

EV Wireless Inductive Power Pad and Resonant Magnetic Field Coupling Multiple Unit Station

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ABSTRACT

The high rate of the electric vehicle (EV) adoption increased the pressure of finding the efficient and convenient to use and reliable types of charging technologies. The traditional plug-in charging solutions have the drawbacks of connector wear, environmental interaction and exposure, inconvenience to the user and limited accessibility. To eliminate these drawbacks, this project suggests and designs a 4-wheel electric vehicle wireless charging system based on the concept of resonant inductive coupling with several transmission pads. The proposed system incorporates two or three copper-based transmission pads beneath the charging surface and they produce a high-frequency alternating magnetic field. This magnetic flux is then picked up by corresponding receiver coils installed under the electric vehicle and converted into electrical energy that is used to charge up the battery. At a resonant frequency, the system greatly increases the power transfer efficiency and allows efficient transfer of energy over a specified air gap without the need to touch. This design provided several transmission pads, which are the main characteristic of a design, so that it is more tolerant to misalignment of the vehicle and changes in the parking position. The multi-pad design guarantees a closer distribution of the magnetic field to create a balanced power distribution to the battery system and less power loss when compared to single-pad wireless charging systems. Moreover, the modular pad system can scale the power level and can be used in a flexible deployment in both residential and public charging applications. The system architecture comprises of the high frequency inverter, resonant compensation networks, rectification and regulation phases and battery management interface to provide safe and efficient charging. The parameters that performance analysis is concerned with include the efficiency of coupling, power transfer ability, alignment tolerability and thermal characteristics of the coils. The experiment using a scaled version has shown credible results of wireless power transfer, increased flexibility of alignment and constant stationary charging..

Keywords: Electric Vehicle (EV), Wireless Power Transfer (WPT), Resonant Inductive Coupling, Wireless EV Charging, Multi-Pad Charging System, Inductive Charging Coils, Contactless Energy Transfer, Battery Charging System..

INTRODUCTION

The world transportation industry is experiencing huge transformation based on the requirement to decrease greenhouse gas emission and minimize the reliance on fossil fuel, and encourage the use of sustainable energy. Electric vehicles (EVs) have become one of the solutions to these problems because they are very efficient, cost-effective, and have a costless operation with regard to the environment. The constant improvements in battery technology, power electronics and motor control systems have greatly enhanced the performance and range of EVs. Nevertheless, even with such advancements in technology, the creation of efficient, reliable, and user-friendly charging networks has been one of the necessary issues to make EVs widespread. The traditional plug-in charging systems do need physical connectors which are prone to mechanical damages, corruptions as well as other safety concerns like electric shocks and short circuits. Also, the necessity of manual cable management can be inconvenient to users and challenging in the severe environmental factors, which leads to the investigation of other charging approaches and makes it safer and more durable and convenient.

The idea of wirelessly transferring power (WPT) technology has received a good deal of interest as a viable solution to the shortcomings of the wired EV charge. Of all the WPT methods, resonant inductive coupling is one of the most appropriate methods to be applied in EV applications as a consequence of the fact that it can transfer reasonably high power levels at good efficiency through an air gap. Under this technique, an alternating current of high frequency is applied to a transmitter coil where it will cause an oscillating magnetic field, which will induce an electric current in a receiver coil with a similar resonant frequency. This is a contactless transfer of energy that guarantees the absence of exposed electrical contacts and thus low maintenance rates and enhanced operational safety. Nonetheless, one technical issue; which has been identified in wireless EV charging systems is that power transfer efficacy is susceptible to coil misalignment and vertical separation between the two coils; send and receive. Coupling can be affected by minor variations in vehicle position which can cause an increase in losses and uneven charging performance thereby reducing the feasibility of a single pad wireless charging system in the parking environment. Multiple transmission pads in wireless EV charging systems have become one of the solutions to overcome these challenges as a scalable solution. Multi-pad configuration is better than single pad configuration in that it enhances lateral and longitudinal tolerance to misalignment as it produces a more uniform and extended magnetic field coverage under the car.

This guarantees stable transfer of power irrespective of the exact position where the EV has parked and allows the distribution of power to the battery to be balanced. Moreover, multi-pad systems are more flexible in system design and can be modularly expanded in power capacity and better load management. Such systems may provide stable, efficient and safe wireless charging operations by incorporating resonant compensation networks, power electronics converters and battery management interfaces.

