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WIDE BANDGAP SEMI-CONDUCTOR INVERTER DESIGN (GAN/SIC)

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ABSTRACT-
Highly efficient and compact power electronic systems are required due to the rapid increase in the world's electricity demand, which is fueled by industrial growth, the integration of renewable energy sources, and electric mobility. Despite being widely utilized, conventional silicon (Si)-based inverters have intrinsic drawbacks include significant switching losses, limited high-frequency operation, and subpar thermal performance. Particularly in high-power and challenging working situations, these limitations result in decreased efficiency, large passive components, and difficulties with thermal control. Wide Bandgap (WBG) semiconductor materials like silicon carbide (SiC) and gallium nitride (GaN) have emerged as viable solutions to these problems because of their superior electrical and thermal properties. This study utilizes advanced WBG semiconductor devices, specifically SiC MOSFETs and GaN HEMTs, for inverter design and analysis. Simulation and modeling are carried out using power electronic design tools to evaluate performance parameters such as switching losses, conduction losses, efficiency, and thermal characteristics. A comparative analysis is performed between conventional Si-based inverters and WBG-based inverters under identical operating conditions. High-frequency switching techniques are implemented to analyze the impact on passive component size reduction and overall system compactness. The proposed work focuses on designing and implementing a high- efficient inverter using GaN and SiC components that can function at high switching frequencies. The technology seeks to greatly lower switching losses and increase power density by utilizing the fast-switching capabilities and high thermal conductivity of WBG materials. Improved thermal stability, less heat generation, increased inverter efficiency, and smaller inductors, capacitors, and filters are all anticipated results. Furthermore, the study expects the inverter system to be more reliable and suitable for high-power and high-frequency applications like electric vehicles and renewable energy systems.
***Keywords:* -** Wide Bandgap Semiconductors, Silicon Carbide (SiC), Gallium Nitride (GaN), High-Frequency Inverter, Switching Loss Reduction, Power Density Enhancement.

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I. INTRODUCTION

Power electronic converters with high efficiency and dependability are in great demand due to the fast rise in the world's electricity consumption, which is being driven by the expansion of renewable energy systems, the electrification of transportation, and industrial growth. For uses including grid integration, industrial drives, and electric vehicles (EVs), inverter systems are essential for turning DC power into AC power. However, traditional silicon (Si) semiconductor-based inverter technologies have a number of drawbacks when it comes to fulfilling contemporary performance standards, especially in high-power and high-frequency applications [Hossain et al., 2024]. Significant switching and conduction losses plague silicon-based power devices, such as MOSFETs and IGBTs, particularly at higher frequencies. In addition to lowering overall efficiency, these losses cause excessive heat generation, necessitating sophisticated thermal control systems. MOSFETs under high-frequency operation shows increased temperature rise due to switching transitions and nonlinear load conditions, highlighting the importance of efficient heat dissipation mechanisms [Cheng et al., 2025]. Additionally, traditional silicon devices have limited thermal conductivity, which restricts their operation in harsh environments and high-temperature conditions.

Another major limitation of silicon-based inverter systems is their inability to operate efficiently at very high switching frequencies. This constraint results in the use of large passive components such as inductors, capacitors, and filters, which increase the overall size, weight, and cost of the system. As modern applications demand compact and lightweight designs, especially in EVs and renewable energy systems, these limitations become increasingly significant [Suthar et al., 2025]. To overcome these challenges, Wide Bandgap (WBG) semiconductor materials such
as Silicon Carbide (SiC) and Gallium Nitride (GaN) have emerged as next-generation solutions in power electronics. These materials offer superior properties, including higher breakdown voltage, faster switching speed, lower on-resistance, and better thermal conductivity compared to silicon devices. SiC MOSFETs, for instance, provide enhanced power density and high-temperature operation capabilities, making them suitable for high-power applications [Lan et al., 2026]. Similarly, GaN devices exhibit excellent high-frequency performance and low switching losses, enabling compact and efficient converter designs [Shankari et al., 2026].

