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Comparative Analysis of Single-Phase MOSFET-Based and IGBT-Based Inverters: A Performance Evaluation

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Abstract

This research paper explores the application of MOSFETs and IGBTs in the development of single-phase inverters. An Inverter is an electronic device or circuit that converts DC power into alternating current AC power. Commencing with an overview of inverters and their versatile applications, the study thoroughly examines the distinct characteristics of MOSFETs and IGBTs. It then provides detailed insights into the hands-on creation of single-phase inverters using these semiconductor components. Employing simulation tools, the study rigorously compares their efficiency, waveform quality, and responsiveness to dynamic changes. These findings contribute valuable information for selecting the most suitable semiconductor technology when designing practical and reliable single-phase inverters across a spectrum of applications.

Keywords: MOSFETs, IGBTs, Single-phase inverters, DC to AC conversion, electronic devices, Semiconductor components, Inverter applications, Versatility of inverters, Characteristics of MOSFETs, Characteristics of IGBTs, Hands-on creation, Simulation tools, Efficiency comparison, Waveform quality, Responsiveness to dynamic changes, Semiconductor technology, Practical design, Reliable inverters, Application spectrum, Technology selection.

1. INTRODUCTION

In the dynamic landscape of power electronics, inverters play a pivotal role in converting direct current (DC) to alternating current (AC), facilitating the efficient and controlled transfer of electrical energy. The choice between Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) and Insulated Gate Bipolar Transistor (IGBT) based inverters has been a subject of considerable interest and scrutiny in recent years. This study aims to shed light on the comparative analysis of MOSFET-based and IGBT-based inverters, delving into their unique characteristics, advantages, and applications.

The significance of this comparative study lies in the crucial role inverters play in various applications, including renewable energy systems, electric vehicles, industrial drives, and uninterruptible power supplies (UPS). The choice between MOSFETs and IGBTs in inverter design can significantly impact the performance, efficiency, and overall reliability of these systems. Understanding the distinct attributes of MOSFET and IGBT technologies is vital for researchers, engineers, and practitioners seeking to optimize inverter designs for specific applications.

The purpose of this study is to provide a comprehensive analysis of MOSFET-based and IGBT-based inverters, considering factors such as power loss, switching frequency, thermal management, and cost. By comparing these two prominent semiconductor devices, we aim to identify the scenarios where each technology excels, guiding the selection process for inverter applications based on specific requirements and constraints.

2. LITERATURE REVIEW

This paper comprehensively explores the advancements, applications, and performance characteristics of single-phase MOSFET-based and IGBT-based inverters in the field of power electronics. The investigation places a significant focus on the utilization of high voltage IGBTs within the Current Source Inverter framework, delving into aspects such as modes in IGBT voltage waveforms, switching transients, and advanced gate drive techniques. Special attention is given to achieving snubber less operation and promoting Active Voltage Control for heightened controllability. Another facet of the survey delves into single-phase inverters employing MOSFETs, with a specific categorization into single-level and multilevel types. Noteworthy advantages of multilevel inverters, particularly in the context of speed control for induction motors, are underscored. The survey also highlights substantial technological advancements in power electronics, anticipating ongoing progress propelled by economic and regulatory factors. Furthermore, a comprehensive overview of power electronic converters is provided, emphasizing their diverse applications across sectors, ranging from milliwatts to hundreds of megawatts. The synthesis of these insights lays the groundwork for an in-depth comparative analysis titled "Comparative Analysis of Single-Phase MOSFET-Based and IGBT-Based Inverters: A Performance Evaluation." This analysis seeks to inform conclusive findings and offer recommendations on the appropriateness of these technologies for specific applications in power electronics, considering nuanced factors such as efficiency, control, and conversion characteristics.