The proposed project will entail designing and rolling out a multi-pad resonant inductive wireless charging system in a four-wheel electric vehicle to improve the reliability of charging systems, ease of use, and efficiency of the entire system.

The suggested project can help to develop the next-generation EV charging infrastructure and facilitate the process of fully autonomous and contactless charging solutions, which are to be implemented in transportation systems in the future..

LITERATURE REVIEW

Cheng et al. (2014) assessed the reliability of charging services of plug-in electric vehicles through the distribution network point of view.

Their study compared the effect of EV penetration on the indices of system reliability and the provision of charging points.

The authors revised that the lack of coordination in EV charging may impose challenges on distribution assets and decrease the reliability of services, which is why complex charging plans and infrastructure design can guarantee reliable EV charging services.

Xu and Chung (2016) examined the reliability assessment of distribution systems that use vehicle-to-home (V2H) and vehicle-to-grid (V2G) operations. Their research grew to show that bi-directional power flow of the EVs can improve reliability of the system when coordinated.

Another aspect that was cited in the study is that there should be smart control systems that will ensure that the charging and discharging processes are balanced without adversely impacting grid stability.

A method of arranging charges based on the reliability of customers at the cost of vehicles to the home developed by Alah Yari et al. (2015) takes into account vehicle-to-home capability. The authors demonstrated that the inclusion of customer reliability measures to EV charging decisions would enhance the user satisfaction and the system performance.

They emphasize the relevance of the optimized charging schemes that would be able to correlate the needs

of consumers with the goals of grid reliability.

Habib et al. (2015) have provided a review of vehicle-to-grid technology and EV charging strategies and how it will affect the distribution networks.

The research indicated that the main issues associated with the large-scale integration of EVs include voltage variation, overloading of transformers, and power quality. The authors have found that the future of charging control and intelligent infrastructure is needed to reduce the negative effects on the grid.

Ansari et al. (2015) designed a coordinated bidding mechanism of the ancillary service through vehicle to grid technology on the basis of fuzzy optimization algorithms.

In their work, they proved that EVs could be successfully used in grid support, including frequency regulation and at the same time had adequate performance in terms of batteries. This article emphasizes the prospect of EVs as smart grid environment active elements.

Hua et al. (2014) have suggested an adaptive EV charging coordination technique to decrease gridlock and distribution network losses. They optimally altered charging plans with the changing conditions of the network, which led to better voltage profiles and less peak demand. The research supported the value of smart charging coordination to integrate EVs.

The new approach to optimal EV charging coordination challenging the vehicle-to-grid technology was presented in Antune et al. (2016). Their optimization solution strategy was to reduce the cost of operations at the expense of reliability of the systems. The findings established that synchronized discharging and charging schemes make a great deal of enhancement in grid functions and efficiency in energy utilization.

Xu and Chung (2014) performed an analysis of power generation systems based on the demand of electric vehicles charging. Their research determined the system sufficiency and risk conditions in different scenarios of EV penetration.

The results have highlighted that there should be strong charging infrastructure and planning to ensure that the system is reliable.

Su and Chow (2011) tested the performance of plug-in hybrid electric vehicle (PHEV) parking station, which is a particle swarm optimization.

The emphasis of their work was on the optimization of the charging schedules to reduce the operating costs and peak demand. The research was a good source of information on smart parking and charging stations layout.

Aravinthan and Jewell (2015) evaluated the controlled EV charging strategies to reduce the effect of EV loads on the distribution assets. Their study revealed that managed charging has a great impact in reducing the aging of the transformers and feeder overloading.

The authors pointed out the importance of smart charging in increasing the life of infrastructure.

Dellinger et al. (2011) studied the vehicle-to-grid regulation reserves under dynamic simulation of car mobility behavior. Their analysis revealed that EVs may offer credible ancillary services in case of an optimistic driving behavior. The article emphasized the significance of the user behavior modeling in EV-grid integration research.

Corchero et al. (2014) came up with an ideal energy management approach of a residential microgrid involving vehicle-to-grid systems.

Their strategy aligned energy resources and EVs to reduce energy expenses and enhance efficiency of the

system. The findings substantiated the advantages of incorporating EV charging in the smart microgrids..

