International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-09, Issue-05, Aug 2023

Design and Simulate Global Wireless Electric Vehicle Charging System

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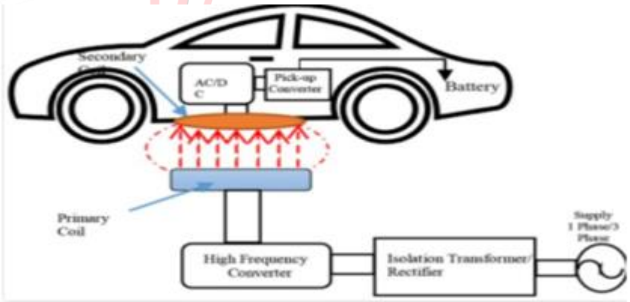
Abstract - Electric vehicle (EV) technology is gaining popularity due to its lower fuel emissions, and it is expected to experience a rapid increase in the near future. Consequently, there is a need for continuous improvements in the charging infrastructure, particularly wireless charging systems. These wireless charging infrastructures can be used for both home and public charging stations, serving private, commercial, and public purposes. The presence of wireless charging stations addresses challenges related to charger connectivity, charging time, and range anxiety, which are major obstacles to the widespread adoption of EVs. The deployment of effective and reliable high- power wireless charging infrastructures at close ranges would enable unrestricted range for EVs. However, the practical implementation of EV wireless charging infrastructure has been hindered by various technological obstacles. These challenges include a poor coupling coefficient between the wireless charging system's transmitter and receiver, interference from foreign objects such as metal or living organisms, and alignment issues with power pads. This thesis proposes solutions to these problems.

Keywords —At Electromagnetic Field, Electromagnetic coupling, Wireless Power Transfer, Electric Vehicle.

I.INTRODUCTION

The increasing environmental concerns, minimal maintenance requirements, and potential as a gasoline-powered vehicle alternative have attracted both consumers and researchers to electric vehicles (EVs) [1, 2, 3, 4]. Numerous research and development efforts in various industries are focused on EV advancements. However, the main challenge lies in the high energy consumption of EVs [5, 6, 7]. Battery and supercapacitor storage systems suffer from limited energy storage, low power delivery, and low energy density [8]. For EVs, these limitations result in small energy storage capacity and extended charging times, posing significant hurdles. While conductive charging requires a physical connection between the car and the charger, wireless charging enables charging without direct contact. There are two wireless charging methods available, as illustrated in Figure 1, which depicts a schematic representation of a static wireless EV charging system component. Inductive wireless charging relies on mutual induction between the transmitter and receiver, utilizing a time- varying magnetic field. The wireless charging system consists of a high-frequency component and a low-frequency ac/dc converter.



II. WIRELESS POWER TRANSFER TECHNOLOGIES.

Significant advancements in mathematics, both theoretical and experimental, have been made since the 19th century. Andre-Marie Ampere formulated Ampere's circuital law, which established the relationship between magnetic field and electric current [1]. Michael Faraday's Law of Induction explained how a time-varying magnetic flux can induce an electromagnetic force in a conductor.

While early researchers recognized the possibility of wireless transmission of electrical energy, their focus was primarily on electromagnetic induction. James Clark Maxwell, in 1864, developed Maxwell's equations, unifying the theories of electricity and magnetism and providing an explanation for the existence of electromagnetic waves.

- In 1890, Nikola Tesla invented the Tesla coil, also known as the Radio Frequency Resonant Transformer (RFRT), capable of transmitting

 DOI : 10.35291/2454-9150.2023.0162

electricity through inductive and capacitive coupling while generating extremely high AC voltages. Tesla demonstrated this technology by illuminating Geissler tubes and incandescent light bulbs. He believed that resonant inductive coupling could extend the range of wireless communication, although he was unable to commercialize his discoveries.

- This article focuses on an in-depth analysis of fast charging infrastructure for electric vehicles (EVs). Electrified transport is considered a potential solution to climate change, but the development of an affordable, reliable, and rapid charging system is crucial for the cost-effective commercialization and widespread acceptance of electric transportation infrastructure. Integrating a well-defined EV fast charging infrastructure with the smart grid offers various opportunities, including vehicle-to-grid (V2G) technology and addressing the intermittent nature of renewable energy sources. The article reviews the latest technologies for rapid EV charging and thoroughly examines the research conducted on the challenges and barriers that need to be overcome for its widespread adoption.
- The article also discusses the differences between conductive and inductive charging techniques.

