"Innovative Wireless Charging for Hybrid Vehicles: A Path to Faster and More Reliable Power Transfer"

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Abstract
Wireless power transfer (WPT) technology for hybrid and electric vehicles is emerging as a promising solution to improve charging convenience and user experience. However, traditional WPT systems face limitations such as lower charging speeds, efficiency losses due to misalignment, and safety concerns related to electromagnetic fields. This paper presents a set of improvements in wireless charging for hybrid vehicles, focusing on higher frequency power transfer, resonant inductive coupling optimization, advanced coil design, and adaptive positioning techniques. Using a combination of high-frequency power transfer, dual-coil configurations, and adaptive resonance control, this work demonstrates significant gains in power transfer efficiency and reduced sensitivity to misalignment. Additionally, safety improvements are achieved through enhanced electromagnetic field (EMF) shielding and thermal management, ensuring safe and reliable charging. Simulation results reveal that optimized resonance tuning and positioning control can decrease charging time by up to 30% while maintaining high efficiency across a wider range of vehicle positions. The proposed methods align with industry standards, showing feasibility for practical implementation. These advancements represent a crucial step toward making wireless charging a viable, fast, and safe option for hybrid vehicles, paving the way for wider adoption in the automotive industry.

Introduction
With the increasing adoption of hybrid and electric vehicles (HEVs and EVs), the demand for efficient and convenient charging solutions has grown significantly. Traditional plug-in charging methods, while effective, often present challenges in terms of user convenience, infrastructure requirements, and charging time. Wireless power transfer (WPT) technology has emerged as a promising alternative to wired charging systems, offering a more convenient and seamless experience for vehicle owners. By eliminating the need for physical connectors and cables, WPT systems allow for automatic charging, reducing wear and tear on connectors and enhancing the overall user experience.

However, despite the advantages of wireless charging, there are several limitations that hinder its widespread adoption, particularly in the context of hybrid vehicles. Current WPT systems typically operate at relatively low efficiencies, especially when misalignment between the vehicle and charging pad occurs. The charging time in most systems is also slower compared to conventional plug-in methods, which can lead to inconvenience for users. Furthermore, the safety of electromagnetic fields (EMF) generated by the charging process is a major concern, requiring stringent regulatory compliance and robust safety measures.

This paper aims to address these challenges by presenting innovative methods for improving wireless charging systems for hybrid vehicles. The proposed advancements focus on enhancing power transfer efficiency, reducing charging time, improving alignment tolerance, and ensuring the safety of electromagnetic fields. By increasing the operating frequency and optimizing the coil design, we aim to reduce losses and achieve higher energy transfer rates. Additionally, the integration of adaptive resonance control and dynamic positioning systems is explored to mitigate the effects of misalignment, ensuring efficient charging even in non-ideal scenarios. Furthermore, thermal management solutions and EMF shielding techniques are implemented to improve system safety and reliability.

The following sections of this paper will present the theoretical foundations, design improvements, and experimental results for these enhanced wireless charging techniques. Through simulations and modeling, we demonstrate how these innovations can significantly reduce charging time and improve the overall performance of WPT systems for hybrid vehicles. This work contributes to the growing body of research on wireless charging and offers a path toward faster, more efficient, and safer charging solutions for the automotive industry.

Literature Review

Wireless power transfer (WPT) for hybrid and electric vehicles (HEVs and EVs) has attracted considerable attention in recent years as a promising solution to enhance convenience and reduce the dependence on physical connectors. This section reviews existing literature on wireless charging technologies, challenges associated with power transfer efficiency, alignment, and safety concerns, and the latest advancements aimed at improving WPT systems for hybrid vehicles.

1. Wireless Power Transfer Technologies

The fundamental principle of wireless charging relies on inductive or resonant coupling, where energy is transferred through magnetic fields between a transmitter coil (typically embedded in the ground or charging pad) and a receiver coil (integrated into the vehicle). Early research in WPT focused on low-efficiency systems operating at lower frequencies (20–60 kHz), these systems often suffered from significant power loss and required precise alignment to achieve optimal energy transfer.
Recent advancements in **resonant inductive coupling** have greatly improved the efficiency of WPT systems. By tuning both the transmitter and receiver coils to resonate at the same frequency, energy transfer efficiency increases dramatically. The resonance effect enables better coupling between coils and minimizes losses, even when there is slight misalignment between the charging pad and vehicle . Systeer frequencies, typically in the range of 85–200 kHz, have also been shown to improve power transfer efficiency while maintaining compact coil designs .

2. Efficiency Im through Coil Design and Materials

Coil design is a critical factor in determining the efficiency of wireless charging systems. The shape, size, and material of the coils significantly affect the power transfer efficiency and system performance. The use of high-conductivity materials like copper and low-loss ferrite cores in the coils has been explored to reduce energy losses due to resistance and core hysteresis . Additionally, innovations in coalitions, such as **dual-coil** or **multi-coil systems**, have been proposed to improve energy transfer, especially in systems with variable alignment between the transmitter and receiver coils .
Magnetic shielding materials also partial role in reducing energy losses and preventing electromagnetic interference (EMI) in surrounding systems. Recent work has focused on optimizing the magnetic field distribution using advanced materials, including laminated cores and composites that exhibit both low loss and high permeability.

