Integrative Study on Combining Drones with Inverters

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Abstract. Drones were initially predominantly used in military contexts, but in recent times, their applications have expanded widely across various sectors, undergoing continual refinement and advancement. Among these applications, inverters play a crucial role as an integral component of drones. Their function involves converting, integrating, and optimizing diverse electrical energy types to ensure the smooth operation of various onboard systems, consequently boosting flight performance and efficiency. This study aims to delve into the operational principles of inverters, identify current challenges, and propose enhancement strategies. Leveraging the fundamental electrical properties of controllable silicon rectifiers (SCR), a novel inverter capable of converting direct current (DC) to alternating current (AC) is devised herein. Advanced PWM techniques and field-effect transistors such as IGBTs are utilized, and the circuit schematic is simulated using Matlab. Research outcomes reveal that the enhanced inverter demonstrates superior efficiency, thus elevating drone performance. Furthermore, this paper suggests avenues for optimizing efficiency and refining waveform analysis. These insightful findings are poised to inform future research endeavors and facilitate further advancements in product design.

Keywords: UAV, Convert, Thyristor, Insulated Gate Bipolar Transistor (IGBT), Silicon Controlled Rectifier (SCR).

1. Introduction

The origin of drones can be traced back to the First World War when they were primarily used for military surveillance. However, the true breakthrough in drone technology dates back to the 1980s. At that time, the US military began investing in the development of unmanned aerial vehicles, with the MQ-1 "Predator" and MQ-9 "Reaper" series being notable examples. Since then, the application fields of drones have gradually expanded, occupying a significant position in military technology.[1]

The rise of drones is the result of multiple interacting factors. Initially, drones were mainly used in the military for reconnaissance, surveillance, and mission execution, reducing risks to personnel.[2] However, drones have now become essential tools in photography and video production. Agricultural drones are used to monitor farmland,[3] collect crop growth data, and implement precision agriculture management. Additionally, drones have enormous potential in monitoring infrastructure such as bridges, power lines, and pipelines. Drones are crucial in disaster response and are used for search and rescue operations and monitoring natural disasters. Drones have achieved significant success in various fields,[4] with advantages including risk reduction, efficiency, flexibility, endurance, cost-effectiveness, data collection and transmission, and multitasking capabilities. These advantages enable drones to play unique roles in different fields, bringing practical convenience and innovation to human society.

However, the power systems of drones have some limitations, especially when alternating current is required. Introducing inverters becomes crucial as they can convert direct current into alternating current to meet the needs of certain devices. Inverters also allow drones to connect to different charging stations, ensuring a more convenient charging process.

Inverters enable drones to provide the required power for these devices, ensuring efficient operation during mission execution. In summary, inverters play a critical role in addressing the limitations of drone power systems, making drones more flexible and adaptable to different mission requirements and energy conditions, thereby promoting the widespread application of drone technology in various fields.

Timothy W. McLain and others are dedicated to modeling, controlling, and optimizing drone systems, publishing multiple related papers mainly discussing drone flight control systems, including sensor technology, path planning, obstacle avoidance algorithms, autonomous navigation, communication systems, and other innovations.[5] Johann W. Kolar has significantly contributed to efficient, high-performance inverter topologies and control. However, few have linked inverters with drones. Inverters enable drones to provide the required power for these devices, ensuring efficient operation during mission execution. Battery charging typically requires alternating current, and drones may need to charge in different locations, which could lead to compatibility issues. Inverters allow drones to connect to various types of charging stations, ensuring a more convenient charging process. To summarize, inverters are essential for overcoming the constraints of drone power systems. They transform direct current into alternating current, enhancing the flexibility and adaptability of drones to diverse mission demands and energy environments. Consequently, this drives the extensive utilization of drone technology across multiple sectors [6.7].

This paper aims to improve the efficiency of inverters in drones, focusing on theoretical analysis to introduce the working principles of inverters. It utilizes MATLAB to design, model, and simulate the improved inverters and finally provides applications based on current experimental results, shortcomings, and future prospects of this experiment.