Magnetic Analysis of Copper Coil Power Pad for Wireless Charging Application with Ferrite Core.

Electric vehicles are gaining popularity due to their environmental friendliness, low maintenance requirements, and potential as an alternative to petrol vehicles. Many companies have dedicated research and development departments focused on EV advancements. However, the limited energy storage range, low energy density, and low power delivery of batteries and supercapacitors are significant drawbacks. Charging an EV takes hours, posing a major challenge. While conductive charging requires a specific connection between the car and charger, wireless charging eliminates the need for physical contact. There are two types of wireless charging: static wireless charging and dynamic wireless charging. Static wireless charging allows for stationary charging without connectors or wiring, while dynamic wireless charging enables charging while the vehicle is in motion, improving the charging process, extending battery life, and reducing battery size. Figure 1 illustrates a schematic representation of an EV wireless charging system component. Inductive wireless charging utilizes mutual induction between the transmitter and receiver, employing a time-varying magnetic field. The wireless charging components facilitate the transfer of power from the charger to the EV.

Design and Interoperability Analysis of Quadruple Pad Structure for Wireless Charging Application for Electric Vehicles.

The introduction of wireless power transfer has brought about a new method of charging electrical devices. However, there are several recent challenges associated with wireless charging of electric vehicles (EVs) that need to be addressed in research and standardization efforts. These challenges include the design of power pads and coil configurations [1]–[7], power converters for high- frequency power conversion [8]–[10], electromagnetic field protections [11]–[13], and detection of metal objects and foreign objects [14].This book focuses on the structural investigation and compatibility of the quadruple power pad design with other coil structures such as rectangular, double D, and DDQ power pads. The main design challenge for the power pad is to maximize the quality factor and optimize the geometric arrangement. The efficiency of wireless power transfer is directly influenced by the coupling between the transmitter and receiver.Two fundamental coil configurations, namely unipolar and bipolar, are commonly used in static wireless charging devices. Unipolar coil arrangements generate vertical magnetic flux with a high coupling coefficient, while bipolar coil arrangements produce horizontal magnetic flux with a lower coupling coefficient and two pairs of magnetic polarities upon excitation [17]. However, the use of a solenoid coil with double-sided magnetic flux generation in wireless charging of electric vehicles is incompatible, as the receiver coil cannot link with all of the flux.

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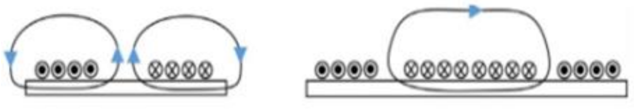

Fig.3 a) Nonpolarized pad Structure. b) Polarized pad structure and its associated magnetic field shape.

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Figure 3. demonstrates that the magnetic field in nonpolarized power pads is concentrated at the center and is perpendicular to the surface, while in polarized power pads, it is parallel at the center. When fully aligned, no significant power (VA) is linked between these pads, indicating that their interoperability is higher when they are out of alignment. Multicoil topologies such as DD (Double D) and BP (Bipolar Pad) consist of multiple sets of mutually decoupled coils [18, 19].Circular coils have minimal eddy currents since they lack sharp edges. The center of a circular coil exhibits a steep magnetic flux peak, which is advantageous for high power transfer. Additionally, the narrow distribution of flux diameter in circular coil structures reduces the susceptibility to misalignment.

Infrastructure for Charging Electric Vehicles in India: A Viability Analysis Cities in India are extremely concerned about the rising pollution levels.

The heavy reliance on internal combustion engine (IC) vehicles as the primary mode of transportation has raised serious environmental concerns. In response to these issues, there is a growing focus on developing efficient and emission-free modes of transportation. Electric and hybrid vehicles have emerged as the most promising alternatives to traditional vehicles. However, the widespread adoption of electric vehicles requires the establishment of charging infrastructure both at homes and in public spaces, similar to fuel stations for IC vehicles. Charging stations for electric vehicles are being deployed globally at different levels, including Level 1, Level 2, and rapid charging. To cater to the specific needs of the Indian market, a comprehensive investigation is necessary to develop a comparable and customized charging infrastructure. This study aims to provide a thorough overview of various technologies and practical options available in terms of power electronic converter topologies, and energy management. The goal is to identify feasible solutions for creating an efficient and effective EV charging infrastructure in India.

