their full potential in the EV charging ecosystem. Addressing challenges such as standardization, safety, and interoperability will be essential for widespread adoption and integration into existing infrastructure.

**References**


**[1]** Lu, F., Zhang, H. and Mi, C., "A Review on the Recent Development of Capacitive Wireless Power Transfer Technology", in: Energies, 2017, vol. 10, no. 11, p.1752, ISSN 1996-1073.

**[2]** Zou LJ, Hu AP, Su YG., "A single-wire capacitive power transfer system with large coupling alignment tolerance", in: Emerging Technologies: Wireless Power Transfer (WoW), 2017 IEEE PELS Workshop on 2017 May 20, pp. 93- 98.

**[3]** Huang L, Hu AP, Swain A, Kim S, Ren Y., "An overview of capacitively coupled power transfer—A new contactless power transfer solution", in: Industrial Electronics and Applications (ICIEA), 2013 8th IEEE Conference on 2013 Jun 19, pp. 461-465.

**[4]** Lu F, Zhang H, Hofmann H, Mi C., "An inductive and capacitive combined wireless power transfer system with LC-compensated topology", in: IEEE Transactions on Power Electronics, 2016, vol. 31, no. 12, pp. 8471-8482, ISSN 0885-8993.

**[5]** Minnaert B, Stevens N., "Optimal analytical solution for a capacitive wireless power transfer system with one transmitter and two receivers", in: Energies, 2017, vol. 10, no. 9, p.1444, ISSN 1996-1073.

**[6]** AL-SAADI M., AL-QAISI M., AL-BAHRANI L., AL-OMARI A., CRACIUNESCU A., "A Comparative Study of Capacitive Couplers in Wireless Power Transfer", in: International Symposium on Fundamentals of Electrical Engineering (ISFEE), 2018.

**[7]** AL-SAADI M., AL-GIZI A., AHMED S., AL-CHLAIHAWI S., CRACIUNESCU A., "Analysis of Charge Plate Configurations in Unipolar Capacitive Power Transfer System for Charging the Electric Vehicles Batteries", in: 12th International Conference Interdisciplinarity in Engineering, 2018.

**[8]** Kusunoki M, Obara D, Masuda M., "Wireless power transfer via electric field resonance coupling", in: Microwave Conference (APMC), 2014, pp. 1360-1362, ISSN 2165-4727

**[9]** Nadir BenaliaID1, Idriss BenlalouiID2, Kouider Laroussi1, Ahmad Elkhateb3, Daniel Eutyche Mbadjoun WapetID4 *, Ammar M. Hassan5, Mohamed Metwally MahmoudID6 Enhancing electric vehicle charging performance through series-series topology resonance-coupled wireless power transfer https://doi.org/10.1371/journal.pone.0300550 March 21, 2024

**[10]** Swapna Manurkar, Harshada Satre, Bhagyashree Kolekar, Pradnya Patil, Samidha Bail mare, "WIRELESS CHARGING OF ELECTRIC VEHICLE", International Research Journal of Engineering and Technology (IRJET), Volume: 07 Issue: 03 | Mar 2020

**[11]** Naoki Shinohara, Yuta Kubo, Hiroshi Tonomura "Wireless Charging for Electric Vehicle with Microwaves",Yuvrajsinh Rathod, Larry Hughes "Simulating the charging of electric vehicle by laser", The 9th International Conference on Sustainable Energy Information Technology (SEIT) August 19-21, 2019, Halifax, Canada,

**[12]** A.P. Kansara; V.B. Patel (2023) Design And Implementation of an Optimized Stationary Wireless Power Transfer System for EV Battery Charging 2023 Innovations in Power and Advanced Computing Technologies (i-PACT) Year: 2023

**[13]** Abhishek Shakya; Mayank Kumar (2022) Implementation of Inductive Wireless Power Transmission system for Battery Charging applications 2022 Second International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT) Year: 2022

**[14]** Abhishek Shakya; Mayank Kumar (2022)Implementation of Inductive Wireless Power Transmission system for Battery Charging applications2022 Second International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT)Year: 2022

**[15]** Aganti Mahesh; Bharatiraja Chokkalingam; Lucian Mihet-Popa (2021) Inductive Wireless Power Transfer Charging for Electric Vehicles–A Review IEEE Access Year: 2021