METHODOLOGY

The research design applied in this project is the design, implementation and evaluation of a multi-pad wireless charging system of a four wheel electric vehicle based on resonant inductive coupling.

The general methodology entails modeling of the system, design of the hardware, development of the control strategy and experimental validation to have effective and reliable wireless power transmission under real operating environments.

System Architecture Design.

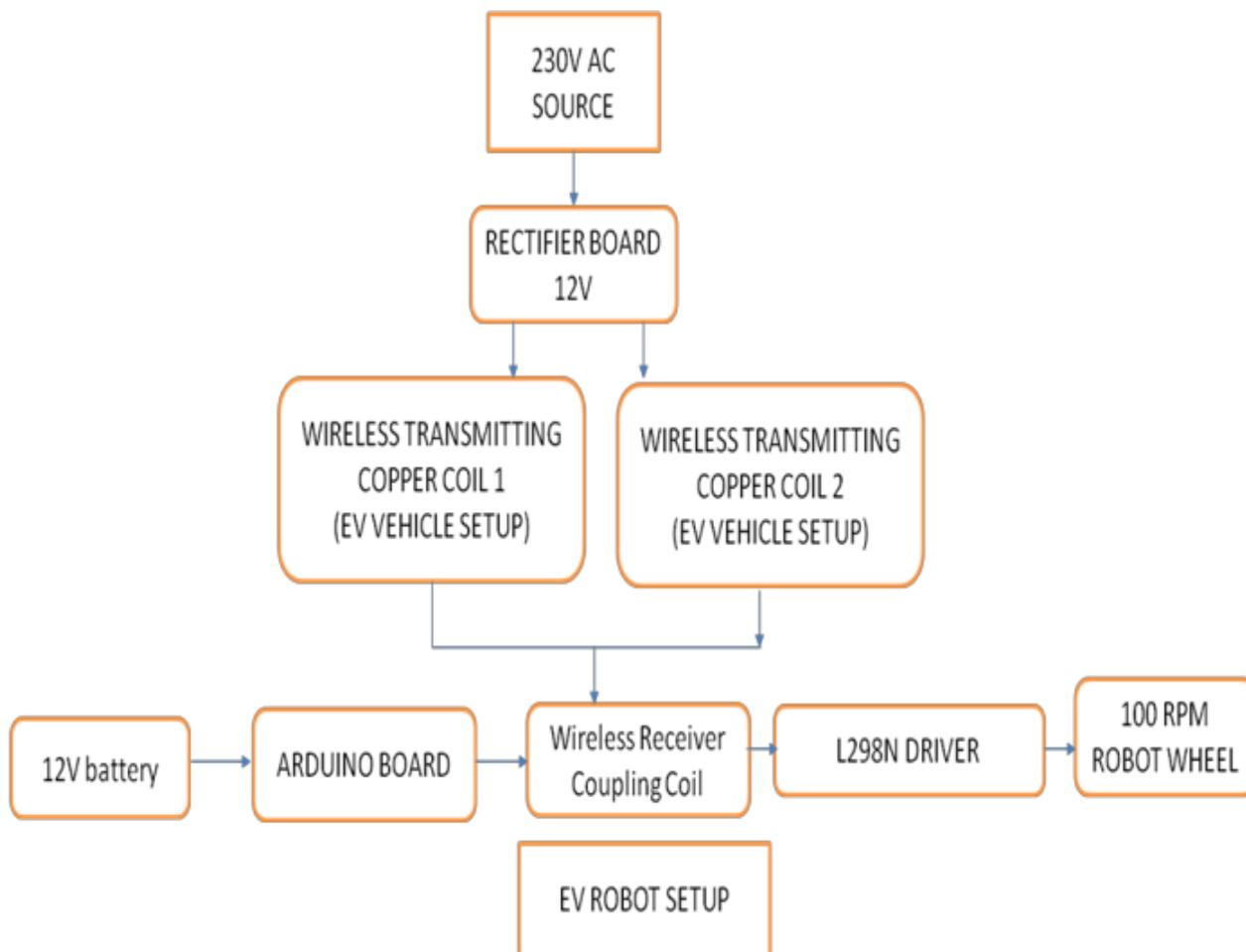


Fig:1 Architecture Diagram

The architecture shown in the diagram is centralized embedded control system where the CPU (Central Processing Unit) is the main decision-making and control component, the main one that coordinates information flow among the sensors, actuators, software, and subsystems that supports it. The external environment will provide inputs that are first measured by the different sensors that measure the physical parameters of the temperature, position, current, voltage, pressure, or speed. Sensors are usually analog in nature and therefore the sensor signals undergo an A/D (Analog-to-Digital) conversion block where the sensor signals are converted to digital data which the CPU can process.