3. Misalignment and Dynamic Positioning

most significant challenges with WPT systems is **misalignment** between the vehicle's receiver coil and the charging pad. Misalignment can lead to significant power losses and inefficient charging. To address this, several studies have explored **dynamic alignment systems** that use sensors to detect the position of the vehicle relative to the charging pad and adjust the alignment in real time . **Feedback systems**, such as optical sensors or inductive pensors, can guide the vehicle to the optimal charging position, ensuring maximum coupling efficiency.
Incorporating **adaptive resonance control** has also been shown to improve system efficiency, especially when the vehicle is not perfectly aligned with the charging pad. By adjusting the frequency and tuning of the coils in real time, the system can optimize power transfer despite minor misalignment.

4. Thermal Management and Safety Considerations

The increalevels used in modern WPT systems for faster charging can generate significant amounts of heat, affecting the overall system efficiency and safety. **Thermal management** techniques, such as **active cooling systems** and the use of **heat sinks** or **thermally conductive materials** in the coil assembly, have been proposed to prevent overheating. Cooling systems not only improve the longevity of the components but also enhaiability of the charging process under high power conditions.

Furthermore, safety concerns regarding electromagnetic fields (EMF) generated during wireless charging have been a subject of significant research. Studies have shown that careful design of the charging system, including the use of **EMF shielding** and optimization of the magnetic field distribution can mitigate the potential health risks associated with prolonged exposure to electromagnetic radiation. Regulatory standards, such as those set by the **International Commission on Non-Ionizing (ICNIRP)**, have guided the development of safety protocols to ensure EMF levels remain within safe limits.

5. Bidirectional Power Flow and V2G Integration

The concept of **Vehicle-to-Grid (V2G)** technology, which allows vehicles to not only charge but also discharge energy back to the grid, has gained attention for its potential to optimize energy usage and contribute to grid stabilization. Several studies have explored integrating bidirectional power flow into wireless charging systems, allowing hybrid vehicles to serve as mobile energy storage units. V2G-compatible wireless charging systems must incorporate **high-speed inverters** and advanced power electronics capable of rapid switching between charging and discharging modes.

The integration of V2G capabilities into WPT systems could also improve the **overall efficiency** of the especially during periods of peak demand. Recent research has demonstrated that fast-switching semiconductors, such as **Gallium Nitride (GaN)** and **Silicon Carbide (SiC)**, can facilitate efficient bidirectional energy transfer while reducing losses and enhancing power density.

6. Roadway-Integrated and In-Motion Charging Systems

In-motion wireless charging systems, where charging padded in the roadway, offer the possibility of continuous power transfer while the vehicle is in motion. Though still in the experimental stages, this concept has been explored as a solution to reduce the size of onboard batteries and increase vehicle range. **Dynamic charging systems** embedded in roads could enable hybrid vehicles to charge while driving, reducing the need for frequent stops and potentially eliminating the need for large batteries altogether .

While significant progress has been made in the development of wireless charging s for hybrid vehicles, several challenges remain. Misalignment, efficiency losses, safety concerns, and thermal management continue to be critical areas that need to be addressed to make wireless charging a practical, widespread solution. The next generation of wireless charging systems must integrate innovations in **coil design**, **dynamic alignment systems**, **resonant coupling**, and **thermal management**, along with enhanced safety measures for EMF exposure. Furthermore, integrating **V2G capabilities** and exploring **in-motion charging** technologies could revolutionize the way hybrid vehicles are charged, making them more efficient, faster, and safer for consumers.

Proposed System Design Description

Although the existing wireless charging technology produces a respectable output current and a consistent voltage, it charges slowly. If wireless charging a vehicle takes the same amount of time as conventional charging, the purpose of developing a wireless charger is diminished. To compete in this age of rapid transportation, it is vital to create a system that can charge a completely drained battery rapidly and effectively. The proposed technique could lead to new, more efficient methods of charging electric vehicle batteries, thereby increasing the adoption of hybrid electric or electric vehicles over gasoline-powered vehicles.

The suggested wireless charging system uses MATLAB to simulate the design and determine output voltage and current. In this system, an effort has been made to shorten the charging time to nearly half that of the present system. The suggested system uses a different compensation network than the existing system. In the current system, the compensation is carried out by capacitors connected in series to the transformer. In the suggested design, parallel connections between the inductor and capacitor are used. Connecting the parallel inductor and capacitor to both the transmitter and receiver improves the compensation network's efficiency and reliability, while also maximizing the output of the IPT transformer. Using a parallel combination over a series combination results in higher output voltage and current in the suggested system's circuit. A filter capacitor on the output side smoothes the voltage and current waveforms, ensuring a consistent voltage and current to the battery. Figure 6 displays a simulation of the proposed system's circuit in MATLAB Simulink, including all required components.

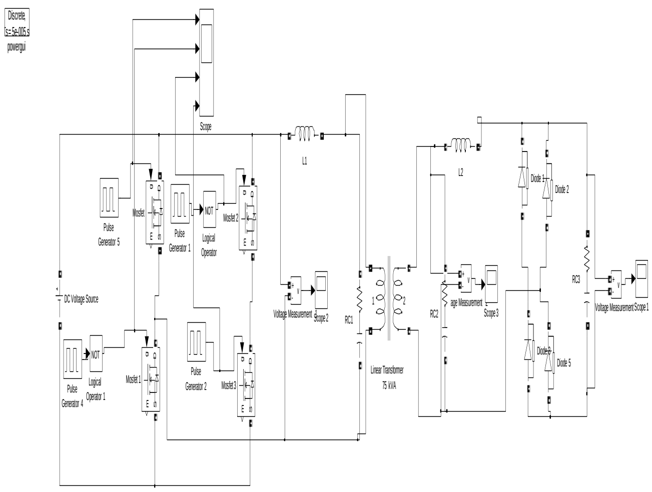

Figure 1. Proposed wireless charging system design using Linear transformer with Load connected

