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Wireless Charging Platform for Drones Using WPT Technology

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Abstract- Drones are becoming indispensable tools in various critical sectors of India, such as agriculture, disaster management, land surveys, mining, and infrastructure mapping. Their ability to access remote, hazardous, or hard-to-reach areas makes them invaluable for tasks, such as crop monitoring, search and rescue, and real-time data collection. However, the effectiveness of drones in these mission-critical applications is often limited by their battery life and the need for frequent recharging, particularly in environments where human access is difficult or impossible. This project addresses this challenge by developing a wireless power transfer (WPT) system for drone charging. The system converted a standard 230V supply into a low-voltage DC output, which was then wirelessly transferred via a high-frequency (100kHz) inverter and coil setup. This WPT system is particularly suited for use in remote or inaccessible locations, where minimizing downtime is critical.

Index Terms- Wireless Power Transfer, Drone Charging, High-Frequency Inverter, Remote Applications

I. INTRODUCTION

Drones have emerged as transformative tools across various critical sectors in India, playing a pivotal role in enhancing their operational efficiency and effectiveness. In agriculture, they facilitate crop monitoring, enabling farmers to make data-driven decisions that boost yields and resource management. In disaster management, drones are invaluable for search and rescue operations, as they provide real-time situational awareness in hazardous environments. Similarly, their application in land surveys, mining, and infrastructure mapping shows their ability to access remote and hard-to-reach areas, ensuring accurate data collection and analysis. Despite their many advantages, the operational effectiveness of drones is often hindered by their limited battery life, which necessitates frequent recharging. This challenge becomes particularly acute in environments in which human access is difficult or impossible, leading to increased downtime and operational delays. To address this limitation, we propose the development of a Wireless Power Transfer (WPT) system specifically designed for autonomous drone charging.

The proposed WPT system effectively converted a standard 230V ac supply into a low-voltage DC output, which was wirelessly transmitted using a high-frequency (100kHz) inverter and coil setup. This ensures optimal power transfer, even in the presence of nonuniform magnetic fields created by the coil arrangement. By automating the charging process, this system eliminates the need for manual intervention, making it particularly suitable for remote or inaccessible locations, where minimizing downtime is critical. An autonomous WPT system enhances the operational efficiency of drones, allowing them to engage in continuous and critical tasks without the constraints imposed by battery life. By ensuring uninterrupted operation, this technology not only expands the usability of drones, but also supports the growing demand for reliable, efficient, and effective solutions in various sectors. This project aims to demonstrate the potential of autonomous drone charging to revolutionize operations in agriculture and disaster management.

The remainder of this paper is structured as follows Section II provides a brief overview of Wireless Power Transfer (WPT) technology. Section III presents a detailed discussion of the proposed design. Section IV illustrates the system's operation through a flow chart, explained in detail. Section V covers simulation results and analysis. Finally, the paper concludes with a summary of key findings and future research directions.