3. METHODOLOGY

This section outlines the experimental setup and procedure employed for the MOSFET-based inverter, utilizing the IRF540 MOSFET. Detailed specifications of the MOSFET and the configuration of the inverter circuit are provided in Fig.1.

a) *MOSFET based Inverter*

Model of the MOSFET	IRF540
Specifications of the MOSFET	
Drain-Source Voltage (VDS)	100 V
Gate-Source Voltage (VGS)	±20 V
Continuous Drain Current (ID)	28 A (at TC = 25 °C) 20 A (at TC = 100 °C)
Pulsed Drain Current (IDM)	110 A
Maximum Power Dissipation (PD)	150 W (at TC = 25 °C)
DC Source	A 12-volt DC battery.

Table 1. MOSFET Details

Configuration of the Inverter Circuit: The configuration of the MOSFET-based inverter is accomplished using Proteus, incorporating the IRF540 MOSFET along with supporting components such as a CD4047BCN IC, 1N4007 diode, resistors, capacitors, a transformer, and a DC source. The IRF540 MOSFET is specified with a drain-source voltage (VDS) of 100V, gate-source voltage (VGS) of ±20V, and continuous drain current (ID) ranging from 20A at 100°C to 28A at 25°C. The inverter circuit is constructed in a push-pull configuration driven by the CD4047BCN IC in its astable mode, generating a square wave output. The CD4047 works by continuously changing the output at pin 10 and 11, producing opposite square wave outputs. These outputs are connected to the gate of the two IRF540 MOSFETs, arranged in push-pull configuration. The MOSFETs, capable of handling high current, are connected to the secondary winding of the transformer, inducing an alternating current (AC) in the primary winding. This AC is not sinusoidal but is effective in powering various devices like a 100W bulb or a small table fan. The configuration is validated using simulation tools in Proteus, offering insights into efficiency, waveform quality, and dynamic responsiveness. The inclusion of the practical details in Proteus ensures the applicability and reliability of the MOSFET-based inverter in real-world scenarios.

Transformer Details: A transformer with primary and secondary windings. Centre-tapped secondary winding connected to +12VCC.The primary winding induces a high voltage AC.

Procedure: The CD4047 operates in astable mode, continuously changing outputs at pins 10 and 11, generating a square wave output. Pins 10 and 11 connect to the gates of two IRF540 MOSFETs arranged in a push-pull configuration. These MOSFETs effectively handle high current through their drain-source paths. The transformer's secondary winding produces alternating current. The induced AC in the primary winding is not sinusoidal but effectively powers non-sensitive electronic devices. Caution: Exercise care and avoid touching the inverter when the LED indicates it is ON to prevent harm.

