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Performance Evaluation and Optimization of Inductive Wireless Power Transfer System for Smartphone Charging Using MATLAB/Simulink

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Abstract
The increasing dependence on smartphones and portable electronic devices has created the need for efficient, convenient, and reliable charging technologies. Conventional wired charging systems are associated with limitations such as cable damage, charging port deterioration, inconvenience, and reduced user flexibility. This research presents the performance evaluation and optimization of an inductive wireless power transfer (WPT) system for smartphone charging using MATLAB/Simulink simulation. The proposed system employs magnetic inductive coupling between transmitter and receiver coils to transfer electrical energy across an air gap without physical connection. A mathematical model of the loosely coupled transformer system was developed considering mutual inductance, coupling coefficient, coil resistance, and resonant operating conditions. The effects of coil turns, separation distance, and coupling coefficient on the transferred voltage, current, and efficiency were investigated. Simulation results demonstrate that improved coil configuration and optimized coupling conditions significantly enhance power transfer performance. The developed model achieved effective wireless energy transfer suitable for low-power smartphone charging applications. The study provides useful design considerations for improving the efficiency and reliability of inductive wireless charging systems.
Keywords: *Wireless power transfer, inductive coupling, smartphone charging, MATLAB/Simulink, mutual inductance, coupling coefficient, optimization.*

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I. Introduction

1.1 Background of the Study

The rapid advancement of portable electronic devices, particularly smartphones, has increased the demand for reliable, efficient, and convenient charging technologies. Modern smartphones support several energy-intensive applications such as multimedia services, internet connectivity, navigation, and artificial intelligence-based applications, which have significantly increased battery consumption. As a result, frequent charging has become a major concern, creating the need for improved charging solutions beyond conventional wired charging systems.

Traditional wired charging methods require direct physical connection between the power source and the electronic device. Although widely used, these systems experience limitations such as cable damage, deterioration of charging ports, inconvenience during operation, and reduced user flexibility. Wireless power transfer (WPT) technology has emerged as a promising alternative by enabling electrical energy transfer without direct electrical contact between the charger and the device. Recent developments in wireless charging have demonstrated its potential in consumer electronics, electric vehicles, medical implants, and other low-power electronic applications due to its improved convenience and reliability (Ahmed et al., 2020).

Wireless power transfer systems operate based on electromagnetic energy transfer principles, where electrical energy is converted into magnetic or electromagnetic fields and transferred through space to a receiving device. Among the available WPT techniques, including microwave, radio-frequency, capacitive, and inductive methods, inductive wireless power transfer remains the most widely adopted approach for smartphone charging because of its safety, compact design, and relatively high efficiency over short distances. The technology utilizes coupled transmitter and receiver coils, where an alternating current in the transmitting coil produces a magnetic field that induces voltage in the receiving coil for battery charging applications (Zhang et al., 2020).

Recent research has focused on improving the efficiency, power density, and reliability of wireless charging systems through optimization of coil design, compensation networks, operating frequency, and coupling conditions. Wireless power transfer performance is strongly influenced by parameters such as mutual inductance, coupling coefficient, coil geometry, and separation distance between the transmitter and receiver

coils. Therefore, proper modelling and optimization of these parameters are essential for achieving efficient energy transfer suitable for smartphone charging applications (Ahmad et al., 2023).

Despite significant progress, challenges such as power losses, reduced efficiency at increased coil separation, and sensitivity to coil misalignment continue to limit wireless charging performance. Consequently, simulation-based analysis using tools such as MATLAB/Simulink provides an effective approach for evaluating system behaviour, optimizing design parameters, and predicting performance before practical implementation.

This study presents the performance evaluation and optimization of an inductive wireless power transfer system for smartphone charging using MATLAB/Simulink. The research develops a wireless charging model based on inductive coupling principles and investigates the effects of coil parameters and operating conditions on voltage transfer, charging current, and overall system efficiency.

