Journal of Electronics and Informatics (ISSN: 2582-3825)
www.irojournals.com/iroei/

Design and Performance Optimization in Wireless Power Transfer System

Vasantharathna S.[1], Paul Samuel I.[2], Arun A.[3], Balamurugan R.[4], Bharath R.[5]

[1]Professor & Head, [2-5]UG Student, Department of Electrical and Electronics Engineering, Coimbatore Institute of Technology, Coimbatore, India

E-mail: [1]hodeee@cit.edu.in, [2]paulsamuelijs@gmail.com, [3]arun268aruchamy@gmail.com, [4]balamurugan56998@gmail.com, [5]bharathsham2003@gmail.com

Abstract

Wireless Power Transfer (WPT) is one of the contactless energy transmission technologies that does not require physical connectors, and it improves efficiency in various applications such as electric vehicles, consumer electronics, and medical devices. In this article, the issue of optimizing the design and performance of an inductive WPT system based on LCC compensation has been proposed for better power transfer efficiency. The system topology consists of a high-frequency H-bridge inverter, coupling coils, and an AC-DC stage for efficient energy transfer. The LCC compensation network used in the system will reduce the impedance mismatch and maximize the coupling coefficient for improving transmission efficiency with larger air gaps. The simulation results correlate with the theoretical model. The proposed design shows an effective result. Thus, the optimized WPT system provides an energy transfer efficiency of 81.7%, affirming its feasibility for sustainable and high-performance applications.

Keywords: Wireless Power Transfer (WPT), Inductive Coupling, LCC Compensation, High-Frequency Inverter, Power Transfer Efficiency, Power Optimization.

1. Introduction

Wireless Power Transfer (WPT) is a revolutionary technology that enables the transfer of power without physical contact, with numerous advantages over traditional wired power supply systems. WPT has generated a great deal of interest due to its promising applications in

DOI: https://doi.org/10.36548/jei.2025.1.002
Received: 18.02.2025, received in revised form: 16.03.2025, accepted: 02.04.2025, published: 11.04.2025

electric vehicles (EVs), biomedical implants, consumer electronics, and industrial automation. The increasing need for efficient, reliable, and contactless power solutions paves a way to develop WPT systems with better performance and higher efficiency. Traditional wired power transmission system faces numerous limitations, including connector degradation, insulation degradation, and limited mobility due to physical connections. Additionally, in dynamic applications such as electric vehicle charging, and biomedical implants, it is not practical or even impossible to maintain a direct wired connection. WPT overcomes these limitations by using electromagnetic fields to transfer energy over a range from short to moderate distances without physical contact, and thus it is an ideal solution for a wide range of applications. Various approaches have been explored to improve the efficiency and reliability of wireless power transfer (WPT) systems. Hybrid WPT systems, which combine inductive power transfer (IPT) and capacitive power transfer (CPT), have been proposed for application in railway environments [1]. Hybrid systems combine the advantages of IPT and CPT synergistically to improve misalignment tolerance and enhance overall efficiency. Studies have also explored WPT systems for e-scooters, focusing on the practical implementation of wireless charging solutions with advanced power converter architectures [2]. In the context of electric vehicle (EV) use, different approaches related to wireless power transfer (WPT) have been studied comprehensively, especially with regards to compensation topologies like series-series (SS), LCC, and double-sided LC compensation [3-4]. The SS topology is commonly viewed as a desired choice for EV charging because of its ability to maintain resonance regardless of load condition variations [5]. High-frequency inverters play a central role in optimizing the performance of WPT systems, particularly in vehicle-to-grid (V2G) arrangements, which require bidirectional power transfer [6]. Research related to 1-MW inductive power transfer for high-speed trains has demonstrated the feasibility of using large-scale WPT solutions [7].

The design of coils and electromagnetic shielding implementation are critical elements that determine the efficiency of wireless power transmission (WPT). The improvement of coil architecture along with shielding elements has been proven to increase power transfer efficiency while simultaneously minimizing electromagnetic interference (EMI)[8]. Additionally, a thorough study of LC/S compensation topologies emphasizes the importance of resonant tuning in attaining greater efficiency in wireless energy transfer systems [9]. Research on the design of H-bridge inverters is also essential for developing WPT to enable efficient generation with low power dissipation. This article focuses on optimizing WPT efficiency through improved coil design, compensation networks, and power electronics. Inductive and capacitive coupling techniques are analyzed to minimize energy losses. The integration of bidirectional power transfer concepts and hybrid IPT-CPT systems highlights the potential of WPT for sustainable and scalable energy solutions [10].

2. Proposed System

The proposed system has the following block diagram explanation. The Figure 1 depicts the block diagram of the proposed system.