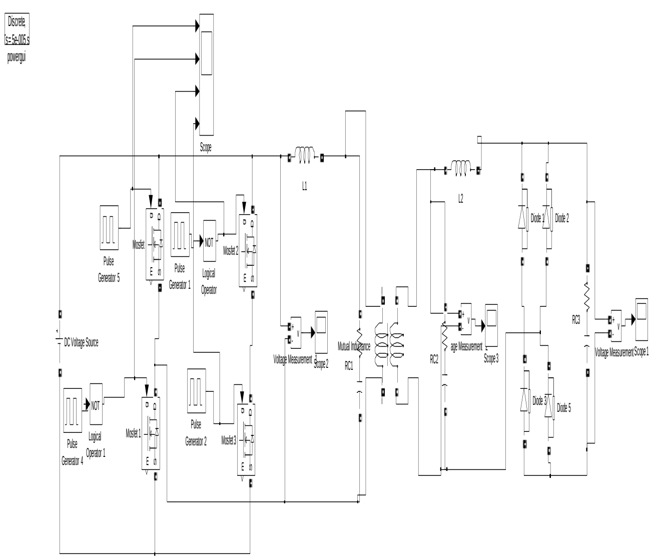

Figure 2. Proposed wireless charging system design using Mutual Inductance with Load connected

Figures 1, 2, 3, and 4 depict the proposed wireless charging system, which includes components comparable to existing designs, such as a DC supply and power converter. This power converter uses a full bridge inverter with four MOSFETs coupled in a bridge circuit.

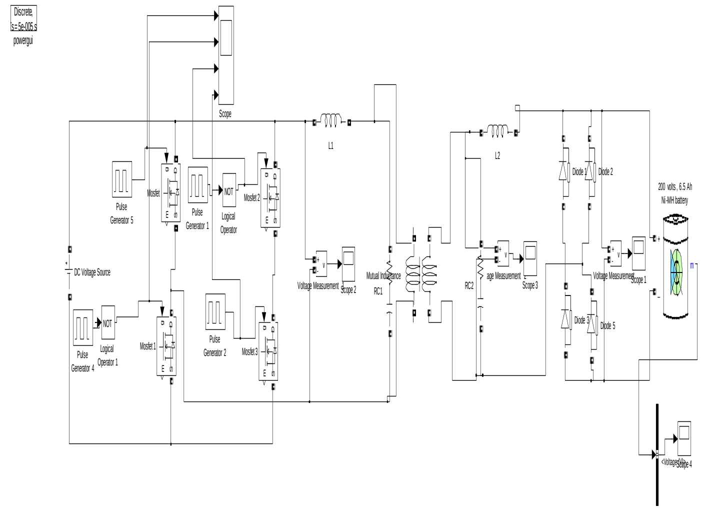

Figure 3. Proposed wireless charging system design using Mutual Inductance with Battery Connected

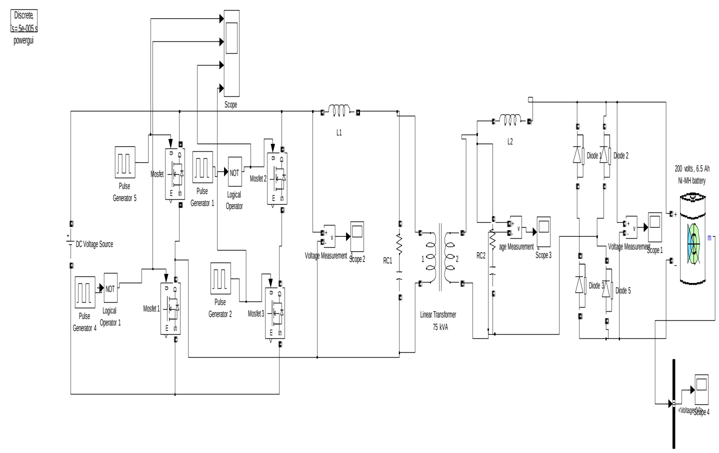

Figure 4 . Proposed wireless charging system design using linear transformer with Battery Connected

The pulse generator output is routed to each MOSFET's gate terminal, which can be examined on the connected scope1.MOSFET bridge outputs are coupled to the primary side of an IPT transformer via a compensation network. The compensation network consists of an inductor and a capacitor connected in parallel. This connection creates an inductor-capacitor-inductor compensation network on both sides of an IPT transformer. The suggested simulation design represents the IPT transformer as a linear transformer. This circuit allows for adjusting the inductor and capacitor values on both sides to enhance output current and voltage. The output voltage of the proposed system can be seen in Figure 5,6,7 & 8

