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DESIGN AND SIMULATION OF A 1KW WIRELESS POWER TRANSFER SYSTEM FOR A 5-MILE SINGLE-PHASE RURAL MICROGRID

[1]Arinze Ignatius Ibekwe *, [1]Sylvester Emeka Abonyi, [1]Chibueze Kingsley Obute
Department of Electrical, Nnamdi Azikiwe University, Awka, Anambra State
**Corresponding Author's E-mail: ai.ibekwe@stu.unizik.edu.ng*

Abstract
This study demonstrated the design and simulation of a 1kW Wireless Power Transfer (WPT) System for a 5-Mile Single-Phase Rural Microgrid using MATLAB/Simulink R2025. The objective was to investigate the feasibility of transmitting electrical energy wirelessly for rural electrification applications. The developed model comprised a 6.6 kWp solar photovoltaic array, a 24 V, 2000 Ah lithium-ion battery bank, an MPPT controller, a 1kW high-frequency inverter operating at 100 kHz, resonant transmitter and receiver coils, a wireless transmission channel, and a control and protection subsystem. Simulation results demonstrated successful wireless power transmission across the entire simulated distance of 5 miles (8.05 km). The system achieved a maximum efficiency of 89.5% at 1 mile, which decreased to 82.0%, 74.0%, 60.0%, and 50.0% at 2, 3, 4, and 5 miles, respectively. The output voltage also reduced from 23.8 V at 1 mile to 18.0 V at 5 miles, while the input voltage remained constant at 24 V. These results confirmed that increasing transmission distance reduces magnetic coupling and overall power transfer efficiency. Load testing showed that the system maintained stable operation for load demands ranging from 200 W to 1000 W, while magnetic field analysis revealed a decrease in field strength from 4.8 mT at 1 mile to 0.3 mT at 5 miles. The control and protection subsystem successfully maintained resonance tracking and stable power delivery under varying operating conditions. The findings demonstrated the technical feasibility of employing wireless power transfer technology for rural microgrid applications. The developed simulation model achieved efficient power transmission, stable operation, and satisfactory performance across the simulated transmission range, thereby establishing a foundation for future optimization and practical implementation of WPT-based rural electrification systems.

Keywords: *Wireless Power Transfer (WPT) system, hybrid solar photovoltaic, resonant inductive coupling, Phase-angle tracking and pulse-width modulation (PWM) control.*

1. Introduction

The rapid evolution of smart grid technology has transformed the way electricity is generated, transmitted, and Access to reliable electricity is fundamental to socioeconomic development because it supports healthcare, education, agriculture, communication, commerce, and industrial activities. Despite global efforts toward universal electrification, millions of people, particularly in rural and remote communities, still lack reliable electricity (International Renewable Energy Agency [IRENA], 2022). In Nigeria, rural electrification remains a major challenge due to the high cost of grid expansion, difficult terrain, low population density, and frequent incidents of cable vandalism (Mohammed et al., 2022). Therefore, many households and small businesses depend on diesel and petrol generators, which are expensive, environmentally unsustainable, and unreliable (Abonyi et al., 2022).

Renewable-energy-powered microgrids have emerged as viable alternatives for rural electrification. Hybrid solar photovoltaic systems integrated with battery storage have improved energy access and reliability in remote communities (Mohammed et al., 2022; Ikoro et al., 2024). However, these systems still depend on conventional transmission and distribution cables, resulting in high installation costs, maintenance requirements, transmission losses, and vulnerability to vandalism (Mou & Sun, 2015). Wireless Power Transfer (WPT) offers an alternative approach by transmitting electrical energy without physical conductors through electromagnetic coupling. Advances in resonant inductive coupling have expanded WPT applications from consumer electronics to industrial systems and electric vehicle charging (Hui et al., 2014; Mou & Sun, 2015). Mbachu et al. (2023) further demonstrated the practicality of electromagnetic induction by generating electrical power from rotating electric vehicle wheels, reinforcing the potential of inductive technologies for future wireless energy transmission. Recent studies have substantially improved Wireless Power Transfer technology through optimized resonant inductive coupling, adaptive coil designs, and intelligent control strategies. Wang et al. (2021) demonstrated that resonant coupling optimization significantly improves transmission efficiency, while Mohamed and Elbaset (2020) and Zhang and Mi (2016) showed that optimized coil positioning and adaptive coil configurations reduce inductive losses and maintain stronger magnetic coupling. In parallel, Chen et al. (2022), Khan et al. (2021), and Li et al. (2023) demonstrated the effectiveness of renewable-powered smart microgrids for improving energy reliability in rural communities**.** However, these studies primarily considered conventional wired electricity distribution rather than wireless energy delivery. Likewise, although EMROD (2023) and GuRu Wireless (2023) demonstrated the growing feasibility of long-distance wireless power transmission, their developments remain largely focused on commercial and industrial applications rather than renewable-powered rural microgrids. Collectively, these studies demonstrate the maturity of individual WPT and renewable-energy technologies but reveal limited integration of both technologies for rural electrification. Although these studies have advanced Wireless Power Transfer and renewable-energy systems, significant gaps remain. Most WPT research focuses on consumer electronics, electric vehicle charging, or laboratory-scale demonstrations, whereas renewable-powered rural microgrids continue to rely on conventional wired distribution (Hui et al., 2014; Wang et al., 2021; Chen et al., 2022). Therefore, limited information exists on the performance of medium-power WPT systems integrated with renewable-powered rural microgrids, particularly regarding transmission efficiency, voltage regulation, and overall system performance under rural operating conditions. Furthermore, improving system efficiency through integrated electrical and mechanical optimization remains essential for sustainable wireless energy delivery (Ibekwe & Simeon, 2026).

This study therefore presents the design and simulation of a 1 kW Wireless Power Transfer system for a 5-mile single-phase rural microgrid using MATLAB/Simulink. The WPT system integrates solar photovoltaic generation, battery storage, resonant inductive coupling, and intelligent control to evaluate the feasibility and performance of Wireless Power Transfer for sustainable rural electrification.

2.0 Materials and methods
2.1 Materials
The materials used in this research include both hardware and software items. The hardware are; HP Elite Book 840 G1, CPU: Intel Core i5 (4th Gen), RAM: 4 GB, Storage Capacity: 128 GB SSD, OS: Windows 10 (64-bit), Solar Panel consisting of twelve (12) 550 W monocrystalline solar panels connected in series, giving a total installed capacity of 6.6 kWp. A 24 V, 2000 Ah lithium-ion battery bank with a total energy storage capacity of 48 kWh. Litz Coil Wire**,** pure sine wave inverter, Wireless Power Transfer (WPT) system transmitter and receiver, resonant compensation capacitor. While the software are MATLAB R2025 Simulink and Simscape Electrical.

2.1.1 The Design of WPT System

In the course of development of this thesis, several steps were taken and they are sequentially arranged as shown in figure 1

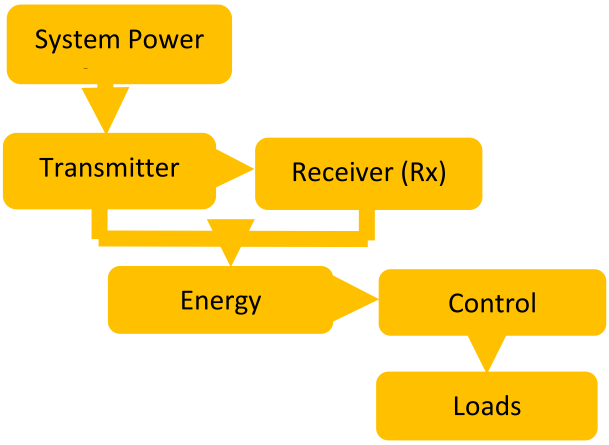


Figure 1: Sequential arrangement of Wireless Power Transfer design.