2.1. Block diagram and Components

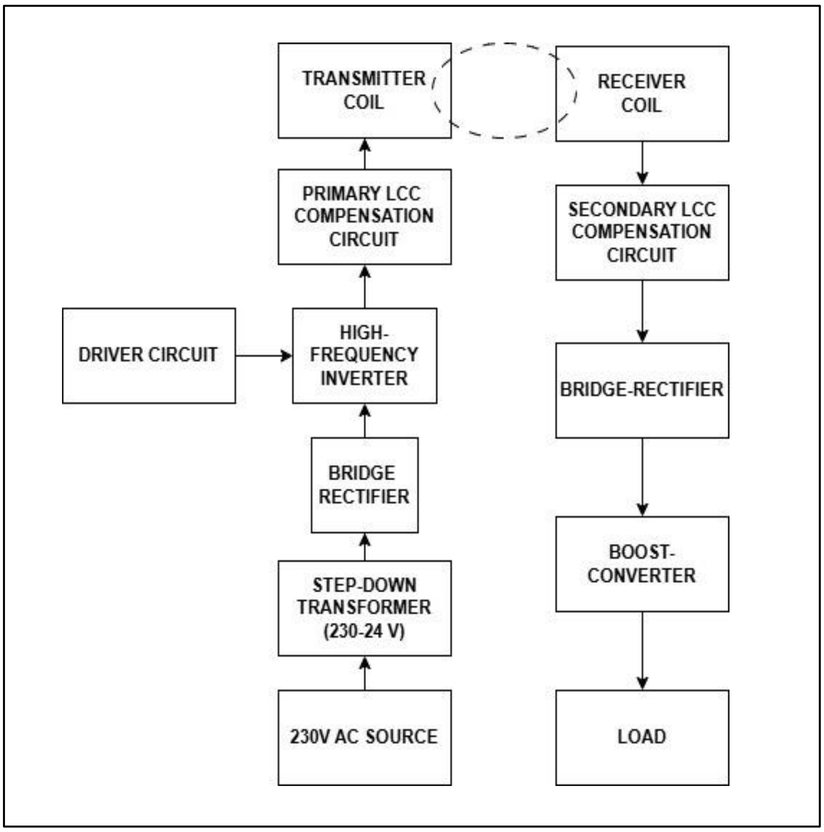


Figure 1. Block Diagram

2.2 Step-down Transformer 230-24V

A step-down transformer to convert 230V AC to 24V AC (Figure 2) is essential in most electrical circuits, delivering precise voltage conversion with high efficiency and reliability. The main winding is linked to the 230V AC mains supply and consists of multiple turns of good-quality copper wire, properly computed to develop the desired voltage ratio.

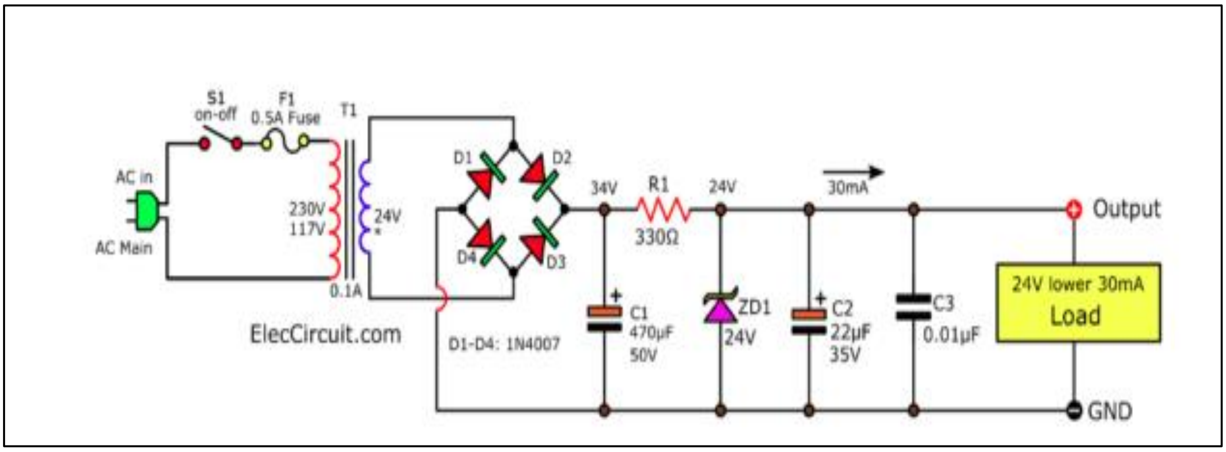


Figure 2. Step-down Transformer[11]

The core, usually of high-permeability grain-oriented silicon steel, minimizes core losses such as hysteresis and eddy currents, thereby improving magnetic coupling efficiency.

2.3 AC-DC Converter (Bridge Rectifier & Filter Circuit)

The topology of an AC-DC converter using a full-wave bridge rectifier (Figure 3) and filtering network is required to convert alternating current (AC) supplied from the mains source to direct current (DC) required to drive electronic loads and systems. The bridge rectifier is constructed using four semiconductor diodes connected in a Graetz structure, which performs full-wave rectification of the sinusoidal AC input, that supports bi-directional current flow and generates a unipolar pulsating DC output. Despite this, the output, having been rectified contains considerable ripple voltage due to the presence of residual AC components, thus providing the use of a filtering network to counteract the ripple effect and deliver a stable DC output.