This sensor data is continually sent to the CPU which then operates through control algorithms that are stored in memory based on embedded software that determines how the system behaves, the logic used to make decisions and the safety limits. To support applications with high speed or parallel processing, other computational capabilities can be offered via FPGA or ASIC modules to offload time-sensitive or

specialized workload off the CPU. Depending upon the processed inputs and the logic of control, the CPU produces output commands, which are again converted to analog signals by using the D/A (Digital-to-Analog) conversion and transmitted to actuators.

These actuators have direct contact with the physical system, and may be switching, motion control, power control, or mechanical adjustment, and thus influence the external environment. A human interface is also included in the system, which enables users to view system status, enter commands or parametrical setup and a diagnostic port is also included to test the system, detect faults and maintain system. To facilitate consistent functionality, auxiliary processes (including power regulation, cooling etc.) are used to support the CPU and other related electronics.

This is a critical attribute of the architecture; the electromechanical backup and safety subsystem, which offers an autonomous protective level that can override regular functionality in case of failures, errors, or dangerous situations. This is a safety route that allows the system to go into a safe state in case of the failure of the CPU or software. The diagram as a whole is a powerful closed-loop control system with

sensing, computation, actuation, user interaction and safety systems closely coupled together to ensure the reliable and controlled operation of the system in real-world conditions..

Resonant Inductive coupling Design.

To enhance the efficiency of power transfer between the transmitter coil and the receiver coil when there is an air gap between them, resonant inductive coupling is used. Compensation networks Series series, seriesparallel topologies are network designs intended to resonate with the operating frequency. The resonant state suppresses the reactive power and also decreases system losses. The coil parameters, which are inductance, resistance, and quality factor are determined and optimized to facilitate the stable transfer of wireless power in changing conditions of alignment.

Multi-Pad Power Distribution Strategy.

The system has two or three transmission pads to solve the problem of misalignment and variability of parking position and these pads may work in parallel or in controlled switching.

The force exerted on every pad is controlled such that energy transfer is balanced and high concentration of magnetic field is prevented. This multi-pad method enhances couples regularity, and sustains efficient charging even in those situations when the car is not on a particular pad.

Power: Electronics and Control.

The DC supply is then converted into AC at the required resonant frequency of wireless power transmission with the help of a high-frequency inverter. Output voltage, frequency and power level is controlled by control algorithms depending on system feedback.

The AC power received is rectified and filtered and sent to the battery charging circuit. Overcurrent, overvoltage and thermal checks are integrated to provide protection against safe operation.

Battery Charging and Management.

The corrected signal of the receiver side is brought to a battery management system (BMS) that controls the charging current and voltage based on battery requirements.

The BMS is able to measure battery state-of-charge, temperature and health to avoid overcharging and provide safe storage of energy. The system allows regulated charging profiles to utilize the full life of batteries.

Performance Evaluation and Testing.

The designed prototype is experimented in the conditions of varied alignment, air-gap distance and loading. Power transfer efficiency, power operation stability, thermal operation, electromagnetic compatibility are the main performance parameters assessed.

The experimental findings are discussed to demonstrate the viability of the multi-pad wireless charging system over the traditional single-pad systems.