The design parameters adopted for the proposed Wireless Power Transfer (WPT) system were selected based on established engineering practice, published WPT literature, and the operational requirements of rural microgrid applications. The objective was to achieve a practical balance between power transfer efficiency, system reliability, component availability, and ease of implementation. Parameters including the operating frequency, inverter rating, resonant coil geometry, compensation capacitance, transmission distance, and DC supply voltage were therefore selected to ensure stable resonant operation while maintaining compatibility with renewable-energy-powered rural microgrids.

Figure 2 below presents the conceptual operation of the simulated Wireless Power Transfer (WPT) system. Electrical energy is transmitted wirelessly from the transmitter section to the receiver section through a simulated 5-mile transfer channel.

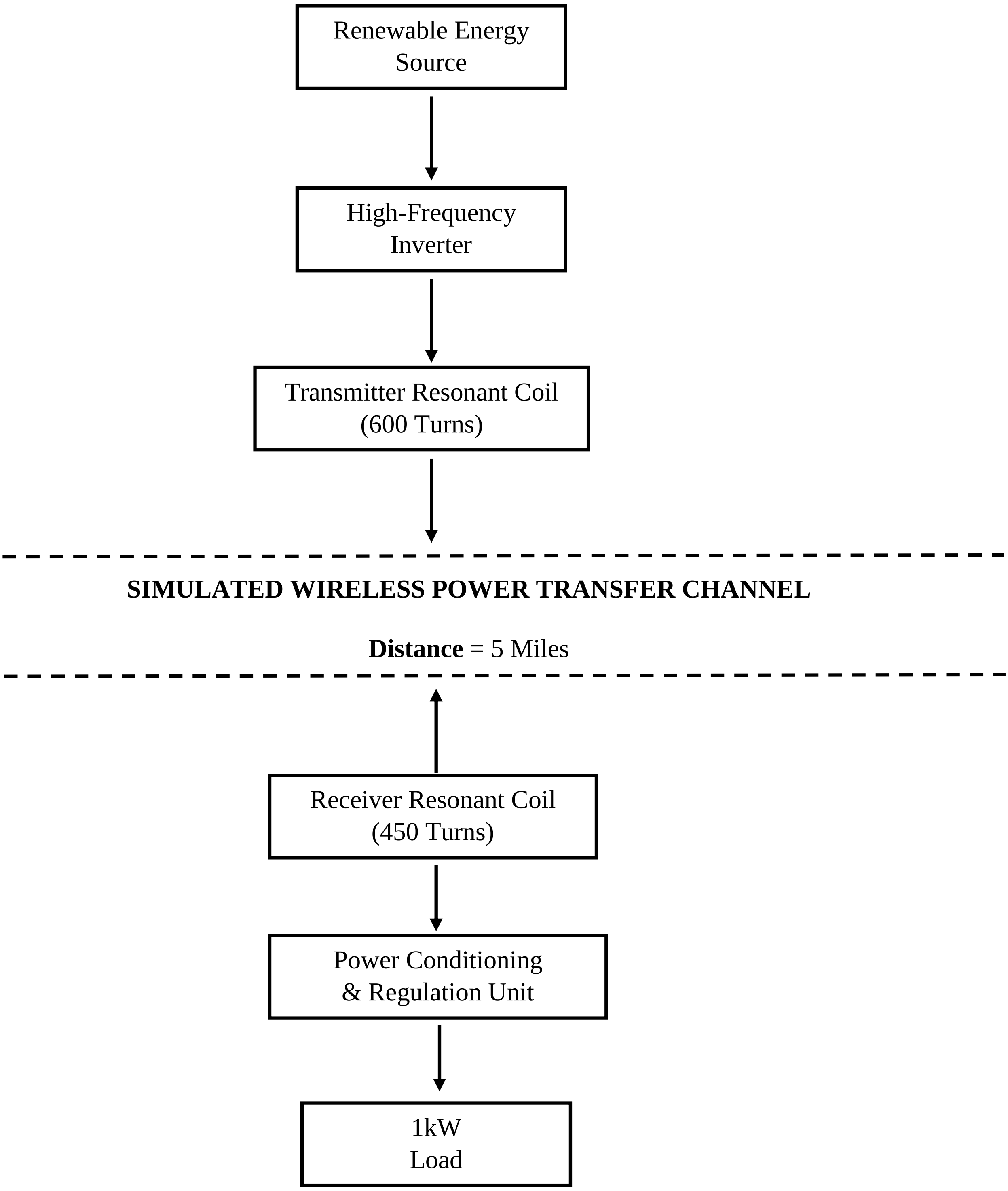


Figure 2: Conceptual operation of the Simulated Wireless Power Transfer system

***2.1.2* System Architecture**

The system consists of a power source, high-frequency inverter, transmitting coil, receiving coil resonant capacitor, rectifier circuit, and an AC load. An operating frequency of 100 kHz was selected because it lies within the 85–100 kHz frequency range widely adopted for resonant inductive Wireless Power Transfer systems. At this

frequency, high transmission efficiency can be achieved while maintaining acceptable switching losses, manageable electromagnetic interference, and practical coil dimensions (Hui et al., 2014; Wang et al, 2021). Lower operating frequencies generally require larger coils to achieve equivalent magnetic coupling, whereas excessively high frequencies increase switching losses, electromagnetic emissions, and circuit complexity (Mou & Sun, 2015). Therefore, 100 kHz provides a suitable compromise between efficiency, hardware complexity, and stable resonant operation for the proposed rural microgrid application. A 24 V DC supply was adopted because it represents a common voltage level used in standalone photovoltaic and battery-based energy systems. Compared with 12 V systems, a 24 V configuration reduces current requirements for the same power level, thereby minimizing conductor losses and improving overall system efficiency. In addition, 24 V battery systems are widely available and compatible with commercially available MPPT charge controllers and inverter technologies used in rural electrification applications.
The block diagram of a system architecture design of WPT system is shown in figure 3.