1.2 Problem Statement

Although wireless charging technology has improved significantly, several challenges still limit its widespread application, including:

a. Low power transfer efficiency
b. Reduction in output power with increased coil separation
c. Poor coupling between transmitter and receiver coils
d. Energy losses due to coil resistance
e. Longer charging time compared with wired chargers

Therefore, there is a need to evaluate and optimize an inductive wireless power transfer system capable of providing improved efficiency for smartphone charging applications.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this research is to evaluate and optimize an inductive wireless power transfer system for smartphone charging using MATLAB/Simulink.

1.3.2 Objectives

The objectives are to:

a. Develop a mathematical model of an inductive wireless power transfer system.
b. Design transmitter and receiver coil configurations suitable for smartphone charging.
c. Investigate the effect of coil parameters on wireless power transfer efficiency.
d. Simulate the proposed system using MATLAB/Simulink.
e. Analyze voltage, current, power transfer, and efficiency performance.
f. Determine optimum operating conditions for improved charging performance.

II. Literature Review

2.1 Inductive Wireless Power Transfer Technology

Wireless power transfer (WPT) has attracted significant research attention due to its ability to provide electrical energy without direct physical connections. Among the different WPT techniques, inductive power transfer (IPT) is considered one of the most practical approaches for short-range applications such as smartphone charging. The operating principle of inductive WPT is based on electromagnetic induction, where an alternating current supplied to the transmitter coil generates a varying magnetic field that induces an electrical voltage in the receiver coil. The transferred energy is then converted into regulated direct current for battery charging.

Li et al. (2021) investigated compensation techniques for inductive wireless power transfer systems and demonstrated that appropriate compensation network design can significantly improve system efficiency and voltage regulation. Their study showed that compensation structures such as LCC networks reduce reactive power losses and improve power delivery capability under different operating conditions.

The efficiency of inductive wireless power transfer systems depends largely on the magnetic coupling between the transmitter and receiver coils. Chen et al. (2021) examined the optimization of magnetic coupling structures and reported that coil arrangement, inductance values, and coupling coefficient have a significant influence on power transfer efficiency. The study emphasized that improving magnetic coupling is essential for reducing energy losses and achieving high-performance wireless charging systems.

2.2 Coil Design and Optimization for Wireless Charging

The design of transmitter and receiver coils plays a critical role in determining the performance of an inductive wireless power transfer system. Parameters such as coil diameter, number of turns, wire size, coil resistance, and operating frequency directly affect the induced voltage and transferred power.

Yao et al. (2021) analyzed the effect of coil parameters on magnetic resonance wireless power transfer efficiency. Their findings showed that optimized coil geometry improves magnetic flux linkage between the coils, resulting in increased output voltage and better energy transfer performance. The study highlighted that

proper selection of coil parameters is necessary to achieve an optimum balance between transfer distance and efficiency.

Wang et al. (2022) investigated design considerations for inductive power transfer systems with improved coupling coefficient. The researchers reported that a higher coupling coefficient increases mutual inductance between coils, thereby improving the amount of power transferred from the transmitter to the receiver. However, they also identified that coil misalignment and increased separation distance reduce coupling effectiveness and cause efficiency degradation.

Park et al. (2022) studied the optimization of coil geometry for wireless charging applications. Their research demonstrated that coil shape, size, and alignment significantly influence magnetic field distribution and charging performance. The study recommended optimized coil structures to minimize magnetic leakage and improve power transfer efficiency in portable electronic devices.

2.3 Efficiency Improvement in Inductive Wireless Power Transfer Systems

Improving efficiency remains one of the major challenges in wireless charging technology. Energy losses occur due to coil resistance, switching losses, leakage magnetic fields, and imperfect coupling between transmitter and receiver coils.