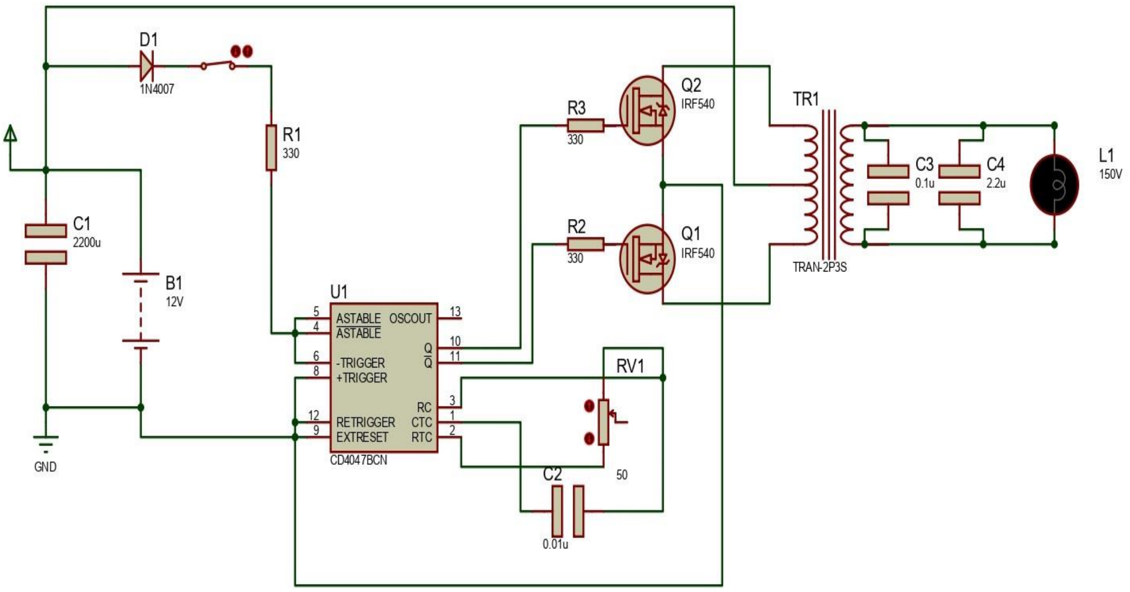

Fig.1 Circuit for MOSFET Based Inverter in Proteus

b) IGBT based Inverter

This section outlines the experimental setup and procedure employed for the IGBT-based inverter, utilizing the IHW20N120R3 IGBT. Detailed specifications of the IGBT and the configuration of the inverter circuit are provided in Fig.2.

Model of the IGBT	IHW20N120R3
Specifications of the IGBT	
Collector-Emitter Voltage (VCE):	1200 V

Collector Current (IC)	20 A
Collector-Emitter Saturation Voltage (VCEsat)	1.48 V
Maximum Operating Junction Temperature (Tvjmax)	175°C
Package	PG-TO247-3

Table 2. IGBT Details

Configuration of the Inverter Circuit: The inverter circuit is established using the IHW20N120R3 IGBT model, characterized by a collector-emitter voltage (VCE) of 1200V and a collector current (IC) of 20A. Employing sinusoidal pulse width modulation (PWM), the design incorporates a triangular wave as the carrier communication signal. This triangular wave is compared with the sine wave through an adder, generating an error signal. Subsequently, the error signal triggers the IGBT switches, resulting in the production of a bipolar sinusoidal output waveform. The IGBT switches are represented by the IHW20N120R3 model, illustrating both positive and negative cycles in the output waveform. The entire configuration is meticulously simulated in MATLAB Simulink, allowing for a comprehensive analysis of the bipolar model. The 12-volt DC battery serves as the primary power source for this model, ensuring its functionality and practicality in this research exploration of the single-phase PWM inverter.

Procedure: Choose appropriate blocks for the IGBT model, including IGBT blocks, PWM blocks, and necessary signal processing blocks. Place an IGBT block into the model and configure its parameters based on the IHW20N120R3 specifications, including collector-emitter voltage, collector current, and gate-emitter voltage. Integrate a PWM block for sinusoidal PWM generation. Configure the PWM parameters, considering the modulation index and carrier frequency Fig.3. Use an adder block to compare the generated triangular wave (carrier signal) with the desired sine wave, producing an error signal. Implement logic to trigger the IGBT switches based on the error signal. Use appropriate logic blocks for this purpose. Connect the output of the IGBT-based inverter to a scope block for visualization.