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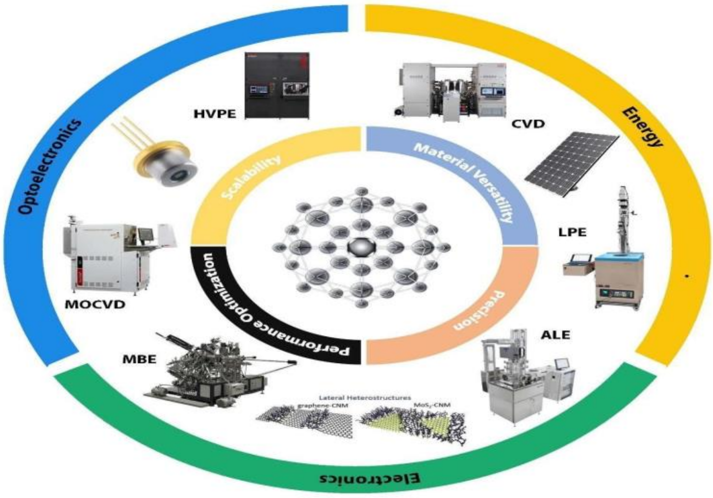

Figure 1: Wide-Bandgap Semiconductors: A Critical Analysis

WBG devices allow inverter systems to operate at much higher switching frequencies, which reduces the size of passive components and the total volume of the system. Research has demonstrated that as compared to traditional silicon-based systems, WBG-based converters may attain greater efficiency and lower energy losses. GaN-based converters, in particular, have shown the capacity to provide increased efficiency and power density, which makes them perfect for medium-voltage and fast-switching applications [Ponnambalam et al., 2025]. Additionally, WBG semiconductor technologies are essential for enhancing the efficiency of renewable energy applications and electric traction systems. SiC-based inverters efficiently under high voltage and temperature conditions. These systems not only improve energy conversion efficiency but also enhance system reliability and reduce operational costs [Soomro et al., 2025]. Despite these advantages, challenges such as higher initial cost, reliability concerns, and complex gate driving requirements still exist in the adoption of WBG devices. However, ongoing research and technological advancements are continuously addressing these issues

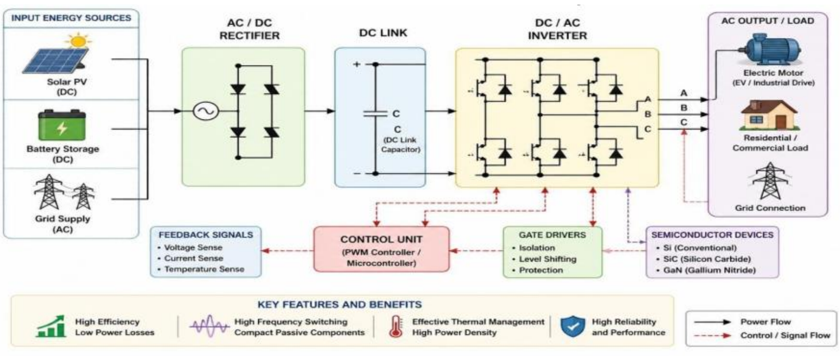

Figure 2: Basic Structure of Power Electronics-Based Inverter System

II. OBJECTIVE

1. To investigate the efficiency, thermal performance, and power density constraints of silicon-based inverters.
2. To use semiconductor devices with wide bandgaps (SiC and GaN) in inverter circuits to enhance performance.
3. To lower the size of filters, capacitors, and inductors by achieving greater switching frequency operating.
4. To increase overall efficiency by reducing switching and conduction losses.

2.1 PROBLEM STATEMENT

Growing demand for electricity due to: Conventional silicon Growing need for electricity because: The efficiency and compactness of conventional silicon (Si)-based inverters are limited in high-power and high-frequency applications. Switching losses in silicon devices result in large energy waste, which lowers inverter systems' overall performance. Si-based devices have reduced thermal conductivity, which makes thermal management difficult and restricts their use in hostile settings. Because silicon inverters have a restricted switching frequency, more passive components (inductors, capacitors, and filters) are needed, resulting in bulkier designs. Wide Bandgap (WBG) semiconductors have emerged as a transformative technology in modern power electronics, addressing the limitations of conventional silicon-based devices. These materials, primarily Silicon Carbide (SiC) and Gallium Nitride (GaN), possess a larger bandgap energy compared to silicon, enabling superior electrical, thermal, and switching performance. The increasing demand for high-efficiency, high-power density, and highfrequency systems has accelerated the adoption of WBG devices in applications such as electric vehicles, renewable energy systems, and industrial drives [Suthar et al., 2025]. WBG semiconductors enable operation at higher voltages, temperatures, and switching frequencies, which significantly improves the efficiency and compactness of power electronic systems.