II. WPT TECHNOLOGY

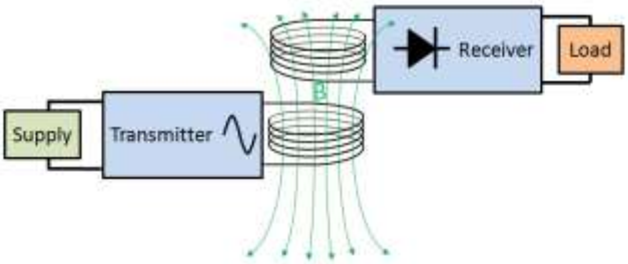

Figure 1 Structure of WPT System

Wireless Power Transfer (WPT) is a cutting-edge technology that allows the transmission of electrical energy without the need for physical wires by utilizing electromagnetic fields for energy transfer. The system typically consists of a transmitter that is connected to a power source and a receiver that captures the transmitted energy. [1] The transmitter generates a time-varying electromagnetic field, typically using coils or antennas to transfer energy across space. The receiver then converts this electromagnetic field back into electrical energy to power an electronic device. WPT can be broadly categorized into two types: near-field (non-radiative) and far-field (radiative) techniques. In near-field methods, energy is transferred over short distances using magnetic or electric fields, with inductive coupling being the most common approach, employed in applications such as wireless charging for smartphones and medical implants like pacemakers. On the other hand, far-field techniques use electromagnetic radiation (e.g., microwaves or lasers) to transfer power over longer distances, with applications ranging from powering drones to solar power satellites. The technology is advantageous in eliminating the need for physical connectors, enhancing mobility, safety, and convenience. However, challenges such as maintaining efficient energy transfer, ensuring safety from electromagnetic exposure, and aligning the transmitter and receiver are still significant hurdles. Despite these challenges, the potential for WPT to revolutionize various sectors, including consumer electronics, electric vehicles, and industrial automation, remains vast, making it a key area for ongoing research and development.

1. Types of WPT Systems

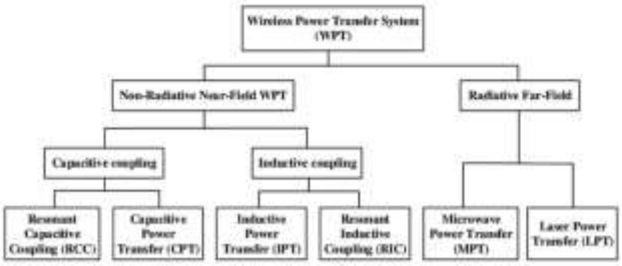

Figure 2 Types of WPT System

Non-Radiative Near-Field WPT Non-radiative near-field techniques transfer power over short distances and rely on the interaction of electric or magnetic fields. These methods are widely used for applications like charging small devices. Two common types of non-radiative near-field WPT are Capacitive Coupling and Inductive Coupling.

Capacitive Coupling Capacitive coupling uses electric fields for the transfer of energy between capacitive plates or electrodes. In this method, an alternating voltage is applied to a capacitor, generating an electric field. The receiver captures the energy from this field and converts it back into electrical power. This method is often used in applications where the distance between the transmitter and receiver is small and the power requirements are low.

Resonant Capacitive Coupling (RCC) Resonant capacitive coupling involves using two capacitors tuned to resonate at the same frequency. This enhances the energy transfer efficiency and allows for a greater range compared to traditional capacitive coupling. RCC systems are commonly used in wireless charging pads for small electronics like smartphones and tablets.

Capacitive Power Transfer (CPT) Capacitive Power Transfer (CPT) uses multiple parallel plates arranged to create electric fields between them. The transmitter induces a voltage in the plates, generating the electric field. The receiver plates, positioned in proximity, capture the power. CPT is mainly used in applications that require low power transfer over short distances, such as charging devices like electric toothbrushes and hearing aids.

Inductive Coupling Inductive coupling utilizes magnetic fields generated by current flowing through coils of wire to transfer energy between a transmitter and a receiver. This is the most widely used near-field WPT technique, especially in applications like wireless charging for smartphones and electric vehicle (EV) charging systems.

Inductive Power Transfer (IPT) Inductive Power Transfer (IPT) involves the use of coils that create a magnetic field when current flows through them. The receiver coil, placed within this magnetic field, induces a current which is then converted into usable power. IPT is the standard technology for charging consumer devices like smartphones, electric toothbrushes, and medical implants.

Resonant Inductive Coupling (RIC) Resonant Inductive Coupling (RIC) takes advantage of the resonance phenomenon to increase the efficiency of inductive power transfer over longer distances. By tuning both the transmitter and receiver coils to resonate at the same frequency, RIC improves power transfer efficiency even when the coils are not perfectly aligned. RIC is frequently used in applications such as electric vehicle charging, where efficient energy transfer over moderate distances is needed.

Radiative Far-Field WPT Radiative far-field techniques allow power to be transmitted over much longer distances compared to near-field techniques. This is achieved by using electromagnetic radiation, typically in the form of microwaves or lasers, to carry energy. The power is transferred via a beam and then captured by a receiver that converts it back into usable electrical power.

Microwave Power Transfer (MPT) Microwave Power Transfer (MPT) uses microwaves as a medium to transmit energy from a transmitter to a receiver. The transmitter sends a focused microwave beam that travels through space, and the receiver captures it using an antenna and converts it back to electrical energy. MPT can deliver power over large distances and has potential applications in satellite power transmission, remote powering of drones, and wireless energy harvesting.