Zhang et al. (2022) proposed design methodologies for improving efficiency in wireless charging systems for portable electronic devices. Their study focused on optimizing system parameters including resonance frequency, coil configuration, and compensation networks. The results showed that optimized operating conditions significantly enhance power transfer efficiency and reduce unnecessary energy losses.

The development of efficient wireless charging systems requires accurate modelling and performance evaluation before practical implementation. Simulation tools such as MATLAB/Simulink provide an effective platform for analyzing electrical behaviour, testing different design parameters, and optimizing system performance. Through simulation-based optimization, researchers can evaluate the influence of coil distance, mutual inductance, coupling coefficient, and load conditions on charging efficiency.

From the reviewed studies, it is evident that inductive wireless power transfer performance is strongly dependent on coil optimization and coupling improvement. Therefore, this research focuses on the performance evaluation and optimization of an inductive wireless power transfer system for smartphone charging using MATLAB/Simulink by investigating coil parameters, charging current variation, output voltage, and system efficiency.

2.4 Wireless Power Transfer Technology

Wireless power transfer is the process of transmitting electrical energy from a source to a load without physical conductors. Different techniques include: 1. coupling Microwave power transfer,2. Radio frequency energy transfer, 3. Capacitive coupling, 4. Inductive coupling and Resonant magnetic.

Inductive coupling remains the most common technique for smartphone charging due to its safety and practical implementation.

2.5 Inductive Wireless Power Transfer Principle

The operation is based on Faraday's law of electromagnetic induction. An alternating current flowing through the transmitter coil produces a changing magnetic field. When the receiver coil is placed within this magnetic field, an induced voltage is generated, which is rectified and regulated for battery charging.

The system consists of: 1. AC/DC power supply,2. High-frequency inverter,3. Transmitter coil,4. Receiver coil, 5. Rectifier circuit, 6. Voltage regulator and Battery load.

III. Methodology

3.1 System Configuration

The proposed wireless charging system consists of two major sections:

Transmitter Side

AC Supply → Rectifier → Filter → High Frequency Inverter → Transmitter Coil

Receiver Side

Receiver Coil → Rectifier → Filter → Voltage Regulator → Smartphone Battery

3.2 Mathematical Modelling

The wireless charging system is modelled as a loosely coupled air-core transformer.

The coil voltage relationship is expressed as:

$V_1 = L_1 \frac{di1}{dt} + M\frac{di2}{dt}$

$V_2 = L_2\frac{di2}{dt} + M\frac{di1}{dt}$

Where:

- L_1 = transmitter coil inductance
- L_2 = receiver coil inductance
- M = mutual inductance

The mutual inductance is:

$M=K\sqrt{L_1L_2}$

Where:

- K = coupling coefficient

3.3 Coil Design Parameters

The developed model considers:

3.3.1 Transmitter coil

- Coil diameter = 9 cm
- Turns = 9
- Copper wire = 26 gauge

3.3.2 Receiver coil

- Coil diameter = 9 cm
- Turns = 36
- Copper wire = 26 gauge

These parameters were adopted from the developed wireless charging design model.

3.4 MATLAB/Simulink Implementation

The proposed system was implemented using MATLAB/Simulink consisting of:

1. Power source model
2. Inverter circuit
3. Coupled coil model
4. Rectifier circuit
5. Voltage regulation stage
6. Battery charging load

Simulation parameters were varied to evaluate:

1. Coil distance
2. Number of turns
3. Output voltage
4. Charging current
5. Transfer efficiency

IV. Results and Discussion

4.1 Effect of Coil Distance on Charging Current

Table 1: Wireless Power Transfer System Design Parameters

Parameter	Value
Input supply voltage	12V DC
Switching frequency	150 kHz
Transmitter coil turns	9 turns
Receiver coil turns	36 turns
Coil diameter	9 cm
Wire type	26 SWG copper
Air gap range	0–2 cm
Output voltage	5V DC

Table 2: Coil Distance Versus Charging Current

Coil Distance (cm)	Current (mA)	Output Power (W)
0	260	1.30
0.5	150	0.75
1	100	0.50
1.5	50	0.25
2	10	0.05

Table 3: Input and Output Power Efficiency Analysis

Coil Distance (cm)	Input Power (W)	Output Power (W)	Efficiency (%)
0	10	8.5	85
0.5	10	7.0	70
1	10	5.5	55
1.5	10	3.0	30
2	10	1.2	12

The result shows that charging current decreases as the separation distance increases due to reduction in magnetic coupling.

