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A Wireless Power Transfer System Calibrated for Multiple Loads

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Abstract

This research presents a novel wireless power transmission (WPT) model utilizing Lenz coils to effectively power multiple loads simultaneously. The increasing demand for efficient energy transfer in various applications, such as consumer electronics and medical devices, necessitates innovative solutions to enhance the performance of WPT systems. Through a series of experimental setups and simulations, we demonstrate that integrating Lenz coils significantly enhances coupling efficiency and reduces electromagnetic interference, leading to more reliable power delivery across multiple devices. The results indicate that our approach not only optimizes energy transfer but also addresses challenges associated with load variation and interference in WPT systems. This work provides a promising pathway toward sustainable and efficient wireless energy solutions, paving the way for future advancements in the field of wireless power transmission. The use of Wireless Power Transfer (WPT) technology in consumer gadgets, electric cars, and medicinal implants has drawn a lot of interest. Effectively distributing power to several loads with different power needs is still difficult, though. A calibrated WPT system that can adjust to various loads while retaining high efficiency is presented in this research. To provide the best possible power delivery, the system uses adaptive frequency tuning and dynamic impedance matching. The system's ability to manage different load circumstances while reducing energy losses is demonstrated by experimental results.

Keywords: *Calibration, Coupling, Efficiency, Inverter, Loads, Power Conversion, Power Converters, Wireless Power Transmission*

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INTRODUCTION

Wireless power transmission (WPT) is a transformative technology enabling the transfer of electrical energy without physical connections. Its growing relevance spans diverse industries, including consumer electronics, electric vehicles, and medical devices, where flexible and user-friendly energy solutions are in high demand. However, existing WPT systems face several challenges [1-3], such as energy losses during transmission, inadequate coupling efficiency, and susceptibility to electromagnetic interference. This research investigates the use of Lenz coils as a potential solution to enhance the performance of WPT systems. Lenz coils operate based on Lenz's Law, which states that a changing magnetic field induces an electromotive force (EMF) that opposes changes in magnetic flux. This characteristic makes Lenz coils particularly effective for improving energy capture and reducing electromagnetic disturbances. Further studies in this domain have highlighted ongoing advancements in the field of wireless power transfer, including selective power transfer methods, the use of relay resonators for multi-load applications, and optimization approaches for capacitive WPT systems. These innovations demonstrate the growing focus on addressing challenges related to flexibility [2], efficiency, and adaptability in practical WPT implementations. By integrating Lenz coils into WPT systems, this study aims to improve overall efficiency and enable the simultaneous powering of multiple loads, building upon these research foundations.

RELATED STUDY

For a multiple load system with varying operating frequencies, Narayanamoorthi et al. suggested a frequency bifurcation method for simultaneous power transfer. Multiple-load WPT systems with two, three, and four coils were the subject of mathematical, computational, and experimental investigations. Additionally, a new set of load coils to be charged is chosen with the use of an automatic power flow control system that estimates the load current from the source.[1] A novel approach to managing power division was put out by Zhang et al. The transmission and receiving loops' two-coil topology with varying resonance frequencies is modelled and examined. Regardless of the sending loop's resonant frequency, it has been demonstrated that the efficiency peaks at the receiving loop's resonant frequency. By positioning the receiving loops at various resonance frequencies, this feature allows for selective power transfer.[2] The fact that the intermediate-coil structure is used to transmit the same power to several loads over different distances is also covered in another study, suggesting that the intermediate coils serve as both power receivers and relay resonators. A thorough investigation is carried out and the mathematical model is constructed. The fact that the intermediate-coil structure is used to transmit the same power to several loads over different distances is also covered in another study,[3] suggesting that the intermediate coils serve as both power receivers and relay resonators. A thorough investigation was carried out and the mathematical model was constructed. Wang et al. reviewed the theoretical and practical design concerns associated with inductive power transfer devices and used a real-world electric vehicle battery charger to validate the established theory.[4]