Laser Power Transfer (LPT) Laser Power Transfer (LPT) uses focused laser beams to transfer energy from the transmitter to the receiver. The laser emits light that is absorbed by a photovoltaic cell or other light-sensitive material on the receiver, which then converts the energy into electrical power. LPT has applications in high-precision, long-range energy transfer, such as in powering satellites or in space-based solar power systems.

2. Transiter Coil and Receiver Coil

Transmitter Coil (Tx Coil) The transmitter coil (Tx coil) in a Wireless Power Transfer (WPT) system is responsible for generating the electromagnetic field that transmits energy. It works by passing alternating current (AC) through the coil, which creates a time-varying magnetic field due to the principle of electromagnetism (Faraday's Law of Induction). [2] The transmitter coil is typically made of copper or other conductive materials to minimize resistance and energy losses. To design the transmitter coil, several factors must be considered, including the number of turns, the size of the coil, the material used, and the operating frequency. The number of turns in the coil directly affects the strength of the magnetic field; more turns create a stronger field. The coil’s shape can vary, with circular or square shapes being the most common, depending on the application. The size of the transmitter coil influences the range of the energy transfer—the larger the coil, the stronger the magnetic field, which can cover a greater distance. The frequency of the alternating current used is also critical: it must match the resonant frequency of the receiver coil for efficient energy transfer. [3] Proper design is essential to ensure that the Tx coil can produce a strong enough field to transfer power over the required distance without significant energy losses.

Receiver Coil (Rx Coil) The receiver coil (Rx coil) captures the electromagnetic energy emitted by the transmitter coil and converts it back into electrical energy. The design of the receiver coil is similar to the transmitter coil, but its primary function is to maximize the capture of the magnetic field generated by the Tx coil. Like the transmitter coil, the receiver coil is typically made of copper or another highly conductive material. [4] To design an effective receiver coil, the number of turns and the coil's size and shape should match the transmitter coil's design as closely as possible to ensure efficient energy transfer. The tuning of the Rx coil is crucial: it must be resonant at the same frequency as the Tx coil to maximize energy conversion. In addition to the coil, the receiver circuit often includes a rectifier (usually a diode bridge) to convert the AC power induced in the coil into DC power, which can then be used to power electronic devices. The distance between the Tx and Rx coils and their alignment is also important: misalignment can result in a significant loss of power transfer efficiency. The receiver coil’s design and placement in the electromagnetic field must be optimized for the specific application to ensure that it captures as much energy as possible while minimizing losses due to inefficiency or distance.

III. PROPOSED SYSTEM

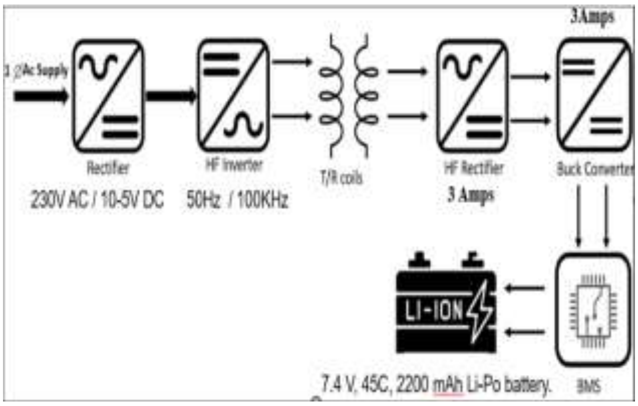

Figure 3. Proposed Design

AC Supply (Input) The Wireless Power Transfer (WPT) system begins with a standard single-phase AC supply, typically 230V from the power grid. This AC voltage is first converted into DC (Direct Current) using a rectifier, commonly a bridge rectifier. The conversion process results in a DC voltage that may be slightly higher than required, but it is filtered to eliminate any ripples, providing a smooth DC output.

DC to High-Frequency AC Conversion (Inverter) This section explains the components and design considerations involved in the inverter system, focusing on the gate drivers and MOSFETs, which are crucial for efficient switching and reliable operation.