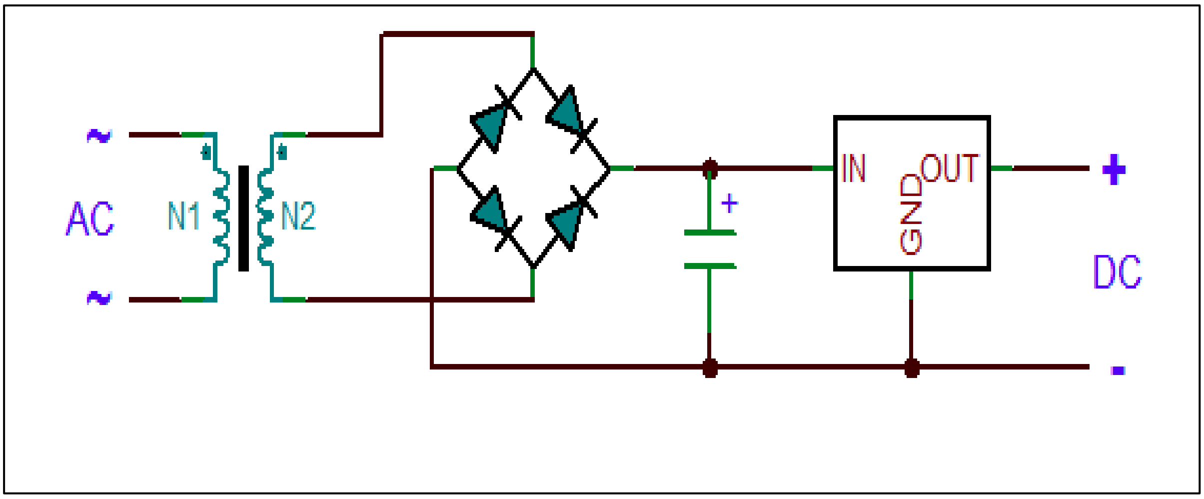


Figure 3. Bridge Rectifier & Filter Circuit[12]

The filter network typically utilizes an electrolytic capacitor of suitable capacitance, which is selected with care based on the characteristics of the load impedance and permissible ripple voltage margins that store the charge and minimize the amplitude of the ripple. When the peak instantaneous levels of the rectified waveform are encountered, the capacitor charges, whereas during the troughs, the capacitor discharges, filtering the pulsating waveform and delivering a stable DC voltage output.

2.4 High-Frequency H-Bridge Inverter

The WPT system requires an H-bridge inverter (Figure 4) which functions as the main device. The developed circuit accepts DC power from the AC-DC converter to generate a controlled AC waveform. The inverter uses four high-speed switches including MOSFETs or IGBTs which take the shape of an 'H'. When the H-bridge switches operate in rapid Pulse Width Modulation (PWM) sequences they create a specific AC voltage waveform at their output terminals. The basic design of an inverter depends on a bridge arrangement of four power-switching devices that normally use MOSFETs.

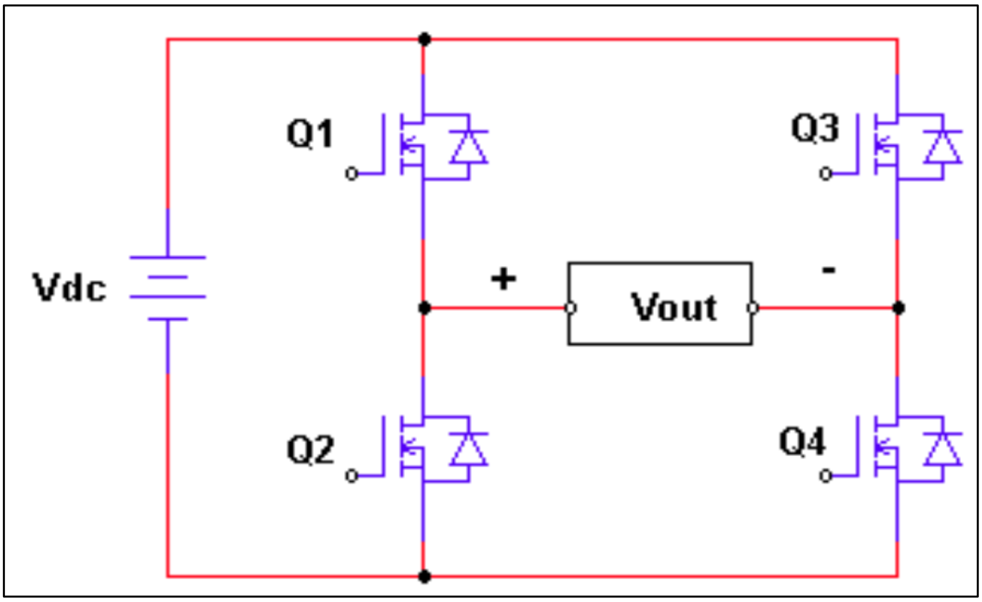


Figure 4. H-bridge Inverter[13]

The semiconductor switch functions alternatively to create AC output from DC input sources by switching pairs diagonally in sequential order. The control circuit produces PWM gate signals at a high frequency to drive the switches which enables precise voltage and frequency regulation of the output. The implementation of high-frequency operation allows the use of smaller electromagnetic elements including transformers and filters because of their built-in high-frequency capabilities. The system's high operating frequency surpasses the output frequency and provides multiple benefits for the system.