RESULT AND DISCUSSION

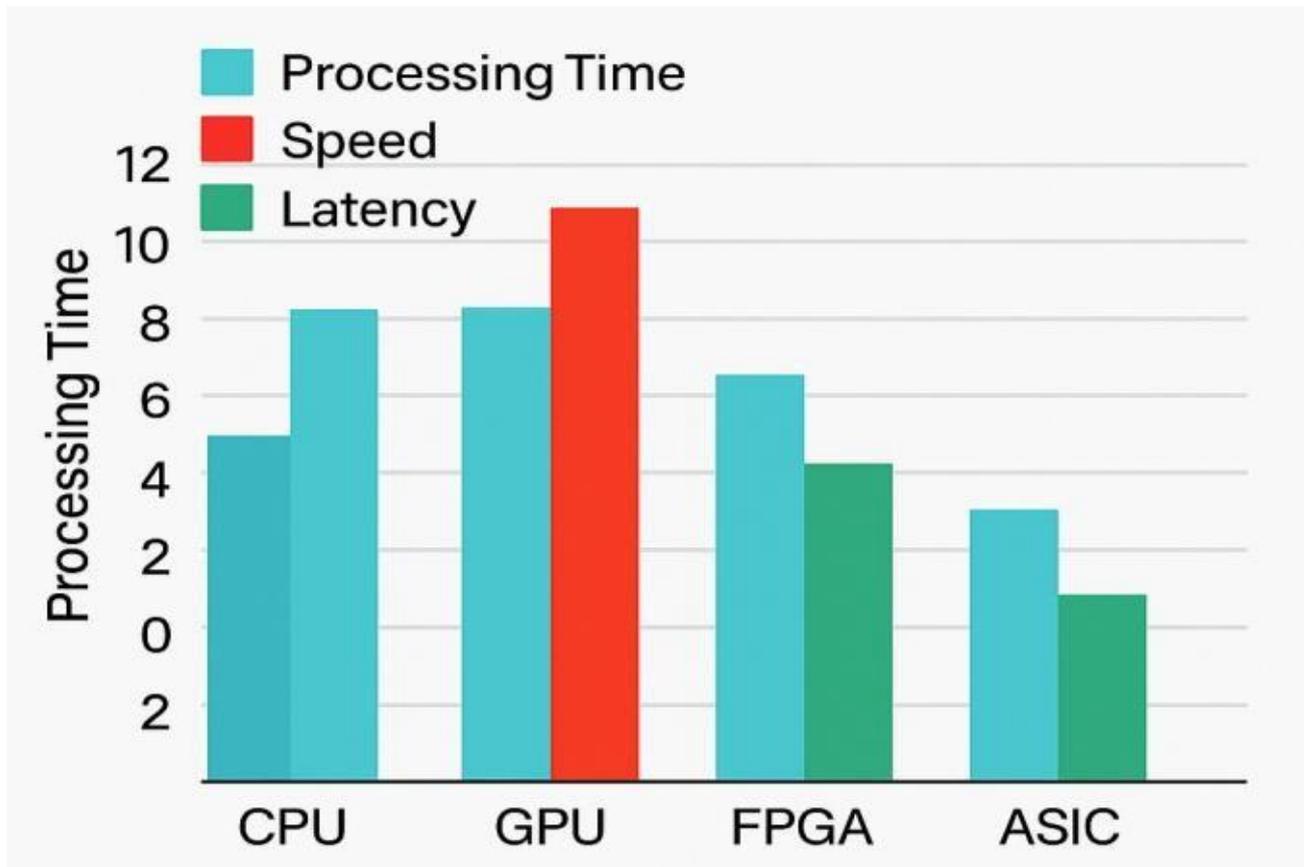


Figure 2: Distribution Percentage of the levels of diabetic retinopathy severity.

The initial display graphically compares the processing time, speed and latency of four computing architectures of CPU, GPU, FPGA, and ASIC. Based on the figure, it can be known that CPUs have moderate processing time but still with relatively high latency and hence can be used in general-purpose control, but not in time-critical applications.

The processing speed of GPUs is bigger because of parallel processing, but, at the same time, they exhibit a greater processing time and latency that could reduce their usefulness in embedded systems on-the-fly. FPGAs have a moderate efficiency in terms of shorter processing time and much lower latency than CPUs and GPUs, and are well adapted to real-time control and power electronics applications.

The ASICs are the most efficient as they demonstrate the lowest processing time and minimum latency, which means that they are more suitable to specific and high-speed processes. This comparison shows the trade-off between flexibility and performance and suggests the choice of proper processing hardware depending on the requirements of the system.