Gate Drivers Inverter systems rely on gate drivers to control the switching of MOSFETs and IGBTs. A gate driver is responsible for translating low-voltage control signals into higher voltage levels needed to switch the power devices. Voltage Levels Gate drivers are used to convert low-voltage control signals (e.g., from microcontrollers or PWM controllers) to the higher voltage levels required for switching MOSFETs or IGBTs. This ensures that the inverter can operate efficiently at high speeds. Drive Strength To facilitate rapid switching, gate drivers must supply sufficient current to charge and discharge the gate capacitance of power devices. This is especially important in high-frequency inverter systems where quick switching is required.

Isolation Inverter systems often operate with high-voltage power circuits. Gate drivers provide electrical isolation between the low-voltage control circuits and high-voltage power circuits, typically through opto-isolators or transformer-based designs.

Protection Features Modern gate drivers include protection mechanisms such as Under Voltage Lockout (UVLO), Over Temperature Protection, and Fault Detection to enhance the reliability and safety of the inverter.

MOSFETs are widely used in inverters for their ability to switch rapidly and efficiently. They convert DC into AC by rapidly switching between conducting and non-conducting states. Fast Switching MOSFETs used in inverters must have fast switching capabilities to generate high-quality AC waveforms. This is critical in applications where high-frequency operation is necessary, such as in motor drives and renewable energy systems.

Low On-Resistance (R_DS (on)) MOSFETs with low on-resistance are preferred because they minimize power losses and heat generation, improving the efficiency of the inverter. Thermal Stability MOSFETs like the IRF540 are designed to handle high current and high power dissipation, ensuring that the inverter operates effectively even in demanding conditions.

UCC21222-Q1 Gate Driver is a dual-channel, high-speed gate driver, designed to drive MOSFETs or IGBTs in high-power applications such as motor drives, power converters, and inverter systems. Key Features Peak Current Output: 4A peak source and 6A peak sink output, ideal for driving power MOSFETs or IGBTs with high gate charge. Dead-Time Control: Prevents cross-conduction between high-side and low-side MOSFETs, ensuring reliable inverter operation. Temperature Range: Operates within a temperature range of -40°C to 150°C, making it suitable for harsh automotive and industrial environments.

The IRF540 is an N-channel MOSFET commonly used in H-bridge configurations within inverter circuits for DC motor control and other power conversion applications. Voltage Rating: Can withstand up to 100V, suitable for high-voltage inverter applications. Current Rating: Continuous drain current of 33A, enabling handling of heavy loads. Thermal Management: Designed to dissipate up to 94W of power, making it suitable for high-power inverter designs. Applications of Gate Drivers and MOSFETs in Inverters

Rectifier: A rectifier is an essential electrical device used to convert alternating current (AC) into direct current (DC). It functions by allowing current to flow in only one direction, thereby effectively transforming the AC waveform into a unidirectional flow. Rectifiers are widely utilized in applications such as power supplies, battery chargers, and other electronic circuits that require DC power. Common types of rectifiers include half-wave and full-wave rectifiers, which differ in the way they process AC input signals. Due to their ability to provide stable DC output, rectifiers play a vital role in powering various appliances and systems. Rectifiers have a diverse range of applications. They are commonly employed in electric welding systems to provide polarized voltage, as well as in mosquito repellents using half-wave rectifiers. Additionally, they are used as signal peak detectors in AM radios and for tasks such as modulation, demodulation, and voltage multiplication in communication systems.

SB540 Diode The SB540 diode is a silicon-based rectifier diode widely used in power applications due to its high efficiency and reliability. It is designed to handle a maximum reverse voltage of 40V and a forward current of up to 3A. One of its key advantages is its low forward voltage drop, which minimizes power loss during operation. This makes the SB540 diode particularly suitable for power supplies, DC-DC converters, and various rectification tasks. The SB540 diode features Schottky barrier chip construction, which enhances its efficiency, along with a guard ring die structure for transient protection. It has a high surge current capability and low power dissipation, making it ideal for high-frequency inverter circuits, free-wheeling applications, and polarity protection. In terms of applications, SB540 diodes are commonly used in switching power supplies and converters, providing efficient rectification and reverse battery protection. They are also employed in disk drives and battery charging systems, where reliable performance and high efficiency are critical.