The usage of smaller inductors and capacitors in output filter design becomes possible through high operating frequency. The successful operation of weight and size-optimized WPT systems heavily relies on this factor. High-frequency operation enables efficient operation of the inverter by reducing its switching losses which delivers improved system performance and reduces the heat output. The control precision of the output voltage waveform increases when using faster switching speeds. The system achieves better output sine wave purity when producing a pure sine wave.

2.5 Coupling Coil

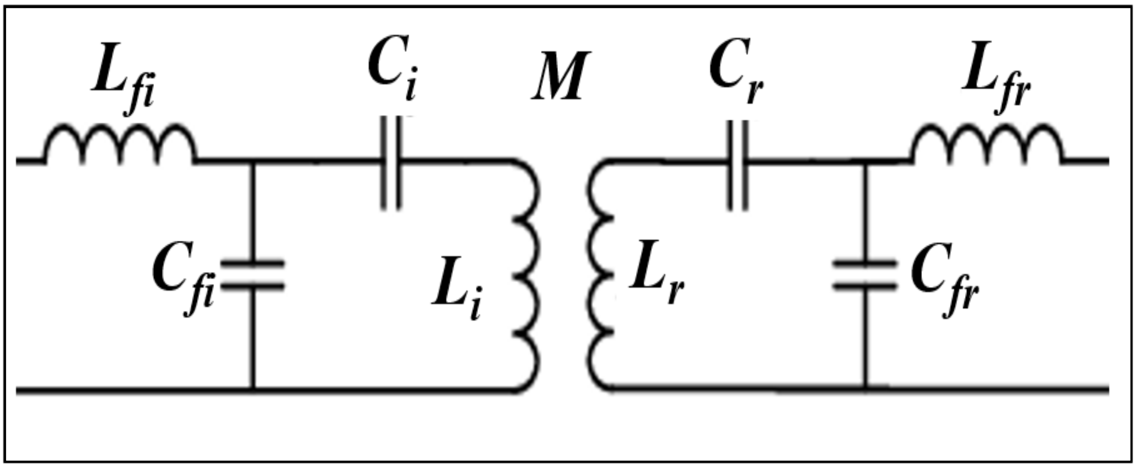


Figure 5. Coupling Coil with LCC Compensation

One of the basic components of contactless energy transfer in wireless power transmission (WPT) systems is the coupling coils that is shown in Figure 5. These coils largely function as transformers but without necessarily using a physical magnetic core. The primary coil, situated on the track bed, is energized with AC current at a specific frequency. This current induces an electromagnetic field that propagates upward. Meanwhile, the secondary coil, located on the underside of the train, interacts with this magnetic field. The magnetic field itself is changing because the AC current varies over time. This effect, known as electromagnetic induction, will develop a current in the secondary coil through its location in the changing magnetic field.

The induced current, which leads to losses, has impedances that make it less efficient. Here, the LCC compensation circuit is added to the system together with the coupling coil, which resonates mainly at resonant frequency wherein the impedance of the combined circuit is minimal. The efficiency of energy transfer between such coils can often be affected by several parameters. One such parameter is k, or the coefficient of coupling. This value refers to the actual level of magnetic flux linkage between the two coils, primary and secondary. The larger the k, the more efficient the transfer of the power.

The distance between these coils, their geometrical pattern, and the material composition contribute to the value of k. LCC compensation has a better coupling coefficient under large air-gap separations. Thus, LCC proves better than SS topology in load independence and coupling efficiency over long distances. The frequency at which an operation is conducted is equally important. The frequency used determines the depth of magnetic fields and, hence, how much current is induced in the secondary winding. The stability of the frequency for the purpose is very important for greater effectiveness. The same security protocols need to be conducted to avoid any public exposure coming from these electromagnetic fields, such as acceptance by the ICES(International Committee on Electromagnetic Safety) and ICNIRP(International Commission on Non-ionizing Radiation Protection).

2.6 AC-DC Converter

The AC-DC converter operates on the receiving end of a WPT system. This is important as the converter does the task of rectifying the incoming AC power. The conversion usually consists of two steps: rectification and filtering. During the first step, rectification, the AC waveform arriving at the diode bridge is rectified with the help of Schottky diodes connected in pairs. This gives a pulsating DC voltage which, however, contains AC ripple and might cause malfunctions with certain other sensitive electronics on board. To smoothen out these ripples, it's feasible to use a capacitor filter of appropriate capacitance.

2.7 Load

The DC voltage supplies a suitable load. The load used is either a lamp or battery rated at 14.8 Volts. 14.8V is chosen so that the designed coil operates on low voltage for safe operation and experimentation.

3. Circuit Design and Simulation

Developing a Wireless Power Transfer system demands a thorough composition of circuit models with suitable component choices followed by optimization methods. The following section describes the process of circuit design implementation along with LCC compensation network installation while yielding simulation outcomes to assess system performance.

