

Resonant Inductive Wireless Power Transfer for Stationary Electric Vehicle Charging: Design, Hardware Implementation, and Experimental Performance Evaluation

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Abstract— This paper presents the design, development, and experimental evaluation of a low-power Inductive Wireless Power Transfer (IWPT) system for electric vehicle charging applications. The system in question uses a high-frequency resonant inductive coupling method in order to transmit electrical energy wirelessly between the transmitter and receiver coils without there being a direct electrical connection. The architecture that has been developed includes an AC–DC power supply, a high-frequency MOSFET inverter, resonant transmitter and receiver coils, rectification and filtering at the receiver end, voltage conditioning, and a DC–DC buck converter for charging the battery. Experiments were carried out to examine how the wireless charging system operates at different operating frequencies and under various transmitter–receiver air-gap conditions. The results show that high-frequency resonant operation is successful, that wireless energy transfer is stable, and that the AC energy received is effectively converted into regulated DC power appropriate for battery charging. Moreover, the experimental analysis shows that the power-transfer capacity is greatly affected by the distance between the transmitter and receiver coils, the power delivered falling as the air gap increases because of the reduced magnetic coupling. The prototype that was developed achieved an overall efficiency of about 55% when the loaded condition chosen was considered. The results confirm that the proposed IWPT architecture is feasible for contactless battery charging and offer a practical basis for future improvements in efficiency, misalignment tolerance, thermal management, and in respect to higher-power electric vehicle charging applications.

Keywords: Inductive power transfer, resonant coupling, electric vehicle charging, wireless charging, high-frequency inverter, coil coupling, air gap, power transfer efficiency.

1. INTRODUCTION

The increasing popularity of electric cars has led to the advancement of charge methods that can deliver energy safely, conveniently, and efficiently while at the same time addressing any challenges posed by traditional wired charging techniques. Despite the widespread application of wired chargers, their reliance on physical contacts makes them susceptible to problems involving wear-and-tear, manual handling, and operation in harsh environments. WPT offers a different strategy by allowing electrical energy transfer without establishing any conductive connection between the charger and the electric car. Among the different WPT techniques, Inductive Wireless Power Transfer (IWPT) is particularly attractive for EV charging because it uses magnetic coupling between transmitter and receiver coils and can be implemented using resonant power-electronic converters.

In an inductive EV charging system, electrical power is converted into a high-frequency alternating signal and supplied to a transmitter coil. The resulting time-varying

magnetic field induces an electromotive force in a spatially separated receiver coil, allowing energy to be transferred across an air gap. Resonant compensation is employed to improve the energy-transfer capability of the coupled coils by establishing suitable inductive and capacitive reactance conditions at the operating frequency. Consequently, the performance of an IWPT system is strongly influenced by the operating frequency, coil inductance, compensation capacitance, magnetic coupling, coil alignment, and separation distance. The developed system uses resonant inductive coupling together with a high-frequency inverter, transmitter and receiver coils, receiver-side rectification and filtering, and a DC–DC voltage-regulation stage for battery charging.

Even though there have been significant advancements in wireless charging technologies, the actual application of such systems still faces various issues. One of the most significant concerns is associated with the sensitivity of the power transferred from the source to the load to alignment errors and air gap changes. When the distance between coils increases, less magnetic coupling and mutual induction takes place. Thus, the receiver's output voltage and the amount of the transferred power decrease. Other types of energy losses are related to high-frequency switching of the inverter, conduction, resistance of coils, magnetic flux loss, rectification, and voltage conversion. All of those factors become more crucial when designing a small-size and affordable prototype, able to perform efficient power transfer under real-world conditions.

In order to analyze these issues in an experimental way, this paper presents an evaluation of a low power stationary IWPT charging system using resonant inductive coupling. The proposed design includes AC-DC power supply, high-frequency inverter, resonant transmitter coil, receiver coil, rectification and filtering circuitry, DC-DC buck converter, and rechargeable battery load. Symmetric transmitter and receiver coils of 19.5 μH are used in order to provide symmetry in magnetic characteristics. Initially, a 22 μH copper coil is used; however, due to higher loss in terms of AC resistance due to skin effect, it is replaced with 19.5 μH coils, which can support a current up to 9.5 A within 60 to 92 kHz frequency range.

Furthermore, the experiments take into account the performance of the circuit at two high frequencies of about 60 kHz and 92 kHz. The voltages measured at the output of the inverter were 154 V and 156 V peak-to-peak respectively, showing that resonant operation is achieved at both these frequencies. At the receiver end, a voltage of 124 V peak-to-peak in sinusoidal form was obtained at the coaxially aligned air gap of 1.5 cm.

One of the central points for investigation in this experiment is the experimental characterization of the influence of the distance between the coils on the charging power delivered. At air gaps of 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 cm, the power delivered by the prototype was 20.64 W, 9.44 W, 6.19 W, 4.67 W, 2.46 W, and 1.57 W, respectively, under the load conditions tested. Thus, this trend is an experimental

evidence of high sensitivity of the developed IWPT system to the coil separation. Under the highest-power tested condition, the system was supplied from a 24-V DC input at approximately 1.56 A, corresponding to an input power of 37.44 W, while the load received approximately 12 V at 1.72 A, corresponding to 20.64 W.

The resulting measured system efficiency was approximately 55.1%. The above losses were explained by the dissertation to be due to inverter switching losses, magnetic coupling losses, coil copper losses, rectifier losses, and voltage-conversion losses.

The principal innovation of this work is the design, hardware realization, and experimental evaluation of a compact and low-power resonant IWPT charge architecture, paying special attention to the effects of high-frequency operation of an inverter and the impact of TX-RX air gap on the power transmitted. Instead of treating wireless charging solely from a standpoint of circuit design, the research experimentally analyzes the whole chain of energy transfer starting from the DC input and ending with the battery charging. Thus, the experimental data gained serve as a basis for future developments of wireless charging systems with higher power and less tolerance requirements.