Buck Converter A buck converter, also known as a step-down converter, is a type of DC-DC converter that reduces the input voltage to a lower, regulated output voltage. These converters are highly efficient, often achieving efficiencies greater than 90%, making them suitable for applications requiring minimal energy loss. Buck converters find extensive use in various domains, such as USB on-the-go devices, point-of-load converters for personal computers and laptops, battery chargers, quadcopters, solar chargers, and audio power amplifiers.

Buck converters can be classified based on their design and operational features. The common types include synchronous and non-synchronous buck converters. Synchronous buck converters use MOSFETs for rectification, improving efficiency and reducing power loss, making them ideal for high-current applications. Non-synchronous buck converters, on the other hand, use diodes for rectification, which are simpler in design but less efficient due to higher conduction losses. Another variation is isolated buck converters, which include a transformer to provide electrical isolation between input and output, often used in sensitive or safety-critical applications.

For the current project, a non-isolated buck converter is employed, specifically the LM2596 module, due to its simplicity, cost-effectiveness, and compatibility with low-voltage, high-current requirements. This type of buck converter is efficient for stepping down voltage while maintaining steady output, making it suitable for powering microcontroller-based circuits and charging batteries. The choice of inductors and capacitors in the buck converter circuit is critical, as they influence ripple current, output stability, and overall efficiency. Advancements in inductor core materials and winding techniques have enabled these converters to operate effectively at higher power levels and switching frequencies, contributing to compact and reliable designs.

LM2596 Buck Converter The LM2596 buck converter is a versatile DC-DC step-down module designed for efficient voltage regulation. Capable of driving loads up to 3A, it features excellent line and load regulation. The module offers fixed output voltages of 3.3V, 5V, and 12V, along with an adjustable version, making it adaptable to various applications. The LM2596 operates at a switching frequency of 150kHz, allowing smaller-sized filter components compared to lower-frequency switching regulators. This module is equipped with a high-precision potentiometer to fine-tune the output voltage and can interface seamlessly with devices like Free UNO and other mainboards. For operation beyond 2.5A output current or 10W output power, it is recommended to attach a heat sink to manage thermal performance. Internally, the LM2596 includes compensation circuitry to minimize external component requirements, simplifying design while maintaining performance. The LM2596 is classified as a non-isolated constant voltage module with non-synchronous rectification. Its ability to operate efficiently across a wide range of input voltages makes it suitable for applications in power supplies, battery charging, and embedded systems. Compared to traditional linear regulators, the LM2596 offers significantly higher efficiency, especially for higher input voltages, due to its switch-mode operation. This efficiency minimizes energy loss and ensures reliable performance in modern electronic systems.

A Lithium Polymer (LiPo) battery is a type of rechargeable battery widely used in applications requiring lightweight, compact, and high-energy-density power sources. LiPo batteries have gained popularity in various fields, including remote-controlled vehicles, drones, smartphones, laptops, and portable electronics. They consist of lithium-ion chemistry housed within a flexible polymer casing, which allows them to be lighter and more adaptable in shape compared to traditional cylindrical or rectangular batteries.

LiPo batteries offer several advantages, including high discharge rates, low self-discharge, and the ability to provide consistent power output. They are available in various cell configurations, with each cell having a nominal voltage of approximately 3.7V. For instance, a two-cell (2S) LiPo battery has a nominal voltage of 7.4V, and a three-cell (3S) battery has 11.1V. Their high discharge rate, often expressed in terms of the "C" rating, enables them to deliver bursts of power, making them ideal for energy-intensive applications like drones and RC cars. For example, a LiPo battery with a 45C rating can discharge at 45 times its capacity, ensuring sufficient power during peak demand.

Despite their benefits, LiPo batteries require careful handling due to their sensitivity to overcharging, over-discharging, and exposure to high temperatures. Specialized charging circuits are used to maintain their longevity and safety by balancing the charge across all cells. Additionally, they must be stored in a charged state to prevent capacity degradation. LiPo batteries are integral to modern electronics, especially in fields like robotics and aviation, where weight and power efficiency are critical. Their versatility and reliability make them an essential component for powering cutting-edge technologies.