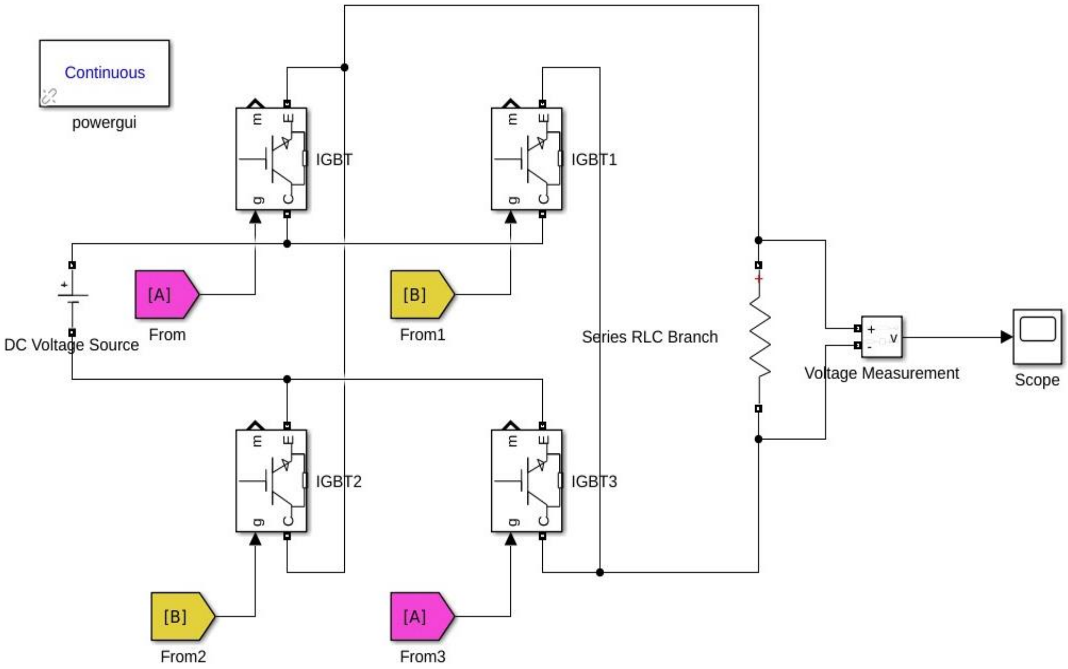

Fig2. Single Phase Inverter using IGBTs.