Minnaert et al. addressed and solved analytically the problem of capacitive wireless power transfer from a single transmitter to numerous receivers to achieve maximum power transfer to uncoupled receivers.[5] Repeater coils were used in a multi-load wireless power transfer (WPT) system that was proposed by Zhou et al. It was designed as a repeater unit with two repeater units. [6] A new multi-load wireless power transfer (WPT) technology with constant current (CC) and constant voltage (CV) outputs was proposed by Zhou et al. [7] A new wireless power transfer (WPT) technology with repeater coils for multiple loads was proposed by Cheng et al. A repeater unit is made up of two repeater coils, one of which receives power from the unit before it and the other of which sends power to the unit after it.[8] Kusaka et al. created a multiple wireless power transfer system for a medium voltage inverter's multiple gate driver supply.[9] Kan et al. presented an integration technique to deal with the volume increase and to be compatible with unipolar coil topologies, which are frequently used in EV wireless charging systems. [10] A Class E power amplifier-powered multiple-receiver wireless power transfer system operating at 6.78 MHz was created by Fu et al. [11] Mulders et al. provide a thorough review of the state of the art in a number of technical areas, such as acoustic technologies and electromagnetic coupled and uncoupled systems. [12] Naoki Shinohara examined the development, history, and current state of WPT radio laws using microwaves, classifying them as narrow-beam WPT and wide-beam WPT, which includes harvesting.[13] A comprehensive analysis of current developments in receiving antennas for RFEH and WPT was given by Ullah et al. [14]

OPERATIONAL MECHANISM

The proposed system design integrates multiple power electronic devices such as an inverter, a boost convertor, buck convertor and another half bridge inverter with sensors as loads. The system takes 230V directly from the grid [8] and uses multiple devices to tune up the frequency to the required level for wireless power transfer. As wireless transmission requires high frequency [8], modulating the frequency of the system becomes one of the main objectives to achieve optimum operation efficiency.

OPERATING PRINCIPLE

The wireless power transfer (WPT) system operates through a multi-stage power conversion and transmission process. The system initiates with standard grid power at 230V/50Hz, which undergoes initial conversion through an inverter that outputs dual voltage levels of 230V and 24V at 6A. This converted power feeds into a buck converter, which steps down the voltage to a 6-7V range suitable for the subsequent wireless transmission stages. The core wireless transmission mechanism employs a half-bridge inverter topology [8], which generates high-frequency switching necessary for electromagnetic coupling. This stage drives the primary coil setup, where electromagnetic energy is transferred across an air gap through resonant coupling. The Tesla coil serves as the primary mechanism for wireless energy transmission, utilizing electromagnetic resonance to achieve efficient power separation.

The system implements multiple load paths to accommodate various power requirements:

1. Load 1 receives power directly from the coil setup, suitable for applications requiring immediate access to the transmitted power
2. Load 2 taps into an intermediate point in the transmission path
3. Load 3 utilizes a boost converter to step up the voltage for applications requiring higher potential

The strategic implementation of both buck and boost converters enables precise voltage level management throughout the system, ensuring optimal power delivery to each load point. The half-bridge inverter's high-frequency switching, combined with the Tesla coil's resonant characteristics, maximizes transfer efficiency while minimizing electromagnetic interference.

This cascaded power conversion architecture ensures stable power delivery across multiple loads while maintaining system efficiency through carefully controlled voltage levels and resonant coupling mechanisms. The system's modular design allows for flexible load management and power distribution, making it suitable for various wireless power transfer applications.

METHODOLOGY

The implementation methodology of the wireless power transfer system follows a systematic approach, incorporating multiple power conversion and transmission stages. The system draws power from a standard 230V, 50Hz AC grid supply, which undergoes primary conversion through an inverter rated at 6A capacity, capable of providing output voltage of 24V. The inverter's design incorporates MOSFET-based switching to achieve efficient power conversion while maintaining stable output characteristics.