2. Principle and working mechanism of the intersection Headings

Inverters are essential electronic devices that convert direct current (DC) energy into alternating (AC) energy. This pivotal component comprises several intricate elements: rectifiers, filters, inverter circuits, control circuits, output filters, and protective circuits.[8]

The rectifier transforms incoming alternating current (AC) power into direct current (DC) power. At the same time, the filter is tasked with smoothing the output DC voltage from the rectifier, thereby eliminating potential ripple and harmonics to optimize output quality. At the core of the inverter lies the inverter circuit, which is responsible for converting DC energy into AC energy. The control circuit represents the intelligent facet of the inverter, which monitors and regulates the output AC's frequency, amplitude, and phase. Additionally, the output filter and protective circuitry refine the output quality further and safeguard the inverter against aberrant operational conditions.

Within the domain of unmanned aerial vehicles (UAVs), inverters assume a pivotal role, facilitating the reception of DC power from diverse sources such as batteries, solar panels, and the like. This DC power is channeled through the rectification stage to effectuate its conversion into a suitably smooth DC output.

Subsequently, the transformed DC traverses through the inverter circuit, where the switching elements therein, typically comprising MOSFETs or IGBTs, undergo periodic activation and deactivation. This cyclical modulation engenders generating an AC approximating a sinusoidal waveform. The operational frequency of these switching elements typically oscillates between several kilohertz to tens of kilohertz. Through the orchestrated interplay of the inverter, the rhythmic switching of these elements engenders a time-varying modulation of the output voltage, thus effectuating the desired AC waveform. Concurrently, the control circuit perpetually scrutinizes the output voltage and current, effectuating requisite adjustments to the operational state of the switching elements to uphold the output voltage and frequency within the predefined parameters. This modulation is conventionally achieved through integrating feedback loops and microcontroller-based systems.

Nevertheless, inverters are beset by challenges, including efficiency losses, volumetric and mass constraints, thermal management difficulties, and electromagnetic compatibility conundrums. Addressing these concerns necessitates a multifaceted approach involving enhancements in efficiency, the espousal of lightweight design paradigms, the incorporation of advanced thermal management methodologies, and the mitigation of electromagnetic interference [9,10]

3. Experimental design

3.1. Introduction to PWM

Addressing these issues, this paper primarily designs an inverter circuit utilizing the PWM (Pulse Width Modulation) technique and Field-Effect Transistors (IGBTs). PWM is a modulation technique commonly employed to control power supplies or actuators in electronic devices. PWM controls the output level by adjusting the pulse width of the signal, thereby achieving precise control over the device.

Specifically, PWM varies the average voltage within one cycle by periodically altering the pulse width of the signal. This modulation technique finds widespread application in digital electronic systems, particularly in power management, motor control, and LED dimming [11-14].

The fundamental principle of PWM involves dividing the signal into two phases within a fixed time period: high and low. By adjusting the ratio of time between the high and low levels, the average voltage of the signal can be modified, thereby regulating the output. If the duration of the high level is predominant, the average voltage will be relatively high; conversely, if the duration of the low level is predominant, the average voltage will be lower.

PWM finds extensive application in control systems due to its effective means of regulating output while maintaining simplicity and cost-effectiveness. In electronic devices, PWM is commonly used to adjust motor speed, control LED brightness, and power inverters, among other applications.[15]

3.2. Introduction to the SCR principle

The robust performance of inverters is primarily attributed to Silicon Controlled Rectifiers (SCRs). SCRs, or thyristors, are semiconductor devices with alternating P and N layers. The most common type is the SCR, a power semiconductor device with three PN junctions, representing the first generation of semiconductor power electronic devices. It can be considered as a composite device composed of two transistors, one PNP and one NPN. It has three external electrodes: anode (A), cathode (C), and gate (G). When a positive voltage is applied between A and C, the device does not conduct. However, it is only conducted when a positive voltage is applied to gate G (with respect to cathode C). Once the thyristor is turned on by applying a positive voltage to the gate, it will continue to conduct even if the voltage on the gate is removed. In China, it is commonly referred to as a silicon-controlled rectifier (SCR) or semiconductor-controlled rectifier (Fig.1)[12].