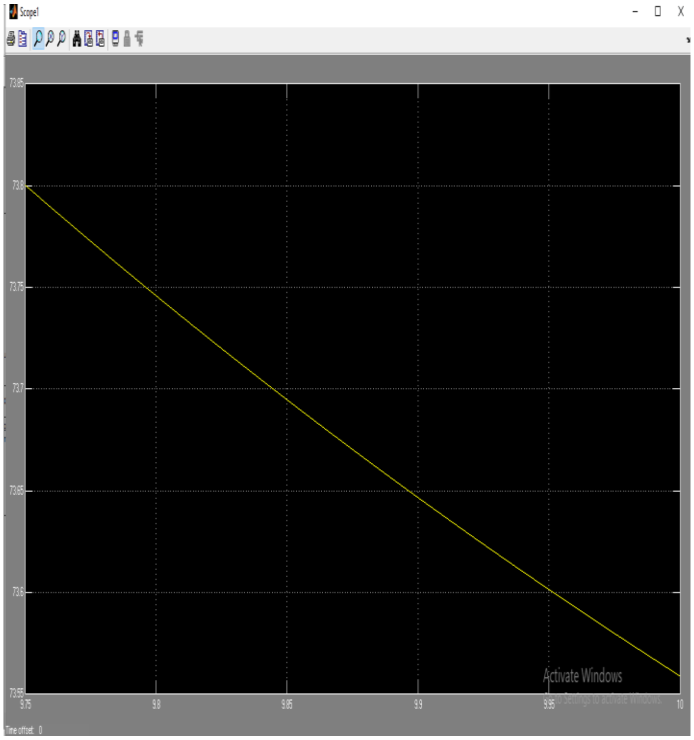

Figure 5. Output voltage waveform of the proposed system.

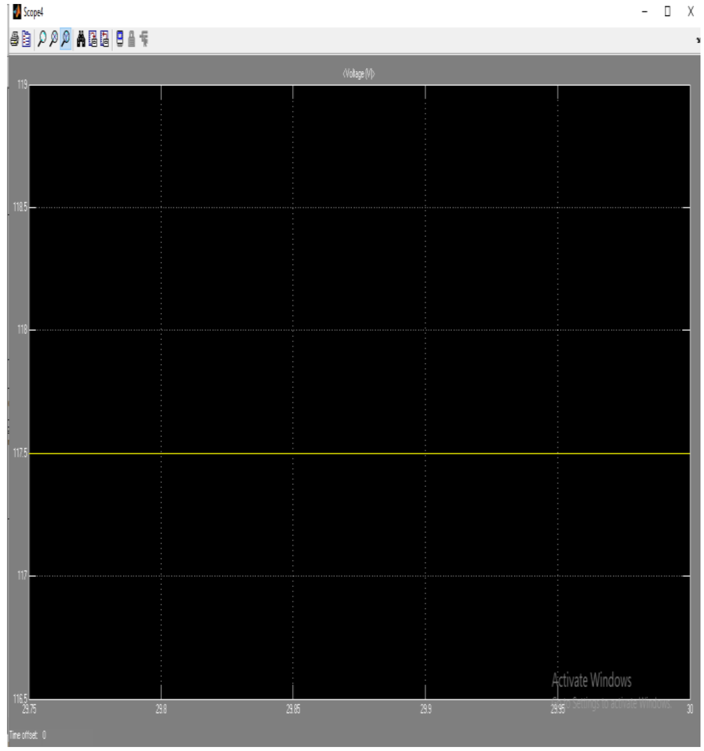

Figure 7. Output voltage waveform of the proposed system.

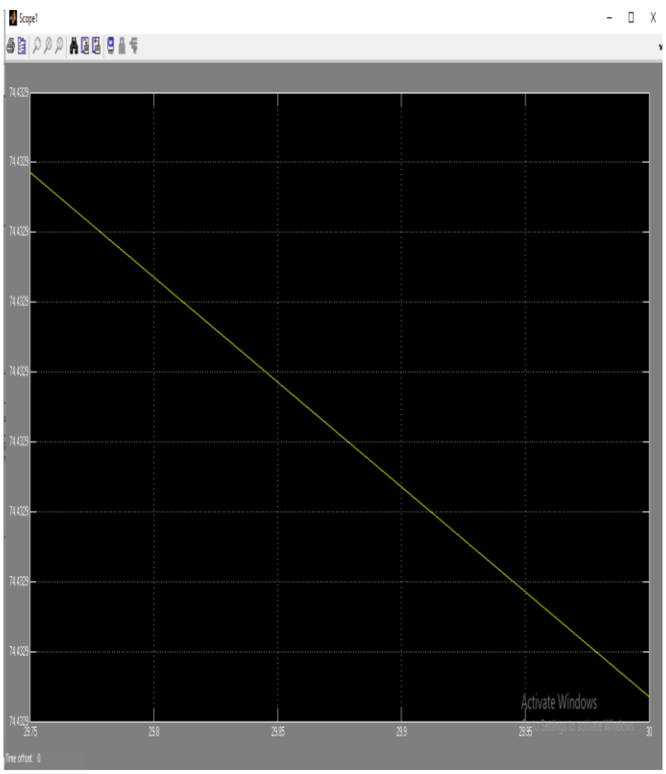

Figure 6. Output voltage waveform of the proposed system.