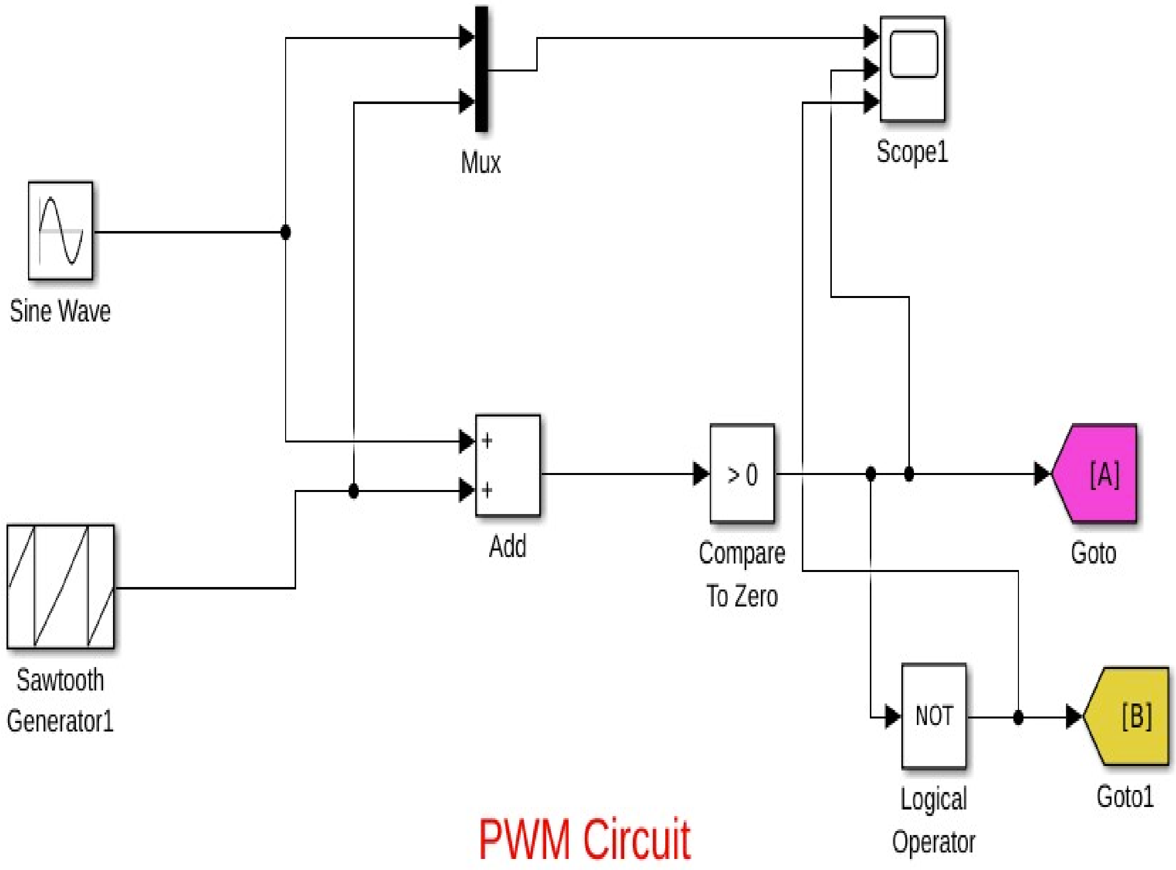

Fig3. Bipolar Triggering Circuit

4. EXPERIMENTAL RESULTS

a. MOSFET based Inverter

In this simulation setup, a MOSFET-based inverter circuit utilizing IRF540 MOSFETs and a push-pull configuration is employed. The initialization process begins with the power-on of the circuit. Oscillations are initiated through the astable mode of the CD4047BCN IC, generating triangular wave outputs at specific pins. These output signals drive the MOSFETs in a push-pull arrangement. An AC load, represented here by a 100W bulb, is then connected to the output of the transformer. The alternating square wave produced by the push-pull configuration induces AC in the load, causing it to glow as the inverter effectively converts DC to AC power.

The performance of the inverter is evaluated by analyzing the waveform of the output voltage using Proteus scope tools. Parameters such as frequency, amplitude, and waveform distortion are examined to assess the quality of the generated AC power. Additionally, efficiency metrics are calculated to gauge the effectiveness of the inverter in converting DC input power to AC output power. Parameters like total harmonic distortion (THD) are also measured to evaluate the purity of the output waveform and the level of distortion introduced during the conversion process. Through this comprehensive analysis, the efficiency and performance of the MOSFET-based inverter can be thoroughly assessed, providing insights into its suitability for practical applications.