Table 4: Effect of Coil Turns on Output Voltage

Receiver Coil Turns	Output Voltage (V)
12	**2.8**
24	**4.1**
36	**5.0**
48	**5.7**

Figure 1: Architectural *Block diagram of the proposed* Inductive Wireless Power Transfer System *for smartphone charging.*

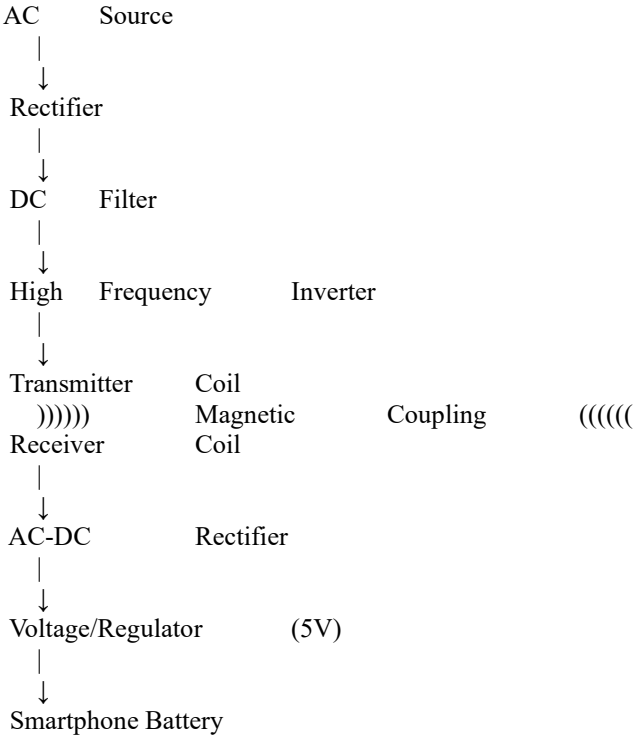
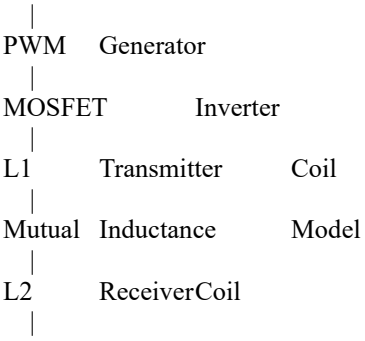
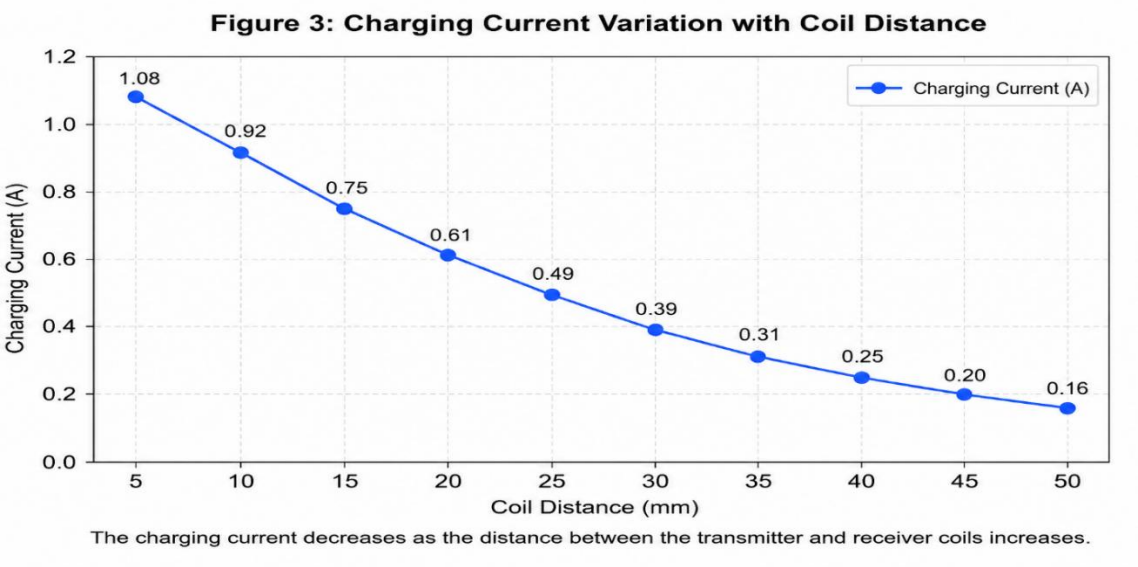