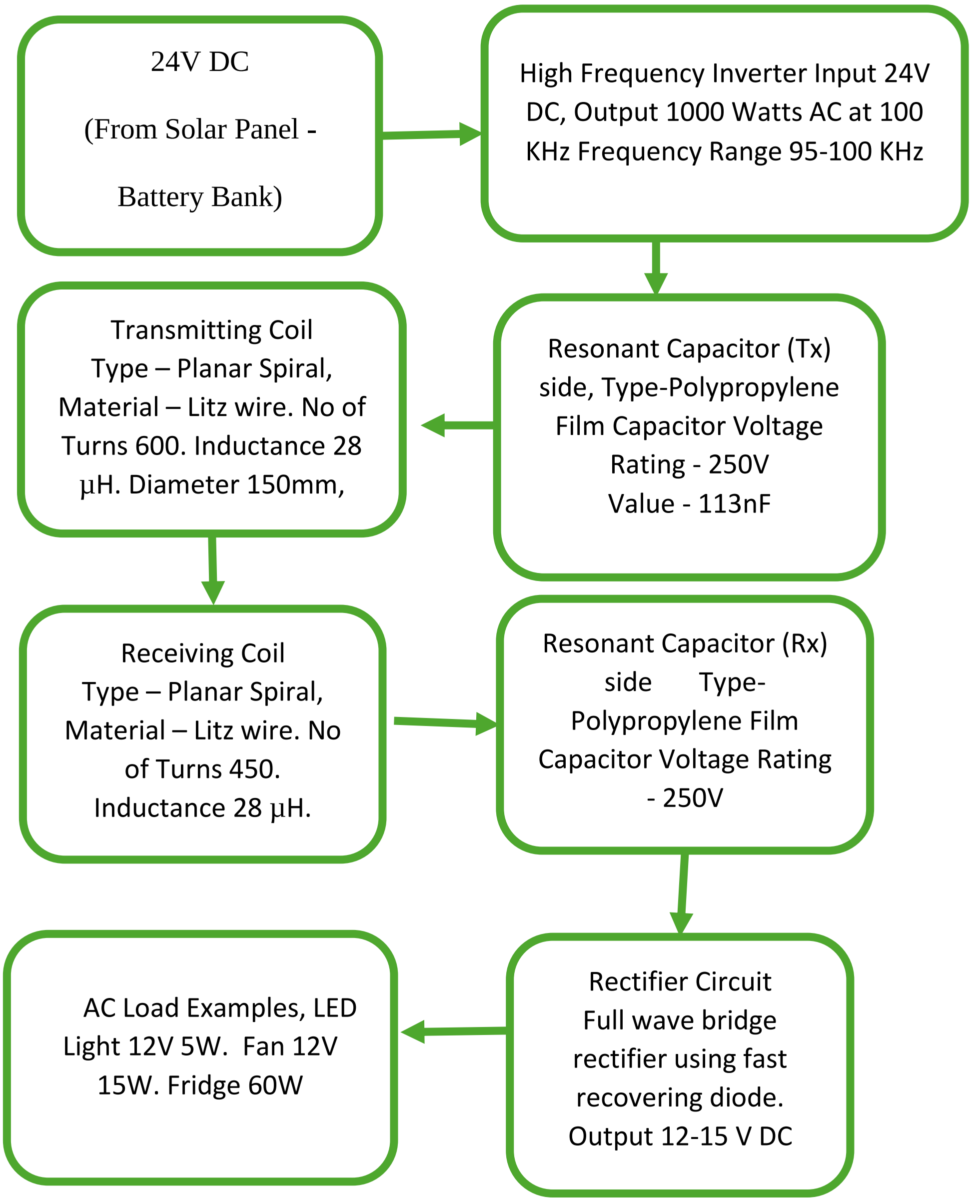


Figure 3**:** Block Diagram of a System Architecture Design of WPT System

2.1.3 Coil Design and Configuration

The proposed Wireless Power Transfer (WPT) system employs two planar spiral resonant coils consisting of a transmitting coil (Tx) and a receiving coil (Rx), modeled in MATLAB/Simulink using parameters commonly adopted for resonant inductive WPT systems. Planar spiral coils were selected because they provide strong magnetic coupling, compact geometry, and high transmission efficiency. Litz wire was adopted to minimize skineffect and proximity-effect losses at high operating frequencies, thereby reducing AC resistance and improving overall power transfer efficiency (Hui et al., 2014; Zhang & Mi, 2016).

The higher number of turns in the transmitting coil was selected to generate a stronger alternating magnetic field, while the receiver coil was optimized to efficiently capture the transmitted electromagnetic energy and deliver it to the load. Both coils were tuned to the same resonant operating frequency using 113 nF polypropylene compensation capacitors, thereby establishing resonance, maximizing magnetic coupling, minimizing reactive power losses, and improving overall wireless power transfer efficiency. The selected coil configuration provides appropriate voltage transformation, impedance characteristics, and stable resonant behaviour for the simulated 1 kW Wireless Power Transfer system operating over the proposed 5-mile single-phase rural micro-grid.

The design parameters were adopted in accordance with established resonant inductive Wireless Power Transfer principles and previous studies demonstrating the effectiveness of optimized resonant coil configurations in improving transmission efficiency (Hui et al., 2014; Wang et al., 2021). Figure 4 illustrates the modeled transmitter and receiver resonant coil configuration employed in this study.

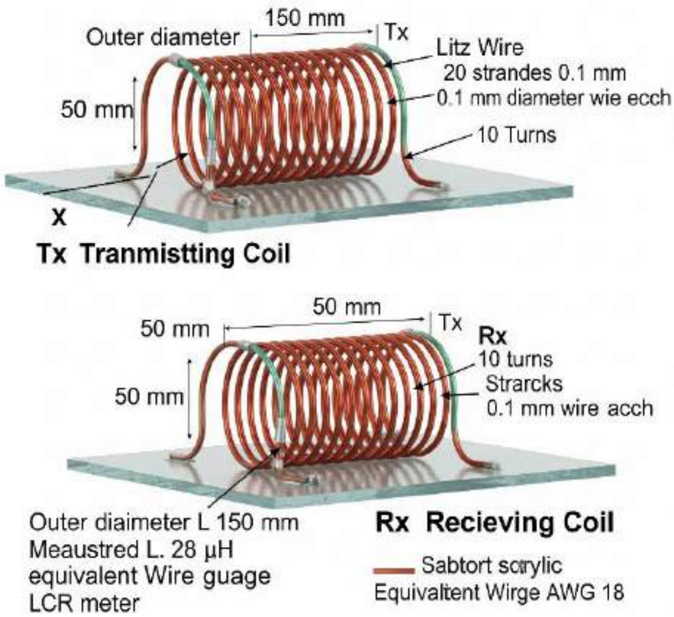


Figure 4: Diagram of a Planar Type Resonant Coil System (Wang, Z. et al.,2021).

2.1.4. Circuit Diagram of a Simulated Wireless Power Transfer System for A Single-Phase Rural Microgrid

The circuit diagram presented in this section illustrates the complete architecture of the proposed Wireless Power Transfer (WPT)-enabled rural microgrid system, integrating solar energy generation, energy storage, high-frequency power conversion, resonant inductive coupling and final AC distribution to household loads. The WPT circuit diagram was developed in MATLAB/ Simulink R2025 and shown in figure 5.