Properties of SiC and GaN: Silicon Carbide (SiC) is widely recognized for its excellent thermal conductivity, high breakdown electric field, and ability to operate at elevated temperatures. These properties make SiC devices highly suitable for high-power and highvoltage applications such as traction drives and grid-connected inverters. SiC MOSFETs offer low on-resistance and high efficiency, along with improved reliability under harsh operating conditions. Additionally, SiC devices demonstrate superior power density and reduced energy losses, making them a key enabler in modern power electronics systems [Lan et al., 2026].

III. LITRETURE REVIWE

Dongsheng Lan et al., "Degradation Mechanism and Reliability Tests for SiC Power MOSFETs: Challenges and Progress" Elsevier, Available online 2026, 100188 https://doi.org/10.1016/j.chip.2025.100188

This review examines the degradation processes and failure mechanisms at both chip and package levels, focusing on device lifetime metrics such as threshold voltage and gate leakage current. Furthermore, it identifies common methods for improving reliability, aiming to support researchers and engineers in enhancing the practical applications of SiC power MOSFETs. Silicon Carbide Metal-Oxide Semiconductor Field-Effect Transistors (SiC MOSFETs) offer significant advancements in power electronics due to their superior thermal conductivity, power density, high breakdown voltage, and high-frequency capabilities

R. Shankari et al., "Vertical gallium nitride MOSFETs: Advanced architectures, fabrication technologies, and performance breakthroughs for high-power applications" Microelectronic Engineering, Elsevier, Volume 302, 2026, 112418 https://doi.org/10.1016/j.mee.2025.112418

The review evaluates the advancements in vertical gallium nitride (GaN) metal-oxidesemiconductor field-effect transistors (MOSFETs) as innovative solutions in power electronics, highlighting their superior performance over silicon-based devices. Key achievements include breakdown voltages over 1400 V, specific on-resistances below 1.4 mΩ·cm², and new device architectures such as FinFET-inspired designs. It discusses various manufacturing techniques and addresses challenges like substrate limitations and cost optimization while underscoring the potential of vertical GaN technology in transforming power electronics.

Jiale Cheng et al., "Thermal behavior and switching losses of MOSFET in high-frequency transformer circuits" Case Studies in Thermal Engineering , Elsevier,Volume 73, Se 2025, 106643.https://doi.org/10.1016/j.csite.2025.106643

The study addresses heat generation in MOSFETs within high-frequency transformer circuits, establishing a measurement system to track temperature variations and current. It reveals that temperature changes correlate with Joule heating; however, the thermal behavior differs between transformer and resistive loads. The experiments demonstrate that transformer coupled MOSFETs have frequency-dependent thermal characteristics, with increased switching duration and associated heat generation due to nonlinear load factors. A novel energy-conservation method was proposed to estimate MOSFET effective resistance during switching, offering insights for optimizing circuit designs. The findings underscore the importance of managing thermal reliability and resonant effects in high-frequency applications.

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Haocheng Wang et al., "Phase change based heat transfer for thermal management of metal-oxide-semiconductor field-effect transistors" Journal of Energy Storage , Elsevier ,Volume 114, Part A, 2025,

This study uses computational fluid dynamics to evaluate the addition of phase change material (PCM) in MOSFET systems for enhanced heat dissipation. Results show PCM significantly improves thermal management, with average MOSFET temperatures decreasing by 49.23 when using PCM-RT70HC compared to no PCM. A rectangular shape is optimal for the MOSFET/PCM system, while PCM-RT69HC offers the best performance, reducing temperatures by 10.4 against the highest temperatures. Shell materials with higher thermal conductivity further.