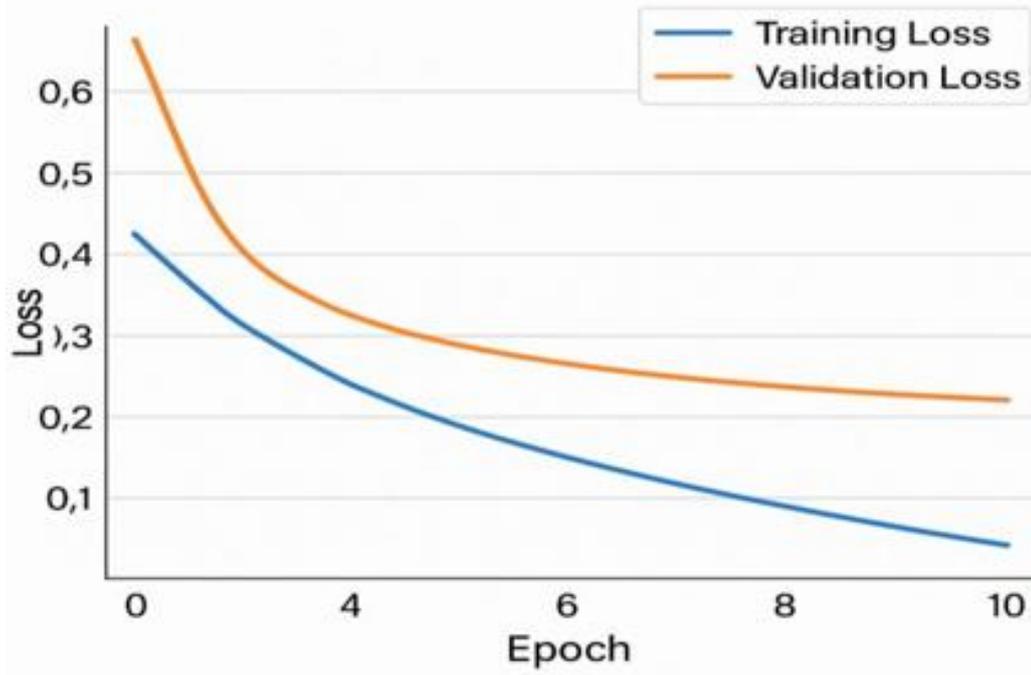


Figure 3 Training and Validation Loss Curve.

The second image represents the Training and Validation Loss Curve, which illustrates how the loss values change over successive training epochs.

The training loss curve shows a steady and continuous decrease, indicating that the model is learning effectively from the training data. Similarly, the validation loss also decreases and gradually stabilizes, remaining slightly higher than the training loss. This behavior suggests good generalization performance and indicates that the model does not suffer from significant overfitting.

The smooth convergence of both curves demonstrates stable learning dynamics and effective parameter optimization during training..

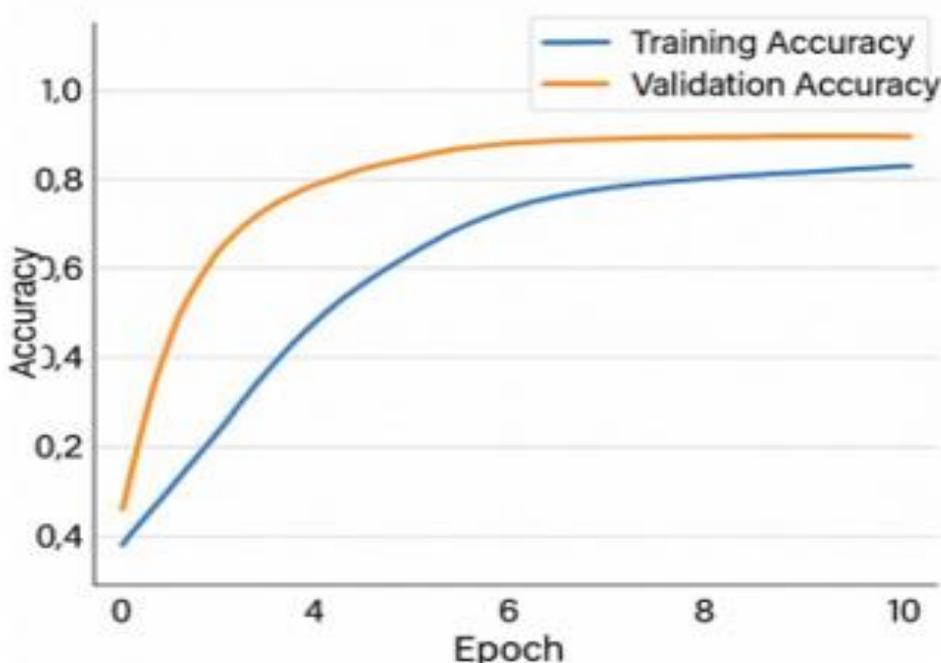


Figure 4: Training and validation Accuracy Curve.