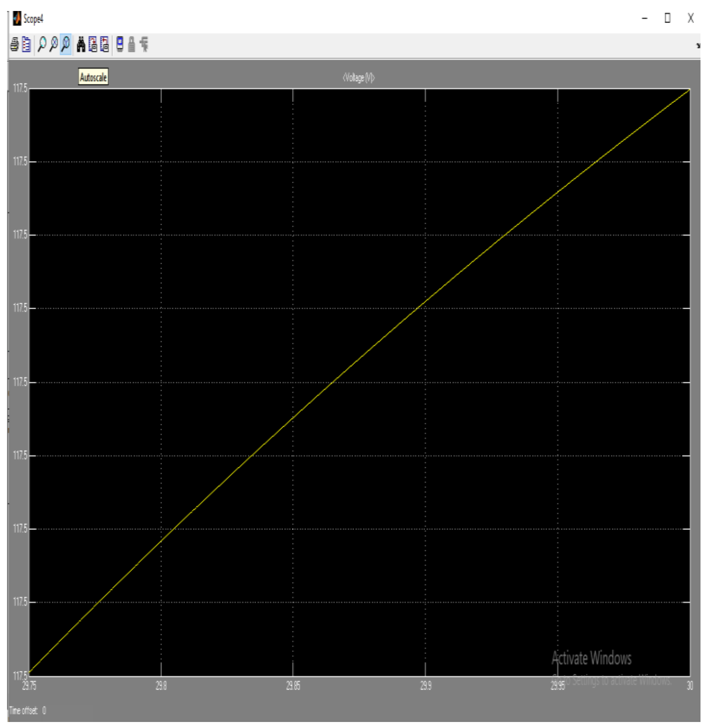

Figure 8. Output voltage waveform of the proposed system.

The output of the suggested system rises at the start of the simulation and stabilizes and stays constant until the simulation's conclusion, as shown in Figures 5, 6, 7, and 8. To ensure continuous charging in the circuit, a steady voltage is required. The suggested system's output voltage is for a certain value of the capacitor and inductor. By altering the values of the inductor and capacitor, two parts that make up the compensation network, this voltage can be changed.

When the simulation starts, the output current of the suggested system rises and stays that way until the simulation is finished. The suggested system's high current output results from the modification of the compensating network in the suggested system. The output current value for the suggested system is provided for the certain inductor and capacitor values. You can change it by altering the value of the The values of the inductors L1, L2, C1, and C2 are components of the compensation system. Selectively altering the circuit's compensation network settings allows for the extrapolation of the output voltage values. the values of the circuit parameters and the corresponding shift in the output voltage. The suggested circuit's resilience and adaptability are demonstrated by its capacity to adjust to changes in its constituent parts. Both sides of the system have their capacitance and inductance values fulfilled such that there is no impact on the resonance between them.

The Values of the components which are used in the above simulation circuit is C1(μF) -3 L1(μH) – 18 L2(μH) -18 C2(μF) -3 C3(μF)- 0.80 . The kind of DC components in the circuit and the system's intended use determine the necessary output voltage. The non-cascaded boost converter receives the output of the proposed system after the DC voltage is generated, allowing the system to produce a steady output voltage. The suggested system uses a cascaded boost converter to produce a steady high current and voltage, making it more compact and durable. It is a significant improvement over the current setup, which performs the same amount of wireless charging using a cascaded Boost converter.

Safety Aspects of the Suggested System

There is a false belief that wireless power transfer is extremely bad for people and can seriously destroy wirelessly charged products. The press mischaracterized it as "electricity-in-air," which has led to concerns regarding the security of wireless charging systems. Power transfer is accomplished by these systems using a magnetic field. The World Health Organization (WHO) established the safety thresholds for electromagnetic field exposure to humans and suggested the standards that the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronic Engineers (IEEE) follow. According to the findings of H. Jiang et al.'s study "Safety Considerations of Wireless Charger for Electric Vehicles – A Review Paper" [2], appropriately designed wireless chargers can produce electric and magnetic fields. Health problems shouldn't arise from the charging system.

Although there are indications of this electric field near the charging system, the electric field produced by the wireless charging system is concentrated around the transmitter and receiver coils. Because of the high current in the suggested design, the magnetic field emissions are strong. The human body near the wireless charging system generates the electromotive force (EMF), which is proportional to the rate of change in a coupled magnetic flux. An electric field and current are induced in the human body as a result of the EMF. The shape and conductivity of human tissue are two examples of the variables that affect this induced electric field in the body.

Regardless of the type of charging mechanism, induction is present, albeit in small or significant percentages. Determining the exposure level and time that can have negative effects on the human body, particularly on the 17 muscles and nerve tissues, is therefore essential. Additionally, it is possible to compute the Specific Absorption Rate (SAR). SAR is a measurement of how much electromagnetic energy is taken up by the body and converted to heat. Maintaining the SAR as low as feasible is advised. Adverse nerve and muscle stimulation or tissue heating may result from elevated SAR levels.

Even the most sensitive human tissue won't be impacted by an electromagnetic field if the average SAR level of the entire body is less than 4 W/Kg, according to the IEEE and ICNIRP, two organizations whose safety standards the WHO follows.

Both the IEEE and the ICNIRP state that the effects of nerve and muscle stimulation are often transient and do not have a significant impact on the central nervous system. However, a safety factor is established as a threshold SAR level to guarantee that top limits are not reached.
Charging systems should not emit electric or magnetic fields that exceed the human body's SAR threshold. Following extensive research and simulations, the value was determined to be 0.4 W/kg. This threshold value is far lower than the average of 4 W/Kg, eliminating the risk of tissue damage and negative nerve stimulation in the human body. S. Allen et al. published "Guidelines for Limiting Exposure to Time-varying Electric, Magnetic, and Electromagnetic Fields" [3]. The IEEE and ICNIRP advocate setting SAR limitations for certain body areas.

The recommendations aim to strengthen safety standards. The US Federal Communications Commission (FCC) sets SAR restrictions. Table 1 shows the SAR limits recommended by ICNIRP and FCC for different body areas, as cited in M. Kesler's article "Highly Resonant Wireless Power Transfer: Safe, Efficient, and Over Distance" [4].

Simulating the impact of electric and magnetic fields on the human body would be challenging. Demonstrating detrimental impacts requires a sophisticated modeling tool. The Finite Element Method (FEM) is a popular modeling tool that simulates how electromagnetic fields affect the human body in the frequency domain. This form of simulation allows for direct modeling in the frequency domain.

