# Design and Development of a Silicon Carbide (SiC) Based Inverter for Motor Control in Electric Two-Wheelers

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***Abstract*—This paper presents the design and simulation of a high-efficiency Silicon Carbide (SiC)-based motor controller for electric vehicle applications. Conventional silicon-based controllers suffer from high switching losses and reduced efficiency at high switching frequencies. To address these limitations, the proposed system utilizes SiC power devices to enhance switching performance, reduce power losses, and improve thermal characteristics. A three-phase inverter topology is implemented and analyzed using simulation tools to evaluate system performance under varying load conditions. The results demonstrate a significant improvement in efficiency, faster switching response, and reduced thermal stress compared to traditional silicon-based controllers. The proposed approach provides a compact, energy-efficient, and reliable solution for next-generation electric vehicle propulsion systems.**

***Index Terms*—Electric Vehicles, Silicon Carbide (SiC), Motor Controller, Three-Phase Inverter, Power Electronics, Efficiency, Switching Losses**

## I. INTRODUCTION

The rapid growth of electric vehicles (EVs) is driving significant advancements in power electronic converters and motor drive systems. Increasing environmental concerns, stringent emission regulations, and the growing demand for energy-efficient transportation have accelerated the adoption of electrified vehicles worldwide [1]. Among various EV categories, electric two-wheelers have gained considerable popularity due to their affordability, compact structure, and suitability for urban transportation. These vehicles require lightweight, compact, and highly efficient motor controllers to maximize battery utilization and overall vehicle performance.

Conventionally, silicon (Si)-based insulated gate bipolar transistors (IGBTs) and MOSFETs have been widely used in traction inverters and motor controller applications. However, conventional silicon devices suffer from several limitations such as high switching losses, lower switching speed, limited operating temperature capability, and reduced power density [1], [3]. These drawbacks reduce converter efficiency and increase thermal stress, particularly under high-frequency switching operation. As EV technologies continue to evolve toward compact and high-performance architectures, traditional silicon-based semiconductor devices are approaching their practical performance limits [3].

Wide bandgap semiconductor devices, particularly Silicon Carbide (SiC) MOSFETs, have emerged as promising alternatives for next-generation electric vehicle power converters [2]. SiC devices provide several advantages including higher breakdown voltage, lower on-resistance, superior thermal conductivity, faster switching capability, and higher temperature operation compared to conventional silicon devices [1], [3]. The reduced switching and conduction losses of SiC MOSFETs enable improved inverter efficiency, reduced cooling requirements, and compact converter implementation suitable for electric two-wheeler applications. Furthermore, SiC-based traction inverters have demonstrated efficiencies exceeding 98% with significantly improved power density [1].

Recent industrial developments have further validated the practical adoption of SiC technology in electric vehicles. Modern EV manufacturers such as Tesla have implemented SiC-based traction inverters to improve system efficiency, switching performance, and vehicle driving range [1]. Due to their superior switching characteristics and reduced parasitic capacitances, SiC devices are highly suitable for high-frequency motor control applications requiring fast dynamic response and compact converter structures [4].

Despite these advantages, the implementation of SiC MOSFETs introduces several technical challenges related to high-frequency switching behavior, electromagnetic interference (EMI), thermal management, gate driving complexity, and voltage balancing [1], [4]. In high-frequency power electronic systems, even small gate signal mismatches can result in significant voltage imbalance and switching stress across semiconductor devices [4]. Therefore, the design of reliable gate driver circuits and proper switching control techniques becomes essential for achieving stable and efficient converter operation.

Several recent studies have focused on transformer-coupled isolated gate driver architectures and synchronized switching techniques for SiC MOSFETs. These approaches provide improved voltage balancing, galvanic isolation, high-speed switching capability, and programmable switching operation for advanced power electronic applications [4]. However, limited work has focused on the implementation of compact SiC MOSFET-based power stages specifically optimized for electric two-wheeler motor controller applications.

Therefore, this work focuses on the design and development of a high-efficiency motor controller incorporating a SiC MOSFET-based inverter power stage for electric two-wheeler applications. The proposed system aims to reduce switching losses, improve thermal performance, and achieve compact converter implementation suitable for next-generation EV systems.

## II. METHODOLOGY / SYSTEM DESIGN

### *A. Overall System Architecture*

Fig. 1 illustrates the overall architecture of the proposed SiC MOSFET-based motor controller for electric two-wheeler applications. The system consists of a 48 V DC supply, DC link capacitor stage, three-phase SiC MOSFET inverter, isolated gate driver circuit, STM32 microcontroller unit, and BLDC/PMSM motor load.