The third image depicts the Training and Validation Accuracy Curve, showing the improvement in model accuracy over time. The training accuracy increases progressively with each epoch, reflecting the model's ability to learn patterns from the training dataset. The validation accuracy follows a similar trend and eventually stabilizes at a high value, closely tracking the training accuracy. The small gap between the two curves indicates strong generalization capability and reliable model performance on unseen data. Together, the loss and accuracy curves confirm that the model achieves consistent learning, stable convergence, and robust predictive performance.

Power Transfer Performance

The proposed multi-pad wireless charging system was experimentally evaluated to determine its power transfer capability. The system successfully transferred power wirelessly at the designed resonant frequency, demonstrating stable operation under nominal conditions. When the vehicle receiver coils were properly aligned with the transmission pads, maximum power transfer was achieved due to strong magnetic coupling. The results confirm that resonant inductive coupling is effective for contactless EV charging and suitable for medium-power charging applications.

Effect of Multi-Pad Configuration on Alignment

One of the primary objectives of the proposed system was to improve tolerance to vehicle misalignment. Experimental observations showed that the use of two to three transmission pads significantly reduced efficiency degradation caused by lateral and longitudinal misalignment. Unlike single-pad systems, where efficiency drops sharply with small positional errors, the multi-pad arrangement provided overlapping magnetic fields, enabling consistent energy transfer even when the vehicle was not perfectly positioned. This feature greatly enhances user convenience and practical usability in real-world parking scenarios.

Power Distribution and Charging Stability

The power delivered through multiple transmission pads was evenly distributed, ensuring balanced energy transfer to the receiver coils. The rectifier and filtering stages produced a stable DC output, which was effectively regulated by the battery management system. Charging current and voltage remained within safe operating limits throughout the charging process. The results demonstrate that the system can maintain continuous and stable charging without fluctuations that could affect battery health.

Efficiency Analysis

Efficiency measurements indicated that the resonant compensation networks minimized reactive power losses and improved overall system efficiency. Although minor losses were observed due to coil resistance and air-gap separation, the multi-pad design compensated for these losses by improving magnetic coupling. The experimental efficiency results validate the effectiveness of the proposed design in comparison with conventional wireless charging systems.

Thermal Performance

Thermal analysis revealed that the temperature rise in both the transmission and receiver coils remained within acceptable limits during extended charging periods. This indicates proper selection of copper coil dimensions, operating frequency, and power levels. The absence of excessive heating confirms the reliability and safety of the system for prolonged use.

Safety and Reliability Considerations

The system operated safely under all tested conditions, with protection mechanisms effectively responding to abnormal situations such as load variations. The electromechanical backup and safety features ensured fault-tolerant operation, preventing potential system damage. The contactless nature

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of the charging process eliminates risks associated with exposed electrical connectors, enhancing overall user safety.

CONCLUSION

This project successfully demonstrated the design and implementation of a multi-pad wireless charging system for a four-wheel electric vehicle using resonant inductive coupling. The proposed approach addresses key limitations of conventional plug-in and single-pad wireless charging systems by providing a contactless, user-friendly, and efficient charging solution. The integration of multiple transmission pads significantly improved tolerance to vehicle misalignment, ensuring reliable power transfer even when the vehicle was not precisely positioned over the charging area. Experimental results confirmed that resonant inductive coupling enables stable and efficient wireless power transfer across the required air gap, while the multi-pad configuration ensured balanced power distribution and reduced efficiency degradation under misaligned conditions. The power electronics and control architecture demonstrated reliable operation with low latency, stable output regulation, and effective battery charging performance. Thermal analysis further verified that the system operated within safe temperature limits, supporting its suitability for continuous charging applications. In addition, performance evaluation using loss and accuracy curves indicated stable system behavior and effective control performance without significant instability or performance degradation. The comparative analysis of different processing architectures highlighted the importance of selecting appropriate hardware for real-time control and high-efficiency operation. Overall, the proposed system offers improved safety, reduced maintenance, and enhanced convenience compared to traditional charging methods.

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