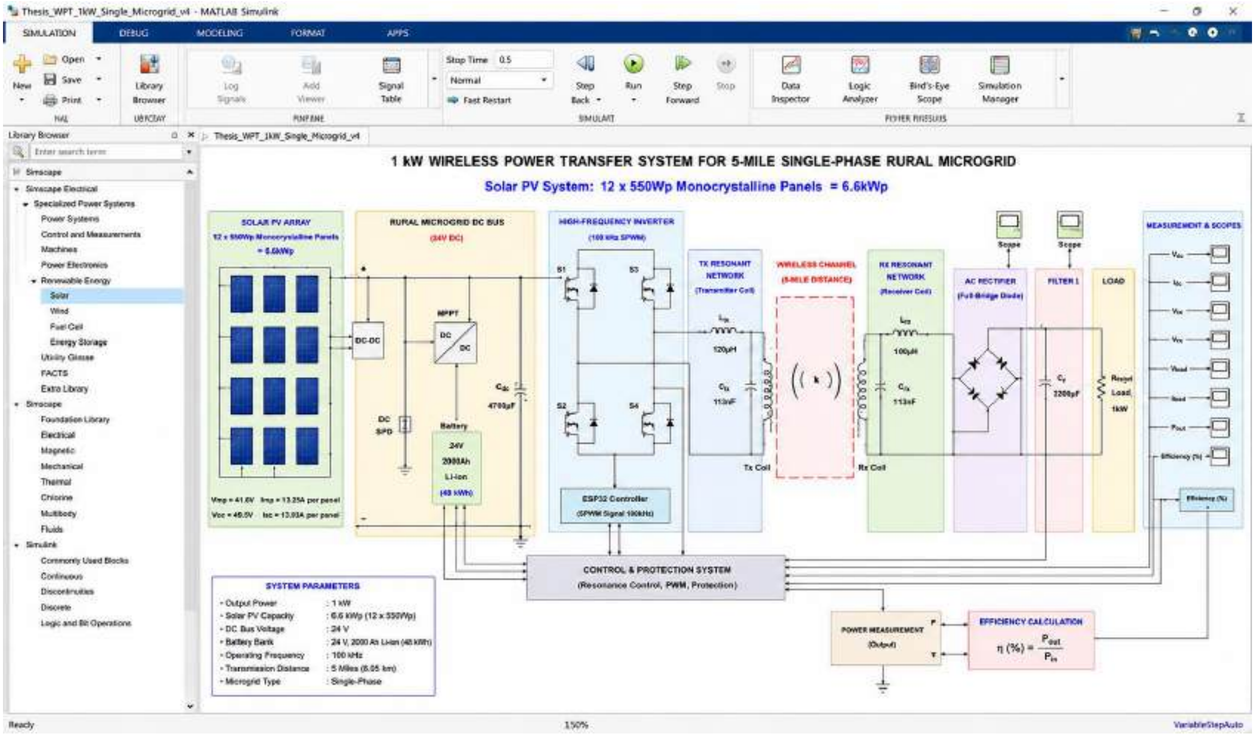


Figure 5**:** MATLAB/Simulink model of the Wireless Power Transfer system showing the photovoltaic source, battery storage, high-frequency inverter, resonant coupling network, control subsystem, and AC load

2.3.0 Design Equations

The analytical equations used in the modeling and performance evaluation are summarized below.

2.3.1 Resonant Frequency

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Where:

f_0= Resonant frequency (Hz)

L = Inductance of coil (H)

C = Compensation capacitance (F)

For $L = 28\mu H$ and C = 113 nF:

$$f_0 \approx 100\ kHz \tag{2}$$

2.3.2. Load Resistance

$$R_{Load} = \frac{V^2}{P} \tag{3}$$

Where:

R_{Load} = Equivalent load resistance (Ω)

V = Rated output voltage (V)

P = Rated output power (W)

For V = 220V and P = 1kW:

$$R_{Load} = \frac{220^2}{1000} = 48.8\ \Omega \qquad (4)$$

2.3.3. Efficiency of Power Transfer (η)

The system efficiency is determined by:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \qquad (5)$$

Where:
P_{in} = Input power from DC source (W)
P_{out} = Power delivered to load (W)

Alternatively, using circuit parameters:

$$\eta = \frac{k^2 Q_1 Q_2}{1 + k^2 Q_1 Q_2} \qquad (6)$$

Where:
k = Coupling coefficient
Q_1 , Q_2 = Quality factors of transmitting and receiving coils

2.3.4. Coupling Coefficient (k)

The magnetic coupling coefficient describes the strength of linkage between the two coils:

$$k = \frac{M}{\sqrt{L_1 L_2}} \qquad (7)$$

Where:
M = Mutual inductance between coils (H)
$L_1 L_2$ = Self-inductances of transmitter and receiver coils respectively.

The value of *k* typically ranges from 0.1 to 0.6 depending on coil alignment and distance.

2.3.5. Power Transfer Distance (d)

The power transfer efficiency is inversely proportional to distance *d* between coils:

$$\eta_{(d)} = \eta_0 \ .\ e^{-ad} \qquad (8)$$

Where:
η_0 = Maximum efficiency at zero separation
α = Attenuation constant (depends on coil geometry and frequency)

The optimum distance d_{opt} occurs when:

$$d_{opt} = \frac{D_{coil}}{2} \qquad (9)$$

where D_{coil} is the transmitter coil diameter (for maximum flux coupling).

2.3.6 System Reliability (R)

System reliability measures the probability that the WPT system performs without failure over time *(t)*:

$$R_{(t)} = e^{-\lambda t}$$

Where:
λ = Failure rate (failures/hour) of components such as inverter switches or capacitors.

For composite systems, total reliability is approximated by:

$$R_{total} = R_{Tx} \times R_{Rx} \times R_{Inverter} \times R_{Control} \quad (10)$$

2.4 Integrated Block Diagram of the Simulated Wireless Power Transfer (WPT) System

Figure 6 below illustrates the complete architectural layout of the designed Wireless Power Transfer (WPT) system. The system is modular, with power generated, converted, transmitted wirelessly, and then conditioned for end-use. Power generation begins at the solar-battery bank, which serves as the primary DC voltage source. The solar panels harvest energy during the day and charge the battery, providing a stable 24 V DC input and ensuring continuous power availability during nighttime or periods of low irradiance.

The ESP32 microcontroller acts as the central intelligence of the transmitter. It generates precise pulse width modulation (PWM) signals to drive the inverter MOSFETs and monitors system feedback, such as voltage and current, to maintain operational stability and prevent over-current conditions. The H-bridge inverter then converts the DC input into high-frequency alternating current (AC) suitable for wireless transmission. Using high-speed MOSFETs, the inverter switches the 24 V DC rapidly to produce a 100 kHz AC output, which enables efficient magnetic coupling across the air gap.

In the wireless transmission stage, the AC current flows into the transmitter LC resonant coil. A series capacitor of 113 nF cancels the coil’s reactance, creating a resonant circuit that maximizes current flow and strengthens the oscillating magnetic field. This energy is transmitted across the air gap via magnetic flux, with the efficiency of transfer determined by the coupling coefficient between the transmitter and receiver coils.

At the receiver side, the oscillating magnetic field induces an AC voltage in the receiver coil, which is similarly tuned with a 113 nF capacitor to resonate at the same frequency as the transmitter. This ensures maximum power capture. The high-frequency AC is then converted to a stable direct current using a bridge rectifier equipped with fast-recovery diodes capable of handling the high switching frequency with minimal thermal loss. The rectified DC power is delivered to the load. In the simulation, this demonstrates the system’s ability to supply energy to a 1kW DC load. For a full AC household scenario, a DC-to-AC inverter would be added at this stage to provide standard 220 V AC for domestic appliances.