2. RELATED WORK AND RESEARCH GAP

WPT has been identified as one of the viable techniques for electric vehicle (EV) charging since there will be no need to use any electrical connectors for transferring power from the charging source to the EV. IPT and RIPT have received many researchers' attentions among other WPT techniques since both are able to transfer power in the form of magnetic coupling through air gap without making any electrical connections. Previous researches have studied many aspects related to EV wireless charging including their working principles, equivalent circuit models, coil configuration, compensation circuits, inverter topologies, control mechanisms, etc.

A. Inductive Wireless Power Transfer for EV Charging

Typical inductive power transmission devices are composed of a utility power supply, a high-frequency inverter, a primary resonant network, a secondary resonant network, a rectifier, and an electrical load. Since there is an air gap between the transmitter and receiver, the coupling coefficient is quite low compared to that of a typical transformer. Hence, compensation capacitors have typically been used to compensate the leakage inductance and ensure resonant operation. The Series-Series (SS), Series-Parallel (SP), Parallel-Series (PS), and Parallel-Parallel (PP) topologies have been extensively studied for EV charging purposes.

Reviews of IPT-based EV charging systems have shown that the selection of coil geometry, operating frequency, compensation topology, and power-converter configuration strongly influences the achievable power-transfer efficiency. In particular, the coupling coefficient is determined by the relative geometry and separation of the transmitter and receiver coils, while resonance is used to improve power-transfer capability under weak magnetic coupling.

B. Coil Design and Air-Gap Dependence

Coil design is one of the most significant factors in an IWPT system. The diameter of the coil, number of turns, properties of the conductor, materials used, frequency of

operation, and distance between transmitter and receiver affect the mutual inductance and coupling factor. At higher frequencies of operation, skin and proximity effect losses may occur in conductors.

Air gap plays a very vital role in EV systems. The increase in separation decreases magnetic coupling as well as leakage inductance, which leads to decrease in power transfer efficiency. Moreover, misalignment along lateral or angular directions changes the mutual inductance, producing variations in received voltage and power output. Recent reviews therefore identify air-gap optimization and misalignment tolerance as continuing challenges in practical wireless EV charging systems.

This observation is consistent with the research gap identified in the present dissertation. The project identifies reduction in power-transfer efficiency due to coil misalignment, limited transfer distance, high-frequency switching and conduction losses, magnetic leakage, EMI, and thermal-management requirements as important unresolved issues in IWPT systems.

C. Compensation Networks and Power Electronics

The compensation network plays a central role in resonant IWPT because it compensates for the reactive characteristics of loosely coupled coils and establishes the desired resonant operating condition. Conventional SS, SP, PS, and PP compensation systems have been well analyzed, but advanced systems like LCC, LCL, and hybrid compensation systems have been suggested to increase efficiency and output control and improve performance in presence of variation in coupling.

However, even though compensation networks of higher order may offer increased tolerance to misalignment and load changes, they typically call for extra inductors, capacitors, sensing systems, and control methods. Thus, they increase the hardware complexity, number of components, cost, and possibly losses. Hence, the following compromise needs to be made when designing a switching power supply.

High-frequency power converters are also essential because the DC input must be converted into high-frequency AC to generate the alternating magnetic field required for inductive energy transfer. However, increasing the switching frequency can introduce additional switching and conduction losses. Therefore, practical IWPT designs require an appropriate compromise among operating frequency, resonant characteristics, coil parameters, switching losses, and transferred power.

D. Misalignment and Output Regulation Challenges

In real-world applications, perfect alignment of the vehicle-side receiver coil and the ground-side transmitter coil is difficult to achieve. Misalignment changes the coupling coefficient and mutual inductance values, and thus influences the input impedance, output voltage, power transferred, and efficiency of the system. There are several current techniques developed to address the problem of misalignment and power transfer. On the other hand, these methods add more complexity to the system both in terms of hardware and controls. In the case of building a small-scale prototype, which has reduced power requirements, a less complex design would have certain advantages in exploring the basics of the interconnection of the operating frequency, spacing of the coils, the received power, and efficiency of the system.

E. Research Gap

Considering the reviewed literature and the technical issues described in the dissertation, the following research gaps appear relevant:

Air-gap sensitivity: The distance between TX and RX increases magnetic decoupling and lowers the efficiency of power transmission.

Misalignment tolerance: Coil misalignment is still a critical issue in achieving the required stability of power transmission.

Power-electronics losses: Switching losses associated with a high-frequency inverter play an important role in limiting system efficiency.

Increased design complexity: Compensating techniques make the system more tolerant to variations of coupling; however, the cost is increased design complexity.

Experimental evaluation: It would be useful to evaluate experimentally the performance of a full IWPT chain, starting from DC source through high-frequency inverter and resonant wireless link to rectification and regulation and ending with the battery load.

F. Positioning of the Present Work

In order to fill those gaps on a prototypical level, this study proposes the development and experimental evaluation of a low-power stationary resonant IWPT system for charging EVs. The proposed system consists of DC power supply, high-frequency inverter, resonant transmitter and receiver coils, rectifying filter unit at the receiver side, voltage regulation unit, and DC-to-DC buck converter for charging the batteries. The dissertation evaluates the performance of the system at various operational frequencies and various TX-RX air-gap distances, and thus experimentally demonstrates the link between coil distance and charging power delivery.

Experimentally, the comparison of the inverter is made between 60 kHz and 92 kHz inverter operation frequencies. In terms of experiment, the inverter output was around 154 Vpp and 156 Vpp for the two operating frequencies of 60 kHz and 92 kHz, respectively. After that, the receiver output was around 56 V DC.