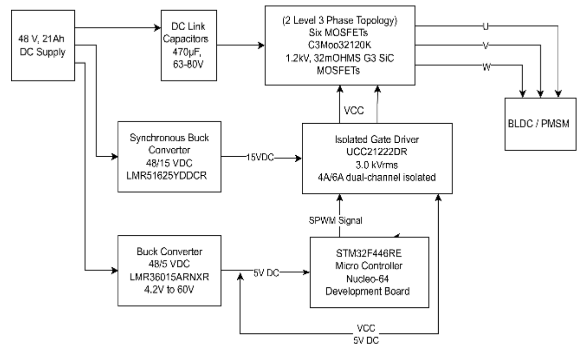



Fig. 1 Overall architecture of the proposed SiC MOSFET-based motor controller for electric two-wheeler applications.

The 48 V battery supply provides the primary input power to the inverter system. A DC link capacitor bank is employed to stabilize the DC bus voltage and reduce voltage ripple during inverter switching operation. The inverter stage utilizes a two-level three-phase topology consisting of six SiC MOSFETs configured in a bridge arrangement to generate controlled three-phase AC output for motor drive applications.

An isolated gate driver circuit based on the UCC21222DR driver IC is used to provide reliable switching pulses to the SiC MOSFETs. The gate driver receives SPWM control signals from the STM32F446RE microcontroller and ensures proper isolation, switching synchronization, and high-speed gate driving operation. Separate buck converter stages are employed to generate regulated 15 V and 5 V DC supplies required for the gate driver and control circuitry, respectively.

The STM32F446RE microcontroller performs SPWM generation and inverter switching control for the motor drive system. The generated PWM signals control the switching sequence of the inverter MOSFETs to produce balanced three-phase output voltages for BLDC/PMSM motor operation.

### *B. Inverter Power Stage Design*

The proposed motor controller employs a conventional two-level three-phase Voltage Source Inverter (VSI) topology for electric two-wheeler motor drive applications, as shown in Fig. 2

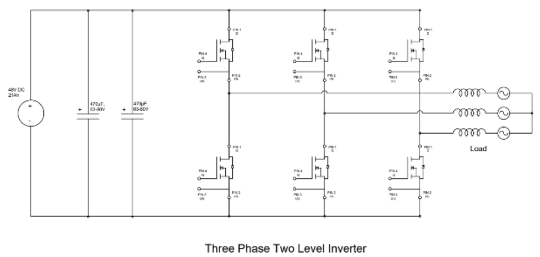



Fig. 2. Three-phase two-level SiC MOSFET-based inverter topology for electric two-wheeler motor controller applications.

The two-level VSI topology is widely utilized in motor drive and transportation systems due to its simple structure, reliable operation, and ease of implementation [5]. The inverter converts the DC input voltage into a controlled three-phase AC output required for BLDC/PMSM motor operation.

The inverter power stage consists of six Silicon Carbide (SiC) MOSFETs configured in a three-phase bridge arrangement. Each inverter leg contains one upper switch and one lower switch operating in a complementary switching manner to generate phase voltages for the motor load. A 48 V DC battery supply is used as the primary input source for the inverter system. Two 470 µF DC link capacitors rated for 63–80 V are connected across the DC bus to stabilize the input voltage and minimize voltage ripple during high-frequency switching operation.

The proposed inverter utilizes C3M0032120K Generation-3 SiC MOSFETs due to their superior switching performance, lower conduction losses, reduced parasitic capacitance, and improved thermal capability compared to conventional silicon-based devices [1], [3]. The low ON-state resistance and high switching speed of SiC MOSFETs enable efficient inverter operation with reduced switching losses and compact thermal design suitable for electric vehicle applications.

Sinusoidal Pulse Width Modulation (SPWM) technique is employed to generate switching pulses for the inverter switches. In SPWM operation, the reference sinusoidal waveform is compared with a high-frequency triangular carrier waveform to determine the switching instants of the inverter devices [5]. The generated PWM signals are applied to the isolated gate driver circuit to control the switching sequence of the SiC MOSFETs and produce balanced three-phase AC output voltages for motor operation.

Proper complementary switching with dead-time insertion is implemented between the upper and lower switches of each inverter leg to prevent shoot-through conditions and improve inverter reliability. The proposed two-level SiC-based inverter topology provides compact implementation, fast dynamic response, reduced switching losses, and improved efficiency suitable for electric two-wheeler propulsion systems.