3.1 Circuit Design

Calculation Of LCC Compensation Circuit Parameters:

The transmitter-side circuit parameters;

$$Cfi = 1/(\omega 2Lfi) \quad (1)$$

$$Ci = 1/(\omega 2(Li - Lfi + Mi)) \quad (2)$$

The receiver-side compensation circuit parameters;

$$Cfr = 1/(\omega 2Lfr) \quad (3)$$

$$Cr = 1/(\omega 2(Lr - Lfr)) \quad (4)$$

The values are assumed as $Li = 100uH$; $Lr = 50uH; Lfi = 50uH$;

Determining Mutual inductance for $(k = 0.0 = 15)$ first;

$$k = M/\sqrt{}(Li * Lr)$$

$$M = 0.15 * \sqrt{}(100 * 10\text{^} - 6 * 50 * 10\text{^} - 6)$$

$$M = 10.6uH$$

To calculate primary side compensated circuit parameters;

The resonant frequency chosen for efficient resonant coupling is $fr = 100kHz$;

From equation (1),

$$Cfi = 1/(\omega 2Lfi)$$

$$Cfi = 1/((2\pi * 100 * 10\ 3)\ 2 * (50 * 10\text{^} - 6))$$

$$Cfi = 50.6\,nF \quad (5)$$

From equation (2),

$$Ci = 1/(\omega 2(Li - Lfi + Mi))$$

$$Ci = 1/((2\pi * 100 * 10\ 3)2(100 * 10^\wedge - 6 - 50 * 10^\wedge - 6 + 10 * 10^\wedge - 6))$$
$$Ci = 41.8nF \tag{6}$$

To calculate secondary side compensated circuit parameters;

Consider ($Lfr = 29uH$);

From equation (3),

$$Cfr = 1/(\omega 2Lfr)$$
$$Cfr = 1/((2\pi * 100 * 10\ 3)2 * (29 * 10^\wedge - 6))$$
$$Cfr = 87.3nF \tag{7}$$

From equation (4),

$$Cr = 1/(\omega 2(Lr - Lfr))$$
$$Cr = 1/((2\pi * 100 * 10\ 3)2(50 * 10^\wedge - 6 - 29 * 10^\wedge - 6))$$
$$Cr = 120nF \tag{8}$$

Finally, the calculated parameters for LCC Compensation are;

$$Li = 100uH$$
$$Lfi = 50uH$$
$$Ci = 41.8nF$$
$$Cfi = 50.6nF$$
$$Lr = 50uH$$
$$Lfr = 29uH$$
$$Cr = 120nF$$
$$Cfr = 87.3nF$$

Figure 6 shows the designed values of the LCC Compensation of Coupling Coil used in the study.

3.2 Simulation Model

A WPT system functions by performing AC-DC conversion then creating high-frequency AC signals for conducting inductive coupling wireless energy transmission. The system uses four essential components including a 230V-24V AC step-down transformer and a bridge rectifier for AC-DC conversion and H-Bridge inverter for AC signal generation and transmission through coupling coils with LCC compensation network and final receiver-side AC-DC conversion for load power supply. The load forms the last phase of this research where the study utilizes either a battery or an LED to justify effective power use. The LCC compensation topology functions as part of the system architecture to improve both power transfer efficiency and load performance stability. Design calculations of inductance and capacitance values for the compensation circuit lead to optimal power flow together with minimum losses at the desired resonant frequency.

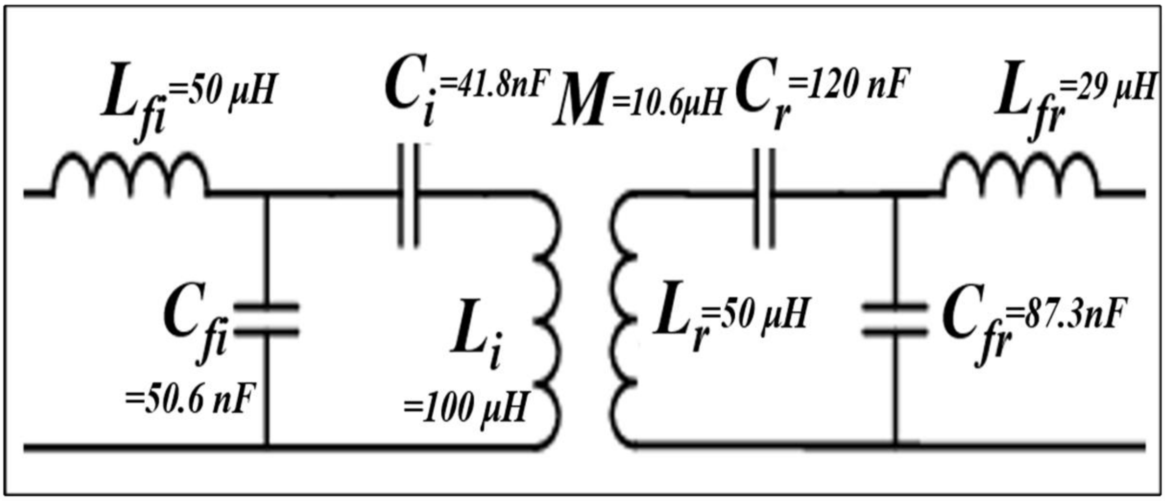


Figure 6. Design Values of Coupling Coil

3.3 Simulation Results

Figure 7 shows that the inverter is powered by a 27V DC supply, and the simulation results indicate that the transmitter produces an AC output of 100 kHz at 26.8V and 0.25A.