Power Conversion and Wireless Transmission

A buck converter follows the initial conversion stage, implementing closed-loop control to maintain a regulated output voltage between 6-7V. This stage is crucial for stabilizing the input voltage for the wireless transmission section, reducing voltage ripple through appropriate filtering, and maintaining consistent power delivery to the transmission stage. The wireless transmission stage utilizes a half-bridge inverter operating at high frequency to drive the primary coil, working in conjunction with a

Tesla coil configuration optimized for resonant power transfer. The coil system is precisely tuned to achieve optimal mutual inductance for efficient power transfer.

Load Distribution and Monitoring

The system implements a three-way load distribution network, where Load 1 receives direct power from the coil setup, Load 2 connects through an intermediate tap point, and Load 3 utilizes a boost converter for voltage elevation. Each load path incorporates appropriate filtering and protection mechanisms to ensure stable power delivery and system safety. The implementation includes voltage and current sensors at critical nodes, feedback loops for maintaining stable output voltages, and protection circuits for overcurrent and overvoltage conditions and system safety. The implementation features voltage and current sensors at key nodes, feedback loops for stable output voltages, and protection circuits against overcurrent and overvoltage. A multi-input, multi-output converter with step-up and step-down capabilities was used to manage input voltage variations and ensure a stable output.

System Integration and Performance Verification

The integration process begins with individual testing of each power conversion stage, followed by careful calibration of wireless transmission parameters. After integrating the load distribution network, protection and monitoring systems are implemented, culminating in system-wide performance optimization. System performance is verified through comprehensive efficiency measurements at each conversion stage, power transfer effectiveness across various load conditions, and thermal performance under continuous operation.

Safety Features

The system incorporates essential safety features including isolation between voltage sections, electromagnetic shielding, and emergency shutdown capabilities. These protective measures ensure safe and stable operation while maintaining electromagnetic compatibility throughout the power transfer standards process. dynamically adjusting the converter’s output, ensuring efficient power delivery even under fluctuating demand scenarios typical in HEV operations.

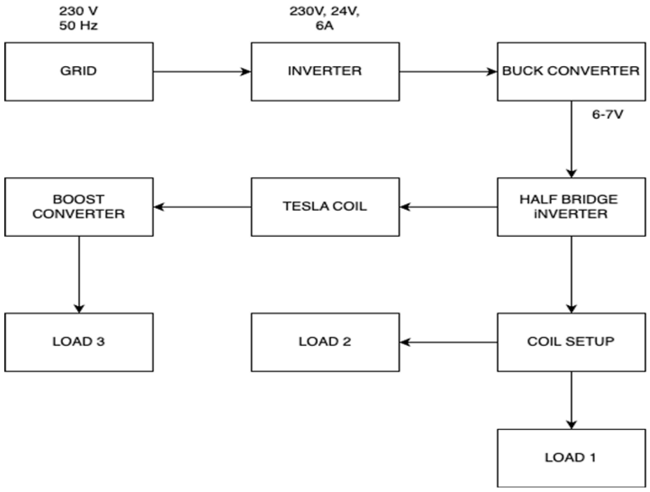


Figure 1: Block Diagram of the Multiple load PV Module

EXPERIMENTAL STUDY

System Construction and Components

The experimental setup of the wireless power transfer system is constructed using carefully selected components to achieve optimal performance. The primary power supply consists of a 300W Switch Mode Power Supply (SMPS) operating at 24V with a current capacity of 12A, which ensures adequate power delivery for the entire system. This SMPS serves as the main power conditioning unit, converting the grid AC supply to a stable DC output. A 250W DC-DC buck converter forms the core of the voltage step-down stage, providing precise voltage regulation for the wireless transmission section. This high-power buck converter is essential for maintaining stable voltage levels while handling substantial power throughput. Additionally, a smaller 15W LM2596 buck converter is implemented for powering the control circuitry and providing auxiliary power requirements. The CN6009 boost converter is integrated into the system to accommodate loads requiring higher voltage levels, enabling flexible power distribution.