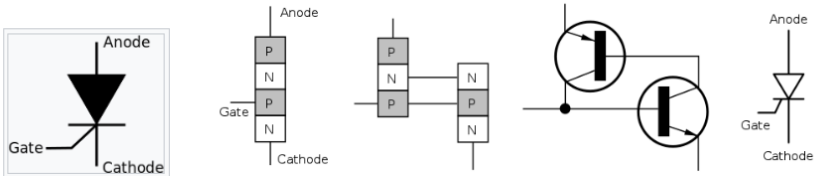


Fig.1. SCR [12]

The notable feature of the silicon-controlled rectifier (SCR) is its controllable unidirectional conduction. However, it comes with apparent drawbacks. Once activated, achieving rapid changes through simple signal control is challenging. Therefore, I opted for IGBT, an improvement based on SCR. The Insulated Gate Bipolar Transistor (IGBT) integrates the attributes of both Field-Effect Transistors (FETs) and Bipolar Junction Transistors (BJTs) into a single semiconductor device. It can be utilized in power control systems to achieve power regulation, switching, and inversion (Fig.2)[13].

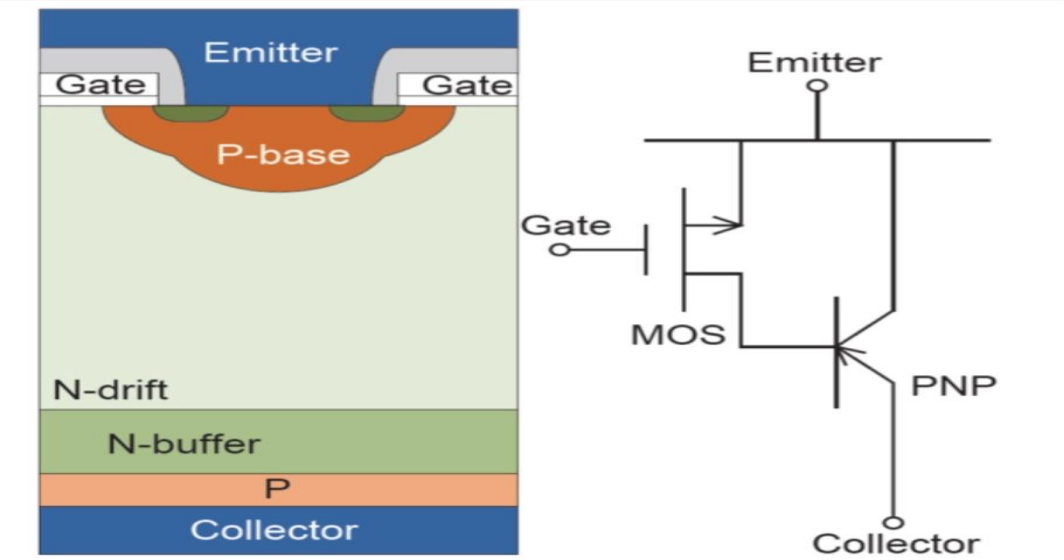


Fig. 2 The structure and equivalent circuit of IGBT [13]

3.3. Voltage input

Fig. 3 illustrates the schematic diagram of the input section of the circuit. This study supplies the circuit with a 220-volt direct current (DC). After locating it in the simulation library, adjustments were made to the voltage parameters to ensure the stable output of 220 volts of direct current.



Fig. 3 DC Voltage Source

3.4. Silicon Controlled Rectifier

As mentioned earlier, the circuit in this paper employs four IGBTs. Each group consists of two IGBTs, totaling two groups, each producing semiconductor switches operating at two different frequencies under the control of pulse signals. Based on the delayed complementary pulse signals of the two groups, the input direct current is converted into square wave alternating current. After configuring the four IGBTs, the observation results indicate that the IGBTs positioned on two diagonals form independent control sets, as shown in Fig. 4. It can be observed from the formula that frequency and period are inversely proportional.[7]

By computing according to the given formula, it can be determined that for a frequency of 50 Hz, the corresponding period should be set to 0.02 seconds. For a single-phase inverter, the phase difference between the two SCR circuits should be half of the period, equivalent to 0.01 seconds. To distinguish the operating time of the two groups of semiconductor switches, where the activation of the first group represents positive current and the second group represents negative current, this paper establishes different operating intervals for each group. Each cycle spans half to ensure the completion of the entire AC output within one cycle.