Figure 8 shows the voltage and current output obtained at the receiver side through simulation are 15.7 V and 0.29 A, respectively,

Figure 9 shows the voltage and current observed at the receiver side rectifier output through simulation are 15.66V and 0. 35A.Therefore, we have an overall efficiency of 81.7%.

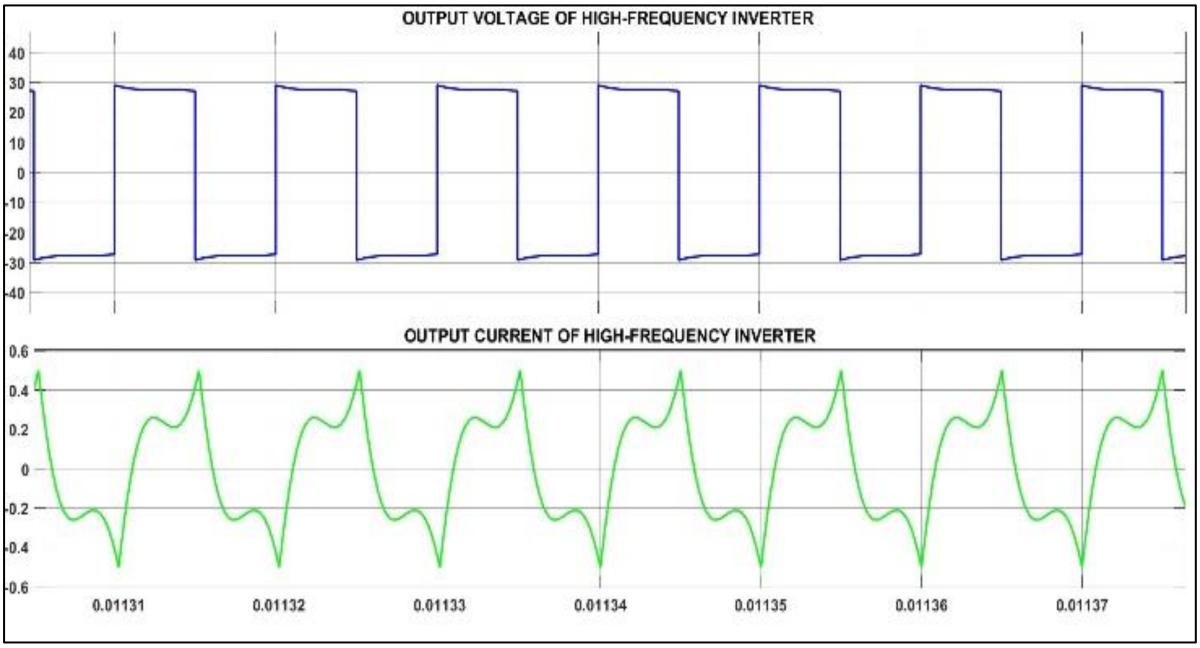


Figure 7. Transmitter Output

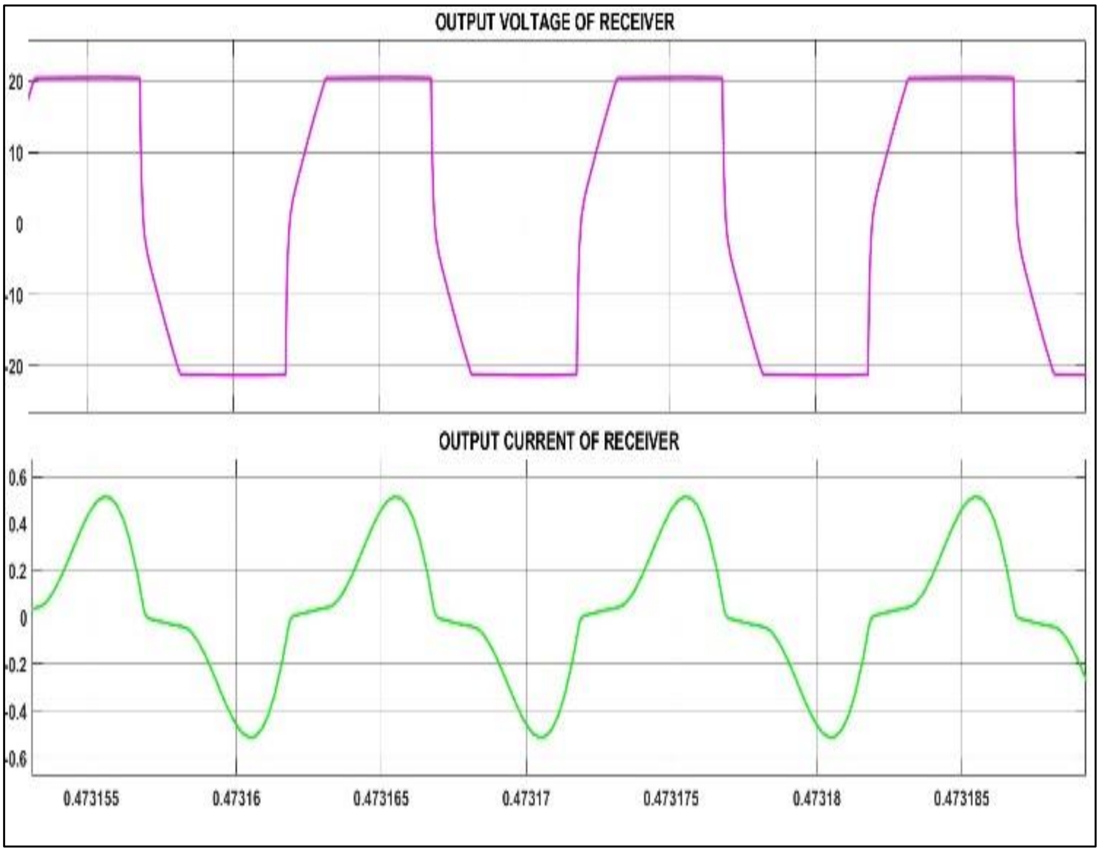
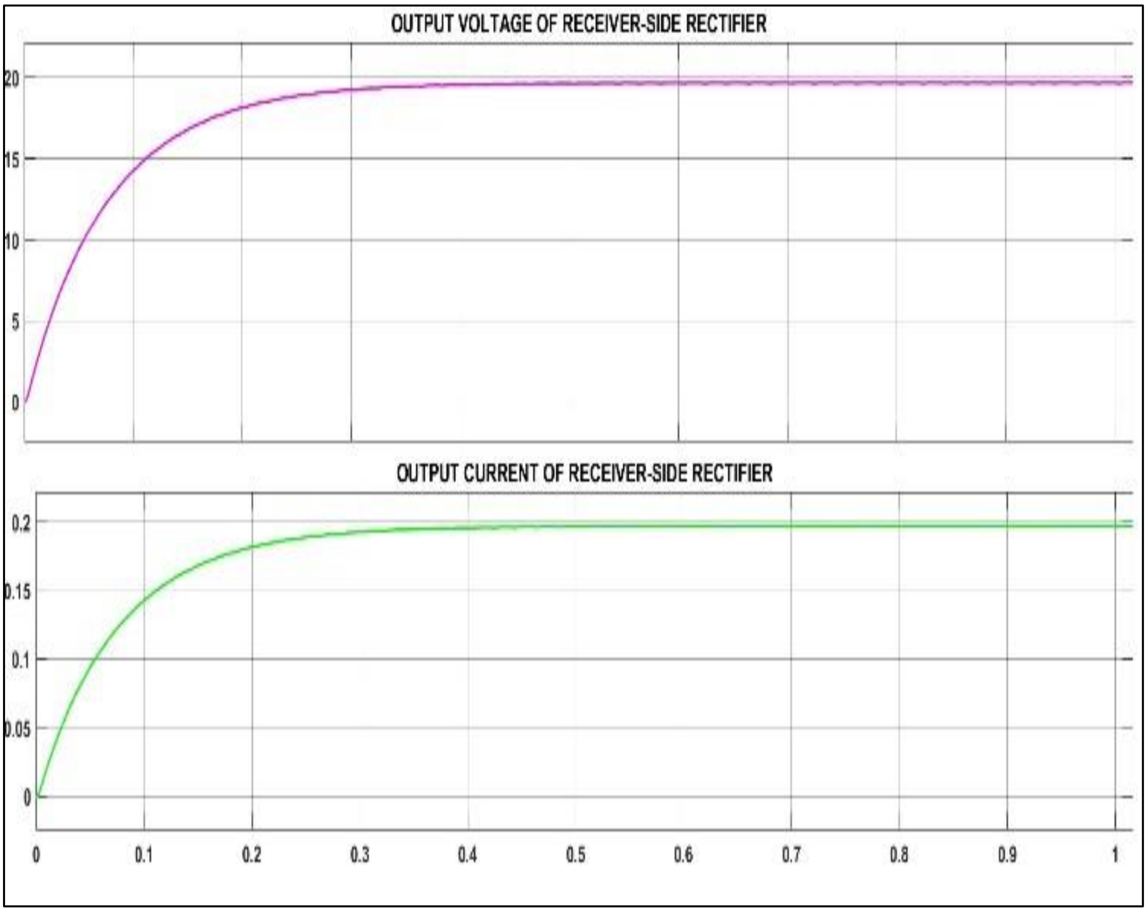


Figure 8. Receiver Output



.