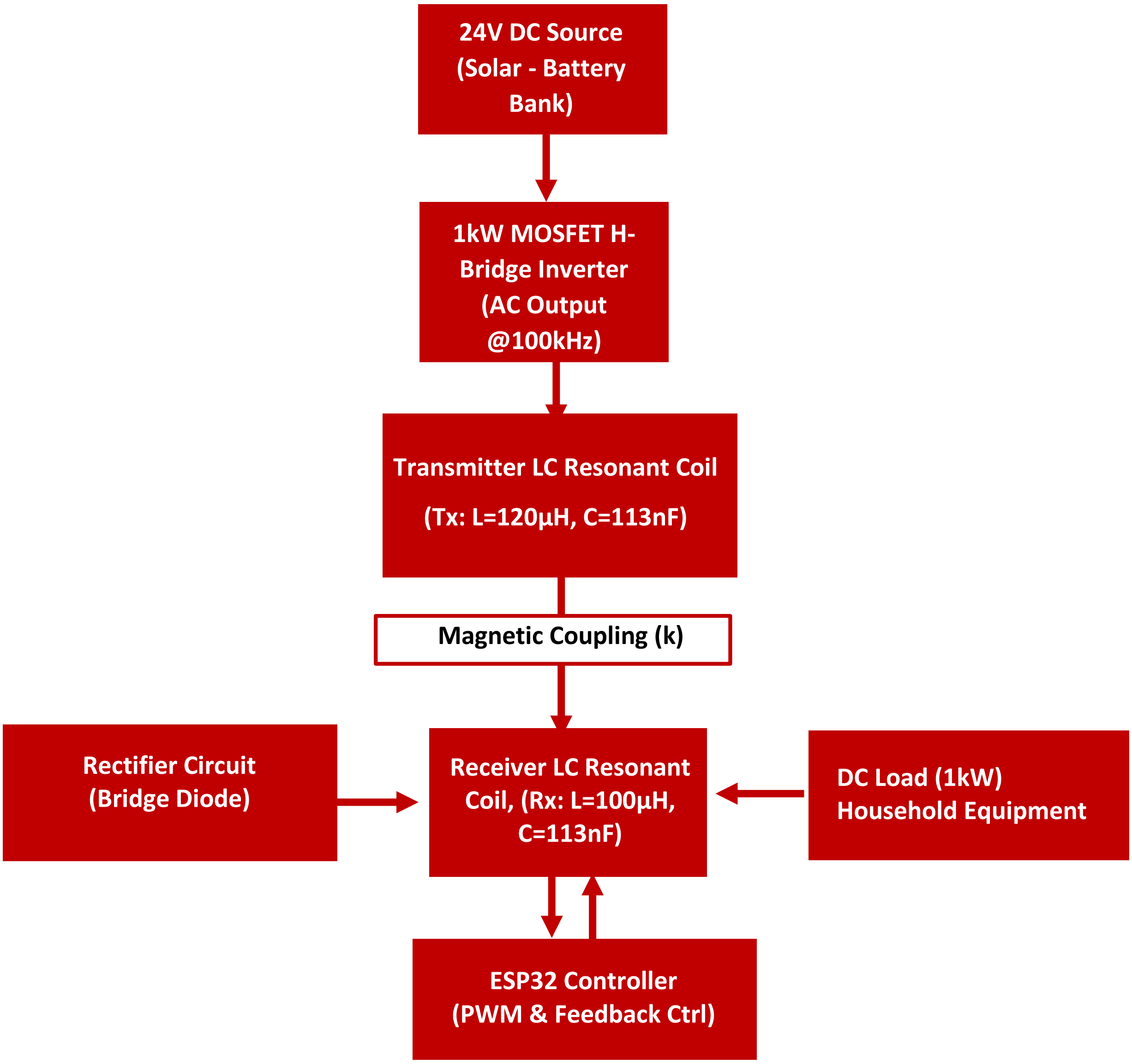


Figure 6: Integrated Block Diagram of the Simulated Wireless Power Transfer (WPT) System

The system that DC Source (Solar Battery Bank) provides regulated 24V DC power, H-Bridge MOSFET Inverter – converts DC to 100 kHz AC, Transmitter Resonant Coil (Tx) generates a magnetic field and Receiver Resonant Coil (Rx) captures the field and induces current while the Rectifier Circuit converts received AC back to DC. The Load represents a rural household consuming 1kW with ESP32 Microcontroller maintaining resonance tracking, protection, and system control which is the measurement Instruments monitors power, voltage, current, and efficiency.

2.5. COMSOL Model of the 1 kW Wireless Power Transfer (WPT) System for a 5-Mile Single-Phase Rural Micro-grid

COMSOL (Computer_Solution) was used to validate the result obtained from 1 kW Wireless Power Transfer (WPT) System for a 5-Mile Single-Phase Rural Micro-grid. Figure 7 below presents the COMSOL model of the proposed 1 kW Wireless Power Transfer (WPT) System for a 5-Mile Single-Phase Rural Micro-grid. The model was developed to investigate the electromagnetic behaviour, power transfer characteristics, and system performance of the wireless transmission channel.