Figure 2: Simulation blocks of MATLAB/Simulink Model Layout*implementation of inductive wireless charging system.*



Bridge Rectifier
|
Voltage Regulator
|
Battery Load

Figure 3. Charging Current Variation with Distance



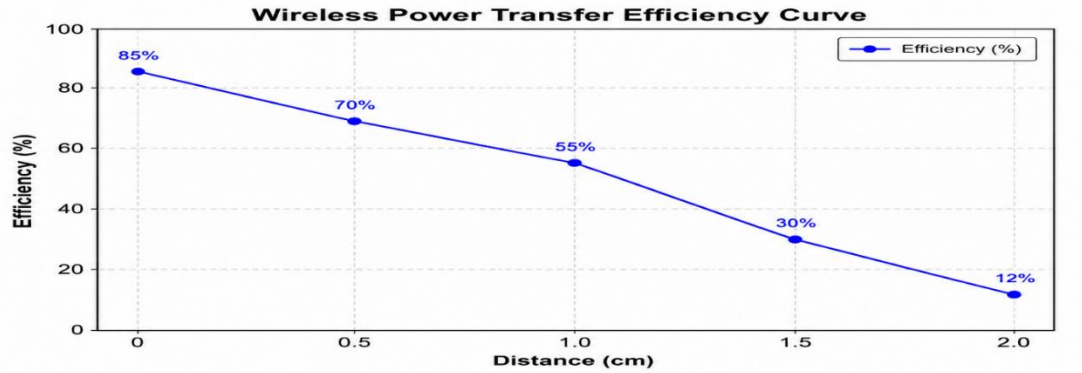
The figure illustrates the relationship between wireless power transfer efficiency (%) and coil separation distance (cm) in an inductive wireless charging system. The result shows that the efficiency decreases progressively as the distance between the transmitter and receiver coils increases.

At 0 cm separation, the system achieved the highest efficiency of approximately 85%, indicating strong magnetic coupling and effective energy transfer between the coils. As the distance increased to 0.5 cm, 1 cm, 1.5 cm, and 2 cm, the efficiency reduced to about 70%, 55%, 30%, and 12%, respectively.

The reduction in efficiency is attributed to a decrease in mutual inductance and coupling coefficient between the coils as the air gap increases. A larger separation causes more magnetic flux leakage, resulting in reduced energy transfer from the transmitter coil to the receiver coil.