IV. RESEARCH METHODOLOGY

4.1 System Architecture

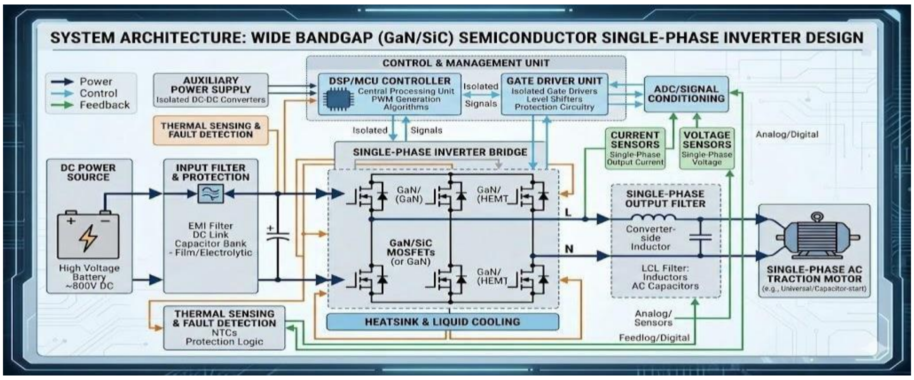

Figure 3: System Architecture

Introduction and Power Source

The system architecture illustrates a single-phase inverter designed to convert direct current (DC) into alternating current (AC) utilizing advanced wide bandgap (GaN or SiC) semiconductors. The power flow begins at the *DC Power Source*, typically represented by a high-voltage battery (e.g., an 800V DC system commonly found in modern electric vehicles or high-power industrial applications). This source provides the raw, continuous direct current required to drive the entire system.

Input Filtering and DC Bus Stabilization

Before the raw DC power reaches the delicate switching components, it passes through the *Input Filter & Protection* stage. This block contains an

Electromagnetic Interference (EMI) filter, which is essential for preventing high-frequency switching noise from feeding back into and disrupting the battery or power grid. Accompanying this is the DC Link Capacitor Bank (usually consisting of durable film or electrolytic capacitors). The DC link acts as an energy buffer; it stabilizes the DC bus voltage, smooths out transient voltage ripples, and supplies the instantaneous bursts of current required by the rapid switching action of the inverter bridge.

The Core Inverter Bridge (GaN/SiC)

The heart of the power conversion process takes place within the *Single-Phase Inverter Bridge*. This section is configured as an "H-bridge" containing four switching devices. Unlike traditional silicon-based designs, this architecture explicitly uses Wide Bandgap (WBG) materials—either Silicon Carbide (SiC) MOSFETs or Gallium Nitride (GaN) HEMTs. Because GaN and SiC possess a wider energy bandgap, these transistors can switch on and off at exceptionally high frequencies while withstanding higher voltages and temperatures. This drastically reduces switching losses and allows for a highly efficient, compact power conversion process.

V. CHAPTER 5 SYSTEM DESIGN

5.1 System Overview of Proposed Inverter

The proposed inverter system is designed using Wide Bandgap (WBG) semiconductor devices, specifically Silicon Carbide (SiC) MOSFETs and Gallium Nitride (GaN) High Electron Mobility Transistors (HEMTs), to achieve high efficiency, high switching frequency operation, and improved power density. The system aims to overcome the limitations of conventional silicon-based inverters by leveraging the superior electrical and thermal properties of WBG materials [Suthar et al., 2025]. The overall architecture of the proposed inverter consists of three primary stages: the input stage, the power conversion stage, and the output stage. The input stage includes a DC power source, which may be derived from renewable energy systems such as solar photovoltaic (PV) panels or battery storage units. This DC input is fed into a DC link, which stabilizes the voltage using capacitors and acts as an intermediate energy storage element [Ponnambalam et al., 2025]. The core of the system is the inverter stage, where DC power is converted into AC power using a bridge configuration of SiC or GaN switching devices. These devices are controlled using advanced Pulse Width Modulation (PWM) techniques, enabling precise control of output voltage and frequency. Due to the high switching capability of WBG devices, the inverter can operate at significantly higher frequencies compared to conventional silicon-based systems, resulting in reduced switching losses and improved efficiency [Shankari et al., 2026]. A dedicated gate driver circuit is employed to provide the required switching signals to the WBG devices. The

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gate driver ensures proper isolation, fast switching transitions, and protection against overvoltage and overcurrent conditions. Since GaN and SiC devices require precise gate control due to their high-speed switching characteristics, the gate driver design plays a critical role in overall system performance [Trivedi et al., 2022]. The output stage of the inverter delivers AC
power to the load, which may include electric motors, grid-connected systems, or residential loads. Filters are incorporated at the output to reduce harmonics and improve power quality. Due to highfrequency operation enabled by WBG devices, the size of these passive components is significantly reduced, leading to a more compact system design [Hamanah et al., 2023].