The important experimental contribution made by this research paper is the quantification of the decrease in power transfer with an increase in distance between the coils. The output of the prototype at an air gap of 1.5 cm was around 20.64 W, while the output reduced as the distance was increased. The output on the battery side under the highest tested power scenario was 20.64 W, leading to the overall efficiency of around 55.1%.

In this sense, the research gap that this article focuses on is not the creation of an entirely novel WPT topology but the experimental realization and study of a miniature, low-power resonant IWPT charging system, especially at different operating frequencies and with variable TX-RX air gap spacing.

3. PROPOSED IWPT SYSTEM AND METHODOLOGY

The designed wireless energy transmission system is conceived as a low-power stationary system for the wireless charging of electric vehicles using Inductive Wireless Power Transfer (IWPT). The system comprises various stages from power conversion to battery charging. This includes power conversion, high frequency resonant excitation, magnetic

wireless energy transfer, rectification and filtering at the receiver side, voltage regulation, and battery charging into one experimental setup. The general idea is to demonstrate the practical wireless energy transmission path and its behavior under various operating frequencies and different gaps between the transmitter and receiver. The design follows the general path of IWPT energy transmission that includes power conversion, wireless magnetic coupling, and rectification and filtering at the receiver side.

A. Proposed System Architecture

The implemented power-flow architecture is:

The system is divided into three functional hardware sections:

1. **Transmitter section:** AC–DC power supply, high-frequency inverter, resonant network, and transmitter coil.
2. **Receiver section:** receiver coil, rectifier, filter, and voltage-conditioning circuitry.
3. **Battery-charging section:** DC–DC buck converter and rechargeable battery.

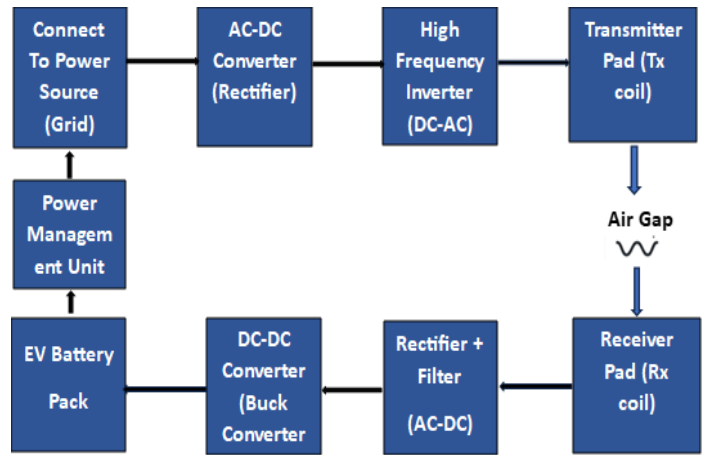


Fig -1: Block Diagram

This architecture enables the high-frequency electrical energy generated by the inverter to be converted into an alternating magnetic field at the transmitter coil. The magnetic field crosses the air gap and induces an AC voltage in the receiver coil. The received AC voltage is subsequently rectified, filtered, regulated, and converted to the required battery-charging voltage and current. Such a power-conversion sequence is also commonly adopted in resonant IWPT systems for EV charging.

The dissertation specifies an 80-W AC–DC SMPS with a nominal output of 24 V DC and 3.33 A as the input supply for the high-frequency inverter. The developed system is intended as a low-power experimental prototype rather than a full-scale commercial EV charger.

B. AC–DC Power Supply

The first stage converts the 230-V, 50-Hz AC grid supply into a regulated low-voltage DC supply. An AC–DC SMPS rated at 80 W is used, providing a nominal 24-V DC output with a maximum current capability of approximately 3.33 A.

The regulated DC output provides the input to the high-frequency inverter. This stage isolates the subsequent experimental power-electronic circuit from direct variation in the AC mains and provides a suitable DC bus for the inverter.

The input power to the inverter during loaded operation is determined from where and are the measured DC-link voltage and current, respectively. The experimental measurements reported in the dissertation indicate a 24-V input and approximately 1.56 A under the selected loaded operating condition, corresponding to approximately 37.44 W input power.

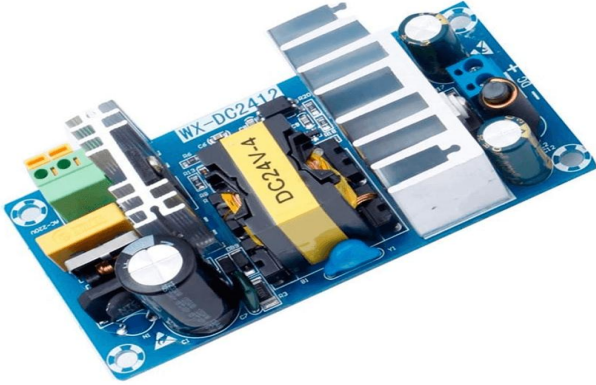


Fig-2: AC-DC Converter

C. High-Frequency Inverter

The second stage converts the 24-V DC supply into high-frequency AC suitable for exciting the resonant transmitter circuit. A MOSFET-based high-frequency inverter is implemented for this purpose.

The high-frequency operation is essential because the transmitter coil must generate a time-varying magnetic field capable of inducing voltage in the spatially separated receiver coil. In resonant WPT systems, the inverter frequency is selected in relation to the resonant characteristics of the coil and compensation network.

Two operating conditions were experimentally investigated:

- Approximately 60 kHz
- Approximately 92 kHz

The measured inverter output was approximately 154 V_{pp} at 60 kHz and 156 V_{pp} at 92 kHz. The 92-kHz configuration produced a stable near-sinusoidal waveform and successfully excited the transmitter resonant network.

Such frequency comparison will serve as an experimental foundation to investigate how operating frequency affects resonant excitation and wireless power transmission.