*C. Gate Driver Circuit*

The proposed inverter system employs the UCC21222DR isolated dual-channel gate driver for driving the SiC MOSFET switches, as shown in Fig. 3.

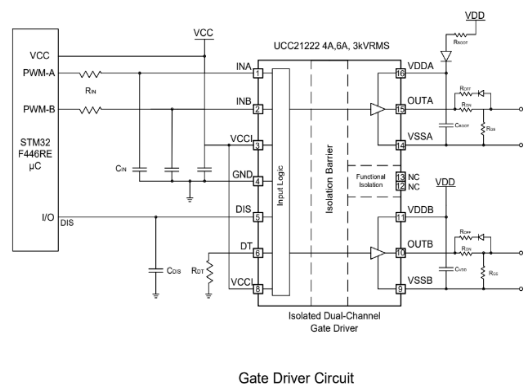



Fig. 3 Isolated dual-channel gate driver circuit using UCC21222DR for SiC MOSFET switching control.

The gate driver provides galvanic isolation between the low-voltage control circuit and the high-power inverter stage, ensuring reliable and safe switching operation. The STM32F446RE microcontroller generates SPWM signals which are applied to the input terminals of the gate driver for controlling the inverter switches.

The UCC21222DR gate driver supports high-speed switching operation with 4 A source and 6 A sink current capability, making it suitable for fast-switching SiC MOSFET applications. Separate gate resistors are utilized to control the turn-ON and turn-OFF switching characteristics of the MOSFETs and minimize switching oscillations. The isolation barrier within the driver improves noise immunity and protects the control circuitry from high-voltage transients generated during inverter operation [4].

Proper dead-time insertion and complementary switching control are implemented to prevent shoot-through conditions between the upper and lower inverter switches. The isolated gate driver architecture improves switching synchronization, inverter reliability, and high-frequency switching performance required for electric vehicle motor controller applications [4].

### *D. SiC MOSFET Selection*

The proposed inverter system utilizes C3M0032120K Generation-3 Silicon Carbide (SiC) MOSFETs in the inverter power stage due to their superior switching and thermal performance compared to conventional silicon-based devices. SiC MOSFETs offer lower switching losses, higher switching speed, lower ON-state resistance, and improved thermal conductivity, making them suitable for high-frequency electric vehicle motor controller applications [1], [3].

The selected SiC MOSFETs feature approximately 32 mΩ ON-state resistance and support efficient high-speed switching operation with reduced power dissipation. Their fast-switching capability and lower parasitic capacitances improve inverter efficiency and reduce thermal stress during operation. In addition, SiC devices can operate at higher temperatures compared to conventional silicon devices, enabling compact converter implementation with reduced cooling requirements [1].

Due to these advantages, SiC MOSFETs are widely adopted in modern electric vehicle traction inverter systems for achieving high efficiency, improved power density, and reliable inverter operation [1], [2].

### *E. Control Strategy*

The proposed motor controller utilizes the Sinusoidal Pulse Width Modulation (SPWM) technique for controlling the switching operation of the three-phase SiC MOSFET inverter. SPWM is widely adopted in motor drive applications due to its simple implementation, stable switching operation, and effective harmonic reduction capability [6].

In the SPWM technique, a sinusoidal reference waveform is compared with a high-frequency triangular carrier waveform to generate PWM switching pulses for the inverter switches. The generated PWM signals control the switching sequence of the SiC MOSFETs to produce balanced three-phase AC output voltages required for BLDC/PMSM motor operation. The modulation process enables control of inverter output voltage and switching operation [6].

The SPWM signals are generated using the STM32F446RE microcontroller and applied to the isolated gate driver circuit for inverter switching control. Proper complementary switching and dead-time insertion are implemented between the upper and lower switches of each inverter leg to prevent shoot-through conditions and improve inverter reliability.

The SPWM control strategy provides smoother output waveforms, reduced harmonic distortion, improved switching performance, and stable motor operation suitable for electric two-wheeler applications

## III. SIMULATION AND ANALYSIS

### *A. Simulation Setup*

The proposed SiC MOSFET-based Inverter was simulated using the PLECS simulation platform to evaluate the inverter switching performance and output characteristics under electric vehicle operating conditions. The simulation model consists of a 48 V DC supply, three-phase two-level SiC MOSFET inverter, isolated gate driver logic, SPWM control strategy, and motor load.