IV. FLOW CHART

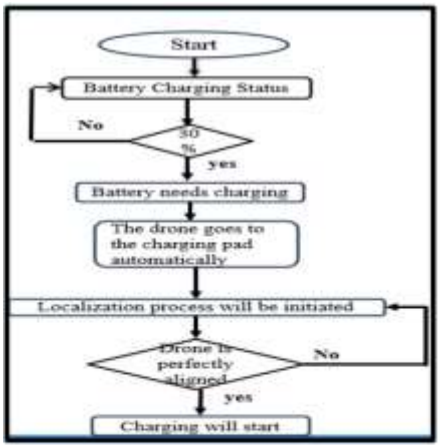

Figure 4 Flow Chart

Explanation of the Flowchart
The process begins by monitoring the drone's Battery Charging Status, which continuously evaluates the current charge level of the drone's battery. Battery Charge Check:

The first decision point assesses whether the battery level has dropped below 30%.If the battery level is above 30%, the drone continues its operation without requiring charging. This step ensures the drone only seeks charging when necessary, optimizing energy use and operational time. If the battery level falls below 30%, the system identifies that the drone requires charging. Autonomous Navigation to Charging Pad:

Once the need for charging is detected, the drone is programmed to autonomously navigate to the charging pad. This eliminates the need for human intervention and leverages pre-programmed flight paths or localization techniques to ensure safe travel to the designated charging location.

Localization Process
After the drone reaches the vicinity of the charging pad, the localization process is initiated. This step ensures the drone's precise positioning over the charging pad to establish an accurate connection. The localization process may involve sensors, cameras, or other alignment technologies to detect and adjust the drone's position. Alignment Check: Once the localization process starts, the system evaluates whether the drone is perfectly aligned with the charging pad: If the alignment is not accurate, the system loops back and makes adjustments to the drone’s position until the alignment is perfect. This ensures a secure connection and prevents charging inefficiencies or hardware damage.[5] If the alignment is verified to be accurate, the process moves to the next step. Charging Process: Once the drone is perfectly aligned, the charging process begins automatically. The system ensures seamless and efficient charging without requiring manual input, making it ideal for continuous and autonomous drone operations. This flowchart represents a robust and automated drone-charging system that prioritizes safety, precision, and efficiency. Such systems are especially useful in applications where drones are deployed for critical tasks like delivery, surveillance, or monitoring, requiring minimal downtime and maximum autonomy.

V. SIMULATION SETUP

I have designed and simulated the circuit in LTSpice, a powerful simulation tool widely regarded as one of the best platforms for power electronics applications. LTSpice stands out from other simulation software due to its speed, accuracy, and versatility in handling complex power electronics circuits. Unlike general-purpose simulators, LTSpice is optimized for switch-mode power supply (SMPS) designs, including buck converters, boost converters, and other topologies critical for power systems. Its ability to simulate with high precision even in the presence of high-frequency switching transients makes it an ideal choice for power electronics engineers.

Additionally, LTSpice provides built-in support for SPICE models of components, including MOSFETs, diodes, and inductors, often pre-optimized for power applications. It offers a user-friendly environment with fast convergence, even in circuits with nonlinear elements or stiff systems. Compared to other simulators, LTSpice is highly efficient in memory usage and simulation speed, enabling users to simulate large-scale circuits effectively. Moreover, its open and free availability, along with robust support from Analog Devices, makes LTSpice a preferred choice for designing, analyzing, and optimizing power electronics circuits.