D. Resonant Transmitter and Receiver Coils

The wireless power-transfer stage consists of two magnetically coupled coils:

- Transmitter (TX) coil
- Receiver (RX) coil

The last prototype makes use of identical TX and RX coils which have an inductance of about 19.5 μ H. The use of identical coils ensures that there is similarity of electromagnetic properties in both the transmitter and receiver side.

At resonant frequency, the two reactances counteract each other, thus making it possible for the system to use the magnetic coupling more efficiently to transfer energy. The use of resonant compensation becomes crucial in loosely coupled systems since it makes up for the reactive nature of the transmitting and receiving coils.

Theoretical operating frequencies of 56.9 kHz and 92.8 kHz are discussed in the dissertation as the resonant operating points of the tested configurations, thus justifying the experimentally chosen 60-kHz and 92-kHz operating frequencies.



Fig-3: TX and RX Coil

E. Principle of Wireless Power Transfer

When the high-frequency inverter supplies the transmitter resonant circuit, an alternating current flows through the TX coil. This produces an alternating magnetic field around the transmitter coil. The magnetic field links with the RX coil and induces an AC voltage according to Faraday's law:

where $\mathcal{E}$ is the induced electromotive force, N is the number of turns, and Φ is the magnetic flux linking the receiver coil.

The strength of the wireless link depends on the mutual inductance between the two coils. The coupling coefficient can be represented as

where M is the mutual inductance and L_1 and L_2 are the self-inductances of the transmitter and receiver coils, respectively. As the separation between the coils increases, the mutual coupling generally decreases, resulting in reduced transferred power. This relationship is fundamental to the air-gap characterization performed in this study.

F. Receiver-Side Rectification and Filtering

The receiver coil produces high-frequency AC as a consequence of electromagnetic induction. Since this AC voltage cannot be directly applied to the DC battery-charging stage, it is converted into DC using a rectifier circuit.

The receiver section therefore consists of:

RX Coil $\rightarrow$ Rectifier $\rightarrow$ Filter $\rightarrow$ Voltage Conditioning

The rectifier converts the received high-frequency AC into pulsating DC, while the filtering network reduces the resulting voltage ripple. Experimental measurements showed an approximately 56-V DC output after receiver-side rectification, filtering, and conditioning. The waveform was reported to be relatively stable with low ripple, demonstrating successful recovery of the transmitted energy.

G. Voltage Regulation and Battery-Charging Stage

The receiver output voltage is higher than the required battery-charging voltage. Therefore, a voltage-conditioning stage is employed before the battery charger. A DC-DC buck converter (XL4016E1) is used to reduce and regulate the received DC voltage to the required battery-charging level. The

experimental system uses a nominal 12-V battery charging output. For the reported experimental condition, the battery-charging output was approximately 12 V and 1.72–1.75 A, corresponding to approximately 20.64–21 W. The DC–DC stage therefore provides an important interface between the variable wireless-link output and the battery load.

H. Experimental Methodology

The experimental methodology was designed to evaluate the complete power-transfer chain rather than only individual circuit stages. The following sequence was adopted:

The AC–DC SMPS was energized from the 230-V AC supply.

The regulated 24-V DC output was supplied to the high-frequency inverter.

The inverter generated high-frequency AC at approximately 60 kHz and 92 kHz.

The resonant network energized the TX coil.

The TX and RX coils were positioned coaxially to establish magnetic coupling.

The induced RX voltage was measured using a digital storage oscilloscope.

The receiver AC was rectified and filtered to obtain DC.

The receiver output was supplied to the voltage-regulation and buck-converter stages.

The battery/load voltage and current were measured.

The TX–RX air gap was varied to investigate the influence of coil separation on delivered power.

The receiver coil was initially evaluated with the coils positioned coaxially at an air gap of approximately 1.5 cm.

I. Air-Gap Characterization

A key part of the methodology is the experimental investigation of the relationship between coil separation and delivered power. The TX and RX coils were tested at different air gaps while maintaining the experimental setup and load conditions.

The output power was reduced significantly with an increase in the air gap distance. At 1.5 cm, the prototype produced about 20.64 W, then about 9.44 W at 2 cm, 6.19 W at 2.5 cm, 4.67 W at 3 cm, 2.46 W at 3.5 cm, and 1.57 W at 4 cm.

The experiment is especially significant in that it shows the practical constraint of the IWPT system created: the capacity for wireless power transfer reduces as the distance between the TX–RX increases.

4. SYSTEM DESIGN AND HARDWARE IMPLEMENTATION

The proposed Inductive Wireless Power Transfer (IWPT) system was conceptualized as a low-power stationary wireless charging system prototype for electric vehicles. The design implementation consists of the input power source, high-frequency inverter, resonant transmitter coil, and receiver coil, rectification and filtering on the receiver side, voltage conditioning stage, and DC-to-DC battery charging stage. This particular architecture corresponds to the overall architecture

of resonant inductive electric vehicle wireless power transfer systems, where the DC energy is converted to high-frequency AC energy, then transmitted using magnetic resonance coupling, rectified, and finally regulated for the battery.

A. Overall System Architecture

The implemented system follows the power-flow sequence: 230

V AC, 50 Hz → AC–DC SMPS → 24 V DC → High-Frequency Inverter → TX Resonant Coil → Air Gap → RX Resonant Coil → Rectifier and Filter → Voltage Regulator → DC–DC Buck Converter → Battery

The complete prototype is physically organized into three functional sections:

1. **Transmitter section:** AC–DC SMPS, high-frequency inverter, resonant network, and TX coil.
2. **Receiver section:** RX coil, rectifier, and filtering network.
3. **Battery-charging section:** voltage-conditioning circuit, DC–DC buck converter, and battery load.

The separation of the transmitter and receiver eliminates the conductive electrical connection between the power source and the load while allowing energy to be transferred through magnetic coupling.

B. AC–DC Input Power Supply

The first hardware stage converts the 230-V AC grid supply into a regulated DC voltage suitable for the high-frequency inverter. An 80-W AC–DC SMPS is used as the input power source.