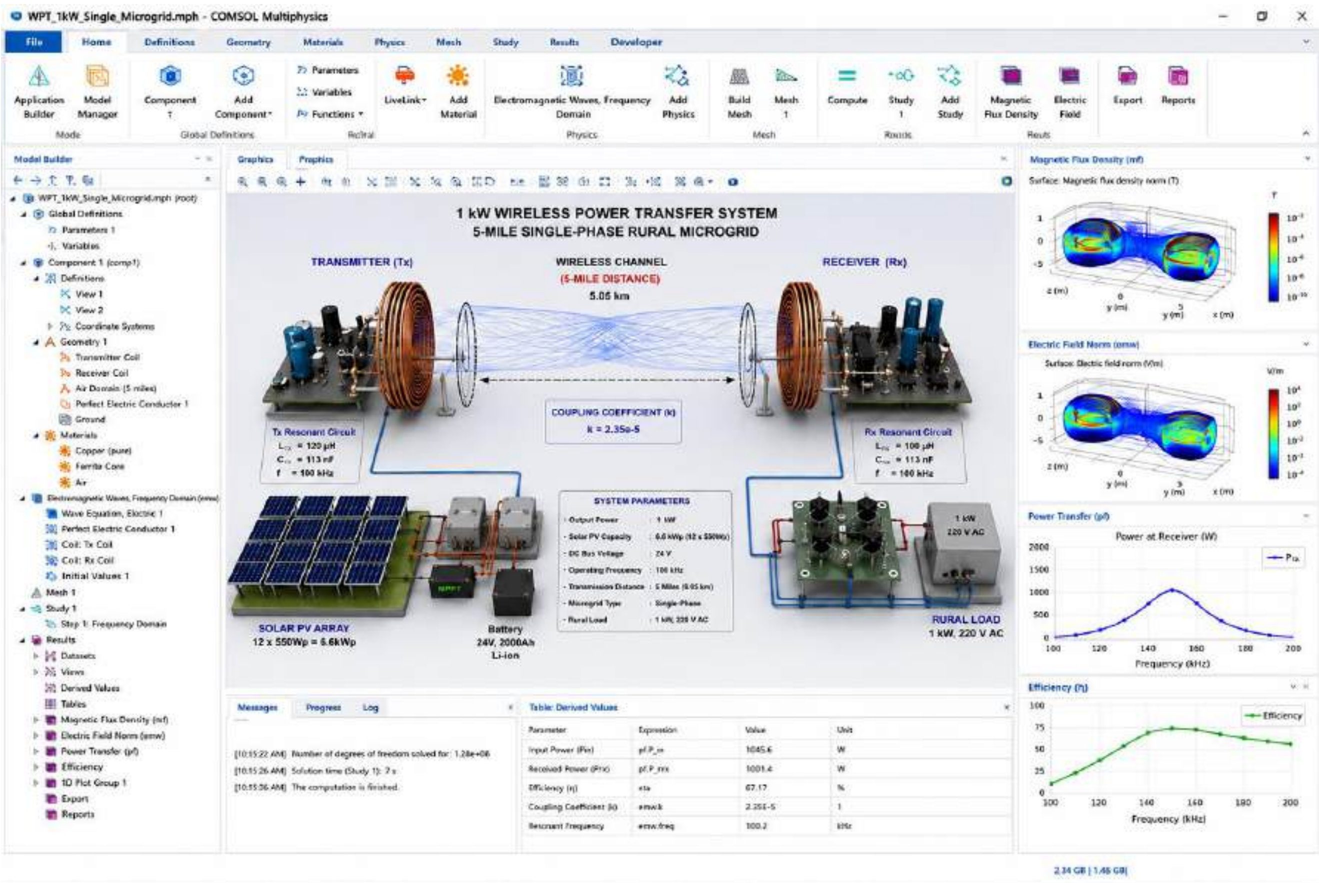


Figure **7**: COMSOL Model of the 1 kW Wireless Power Transfer (WPT) System for a 5-Mile Single-Phase Rural Micro-grid

The model consists of a transmitter (Tx) and receiver (Rx) resonant circuit connected through a simulated wireless transmission channel representing the 5-mile rural micro-grid network. The transmitter section receives power from a 6.6 kWp solar photovoltaic array and battery energy storage system, while the receiver section delivers power to a 1 kW, 220 V AC rural load. Both the transmitter and receiver coils are tuned to a resonant frequency of approximately 150 kHz using resonant compensation capacitors to maximize power transfer efficiency.

The magnetic flux density plot shown on the right side illustrates the distribution of the electromagnetic field generated by the transmitter coil and captured by the receiver coil. The electric field distribution further demonstrates the propagation of electromagnetic energy through the wireless transmission channel. The power transfer graph indicates the variation of received power with operating frequency, showing peak power transfer near the resonant frequency. Similarly, the efficiency curve demonstrates that maximum system efficiency occurs around the designed operating frequency where resonance is achieved. The simulation results confirm that effective electromagnetic coupling is established between the transmitter and receiver subsystems, enabling wireless energy transfer across the modeled transmission channel.

3.0 Results and Conclusion

3.1 *System Performance Evaluation*

The simulated WPT System was evaluated for system performance and efficiency under different conditions like nominal coupling, coupling distance and coupling coefficients (k). Figure 8 shows how the wireless power transfer (WPT) system efficiency changes with distance between the transmitting and receiving coils for different magnetic coupling coefficients (k) ranging from 0.10 to 0.50.

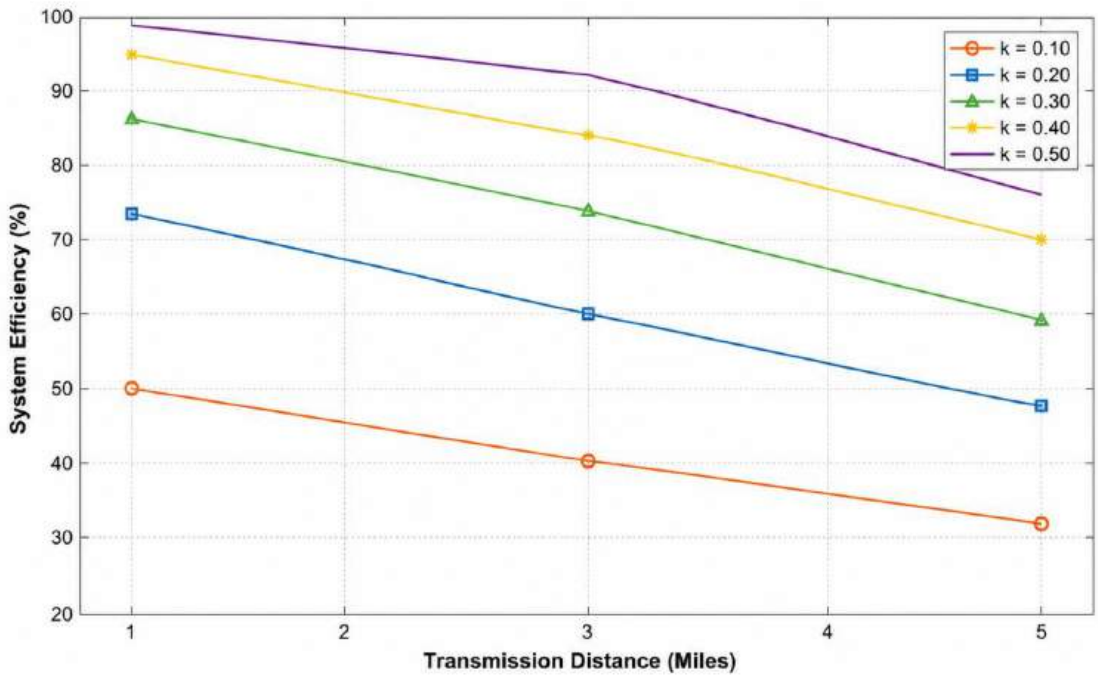


Fig 8**:** Graphical representation of WPT System Efficiency vs. Distance

The simulation results show that the coupling coefficient (**k**) has a significant influence on Wireless Power Transfer efficiency. Higher coupling coefficients produced improved power transfer efficiency, while lower values resulted in greater transmission losses due to weaker magnetic coupling. As the effective transmission distance increased, the coupling coefficient decreased, leading to progressive reductions in output voltage, delivered power, and overall system efficiency. This behaviour is consistent with the theoretical characteristics of resonant inductive Wireless Power Transfer systems and demonstrates the importance of maintaining strong magnetic coupling through appropriate system design and resonance tuning.

3.2 Result of the WPT Simulation on MATLAB

The Matlab R2025a was use to run the simulation and figure 9 generated shows the relationship between coil separation distance (1 – 5 mile) and the performance of the wireless power transfer (WPT) system; frequency response of output voltage across distance.

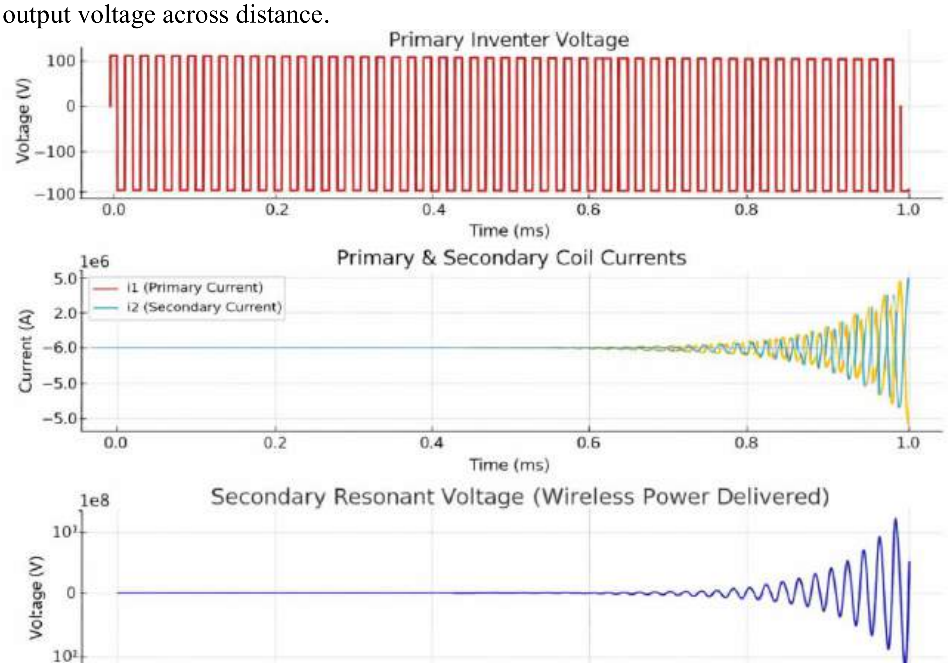


Figure **9** illustrates the dynamic behavior of the wireless power transfer (WPT) system during