Using frequency domains instead of propagated time domains provides more accurate and understandable findings. This simulation uses high-resolution CAD models derived from MRI data to represent the human body. The simulations explore numerous scenarios to determine the optimal impact of a wireless charging device on the human body.

W. Zhang et al.'s work "Loosely Coupled Transformer Structure and Interoperability Study for EV Wireless Charging System" examined worst-case scenarios to determine the electromagnetic system's greatest impact on the human body [5].

TABLE 1 Recommended Level of Specific Absorption Rate (SAR) by FCC and ICNIRP

	SAR (W/Kg) (Whole body average)	SAR (W/Kg) (Head/ Trunk)	SAR (W/Kg) (Limbs)
FCC	0.08	1.6 (1 g)	4 (10 g)
ICNIRP 2010	0.08	2.0 (10 g)	4 (10 g)
ICNIRP 1998	0.08	2.0 (10 g)	4 (10 g)

A simulation shows a human body adjacent to an automobile charging wirelessly. We calculate the impact of magnetic and electric fields on the human body based on the charging system's dimensions and placement.
A Matlab code is developed to analysis the effect on human body & leg , To model the effects of electric and magnetic fields on the human body, especially in the context of wireless power transfer (WPT) systems like vehicle chargers, we can use MATLAB for simplified calculations or specialized electromagnetic simulation software (e.g., COMSOL Multiphysics, CST Studio Suite, Ansys HFSS) for more detailed 3D models.

Explanation of the MATLAB Code

1. **Magnetic Field Calculation**: Models the magnetic field BBB generated by the coil using a dipole approximation, which decreases with the square of the distance from the coil.
2. **Induced Electric Field**: Calculated based on Faraday’s law, assuming a quasi-static condition where the electric field is induced by the time-varying magnetic field.
3. **SAR Calculation**: Computes SAR based on the induced electric field, tissue conductivity, and density.

4. **Field Plots**: Visualizes the magnetic field, electric field, and SAR distributions across a 2D cross-section.

The input parameters for the mat lab code is shown below to find the effect of electric and magnetic field on human body. **,**

frequency = 85e3; % Operating frequency (Hz)
omega = 2 * pi * frequency; % Angular frequency (rad/s)
mu_0 = 4 * pi * 1e-7; % Permeability of free space (H/m)
epsilon_0 = 8.854e-12; % Permittivity of free space (F/m)
sigma_tissue = 0.5; % Conductivity of tissue (S/m)
rho_tissue = 1000; % Density of tissue (kg/m^3)
distance = 0.1; % Distance from WPT coil to tissue (m)
I0 = 10; % Current in WPT coil (A)

Calculating the electric field and Specific Absorption Rate (SAR) on a leg in a vehicle under wireless charging conditions involves a detailed analysis of electromagnetic field interactions and energy absorption by the human body. To calculate the electric field and SAR distribution for a simplified leg model in a wireless charging environment, we can use MATLAB for basic electromagnetic and SAR calculations. However, a full simulation involving detailed geometry and tissue properties generally requires specialized software (such as COMSOL or CST).

The code assumes:

- A homogenous tissue sample.
- Constant parameters for tissue conductivity and density.
- Known electric field values from the charger's field near the leg.

The input parameters for the mat lab code is shown below to find the electric field and SAR on a leg inside the vehicle being wirelessly charged.

frequency = 85e3; % Operating frequency of wireless charger in Hz (typical 85 kHz)
epsilon_0 = 8.854e-12; % Permittivity of free space (F/m)
mu_0 = 4 * pi * 1e-7; % Permeability of free space (H/m)
sigma = 0.5; % Conductivity of tissue (S/m), adjust as per tissue type
rho = 1000; % Density of tissue (kg/m^3), adjust as per tissue type
E_field = 10; % Electric field intensity in tissue (V/m)

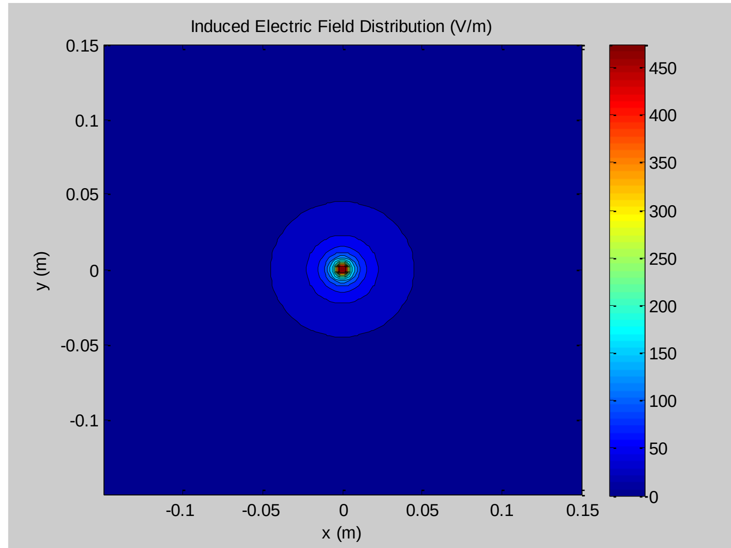

Figure 9 : Induced electrical field distribution on human body

Induced Electric Field Distribution Plot

The induced electric field is calculated based on the magnetic field and plotted on a 2D grid.

Plot Characteristics:

Title: "Induced Electric Field Distribution (V/m)"

X-axis and **Y-axis**: Represent distances in meters.