In the simulation circuit, achieving this requires introducing a delay between the two groups of switches. In this paper, the delay for the first group of switches is set to 0, indicating that they start operating 0.01 seconds after the system starts. The delay for the second group of switches is set to 1/100, meaning that they start operating 0.01 seconds after the previous group of switches has been

operating for 1/100 seconds and is turned off. By completing these steps, a complete AC cycle can be achieved. This process is then continuously repeated, generating stable 220 volts, 50 Hz AC power. To enhance the continuity of the AC output, this study adjusts the pulse width to 50. This modification enables the system to produce positive and negative outputs continuously within one cycle.[9]

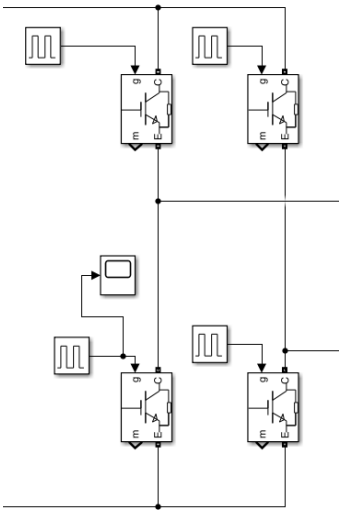


Fig. 4. IGBT

Fig. 5 and Fig. 6 separately show the different pulse generators with and without delay.