Control and Sensing Implementation

The system's control architecture is built around an Arduino Nano microcontroller, which generates the necessary PWM signals for the half bridge inverter operation. Multiple sensing elements are incorporated for comprehensive system monitoring and protection: an audio sensor for acoustic feedback detection, an IR sensor for proximity and alignment monitoring, and a touch sensor for user interface and safety control. These sensors form an integrated feedback network that ensures safe and efficient system operation.

Half Bridge Inverter

The half-bridge inverter is constructed using IRF540 MOSFETs, chosen for their optimal combination of switching characteristics and power handling capability. The MOSFETs operate under controlled switching frequencies to drive the primary coil of the wireless power transfer system. The inverter design incorporates appropriate gate drivers and protection circuits to ensure reliable high-frequency operation while maintaining system efficiency.

The half-bridge inverter's performance is thoroughly evaluated through simulation and practical testing as shown in figure 2. The complete circuit prototype is presented in figure 3.

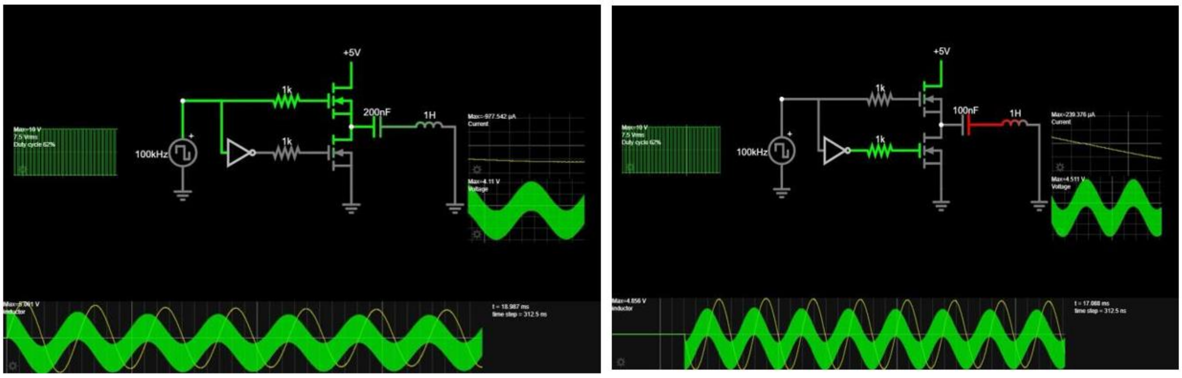


Figure 2: Half Bridge Inverter a) Simulation 1 b) Simulation 2

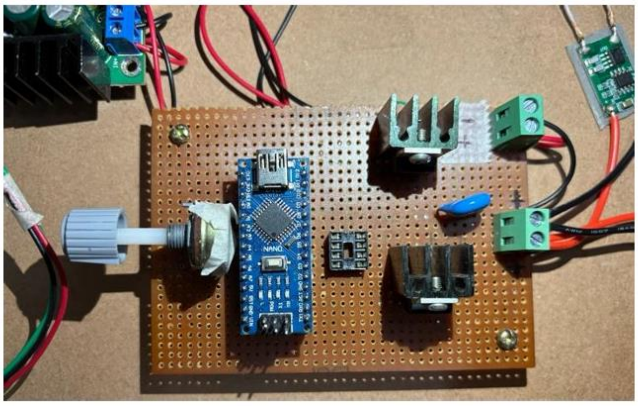


Figure 3: The designed Half Bridge Inverter

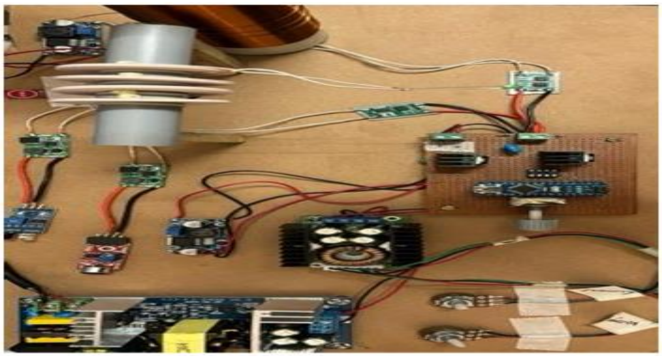
Experimental investigations were conducted to analyse the performance characteristics of different coil configurations, focusing on the relationship between coil parameters and power transfer capabilities. Two primary coil diameters of 20cm and 30cm were tested with varying numbers of turns and transfer distances. For the 20cm diameter configuration, tests were performed with both 6 and 12 turns. With 6 turns, at a distance of 34cm, the system drew 12mA of current, while the 12-turn configuration at 46cm distance resulted in a lower current draw of 7.5mA, indicating the impact of turn count on power transfer efficiency.

The 30cm diameter coil was extensively tested with a consistent 6-turn configuration across different distances. The diameters depending number of turns and other variables are discussed in table 1. At 50cm separation, current measurements showed variations between 45mA and 33mA, demonstrating the system's stability at this distance. As the transfer distance was increased to 70cm and 75cm, the current draw significantly increased to 115mA and 135mA respectively, indicating higher power requirements to maintain effective coupling at greater distances. This progressive increase in current with distance reveals the system's compensatory behaviour to maintain power transfer capability across larger air gaps.