5.2 Selection of Semiconductor Devices

The selection of semiconductor devices is a critical aspect in the design of high-performance inverter systems. In this study, Wide Bandgap (WBG) semiconductor devices, namely Silicon Carbide (SiC) MOSFETs and Gallium Nitride (GaN) High Electron Mobility Transistors (HEMTs), are selected due to their superior electrical characteristics, high efficiency, and capability to operate at high switching frequencies. These devices are chosen to overcome the limitations of conventional silicon-based devices and to enhance the overall performance of the inverter system [Suthar et al., 2025].

Silicon Carbide (SiC) MOSFETs are widely used in high-power and high-voltage applications due to their excellent thermal conductivity and high breakdown voltage capability. These devices are capable of operating at elevated temperatures and offer lower switching losses compared to traditional silicon-based MOSFETs and IGBTs. The high electric field strength of SiC allows for thinner drift regions, resulting in reduced on-resistance and improved efficiency [Lan et al., 2026]. Typical specifications of SiC MOSFETs used in inverter applications include voltage ratings in the range of 650 V to 1700 V, making them suitable for medium-to highpower systems. They exhibit low on-state resistance ($R_{DS(on)}$), which reduces conduction losses, and fast switching characteristics that minimize turn-on and turn-off losses. Additionally, SiC devices can operate at junction temperatures exceeding 200°C, significantly improving thermal performance and reliability [Shahjalal et al., 2023].

Gallium Nitride (GaN) HEMTs are selected for their exceptional high-frequency performance and ultra-fast switching capabilities. These devices are particularly suitable for applications requiring compact size and high efficiency, such as DC-DC converters, EV chargers, and low- to medium-power inverter systems. GaN devices exhibit high electron mobility, which enables rapid switching transitions and significantly reduces switching losses [Shankari et al., 2026].

5.3 Inverter Topology Design

The inverter topology plays a crucial role in determining the performance, efficiency, and reliability of the overall power conversion system. In this study, advanced inverter topologies are designed using Wide Bandgap (WBG) semiconductor devices such as Silicon Carbide

(SiC) MOSFETs and Gallium Nitride (GaN) HEMTs. These devices enable high-frequency switching, reduced losses, and improved power density, making them suitable for modern inverter architectures [Suthar et al., 2025]. The selection of inverter topology depends on the application requirements, including power rating, output waveform quality, and system complexity. Among various configurations, single-phase and three-phase inverter topologies are widely used in practical applications such as residential systems, industrial drives, and electric vehicles [Hossain et al., 2024].

A single-phase inverter is commonly used in low- to medium-power applications such as residential loads, small renewable energy systems, and uninterruptible power supplies (UPS). The most widely used configuration is the full-bridge (H-bridge) inverter, which consists of four switching devices arranged in a bridge structure. These switches are controlled using Pulse Width Modulation (PWM) techniques to generate an AC output from a DC input source. In the proposed design, SiC or GaN switches are used in the H-bridge configuration to achieve high switching speed and improved efficiency. The inverter operates by alternately switching pairs of devices to produce a sinusoidal output waveform. The use of WBG devices significantly reduces switching and conduction losses, enabling higher efficiency and compact system design [Trivedi et al., 2022].

VI. RESULT & DICUSSION

6.1 Simulation Results of SiC/GaN-Based Inverter

The proposed inverter using Wide Bandgap (WBG) semiconductor devices, such as SiC MOSFETs and GaN HEMTs, was simulated to evaluate its performance improvements over conventional systems. The results demonstrate significant improvement in output waveform quality, switching performance, and efficiency. Performance at High Frequencies Because SiC and GaN devices can switch quickly, the WBG-based inverter can function well at higher switching frequencies. With less ripple and harmonic distortion, the output waveform is smoother. Smaller passive components may be used thanks to high-frequency operation, which helps create a more compact system design. Efficiency Gain The efficiency of the inverter is significantly higher than that of the silicon-based system. Diminished switching and conduction losses result in lower power dissipation and improved energy conversion. Additionally, better thermal performance minimizes heat generation, enhancing system reliability and lifespan. Overall, the WBG-based inverter provides superior performance in terms of efficiency, power quality, and compactness.