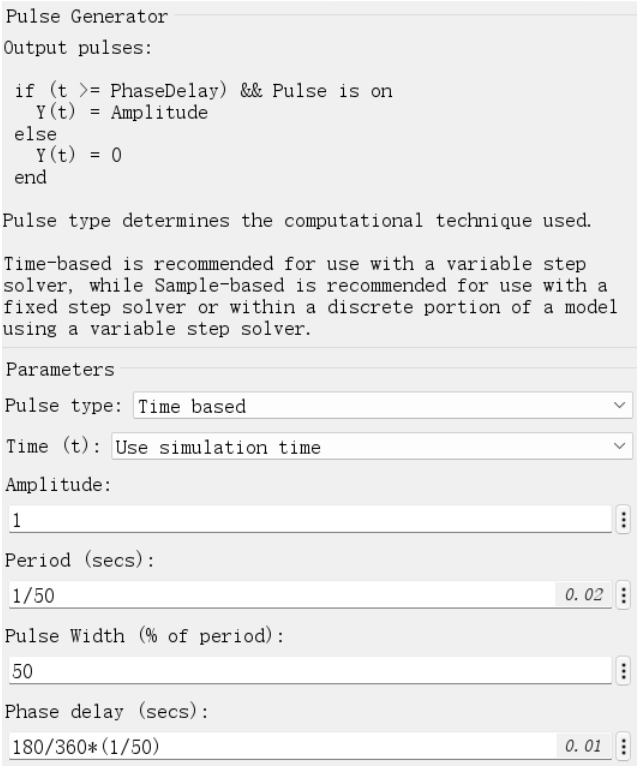


Fig. 5 A pulse generator with delay

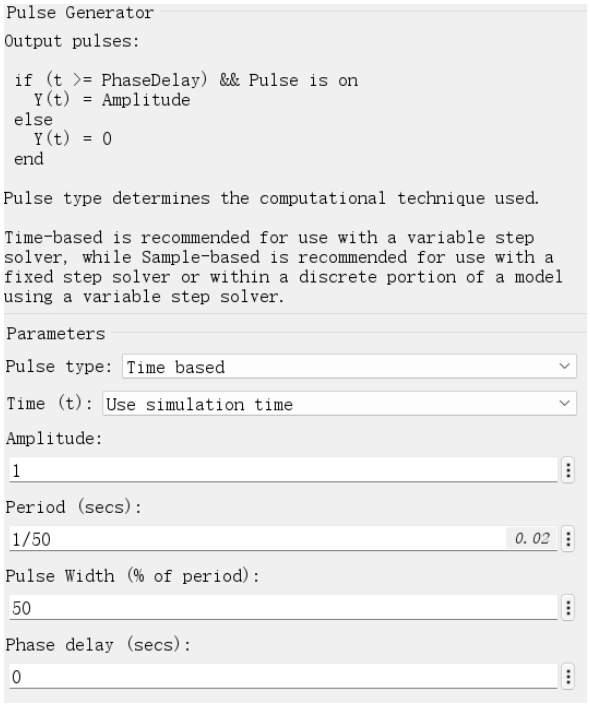


Fig. 6 A pulse generator without delay

4. Results

Fig. 7 depicts the complete circuit diagram simulated in Matlab, representing an inverter circuit utilizing bridge rectification, IGBTs, and incorporating PWM technology. This circuit is designed to convert direct current into alternating current, capable of generating periodic alternating voltage. Ultimately, it produces a regular square wave output.

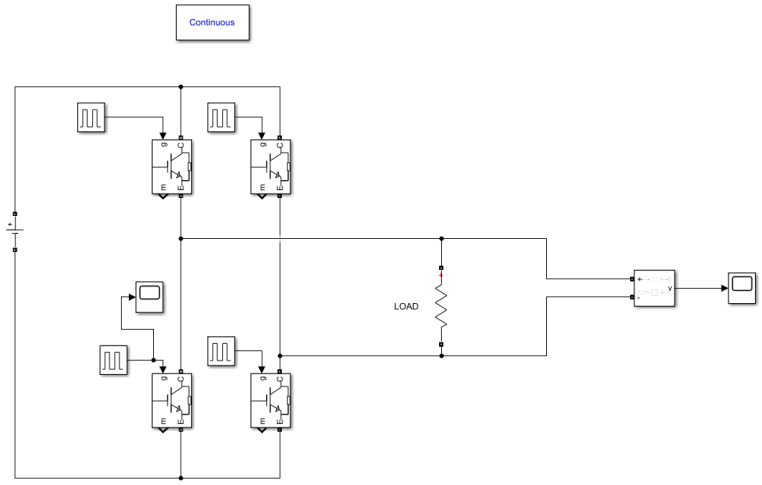


Fig. 7 Simulation circuit

In the output section, voltage meters and oscilloscopes are used to monitor whether there is a stable and reliable square wave alternating current across the load resistor. As shown in Fig. 8 on the oscilloscope, it can be observed that after the conversion above stages, the original 220-volt direct current is successfully converted into a smooth square wave pattern. When the pulse width is set to 25, the voltage square wave generated from the 220-volt alternating current produces a continuous smooth waveform (Fig. 9). However, this waveform is not a smooth square. A smooth square wave is generated only when the pulse width is set to 50.[11]