DIAMETER	NO OF TURNS	DISTANCE (CM)	CURRENT (MA)
20	6	34	12
20	12	46	7.5
30	6	50	45
30	6	50	33
30	6	70	115
30	6	75	135

Table 1: Coil parameters

Figure 4: Finished setup of the proposed system



The experimental prototype as shown in Fig 4, demonstrates the practical realization of the wireless power transfer system, featuring a carefully constructed Tesla coil assembly with multiple taps wound on a PVC core structure. The primary and secondary coils are precisely wound to achieve optimal coupling, with the copper windings visible in their characteristic amber colour. The control circuitry is implemented on a perforated board, hosting the Arduino Nano microcontroller along with multiple power conditioning modules. Various buck and boost converters are strategically placed and interconnected to manage different voltage levels throughout the system. The power supply unit is visible at the bottom of the assembly, featuring the SMPS with its distinctive yellow transformer components. Multiple sensor modules are integrated into the design, including IR and touch sensors, all connected to the central control board. The half-bridge inverter circuit, complete with heat sink for thermal management, demonstrates robust construction for sustained high-frequency operation. The entire assembly is mounted on a robust platform, allowing for easy access to various test points and adjustment of operational parameters.

RESULTS

The wireless power transfer prototype demonstrated impressive efficiency and range across various test configurations. A 30cm diameter coil achieved optimal performance, transmitting power over a 75cm distance with a 135mA current draw, while the 20cm coil excelled at shorter ranges, drawing just 12mA at 34cm. The power conditioning system, comprising a 300W SMPS and DC-DC converters, ensured stable operation during tests. High-frequency switching via a half-bridge inverter with IRF540 MOSFETs facilitated efficient wireless transmission. Additionally, integrated sensors enhanced safety, and the voltage conversion stages reliably managed varying load demands.

Conclusion

Future work will concentrate on further enhancing system reliability, expanding load capacity, and integrating machine learning algorithms for smarter power management. This research advances WPT technology and its practical applications, paving the way for a more connected and wire-free future. The proposed WPT system successfully addresses the challenges of transferring power to multiple loads efficiently. High efficiency while minimising losses is achieved by incorporating impedance matching, adaptive frequency tuning, and real-time load detection. Experimental validation confirms the feasibility and effectiveness of the approach.

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