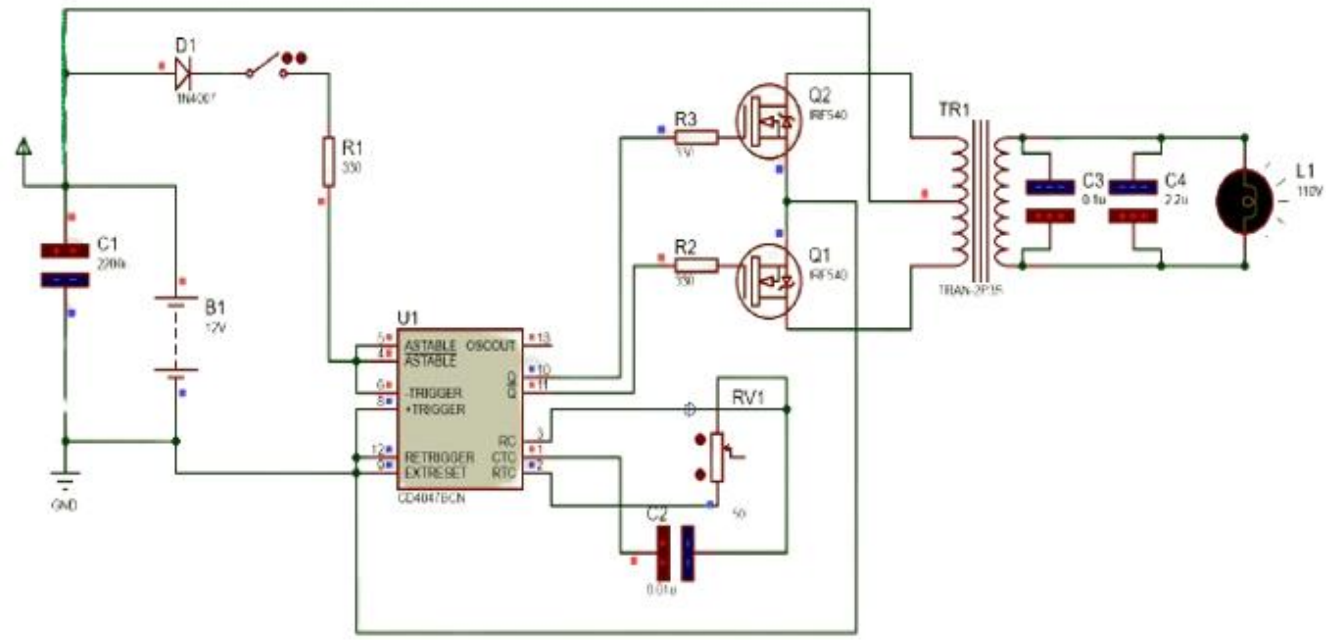

Fig.4 Simulation of MOSFET Inverter with AC load.