The 24-V DC output serves as the DC bus for the high-frequency inverter. During the experimental investigation, the actual input voltage and current were measured rather than relying only on the nominal SMPS rating.

C. High-Frequency Inverter

The 24-V DC supplied by the SMPS is converted into high-frequency AC using a MOSFET-based inverter. The high-frequency excitation is required to establish the alternating magnetic field necessary for inductive energy transfer.

An IPP082N10NF2SAKMA1 N-channel MOSFET is used as the principal switching device. The device has a nominal voltage rating of 100 V and a low on-state resistance, making it suitable for the low-voltage, high-current switching stage of the prototype.

The inverter was experimentally operated at approximately 60 kHz and 92 kHz. The measured inverter output voltages were approximately 154 V_{pp} at 60 kHz and 156 V_{pp} at 92 kHz. These operating conditions were selected in accordance with the resonant characteristics of the transmitter network.

The high-frequency inverter therefore performs two functions: it converts the DC input into AC excitation and establishes the operating frequency required for resonant operation of the wireless power-transfer stage. The generated high-frequency AC signal is applied to the transmitter coil through the resonant compensation network. This produces an alternating magnetic field that enables energy transfer to the receiver coil through inductive coupling.

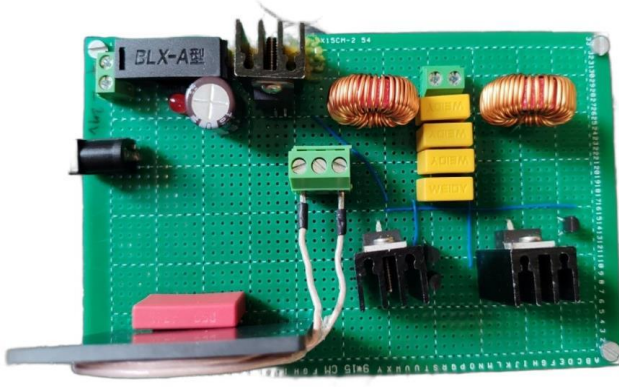


Fig-4: 60 KHZ High Frequency Inverter

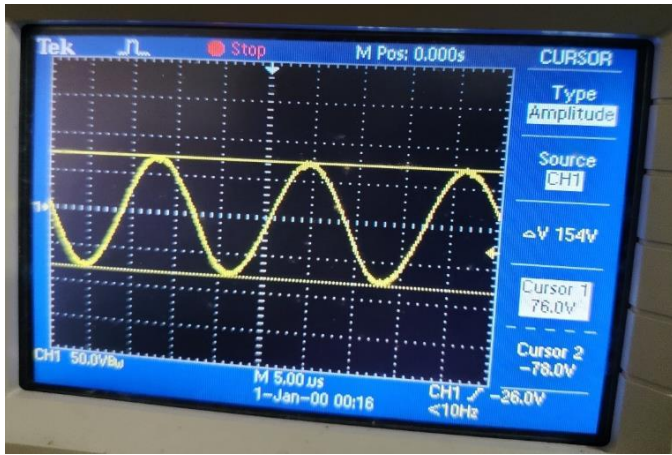


Fig-5: 60 KHZ Inverter Output Waveform

D. Resonant Transmitter Circuit

The high-frequency inverter output is applied to the transmitter resonant network consisting of the TX coil and compensation capacitance.

The purpose of the resonant network is to compensate the inductive characteristics of the coil and facilitate effective high-frequency excitation. Resonant compensation is particularly important in IWPT systems because the transmitter and receiver are loosely coupled compared with a conventional transformer.

In the developed prototype, the original resonant-capacitor arrangement was modified during hardware development to obtain the required resonant operating condition. The final configuration used parallel film capacitors to obtain the required effective capacitance.

E. Transmitter and Receiver Coil Design

The TX and RX coils constitute the main electromagnetic coupling interface of the system. The final prototype uses identical 19.5- μH coils, selected for both transmitting and receiving functions.

An earlier 22- μH copper coil was evaluated during development. However, increased AC resistance associated with high-frequency operation resulted in increased losses. The coil configuration was consequently modified, and the 19.5- μH coil was selected for the final prototype.

The use of identical coils simplifies the experimental

investigation by providing approximately symmetrical transmitter and receiver inductive characteristics.

F. Resonant Frequency Selection

The resonant frequency is determined depending on the inductance of the chosen coil and capacitance for compensation. For the designed system, the theoretical values of the resonant frequency are about 56.9 kHz and 92.8 kHz.

The Both frequencies were successfully confirmed by the inverter waveform measurements, and the 92-kHz approximately frequency was selected to characterize the wireless transfer process.

G. Wireless Power-Transfer Interface

When high-frequency current flows through the TX resonant coil, a time-varying magnetic field is generated around the coil.

The RX coil positioned across the air gap intercepts a portion of this magnetic flux and develops an induced AC voltage.

The induced voltage can be expressed using Faraday's law:

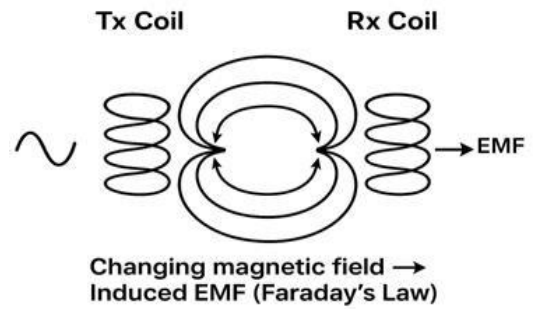


Fig-6: Faradays's Law of Magnetic Induction

where N presents the number of receiver-coil turns and Φ represents the magnetic flux linking the receiver.