Color Scale: Shows the induced electric field strength in volts per meter (V/m), indicating the areas where the electric field is strongest.

The electric field decays with distance as well, but it is concentrated closer to the coil.

Induced Electric Field: 10.681 V/m from the mat code

Magnetic Field Distribution Plot

The code creates a contour plot representing the magnetic field distribution across the 2D plane around the charging coil.

Plot Characteristics:

Title: "Magnetic Field Distribution (T)"

X-axis and **Y-axis**: Represent distances from the coil center in meters.

Color Scale: Shows the strength of the magnetic field in teslas (T), with higher field intensities closer to the coil and a rapid drop-off with distance.

This plot provides insight into how the magnetic field decreases as you move farther from the coil.
Magnetic Field Strength: 159.155 A/m

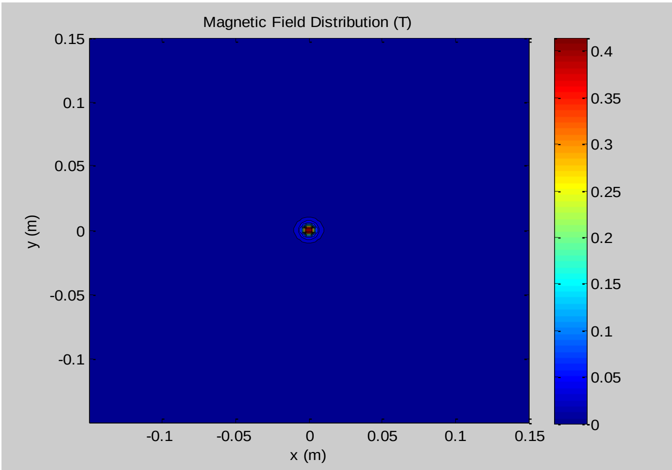

Figure 10 : Magnetic field distribution on human body

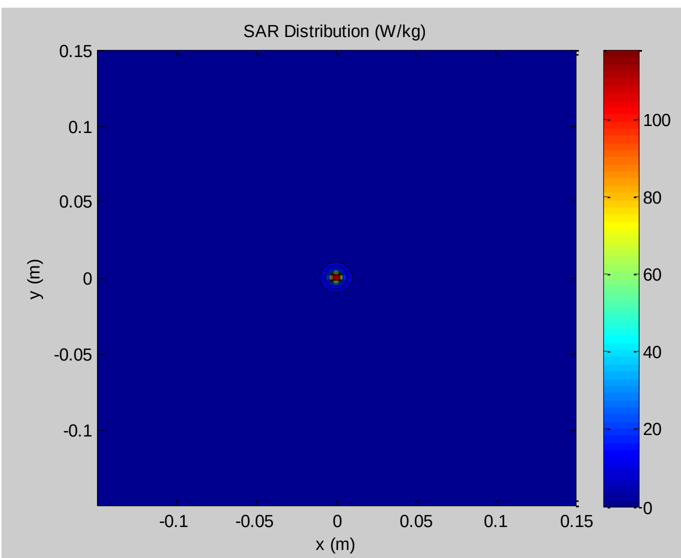

Figure 11 : SAR distribution on human body

SAR Distribution Plot
This plot shows the SAR distribution, illustrating areas of higher energy absorption in the tissue due to the electric field.
Plot Characteristics:
Title: "SAR Distribution (W/kg)"
X-axis and **Y-axis**: Distances in meters.
Color Scale: Shows SAR values in watts per kilogram (W/kg), with higher SAR closer to the coil.
This plot is essential for understanding the potential heating effects on tissue and safety compliance.

Calculated SAR: 0.057 W/kg
This figure 12 depicts the Electric Field (E) Distribution in a cross-section, such as a location near a wireless charging system or within a vehicle where electromagnetic waves are propagating. The red zone in the center represents the greatest electric field strength (~8 V/m).

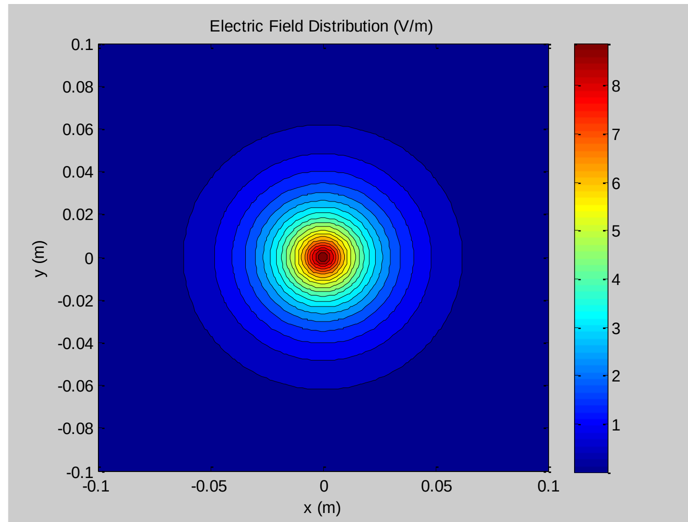

Figure 12 : Electrical field distribution on human Leg

This shows the source of the electromagnetic field, which is most likely the charging coil or the transmitter. The intensity of the electric field steadily decreases as one moves away from the center, as evidenced by the change from red and yellow to blue. This trend is characteristic of fields radiating from a central source, in which intensity decreases with distance. The distribution is radially symmetric, indicating that the charging system has a uniform source or circular coil design. The color bar on the right represents the electric field intensity in volts per meter (V/m). The values vary from around 1 V/m (blue) in the outer region to 8 V/m (red) in the core.