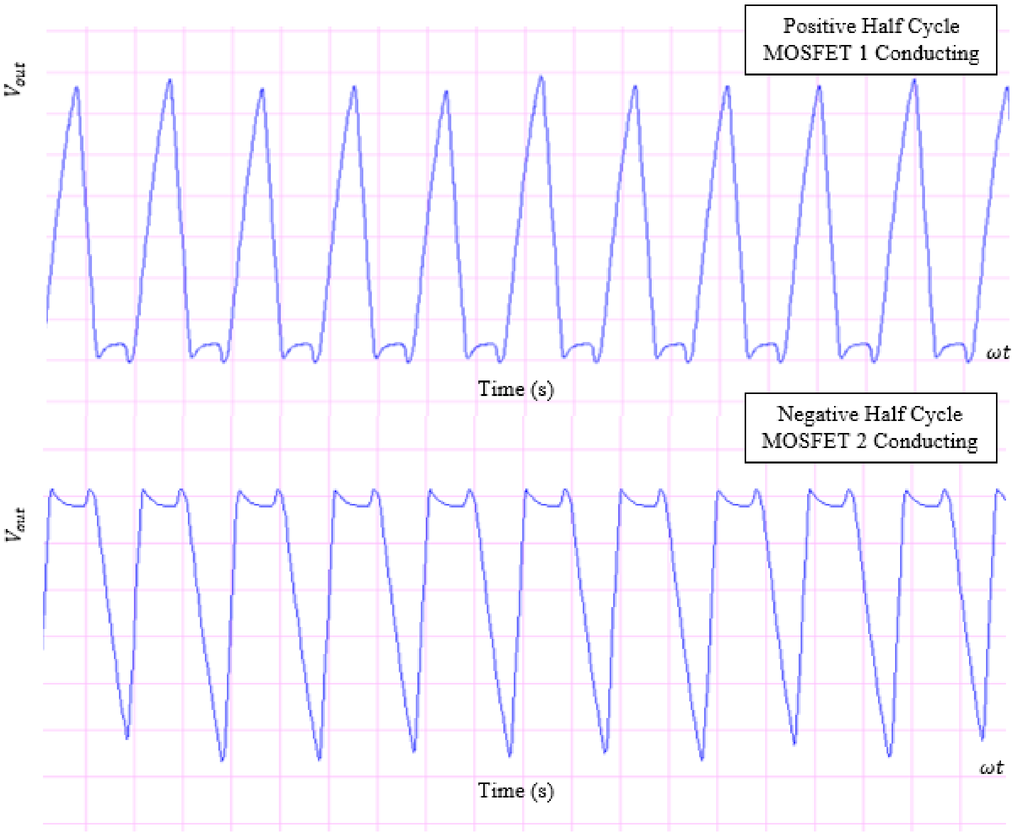

Fig.5 Output Waveform of AC Load Side

b. IGBT based Inverter

In this Simulink simulation setup, the focus lies on implementing an IGBT-based inverter configured for sinusoidal pulse width modulation (SPWM) to drive a resistive AC load. The initialization phase involves setting up the parameters of the IGBT model, crucial factors such as collector-emitter voltage, collector current, and gate-emitter voltage, ensuring accurate representation of the physical components within the simulation environment. Additionally, a sinusoidal PWM generation block is incorporated to facilitate the generation of SPWM signals essential for modulating the IGBT switches effectively.

The heart of the SPWM technique lies in generating precise PWM signals by comparing a carrier signal, typically a triangular wave, with a reference sine wave. This process yields an error signal, pivotal for accurately triggering the IGBT switches. By comparing the generated PWM with the reference sine wave, an error signal is created, dictating the switching behavior of the IGBTs. Proper modulation ensures optimal control over the inverter output, facilitating the generation of high-quality sinusoidal AC waveforms.

During simulation execution, the dynamic behavior of the IGBT-based inverter and its response to the PWM signals are observed in real-time. A resistive AC load is connected at the output of the inverter to simulate practical load conditions, enabling thorough observation of the system's performance under varying loads. The behavior of the AC load is closely monitored, providing insights into how the inverter interacts with and powers the connected load, crucial for assessing its practical applicability.

The analysis phase involves thorough examination of the output waveform characteristics using Simulink waveform analysis tools. Parameters such as frequency, amplitude, and distortion are meticulously analyzed to ensure the generated AC waveform meets the desired specifications. Furthermore, key performance metrics, including efficiency, total harmonic distortion (THD), and output stability, are evaluated to gauge the overall performance and reliability of the IGBT-based inverter. This comprehensive analysis facilitates informed decision-making regarding the suitability of the inverter for various real-world applications, ensuring optimal performance and efficiency.