Figure 9. Rectified Receiver Output

4. Results and Discussion

Table 1. Results Observed

System	Voltage (V)	Current (A)
Transformer Output	20.7V AC	0.001A
Rectifier Output	27V DC	0.22A
Inverter Output	26.8V AC	0.25A
Coupling Coil Output	15.7V AC	0.29A
Receiver Rectifier Output	15.66V DC	0.35A

The WPT system converts the 230V AC to 20.7V AC using a step-down transformer. This 20.7V is provided as input to the rectifier which generates a stable 27V DC. The stable 27V DC is then given as input to the H-Bridge inverter converting the output as 26.8V AC, and it was transmitted wirelessly from the coupling coils providing 15.7V AC output. The output of the coupling coil 15.7V AC is then converted into 15.66V DC by the rectifier on the receiver-side which can be connected to the load. The designed values of the coupling coil are derived as follows, $Li = 100\mu H, Lr = 50\mu H, Cfi = 50.6nF, and\ Cr = 120nF$ and all the parameters are derived based on the frequency at 100kHz, hence reducing impedance and maximizing power transfer. Thus, the system efficiently powered the 14.8V battery and an LED, providing the feasibility for the use of the system in wireless charging of devices at low powers. The WPT system efficiently transmitted power wirelessly with minimal loss of power, ensuring the LCC compensation topology is effective in enhancing energy transfer while stabilizing the system. Thus, the overall efficiency achieved from the proposed system is 81.7%. Table 1 depicts the results observed.

5. Conclusion

The increasing demand for efficient, contactless power transmission has driven the need for Wireless Power Transfer (WPT) as a viable alternative to conventional wired systems. Traditional power transmission methods rely on physical connectors, which are prone to wear and tear, require frequent maintenance, and limit mobility. These challenges make WPT an attractive solution, particularly in applications such as electric vehicles, consumer electronics, and industrial automation, where safe and reliable power delivery is essential. The proposed design WPT system enhances power transfer efficiency ensuring stable operation. To achieve this, a high-frequency inverter, LCC compensation network, and optimized coupling coils were used into the system. The LCC compensation technique was selected to improve resonance, reduce impedance mismatches, and enhance power transfer efficiency even at larger air gaps. The system was tested through a MATLAB environment achieving an efficiency of 81.7%. The future research will focus on hardware implementation in order to validate the real-world performance under dynamic conditions.

References

[1] Luo, Bo, Tao Long, Limou Guo, Ruimin Dai, Ruikun Mai, and Zhengyou He. "Analysis and design of inductive and capacitive hybrid wireless power transfer system for

railway application." IEEE Transactions on Industry Applications 56, no. 3 (2020): 3034-3042.

[2] Skorvaga, Jakub, Michal Frivaldsky, and Miroslav Pavelek. "Design of a wireless charging system for e-scooter." Elektronika Ir Elektrotechnika 27, no. 2 (2021): 40-48.

[3] Yang, Yang, Mohamed El Baghdadi, Yuanfeng Lan, Yassine Benomar, Joeri Van Mierlo, and Omar Hegazy. "Design methodology, modeling, and comparative study of wireless power transfer systems for electric vehicles." Energies 11, no. 7 (2018): 1716.

[4] Frivaldsky, Michal, and Miroslav Pavelek. "In loop design of the coils and the electromagnetic shielding elements for the wireless charging systems." Energies 13, no. 24 (2020): 6661.

[5] Yang, Yang, Yassine Benomar, Mohamed El Baghdadi, Omar Hegazy, and Joeri Van Mierlo. "Design, modeling and control of a bidirectional wireless power transfer for light-duty vehicles: G2V and V2G systems." In 2017 19th European Conference on Power Electronics and Applications (EPE'17 ECCE Europe), IEEE, 2017. P-1.

[6] Patil, Devendra, Matthew K. McDonough, John M. Miller, Babak Fahimi, and Poras T. Balsara. "Wireless power transfer for vehicular applications: Overview and challenges." IEEE Transactions on Transportation Electrification 4, no. 1 (2017): 3-37.

[7] Kim, Jae Hee, Byung-Song Lee, Jun-Ho Lee, Seung-Hwan Lee, Chan-Bae Park, Shin-Myung Jung, Soo-Gil Lee, Kyung-Pyo Yi, and Jeihoon Baek. "Development of 1-MW inductive power transfer system for a high-speed train." IEEE Transactions on Industrial Electronics 62, no. 10 (2015): 6242-6250.

[8] Mai, Ruikun, Bo Luo, Yangqi Chen, and Zhengyou He. "Double-sided CL compensation topology based component voltage stress optimisation method for capacitive power transfer charging system." IET Power Electronics 11, no. 7 (2018): 1153-1160.

[9] Wang, Yijie, Yousu Yao, Xiaosheng Liu, Dianguo Xu, and Liang Cai. "An LC/S compensation topology and coil design technique for wireless power transfer." IEEE Transactions on Power Electronics 33, no. 3 (2017): 2007-2025.

[10] Mohamed, Ahmed AS, Dueal Allen, Tarek Youssef, and Osama Mohammed. "Optimal design of high frequency H-bridge inverter for wireless power transfer systems in EV applications." In 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), IEEE, 2016. 1-6.

[11] https://www.eleccircuit.com/24v-2a-power-supply-circuit/

[12] https://www.instructables.com/AC-to-DC-Conversion/

[13] Mohamed, Ahmed AS, Dueal Allen, Tarek Youssef, and Osama Mohammed. "Optimal design of high frequency H-bridge inverter for wireless power transfer systems in EV applications." In 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), pp. 1-6. IEEE, 2016.