In summary, to address environmental concerns and promote sustainable transportation, electric and hybrid vehicles are being considered as replacements for traditional vehicles. Establishing appropriate charging infrastructure, tailored to the Indian market, requires a detailed examination of technologies, power quality, converter topologies, and energy management options.

Wireless Charging Efficiency Improvement for Electric Vehicles via Coil Misalignment Reduction.

In response to the depletion of fossil resources and increasing pollution levels, plug-in electric vehicles (xEVs), hybrid electric vehicles, and electric vehicles are emerging as viable solutions in the automotive sector. However, one of the challenges faced by xEV consumers is range anxiety, which can be addressed through various charging techniques. The establishment of a charging infrastructure is a crucial barrier to widespread xEV adoption.In the developing xEV market, wireless charging technology is gaining popularity as a promising solution. However, one of the significant obstacles in the commercialization of wireless charging is the misalignment between the vehicle and the charging pad. To tackle this issue, this study proposes a method that involves carefully adjusting the position of the receiver coil in response to the magnetic field of the transmitter. By implementing sensor control and receiver coil movement, the alignment between the coils can be significantly improved.

Keywords: Sensor control, Receiver coil movement, Misalignment, Wireless Charging.

The depletion of fossil fuels and the escalating levels of pollution have prompted global efforts to adopt xEV technology as a means to conserve resources and reduce pollution. While xEVs have gained a market niche, the current technology is not always user-friendly, requiring owners to plug in their vehicles for charging, which can be inconvenient. Moreover, there are safety concerns related to wiring trip hazards and contact wear. As a solution to these challenges, wireless charging is being explored as a viable alternative.

Inductive Power Transfer (IPT) is a wireless charging method that offers convenience and safety by eliminating the need for physical connections. However, there are drawbacks associated with IPT that need to be addressed before its widespread adoption. One significant challenge is the reduction in power transfer efficiency caused by lateral and horizontal misalignments between the transmitter and receiver coils. Researchers are actively working to overcome the issue of coil misalignment and improve system efficiency.

 DOI : 10.35291/2454-9150.2023.0162

Various design considerations have been proposed to mitigate misalignment effects in IPT systems. For example, a design and optimization approach using ferrite cores has been suggested to enhance misalignment tolerance and minimize core loss in Plugin Hybrid Electric Vehicle (PHEV) wireless charging systems. Another approach involves utilizing parallel and orthogonal windings in the receiving coil sets to improve power transfer efficiency. Additionally, a multi-coil-based WPT system has been introduced to achieve high tolerance for power transfer efficiency and data bandwidth.

This system utilizes multiple transmitter and receiver coils, including a second coil to maximize power transfer efficiency as the distance and angle between the coils increase.

To investigate the impact of coupling between transmitters and receivers on system performance, studies have been conducted considering perfect alignment as well as scenarios involving multiple transmitter and receiver coils.

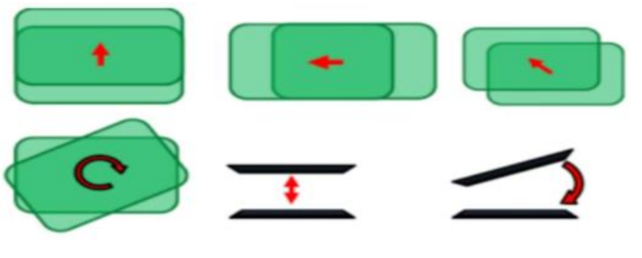


Fig.4 Misalignment positions a) X axis b) Y axis c) XY axis d) Rotational e) Vertical f) Inclined.

One step towards sustainable transportation.