The effectiveness of this magnetic coupling depends strongly on the relative position and separation of the coils. In particular, increasing the air gap generally reduces the coupling coefficient and mutual inductance, thereby reducing transferred power. This is a recognized limitation of resonant inductive EV charging systems.

For this reason, the developed hardware was designed so that the TX–RX separation could be varied experimentally.

H. Receiver-Side Rectifier and Filter

The voltage induced in the RX coil is high-frequency AC and therefore cannot be directly applied to the DC battery-charging stage. A receiver-side rectifier is consequently used to convert the received AC voltage into DC.

The receiver stage consists of:

RX Coil → Rectifier → Filter Capacitor → DC Output

A Schottky rectifier configuration using SR5200 diodes is employed in the receiver circuit. The rectified output is filtered using capacitors to reduce voltage ripple and provide a relatively stable DC voltage. The measured receiver-side output was approximately 56 V DC after rectification and

filtering. This voltage was subsequently reduced to a suitable level for the DC–DC converter.

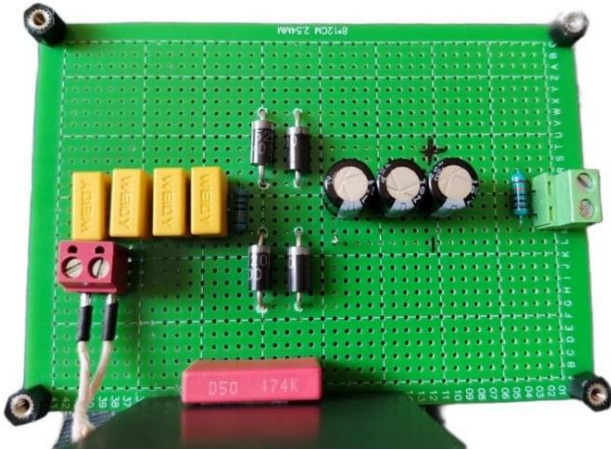


Fig-7: Receiver Circuit

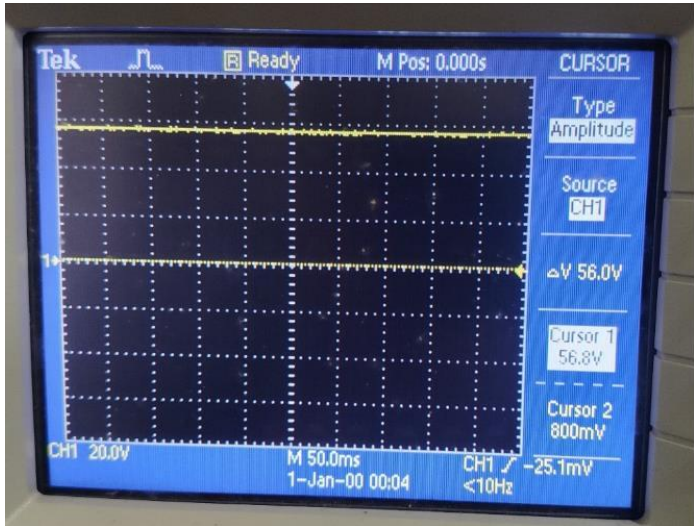


Fig-8: Receiver Circuit Output Waveform

I. Voltage Regulation and DC–DC Conversion

Because the receiver-side DC voltage is higher than the required battery-charging voltage, an intermediate voltage-conditioning stage is incorporated.

The developed system uses an LM7812 linear regulator in the control/gate-driver supply section and an XL4016E1 DC–DC buck converter in the battery-charging stage.

The XL4016E1 provides adjustable DC output regulation and is used to obtain the required battery-charging voltage. The final experimental system was configured for approximately:

5. EXPERIMENTAL SETUP AND TEST CONDITIONS

The developed IWPT prototype was experimentally evaluated to verify the operation of the high-frequency inverter, resonant wireless power-transfer link, receiver-side rectification and filtering, and battery-charging stage. The experimental investigation was primarily focused on two parameters: operating frequency and TX–RX coil separation (air gap). The tests were performed using a regulated 24-V DC input and a rechargeable battery load connected through the DC–DC buck converter. The experimental arrangement and test conditions were selected to characterize the practical power-transfer

capability of the implemented system.

A. Experimental Hardware Arrangement

The transmitter and receiver coils were positioned facing each other with their axes aligned to provide coaxial coupling. The receiver-side output was subsequently connected to the buck converter and battery/load.

The AC–DC SMPS provided the regulated 24-V DC input to the high-frequency inverter. The inverter was tested at approximately 60 kHz and 92 kHz. The final load condition was a 12-V, 2600-mAh rechargeable Li-ion battery pack with an integrated BMS.

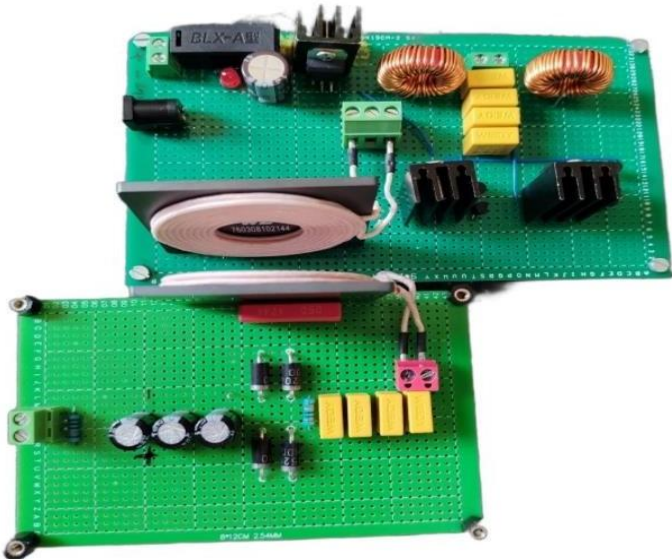


Fig-9: Wireless Power Transfer between TX and RX Coil

with a charging current of approximately 2 A under the intended battery-charging configuration. The buck converter therefore serves as the final power-conditioning stage between the wireless receiver and the battery.