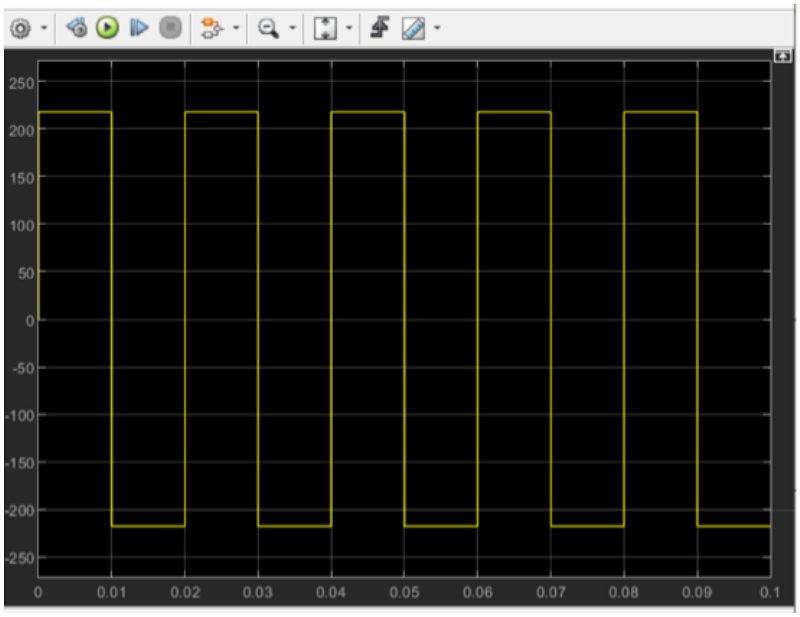


Fig. 8 The square wave of voltage on the oscilloscope

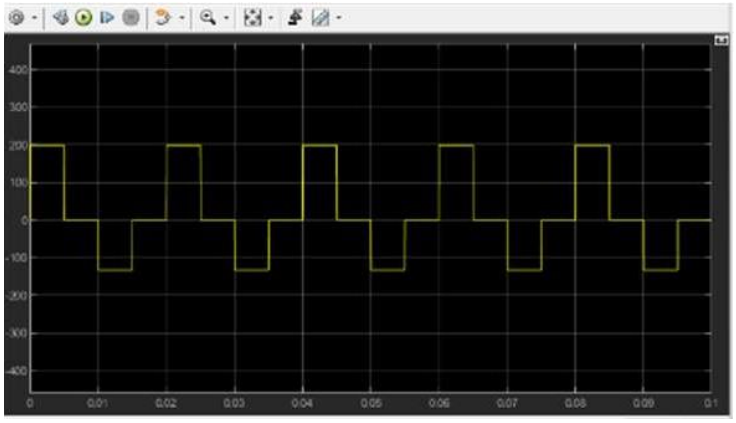


Fig. 9 The square wave of voltage when the wave width is 25.

5. Limitations and Technical Recommendations for Improvement of Inverters Using IGBT

The design and operation of single-phase inverters utilizing Insulated Gate Bipolar Transistors (IGBTs) may encounter certain limitations. Here are suggestions and improvement directions to facilitate potential product development:

IGBT inverters may introduce harmonic distortion, which can adversely affect the quality of the output waveform. Therefore, employing efficient filtering techniques, utilizing multi-level inverter configurations, or exploring other advanced topology structures to reduce harmonic distortion and enhance waveform purity is recommended.

IGBT inverters may experience energy losses during operation, leading to reduced efficiency. Therefore, it is recommended that advanced heat dissipation designs be implemented, circuit topology structures are optimized, and inverter efficiency is enhanced. Choosing high-performance GTO modules and heat-dissipation materials is crucial.

The control strategy of IGBT inverters may impact system stability and dynamic response. Therefore, it is recommended that advanced control algorithms, such as Space Vector Modulation (SVM), be adopted to optimize inverter performance. In-depth research and simulation testing of control strategies are crucial to ensure system stability and controllability.

6. Conclusion

This paper presents the design, modeling, simulation, and characterization of a single-phase unmanned aerial vehicle (UAV) power inverter using MATLAB and Simulink. The research covers the background and working principles of the inverter and the voltage input control of the controllable silicon-controlled rectifier. Building upon previous studies, this paper provides suggestions for the future improvement and potential commercialization of the inverter unit. Inverters are key components in UAVs, which convert direct current into alternating current. Addressing efficiency issues in UAV inverters, this paper proposes improvement strategies. PWM technology and IGBT transistors are employed. PWM technology enables periodic control of the output alternating current, enhancing the final output efficiency and allowing precise output voltage control. As advanced field-effect transistors on the market, IGBT transistors offer advantages such as fast switching speed, simple drive circuits, low power consumption, and good stability. The paper simulates and successfully outputs the circuit diagram using MATLAB. Experimental results demonstrate periodic 220V stable alternating current, presenting a stable square wave pattern in MATLAB. Compared to conventional inverters, the experiment yields higher efficiency, and due to PWM control, the voltage output is more stable and easier to control. However, issues such as imperfect waveform graphs persist in the experimental results. The paper proposes feasible future experimental and research directions. Although the simulated circuit design in this paper is simple, its iterative design, simulation, and analysis process is crucially valuable for improving power inverters in industrial applications.

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