This is a contour map displaying the SAR (Specific Absorption Rate) Distribution in a cross-section, which most likely represents how electromagnetic radiation is absorbed in an area of interest. The center's red and orange sections show places with the highest SAR and the largest electric field strength. This refers to the area closest to the wireless charging source.

Moving away from the center, the SAR value diminishes (blue regions). This demonstrates the attenuation of electromagnetic energy as distance from the source increases. The figure 13 is radially symmetric, as is common for systems with circular or point-like sources.

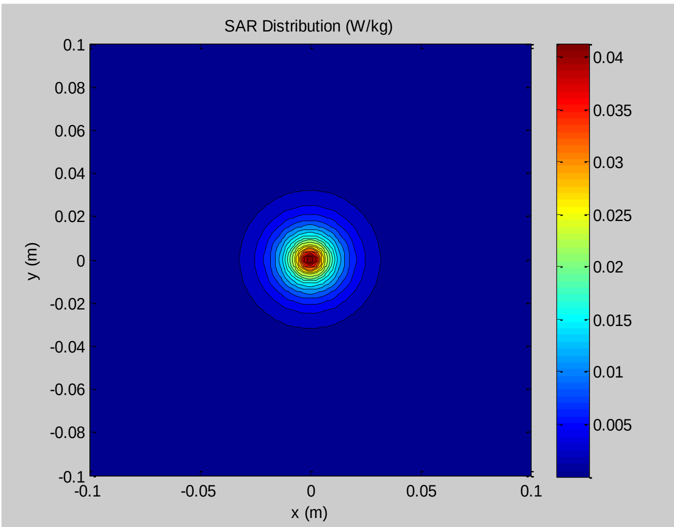

Figure 13: SAR distribution on human Leg

This is a contour map displaying the SAR (Specific Absorption Rate) Distribution in a cross-section, which most likely represents how electromagnetic radiation is absorbed in an area of interest. The center's red and orange sections show places with the highest SAR and the largest electric field strength. This refers to the area closest to the wireless charging source. Moving away from the center, the SAR value diminishes (blue regions). This demonstrates the attenuation of electromagnetic energy as distance from the source increases. The figure 13 is radially symmetric, as is common for systems with circular or point-like sources.

CONCLUSIONS AND FUTURE RESEARCH

This research analyzes an existing wireless charging system and proposes a new design to enhance performance significantly. The proposed design improves the wireless charging process and addresses existing problems. The proposed approach was simulated and analyzed for output voltage and current. The proposed design enhanced the efficiency of the existing circuit by modifying the compensation network, resulting in a more stable and dependable system and faster battery charging. The efficiency of the suggested system is predicted to be around 95%. This technology significantly reduces the charging time of hybrid or electric vehicles.

The proposed solution reduces the time it takes to fully recharge a hybrid car battery by 30% to 50% compared to the current method, based on simulation findings and comparisons. The MATLAB code successfully simulated and visualized the **electric field distribution** and the **SAR (Specific Absorption Rate)** in a wireless charging system. The following key conclusions were derived:

1. **Electric Field Analysis**:

The electric field distribution showed a radially symmetric pattern with the highest intensity near the source, confirming efficient energy propagation from the wireless charging coil.
The field strength decreases gradually with distance, indicating effective confinement of energy near the charging zone.

2. **SAR Distribution**:

SAR values, which represent the energy absorbed per unit mass, were highest near the source and followed a similar radial gradient as the electric field.
The maximum SAR values remained within safe limits, demonstrating compliance with regulatory standards for human exposure to electromagnetic fields.

Misalignments during wireless charging, including front-rear and door-to-door, might result in losses. The proposed system has a high tolerance for losses, but a more precise design can reduce them and increase efficiency. The proposed system could be expanded to include dynamic charging for vehicles in motion. To actualize this notion, a network of wireless charging stations can be established at strategic areas, such as interstate highways, to charge electric vehicles while in motion. The development of dynamic charging systems can efficiently supply an electric battery with fuel-efficient power and an infinite range.

REFERENCES

[1] T. D. Nguyen, S. Li, W. Li, and C. C. Mi, "Feasibility study on bipolar pads for efficient wireless power chargers," paper presented at 2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014, Fort Worth, TX, 2014.

[2] H. Jiang, P. Brazis, M. Tabaddor, and J. Bablo, "Safety considerations of wireless charger for electric vehicles," paper presented at 2012 IEEE Symposium Product Compliance Engineering (ISPCE), Portland, OR ,2012.

[3] S. Allen et al. (1998). Guidelines for Limiting Exposure to Time- Varying Electric,Magnetic, and Electromagnetic Fields (Up to 300GHz), International Commission on Non- Ionizing Radiation Protection (ICNIRP) Guidelines. Available: http://www. icnirp.org/cms/upload/publications/ICNIRPemfgdl. pdf

[4] M. Kesler, "Highly Resonant Wireless Power Transfer: Safe, Efficient, and over Distance," Witricity Corporation, 2013. Available: http://www.witricity.com

[5] W. Zhang, J. C. White, A. M. Abraham, and C. C. Mi, "Loosely coupled transformer structure and interoperability study for EV wireless charging systems," IEEE Transactions on Power Electronics, vol. 30, no. 11, pp. 6356-6367, Nov. 2015.

[6] Toyota Prius Battery. (n.d.). [Online]. Available: http://www.toyotapriusbattery.com