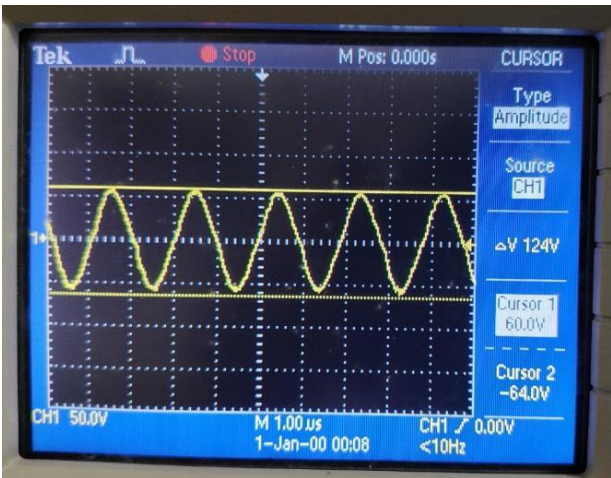


Fig-10: Wireless Power Transfer Output

A. Measurement Instruments

The DSO that is used in the experiment possesses 25-MHz bandwidth, 500-MS/s sampling speed and has two input channels. Hence, it is well suited for examining the high-frequency waveform of the inverter and receiver. The DMM

was used for measuring the DC supply voltage, receiver output voltage, and load current.



Fig-11: DC-DC Converter

D. 60-kHz Inverter Test

In case of the 60-kHz experiment, the power supply was connected to the inverter that was being used to excite the transmitter resonant circuit. This network comprised of four 0.1 μ F capacitors connected in parallel, which resulted in the capacitance value of 0.4 μ F.

A waveform of the inverter output was obtained by the use of the DSO. A waveform that is sinusoidal with a peak-to-peak voltage of about 154 Vpp was obtained. The waveform ranged from +76 V to -78 V.

With an air gap of 1.5 cm, the voltage produced by the receiving coil was a sinusoidal waveform of 124 Vpp, which corresponds to +62V and -62V peak voltages. This was measured when both coils were kept aligned axially.

E. 92-kHz Inverter Test

The second experiment was conducted around 92 kHz using the same input of 24 V DC and TX coil of 19.5 μ H. The output voltage of the inverter was about 156 Vpp.

The result of the experiment revealed that both sets of frequencies produced stable waveforms and could effectively excite the wireless power transfer system. The set of 92 kHz produced a higher inverter output voltage compared to the 60 kHz set; however, the difference was not significant.

F. Coil Alignment and Air-Gap Conditions

TX and RX coils were first aligned in coaxial fashion to ensure proper coupling between the two. Then the air gap between the two coils was changed to study the impact of distance on voltage received and power transmitted.

The exact same procedure for measurement was used for all separation distances, recording the voltage and current load on the output of the charger circuit.

Dissertation recognizes coil alignment and gap spacing as critical factors in magnetic coupling and hence power transfer.

G. No-Load and Loaded Tests

Two principal electrical loading conditions were considered.

1) No-Load Condition

No-load testing was done to confirm that the inverter and the resonant coupling circuit were working properly without connection to the battery or load. The no-load test conditions that were observed involved 24 V at the input level with approximately 0.5 A of current flow.

2) Loaded Condition

The loaded test was conducted with the battery/load connected through the buck converter. At the selected 1.5-cm air gap, the system operated from a 24-V DC input and drew approximately 1.56 A, corresponding to:

The load-side voltage and current were approximately 12 V and 1.72 A, respectively:

The corresponding reported overall efficiency was:

These values represent the complete system performance under the selected loaded test condition.

H. Air-Gap Test Conditions

The air-gap experiment was performed under the following conditions:

TX and RX coils maintained in coaxial alignment.

High-frequency inverter operated under the selected resonant condition.

24-V DC input supplied to the inverter.

Receiver output processed through the rectifier, filter, and buck converter.

Battery/load connected at the output.

TX–RX separation progressively increased from 1.5 cm to 4 cm.

Load voltage and current recorded for each air-gap condition.

Table -1: Air Gap Testing Measurement

Air Gap (cm)	Load Voltage (V)	Load Current (A)	Output Power (W)
1.5	12.0	1.72	20.64
2.0	7.8	1.21	9.44
2.5	5.6	1.105	6.19
3.0	4.8	0.973	4.67
3.5	3.4	0.724	2.46
4.0	2.5	0.628	1.57

6. RESULTS AND DISCUSSION

The developed Inductive Wireless Power Transfer (IWPT) prototype was experimentally evaluated to verify high-frequency inverter operation, wireless energy transfer, receiver-side power conditioning, battery charging, and the effect of TX–RX coil separation on delivered power. The experimental

investigation was performed using a regulated 24-V DC input and coaxially aligned transmitter and receiver coils. Both approximately 60-kHz and 92-kHz operating conditions were investigated, followed by a detailed air-gap characterization.

A. High-Frequency Inverter Performance

The high-frequency inverter was initially tested under no-load and loaded conditions to verify its switching and resonant operation. With a frequency of about 60 kHz, the inverter gave an output voltage of 154 V_{pp}, which varied from around +76 V to −78 V. It was observed that the waveform had stable sinusoidal properties, which indicated that the transmitter circuit was excited properly.

B. Receiver-Side Wireless Power Transfer

The high-frequency excitation generated by the transmitter coil produced an induced voltage in the receiver coil through magnetic coupling. Under coaxial alignment and an air gap of approximately 1.5 cm, the receiver coil produced an approximately sinusoidal waveform with a measured peak-to-peak voltage of approximately 124 V_{pp}.