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6.2 Model Photos

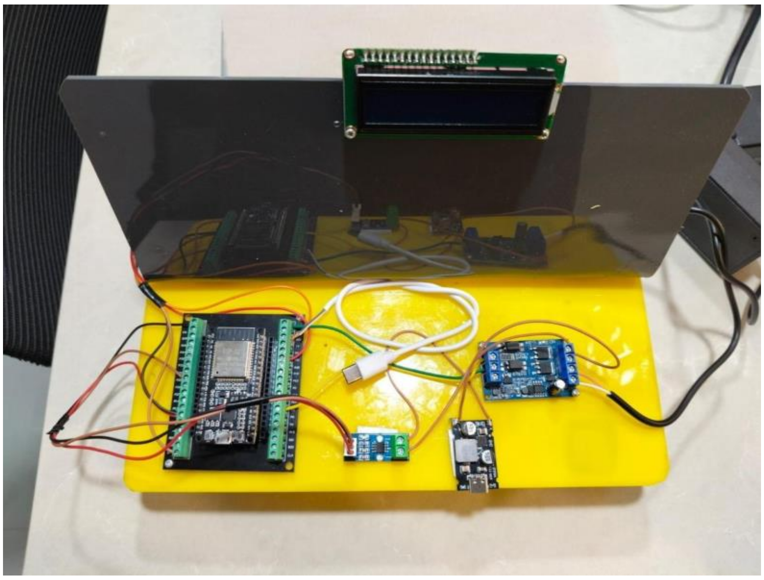

Photo 1: Model Photo

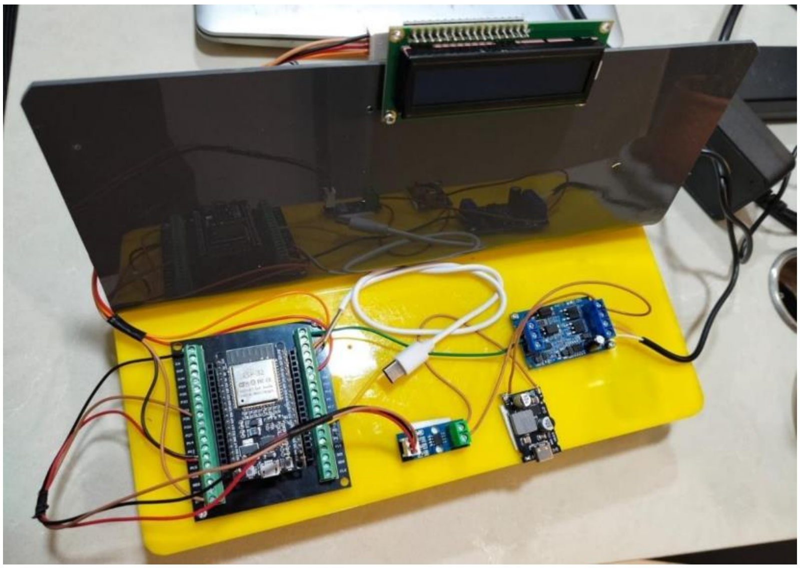

Photo 2: Model Photo

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VII. CONCLUSION

In comparison to traditional silicon-based designs, the study shows that the performance of inverter systems is much improved by the employment of Wide Bandgap (WBG) semiconductor devices, notably Silicon Carbide (SiC) MOSFETs and Gallium Nitride (GaN) HEMTs. The suggested inverter achieves increased efficiency, lower switching and conduction losses, and better thermal management by utilizing the superior electrical and thermal characteristics of WBG materials. Higher switching frequencies allow for a significant reduction in passive component size, making the system lighter and more compact while also increasing power density. Additionally, superior output waveform quality with less harmonic distortion is a result of the enhanced switching characteristics. Overall, the findings demonstrate that WBG-based inverters offer a dependable, effective, and cutting-edge solution for contemporary
applications such as electric vehicles, renewable energy systems, and high-performance industrial drives, making them a key technology for next-generation power electronics.

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