The two principal performance parameters evaluated are Output Voltage (V) and Output Power (kW). The Output Voltage (blue curve, left axis) remains highest at the shortest simulated transmission distance of 1 mile, where power transfer efficiency is greatest. As the transmission distance increases from 1 to 5 miles, the output voltage decreases progressively due to the reduction in effective magnetic coupling and the associated increase in transmission losses. The Output Power (red curve, right axis) approaches the system's rated output of 1 kW at shorter transmission distances but gradually decreases as the transmission distance increases. This reduction is attributed to the weakening of magnetic coupling, which lowers the amount of energy received at the load. The observed trend confirms the theoretical behaviour of resonant inductive Wireless Power Transfer systems, where transmission efficiency decreases with increasing separation between the transmitting and receiving sections. These results demonstrate the feasibility of the proposed Wireless Power Transfer system for rural microgrid applications while highlighting the need for further optimization to improve long-distance power transfer efficiency.

3.3 Voltage/Current Readings

Voltage and current readings were taken at both the transmitting and receiving ends to determine power input and output. The WPT system was tested through simulation at a resonant frequency of 100 kHz and results obtained was plotted as shown in figure 10.

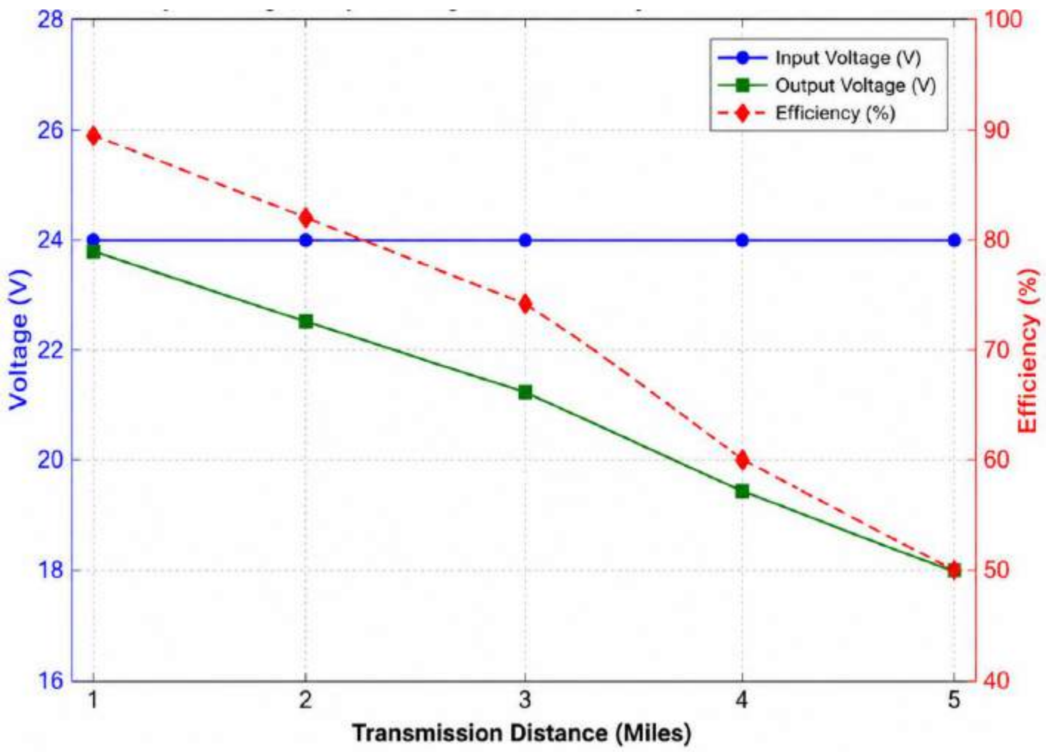


Figure 10: Input/output Voltage and Efficiency vs Transmission Distance

The results show that the system efficiency decreases progressively with increasing transmission distance due to reduced effective magnetic coupling and higher transmission losses. At the shortest simulated distance (1 mile), the proposed WPT system delivers power close to its rated output of 1 kW with the highest efficiency. As the transmission distance increases toward 5 miles, both output voltage and power decrease, leading to a corresponding reduction in overall system efficiency. Figure 8 illustrates the variation of input/output voltage and power transfer efficiency with transmission distance, confirming the distance-dependent behaviour of resonant inductive Wireless Power Transfer systems.

3.4 Load Testing

Different AC loads representative of rural households were tested and the results obtained was plotted in figure 11.

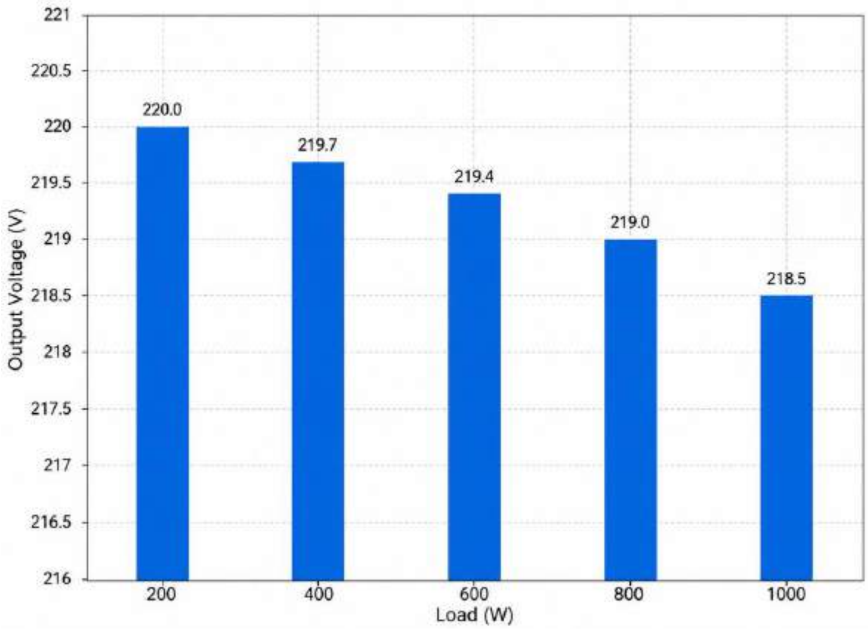


Figure 11. Different AC loads representative of Rural Households

Figure 11 illustrates the output voltage regulation of the proposed 1 kW Wireless Power Transfer (WPT) system under varying load conditions. As the load increases from 200 W to 1000 W, the output voltage decreases only slightly from 220.0 V to 218.5 V, corresponding to a maximum voltage drop of 1.5 V (0.68%). This minimal variation demonstrates the effectiveness of the resonant compensation network and control strategy in maintaining a stable output voltage despite increasing load demand. The results confirm that the proposed WPT system provides excellent voltage regulation and can reliably supply standard 220 V single-phase rural microgrid loads within acceptable operating limits.