After rectification and filtering, the receiver circuit produced approximately 56 V DC. This output was subsequently processed through the voltage-conditioning and DC–DC buck-converter stages to obtain the required battery-side voltage.

These measurements confirm that the developed resonant magnetic link successfully transferred electrical energy across the physical separation between the transmitter and receiver without a conductive connection.

The maximum measured output power was 20.64 W at a 1.5-cm air gap. As the separation increased, both load voltage and current decreased, resulting in a substantial reduction in delivered power. At 4 cm, the measured output power was only 1.57 W.

The reduction in output power can be attributed, within the experimental interpretation of the dissertation, to reduced magnetic coupling, reduced mutual inductance, and increased magnetic flux leakage as the distance between the coils increases. These results demonstrate that the developed prototype is highly dependent on TX–RX separation and that maintaining an appropriate coil distance is important for obtaining useful charging power.

C. Overall Discussion

The experimental results demonstrate three important characteristics of the developed IWPT system.

First, the high-frequency inverter successfully operated at both approximately 60 kHz and 92 kHz, producing stable high-frequency waveforms. The measured output voltages of 154 V_{pp} and 156 V_{pp} indicate that both operating conditions were capable of exciting the resonant transmitter circuit.

Second, successful wireless energy transfer was demonstrated between the TX and RX coils. The receiver produced a measurable AC voltage, which was subsequently rectified, filtered, regulated, and supplied to the battery/load.

Third, the air-gap experiment clearly demonstrated the dominant effect of coil separation on the delivered power. Increasing the air gap from 1.5 cm to 4 cm reduced the output power from 20.64 W to 1.57 W. This represents a reduction of approximately 92.4% relative to the 1.5-cm result, calculated from the reported measurements.

Therefore, the experimental results validate the basic feasibility of the proposed low-power IWPT architecture while

also demonstrating its principal practical limitation: strong sensitivity to the TX–RX air gap.

7. LIMITATIONS AND FUTURE SCOPE

A. Limitations

Despite the success in achieving contactless power transmission and charging of the battery, there were several limitations found out from the experiment.

Limited Transfer Distance

The key limitation here is the significant dependence of the output power on the TX–RX gap. The power was reduced from 20.64 W at 1.5 cm to 1.57 W at 4 cm. In other words, the prototype cannot be used to achieve efficient power transmission at large distances.

Misalignment Sensitivity

Coaxial alignment was the main alignment approach used during the experimentation in terms of positioning of the transmitting coil with respect to the receiving coil. As a result, the current experimental data do not offer a full quantitative evaluation of the misalignment tolerance.

Overall System Efficiency

The efficiency of 55.1% that has been stated in this study shows the huge losses incurred during the whole power conversion process. The loss mechanisms highlighted in the study are inverter losses, coil losses, magnetic leakage, rectifier losses, and voltage conversion losses.

High-Frequency Switching Losses

High-frequency switching helps in achieving the resonant wireless power transfer; however, it results in losses due to switching and conduction. These losses affect the efficiency of the prototype designed and need further improvement.

Low-Power Prototype

This system has been experimentally validated at approximately 20.64 W maximum output power. Hence, it can be considered an experimental low-power validation and not an actual EV charging system. There is still need for further work to develop this architecture for actual EV charging purposes.

Thermal and EMI Considerations

Thermal management and EMI are recognized as key issues with regards to higher power IWPT systems from the dissertation. However, these areas were not quantitatively evaluated in detail in this current low-power experiment.

A. Future Scope

The following improvements can be considered for future development:

Optimization of the shape of the coil: The optimization of the geometry of the coil will enhance the coupling and reduce the loss due to copper.

Misalignment tolerance coils: The study of various shapes of the coil along with the use of more than one coil is required for misalignment tolerance.

Frequency and compensation control adaptively: Perform closed-loop control in order to vary the operating frequency or compensation parameters depending on coupling and loading changes.

Higher efficiency power converters: Change the current switching configuration with optimized inverter configurations that have higher frequencies along with suitable soft-switching methods.

Better compensation networks: Explore modern compensation networks like LCC/LCL topology to enhance immunity to coupling and loading effects.

High power operation: Scale the prototype from the currently demonstrated low power to actual EV charging power while achieving satisfactory thermal and electromagnetic performance.

Thermal Management: Implement thermal analysis and cooling of the inverter, coils, rectifier, and power conditioning components systematically.

EMI and magnetic field analysis: Measurement of electromagnetic emissions and studies related to shielding and/or magnetic field containment solutions.

Battery charging through closed loop: Design and develop a feedback control system that will maintain the required battery voltage and current irrespective of air gap variations, misalignment, and state of battery charge.

Wireless dynamic charging: Develop the idea of stationary charging towards dynamic charging scenarios where the automobile is getting charged while moving over specially designed transmitting sections.

These developments would improve the efficiency, tolerance, scalability, safety, and practical applicability of the proposed IWPT concept.

8. CONCLUSION

In this paper, the design, realization through hardware, and experimental investigation of a resonant Inductive Wireless Power Transfer (IWPT) scheme for electric vehicle battery charging was investigated. From experiments, it was demonstrated that the realized circuit is capable of performing wireless energy transfer at frequencies of around 60 kHz and 92 kHz, while operating in the resonant mode. With an air gap of 1.5 cm in the coaxial alignment, an output power of 20.64 W, and an efficiency of about 55.1% at 12 V, 1.72 A was obtained.

From the experimental results, it can be observed that the transferred power is greatly dependent on the TX-RX coil separation, and it becomes much lower as the air gap between the two coils is increased. Even though the design is capable of proving the working principle of resonant IWPT for low power charging, it suffers from the drawback of having short-range operation, sensitivity to coil positioning, and low efficiency. In future, efforts will be made to enhance the performance of the system in terms of increased range of operation, tolerance to coil misalignment, efficiency, and operation at high power levels.

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