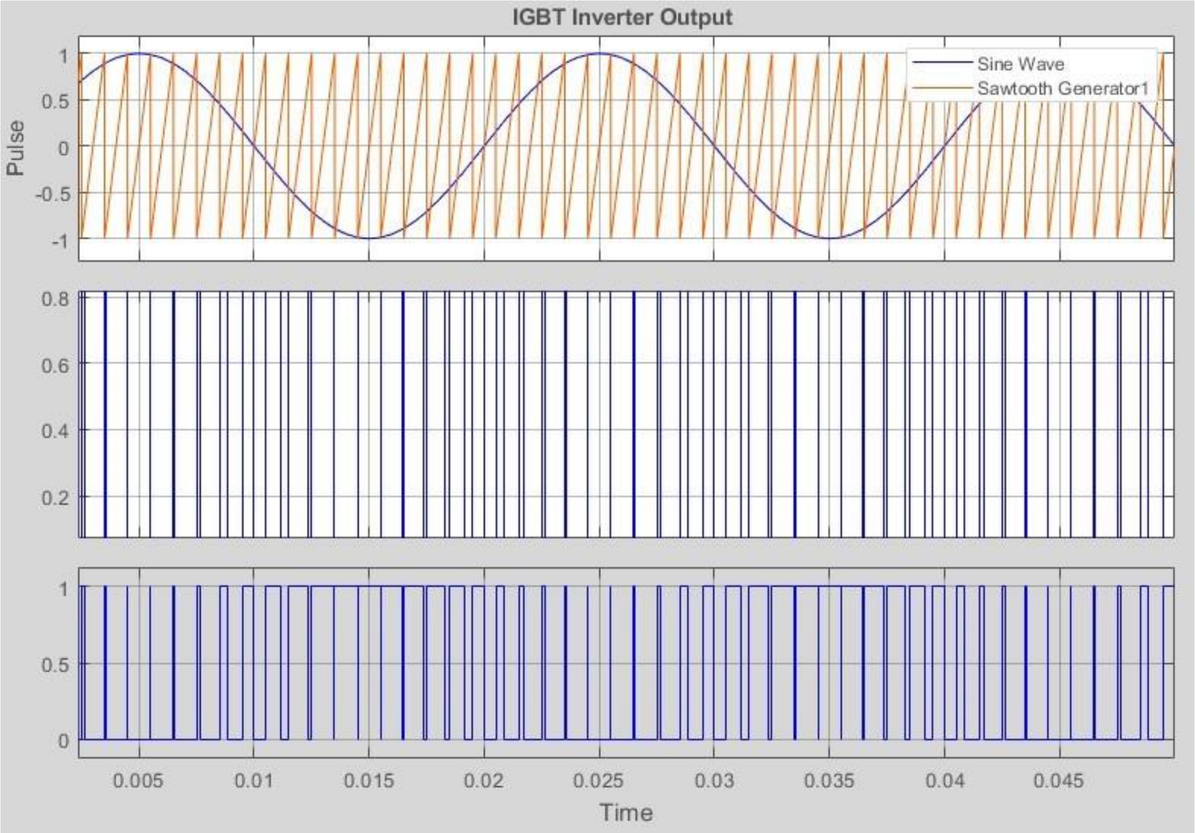

Fig.6 Output Waveform of IGBT Inverter

5. INFERENCE

a. *Efficiency and Performance:*

Both MOSFET and IGBT-based inverters demonstrate efficiency in converting DC to AC power. However, IGBT-based inverters exhibit higher efficiency due to their lower saturation voltage and higher current-carrying capacity compared to MOSFETs.

b. *Dynamic Response:*

The dynamic response of both inverters to load variations and parameter adjustments differs slightly. MOSFET-based inverters typically offer faster switching speeds, making them suitable for applications requiring rapid response times. On the other hand, IGBT-based inverters provide better stability and reliability under varying load conditions.

c. *Waveform Quality:*

While both inverters produce AC output waveforms, the waveform quality may vary. MOSFET-based inverters tend to exhibit higher harmonic distortion levels compared to IGBT-based inverters, resulting in poorer waveform quality. This can affect the performance of sensitive electronic devices connected to the inverter output.

d. *Complexity and Control:*

In terms of design complexity and control, MOSFET-based inverters are relatively simpler to implement due to their straightforward drive circuitry and lower gate capacitance. In contrast, IGBT-based inverters require more intricate control algorithms and drive circuitry, but offer superior performance and robustness in high-power applications.

e. *Application Suitability:*

The choice between MOSFET and IGBT-based inverters depends on the specific application requirements. MOSFET-based inverters are suitable for low to medium-power applications where cost-effectiveness and simplicity are prioritized. Meanwhile, IGBT-based inverters excel in high-power applications demanding superior efficiency, reliability, and waveform quality.

CONCLUSION

Through the conducted experiments and the subsequent comparative analysis, it becomes evident that both MOSFET-based and IGBT-based inverters are integral components in power electronics, each offering distinct advantages and trade-offs. MOSFET-based inverters, demonstrated through Proteus simulation, exhibit simplicity in design and rapid switching speeds, making them suitable for low to medium-power applications. However, they may suffer from higher harmonic distortion levels, impacting waveform quality. Conversely, IGBT-based inverters, exemplified via MATLAB Simulink, showcase superior efficiency, stability, and waveform quality, particularly in high-power scenarios. Despite their more complex control requirements, IGBT-based inverters provide robust performance and reliability under varying load conditions.

In selecting between MOSFET and IGBT-based inverters, application-specific requirements play a pivotal role. MOSFET-based inverters are preferred for cost-effective solutions with moderate power demands, while IGBT-based inverters excel in applications necessitating high efficiency, precise control, and superior waveform fidelity. Overall, the experiments underscore the importance of aligning inverter technology with the specific needs of the application, ensuring optimal performance and reliability in diverse power conversion scenarios.

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