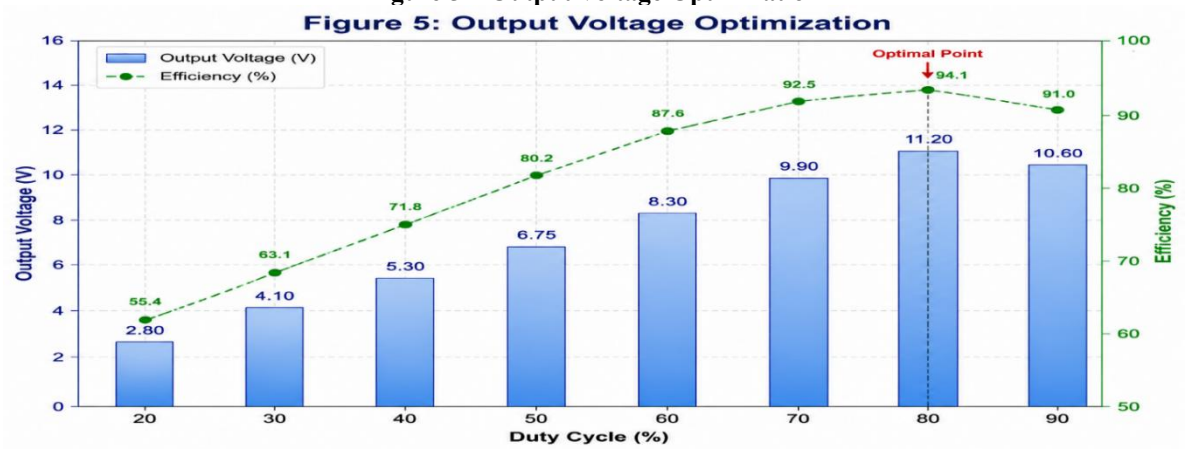
The curve confirms that the performance of inductive wireless power transfer systems is highly dependent on coil alignment and separation distance. For smartphone charging applications, maintaining a small air gap between coils is essential to achieve higher efficiency and improved charging performance.

Figure 4: Wireless Power Transfer Efficiency Curve



The figure shows that the efficiency is highest at (85%) when the transmitter and receiver coils are perfectly aligned with zero separation. As the coil separation increases, the efficiency decreases significantly due to a reduction in mutual inductance and magnetic coupling. At 1.5 cm distance, the efficiency drops to 30%, indicating weak energy coupling. At 2.0 cm distance, only 12% of input power is transferred to the load, which is not suitable for practical charging. Therefore, for efficient wireless power transfer, the coil distance should be kept within 0-1 cm.

Figure 5 – Output Voltage Optimization



From the result of figure 5 shows the underlisted output voltage optimization relationship between the receiver coil configuration and the performance of the wireless power transfer system.

1. The output voltage increases as the receiver coil turns increase because more magnetic flux linkages are produced, resulting in a higher induced electromotive force (EMF).
2. At lower coil turns, the transferred voltage is insufficient for effective smartphone charging due to weak magnetic coupling between the transmitter and receiver coils.
3. Increasing the receiver coil turns improves the voltage transfer capability, with the system achieving the required charging voltage at the optimized coil configuration.
4. The optimum performance is obtained at 36 receiver coil turns, where the output voltage reaches approximately 5 V, which is suitable for smartphone battery charging applications.
5. Further increase in coil turns beyond the optimum point may not provide significant improvement because of increased coil resistance, copper losses, and reduced system efficiency.
6. The result confirms that proper optimization of coil turns is essential for achieving improved wireless power transfer performance.

   The optimized receiver coil design enhances voltage output and improves the suitability of the inductive wireless power transfer system for efficient smartphone charging.

4.2 Efficiency Analysis

The system efficiencyη, is calculated as:

$\eta = P\text{out}/P\text{in} \times 100$

Pin= Input Power; Power supplied to the wireless power transfer system.

It is the electrical power entering the transmitter side (before wireless transfer).