Electrical energy plays a crucial role in powering various industries and establishments. In an effort to reduce environmental impact caused by fossil fuel-powered machinery, researchers are exploring alternatives. Wireless power transfer (WPT) offers a promising solution to simplify and enhance the use of electrical power for operating equipment. WPT enables the transmission of electrical energy from a source to a device without the need for physical wires. It can be employed for mid-range to long-range power transmission using different methods. WPT is particularly useful in situations where wired connections are challenging, risky, hazardous, or impractical. Examples include wireless charging of artificial organs and dialysis equipment, eliminating the need for repetitive removal.WPT finds application in various fields such as traffic management sensors, electric vehicle charging, and powering inaccessible equipment. In wireless communication, the focus is primarily on information delivery rather than transmission efficiency. However, in WPT, transmission efficiency is a key consideration, aiming to achieve maximum power transmission with minimal losses. This review article provides an overview of the technical challenges associated with WPT technology across different applications and discusses the current state of sustainability evaluations for WPT systems, with a specific emphasis on their use in electric vehicles.

In terms of historical advancements, significant progress has been made in mathematics, both theoretically and experimentally, since the early 19th century. Andre-Marie Ampere's circuital law established the relationship between magnetic fields and electric currents. Michael Faraday's Law of Induction explained how a time-varying magnetic flux induces electromagnetic force in a conductor. While various researchers observed the wireless transmission of electrical energy, their understanding was limited to electromagnetic induction. James Clark Maxwell, in 1864, provided a comprehensive explanation of electromagnetic induction through the development of Maxwell's equations, which unified the principles of electricity and magnetism. Maxwell also predicted and explained the existence of electromagnetic waves.

III. RELATED WORK

The electromagnetic spectrum can be divided into two categories: non-ionizing radiation and ionizing radiation. Non-ionizing radiation refers to electromagnetic waves with insufficient energy to ionize tissues. Wireless power transfer (WPT) systems utilize electromagnetic waves in the non-ionizing region of the spectrum.

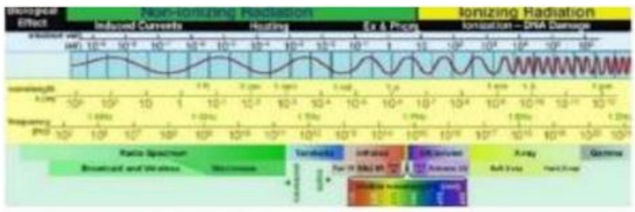


Fig. 3. The Electromagnetic Spectrum

WPT systems vary in terms of frequency, power, and transmission distance. However, when a WPT system is placed in close proximity to the human body, it can generate electromagnetic field (EMF) exposure concerns. To ensure the safety of individuals, exposure limits have been established.

Additionally, placing a WPT system near other electrical circuits can lead to electromagnetic compatibility (EMC) problems. To prevent interference with other systems, EMC susceptibility tests and EMI protection measures are required.Various standards and regulations govern the EMF and EMC safety considerations, interoperability requirements, and test methods for WPT systems. These standards take into account different application types and address the concerns associated with EMF and EMC.Scheduling algorithms play a crucial role in WPT systems. One such algorithm is the "first access, first charge" scheduling approach, where time is divided into equal charging windows. Devices requesting wireless power are added to a queue, and the algorithm serves them in sequence. Other scheduling techniques, such as time multiplexing and spatial multiplexing, are explored for fairness among

 DOI : 10.35291/2454-9150.2023.0162

wireless energy receivers, considering both homogeneous and heterogeneous scenarios.

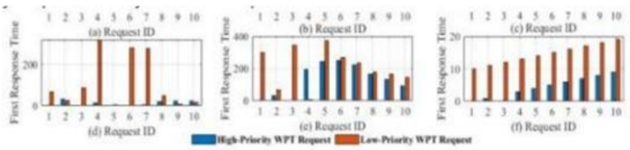
Research has also focused on WPT scheduling algorithms based on context learning. These algorithms consider IoT devices and wireless power transmitters with antennas. Devices communicate their need for WPT before a time slot begins, and the transmitter schedules each beam by allocating appropriate transmit energy. The algorithm aims to meet the minimum power requirements of various devices while receiving limited feedback on the power gathered.

In the context of the industrial Internet of Things (IIoT), WPT approaches are discussed, involving multiple wireless power transmitters, IoT nodes, and a centralized controller. Optimizing the distribution of wireless power transmitters to different nodes is addressed as an optimization problem. Generic solutions that consider the wide variety of device types in real deployments are required.WPT methods may also incorporate reconfigurable intelligent surfaces, which can be used to enhance wireless power transfer in linear architectures.