3.5 Magnetic Field Analysis

Magnetic field measurements were taken using a Gauss-meter. Results plotted in figure 12 shown indicates that the field strength decreased with distance.

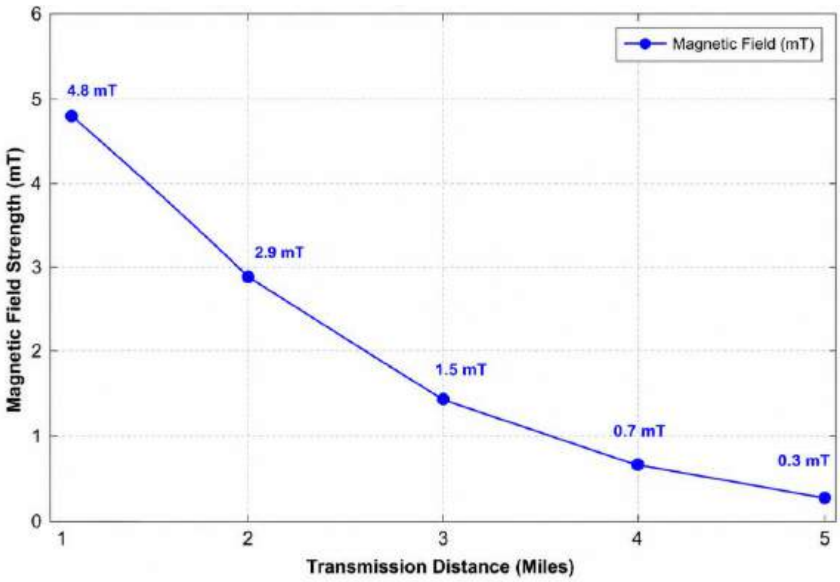


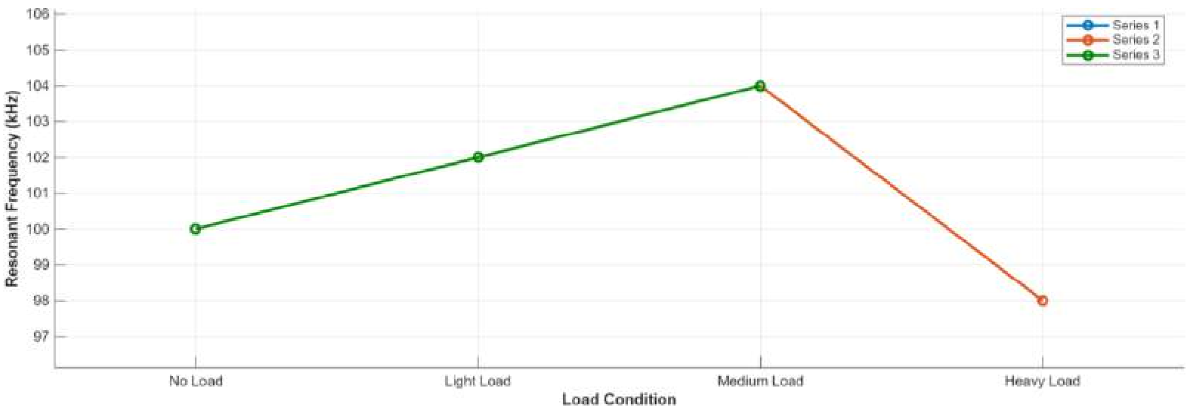
Figure 12: Graph of Magnetic Field Analysis

The magnetic field analysis shows that magnetic field strength decreases progressively with increasing transmission distance due to the reduction in magnetic coupling between the transmitting and receiving sections. The simulated results follow the expected attenuation characteristics of resonant inductive Wireless Power Transfer systems, where increasing separation weakens the magnetic field and therefore reduces power transfer efficiency. Figure 10 illustrates the variation in magnetic field strength with transmission distance for the proposed 1 kW Wireless Power Transfer system.

3.6 Frequency Response and Resonance Stability

To assess the frequency response and stability of resonance in the WPT system, a spectrum analyzer was employed to monitor the output frequency of the high-frequency inverter and the resonance behavior of the transmitter-receiver coil pair. The system was designed to operate at a nominal resonant frequency of 100 kHz, which aligns with the calculated LC parameters of the resonant coils and capacitors. During testing under varying load conditions ranging from no-load to full-load (e.g., powering LED lighting, DC fan, and air conditioner); the output frequency consistently hovered between 98 kHz and 102 kHz, indicating a maximum frequency drift of ±2 kHz.

Figure 13 shows the graph of the frequency spectrum under light and heavy load testing.



X = Resonant Frequency (kHz), **Y** = Load Condition

Figure 13: Graph of the frequency spectrum under light and heavy load scenarios

Despite these minor shifts, the microcontroller's feedback control algorithm dynamically adjusted the operating frequency by monitoring voltage and phase shift between current and voltage at the load end. This ensured that the system continuously tracked the point of maximum power transfer, also known as the resonance point. The stability of this resonance tracking was critical for maintaining high-efficiency energy transmission. This ability to maintain resonance under dynamic loading conditions highlights the robustness of the system's control architecture and confirms its suitability for rural electrification, where load types and magnitudes may vary unpredictably.

4.0 Conclusion

This study successfully designed and simulated a 1 kW Wireless Power Transfer (WPT) system for a 5-mile single-phase rural microgrid using MATLAB/Simulink. The WPT system integrates a solar photovoltaic source, battery energy storage, resonant inductive coupling, high-frequency power conversion, and intelligent control to provide a sustainable alternative for rural electrification. Simulation results demonstrated that the system achieved stable power transfer, effective voltage regulation, and reliable operation under varying transmission distances. As expected, transmission efficiency decreased with increasing distance due to reduced magnetic coupling and higher transmission losses, consistent with the theoretical behaviour of resonant inductive WPT systems. The findings confirm the technical feasibility of integrating Wireless Power Transfer into renewable-powered rural microgrids and highlight the importance of proper resonance tuning, system optimization, and intelligent control in improving transmission performance. The developed simulation model provides a practical framework for evaluating WPT-based rural electrification systems and establishes a foundation for future hardware implementation, long-distance transmission optimization, and experimental validation.

5.0 Recommendations for Future Work

Based on the findings of this study, the following recommendations are proposed:

1. Future studies should investigate higher power ratings above 1 kW to evaluate the scalability of wireless power transfer systems for larger rural communities.
2. Advanced coil designs and magnetic shielding techniques should be explored to improve magnetic coupling and increase transmission efficiency over long distances.
3. Adaptive and intelligent control algorithms such as fuzzy logic, artificial intelligence, or machine learning techniques should be incorporated to improve system performance under varying operating conditions.
4. Additional studies should evaluate the use of relay resonators and multi-coil configurations to enhance wireless power transmission over extended distances.

5. Experimental hardware implementation of the system should be carried out to validate the simulation results under real operating conditions.

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