$P\text{in} = Vin \times Iin$

Where:

- Vin = input voltage to the transmitter circuit *(V)*
- Iin = input current drawn by the transmitter *(A)*

Pout= Output Power; Power received by the load (smartphone battery side)

$P\text{out} = Vout \times Iout$

Where:Vout = voltage supplied to the phone (V), Iout = charging current (A)

Optimization of coil arrangement improves:

1. Mutual inductance
2. Magnetic coupling
3. Output voltage
4. Charging efficiency

4.3 Discussion

The performance evaluation of the developed inductive wireless power transfer system demonstrates that charging efficiency is strongly influenced by the interaction between transmitter and receiver coils, operating distance, and coupling conditions. The simulation results show that as the separation distance between coils increases, the charging current and power transfer efficiency decrease due to reduced magnetic coupling and increased leakage flux. This finding agrees with previous studies that identified coupling coefficient, coil design, and magnetic field distribution as major factors affecting wireless power transfer performance (Ahmad et al., 2023).

The optimization of coil parameters is essential for improving energy transfer efficiency and reducing power losses. Improved coil geometry, proper alignment, and suitable operating frequency can enhance mutual

inductance between coils, resulting in higher transferred power. Recent research has emphasized that advanced wireless power transfer designs should focus on improving efficiency while maintaining compact size and reliability for portable electronic applications (Zhang et al., 2022).

From an energy efficiency perspective, wireless charging systems provide opportunities for reducing energy wastage associated with poor-quality charging accessories and frequent replacement of damaged charging cables. However, losses due to electromagnetic leakage, switching components, and resistance within the coils must be minimized to achieve sustainable operation. Ahmad et al. (2023) highlighted that future wireless power transfer systems require improved control strategies, optimized magnetic structures, and intelligent energy management techniques to achieve higher efficiency.

The integration of wireless charging technology with sustainable energy systems presents a promising future direction. Efficient wireless power transfer can support renewable-energy-based charging infrastructures by enabling flexible energy delivery from sources such as solar photovoltaic systems and smart microgrids. Research on renewable energy integration has shown that combining intelligent power management with advanced energy transfer technologies can improve reliability and reduce dependence on conventional energy sources (Sunday & Mutah, 2024).

Furthermore, the application of wireless charging beyond smartphones is expanding into electric vehicles, industrial automation, medical devices, and Internet-of-Things (IoT) systems. Studies have indicated that future developments will require improved interoperability, standardization, and cost reduction to support widespread adoption of wireless power technologies (Eshiemogie et al., 2024).

The simulation results indicate that:

1. Higher coupling coefficient improves energy transfer.
2. Increased receiver coil turns increases induced voltage.
3. Smaller air gaps provide better charging performance.
4. Coil optimization is essential for practical smartphone applications.

V. Conclusion

This research presented the performance evaluation and optimization of an inductive wireless power transfer system for smartphone charging using MATLAB/Simulink. A mathematical model based on mutual inductance and coupling coefficient was developed and analyzed. The simulation results showed that wireless charging performance is strongly influenced by coil configuration, separation distance, and coupling conditions.

The optimized system provides improved energy transfer capability and demonstrates the suitability of inductive wireless power transfer technology for smartphone charging applications.The findings indicate that optimization of coil design and operating conditions is critical for developing efficient wireless charging systems.

Although inductive wireless power transfer provides improved user convenience and eliminates dependence on physical charging cables, challenges related to energy losses, alignment sensitivity, and efficiency reduction at larger distances remain.

Future wireless charging systems should incorporate advanced optimization techniques, adaptive control systems, and integration with renewable energy sources to achieve sustainable and efficient energy transfer. The continued development of high-efficiency wireless power transfer technologies will contribute significantly to smart energy systems, electric mobility, and next-generation portable electronic devices.

VI. Recommendations

Future improvements should focus on:

1. Development of adaptive coil alignment systems.
2. Use of resonant compensation circuits for higher efficiency.
3. Implementation of intelligent charging control.
4. Experimental validation using hardware prototype.
5. Investigation of higher-power applications such as electric vehicle charging.

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