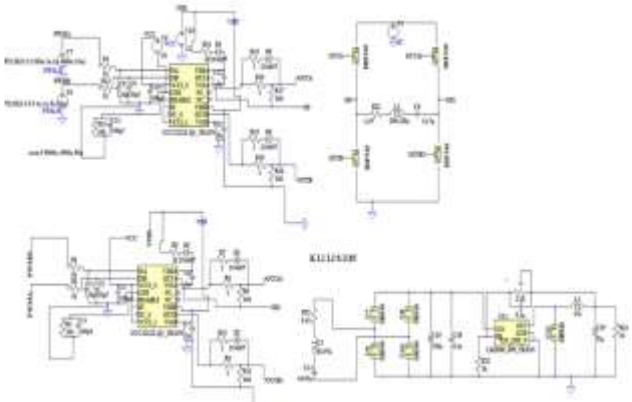

Fig 5 Simulation Setup

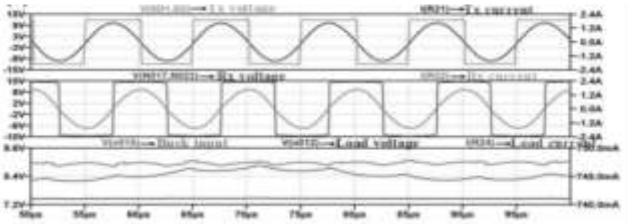

Fig 6 Results

The waveform analysis illustrates the voltage and current characteristics across various stages of a wireless power transfer system, specifically for a drone charging application. The first graph represents the transmitter (Tx) voltage and current, showcasing a sinusoidal pattern, indicating the high-frequency AC signal used for energy transfer. The second graph depicts the receiver (Rx) voltage and current, which also exhibit sinusoidal characteristics, but with amplitude changes due to coupling and circuit impedance. The third graph highlights the buck converter's input voltage, load voltage, and load current. The buck converter efficiently steps down the received voltage to charge the drone battery, maintaining a relatively stable output voltage (around 8.4-9.6V) and load current (approximately 740-750mA). These waveforms collectively demonstrate the operation of the wireless power transfer system, emphasizing the efficiency of energy transfer and regulation through the buck converter to provide stable power for the load.

VI. CONCLUSION

The proposed Wireless Power Transfer (WPT) system addresses the critical challenge of autonomous drone charging by introducing an efficient and reliable energy transfer mechanism. It utilizes a 100kHz high-frequency inverter, which ensures stable and effective power transmission over short distances, making it ideal for drones that need to operate in environments where physical connections for charging are either impractical or impossible. The incorporation of a buck converter further refines the system by precisely regulating the output voltage, ensuring compatibility with the specific charging requirements of the drone's battery. This prevents issues such as overcharging or undercharging, which can compromise battery life and performance. The system's design is particularly advantageous for applications in remote or inaccessible areas, where manual intervention for charging drones is not feasible. Examples include agricultural monitoring in vast farmlands, disaster response in hazardous zones, and logistics operations in isolated regions. By reducing the downtime required for frequent recharging, the system enhances the operational efficiency and reliability of drones, enabling them to perform longer missions with minimal interruptions. This WPT solution is a forward-thinking approach to supporting the rapidly growing drone industry in India. It aligns with the increasing demand for autonomous and sustainable energy systems, catering to a variety of sectors such as precision agriculture, disaster management, logistics, and surveillance. The system's innovative design not only addresses immediate charging challenges but also contributes to the broader goal of advancing drone technology for critical and transformative applications.

Future Scope

The proposed Wireless Power Transfer (WPT) system offers a cutting-edge solution to the pressing challenge of autonomous drone charging. Leveraging a 100kHz high-frequency inverter, the system ensures efficient and stable energy transfer across short distances, making it highly effective for drone applications. A key feature of the design is the inclusion of a buck converter, which precisely regulates the output voltage to meet the specific requirements of the drone's battery. This eliminates the risks of overcharging or undercharging, thereby ensuring safe and optimal charging conditions. The system is particularly advantageous for use in remote or difficult-to-access locations where manual charging methods are impractical. This makes it an ideal choice for operations in areas such as agriculture, disaster relief, and logistics, where drones are increasingly deployed for critical tasks. By significantly reducing the downtime associated with frequent recharging, the system enhances the operational efficiency and reliability of drones, allowing them to perform extended missions with minimal interruptions. This innovative WPT solution aligns with the rapid growth of the drone market in India, addressing the increasing demand for autonomous and efficient energy systems. Its design not only addresses the immediate challenges of drone charging but also supports the broader advancement of drone technologies in applications that are pivotal for economic and social development.

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