Overall, the discussed literature highlights the challenges and advancements in WPT technology, including EMF and EMC concerns, scheduling algorithms, and optimization techniques for various application scenarios.

IV. RESULTS & DISCUSSION

The proposed WPT scheduling system in the simulations maintains two priority queues: a high- priority queue and a low-priority queue. Each request through the system is assigned priority values for the respective queues. The simulations analyze the scheduling strategies on a request-by-request basis, considering all WPT requests in the system. The requests are categorized as high priority or low priority, with high priority requests being scheduled first. The simulations assume that all requests arrive instantly at system startup, and the completion time and initial response of each request are recorded.



The performance of the proposed WPT scheduling system is compared with the first-access first- charge (FAFC) WPT scheduling system presented in a previous study. The simulations are conducted using MATLAB, and the remaining charging time for high-priority and low-priority requests at system startup is recorded.The suggested WPT scheduling method based on remaining charging time shows evidence of the requests' completion time. The algorithm generally favours requests with more charging time left but also considers requests with shorter charging time by updating their priority based on waiting time. The first response times of the requests are slower for requests with higher remaining charging times compared to those with lower remaining charging times. The designed WPT scheduling approach aims to avoid starvation of low-priority requests, resulting in a fair difference in initial response times between high and low priority requests are Compared to the FAFC scheduling method, the suggested throughput-based WPT scheduling technique performs better in terms of overall throughput for all WPT requests considered in the simulation. The suggested scheduling strategies prioritize high-priority requests, while dynamic priority recalculation increases the importance of low-priority requests based on their waiting time, ensuring that initially low-priority requests also receive WPT service. The throughput-based approach generally exhibits reduced finish times for both high and low priority requests compared to the FAFC approach.

Additionally, the simulations review the efficiency and dependencies of static and dynamic wireless charging technologies. Technical aspects such as operational frequency, power transfer, coil design misalignment, compensation topologies, and the challenges associated with them are discussed.

Some of the technical challenges include constructing small-sized coils with high power transfer rates, managing interference between high-frequency electromagnetic fields and radio waves, achieving proper alignment between transmitter and receiver coils, understanding the impact of electromagnetic fields on sensors used in cars, considering resonance for alignment tolerance, and dealing with foreign objects that may affect system temperature and size.

The implementation of wireless charging systems addresses issues such as poor power transfer efficiency due to large air gaps and inadequate coupling coefficients between transmitter and receiver coils. Traditional methods for detecting foreign objects present difficulties, as they may be effective for detecting metal objects but not biological ones. Ultrasonic detection is an option but may require upfront capital expenditure.

Overall, the discussed research highlights the performance and challenges of WPT scheduling systems, as well as the technical considerations and limitations of wireless charging technologies.

V. CONCLUSION

The described WPT system and methods are designed to accommodate a variety of wireless power receiver devices, including IoT devices, smartwatches, smartphones, laptops, etc. Two different techniques are presented: one prioritizes WPT requests that can increase system throughput, while the other prioritizes requests that require longer charging times. The methods periodically recalculate the priorities of existing requests to avoid starving low-priority requests and provide appropriate service to them, while still offering high-priority service to prioritized requests. These methods are

 DOI : 10.35291/2454-9150.2023.0162

generic and can be applied to various WPT scheduling metrics.

Based on simulation outcomes, the proposed system and approaches perform well and outperform current WPT scheduling methods. They can handle different types of wireless power receiver devices, provide prioritized WPT service, and prevent starvation of low-priority requests. The choice of which scheduling algorithm to use depends on the specific requirements of the situation:

Throughput-based scheduling: This algorithm should be employed in situations where the response time of the WPT service is crucial. It is also suitable when the charging times of devices vary widely.Charging-time-based scheduling: This approach is appropriate when the charging time of the device is the critical factor.

In summary, the proposed WPT scheduling algorithms offer flexibility, prioritization, and avoidance of starvation for low-priority requests. The choice between the throughput-based and charging- time-based algorithms depends on the specific requirements of the situation at hand.

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