The inverter power stage utilizes six SiC MOSFET switches arranged in a conventional three-phase bridge topology. SPWM switching pulses are generated and applied to the inverter switches through the gate driver circuit to produce controlled three-phase AC output voltages for motor operation. The simulation was performed to analyze the inverter switching behavior, input control signals, output voltage waveforms, and output current characteristics

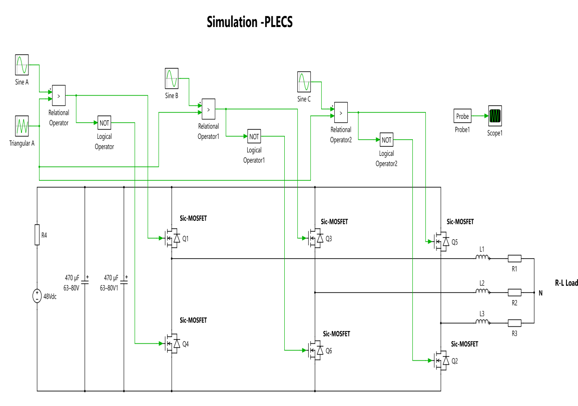



Fig. 4 PLECS simulation model of the proposed SiC MOSFET-based Inverter system.

The simulation parameters used in the proposed system are listed in Table I.

Table I. Simulation Parameters

| Simulation Parameters | | |
|---|---|---|
| Sr.No. | Parameter | Value |
| 1. | DC Input Voltage | 48 V |
| 2. | Inverter Topology | 3-Phase Two-Level VSI |
| 3. | Switching Device | SiC MOSFET |
| 4. | PWM Technique | SPWM |
| 5. | Switching Frequency | 10 kHz |
| 6. | Simulation Software | PLECS |
| 7. | Load | Inductive |

*B. Input Control Signal Analysis*

The SPWM control technique was utilized to generate switching pulses for the inverter switches. In this method, the sinusoidal reference signal is compared with a high-frequency triangular carrier waveform to generate PWM gate pulses for the SiC MOSFETs [6]. Fig. 5 shows the generated SPWM switching signals applied to the inverter switches. The generated pulses provide proper switching control for the upper and lower MOSFET switches of each inverter leg.

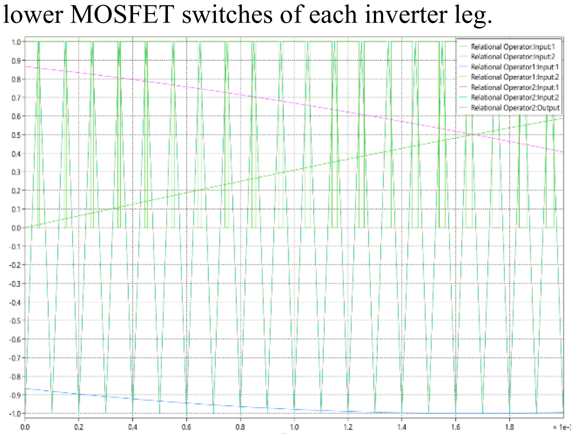


Fig. 5 Simulated SPWM gate pulse signals for inverter switching control.

In a three-phase system, three sine waves are used with a phase difference of 120° between them. These are compared with a common triangular wave to generate three PWM signals. These PWM signals control the inverter switches, resulting in an output voltage that approximates a sinusoidal waveform

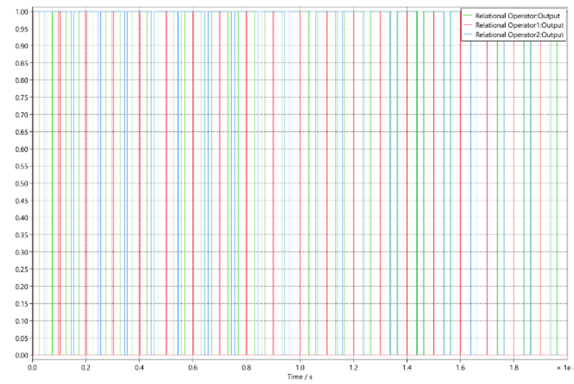


Fig. 6 Comparator output

The modulation index determines the amplitude of the output voltage. By adjusting the amplitude of the sine wave relative to the triangular wave, the output voltage can be controlled. SPWM offers advantages such as reduced harmonic distortion, better efficiency, and smoother output compared to square wave inverters

*C. Output Voltage Analysis*

The output voltage waveform of the proposed three-phase inverter was analyzed using PLECS simulation. The inverter successfully converted the 48 V DC input supply into controlled three-phase AC output voltages suitable for motor drive operation.

Fig. 7 shows the simulated inverter output voltage waveform. The generated output demonstrates balanced three-phase switching operation with proper phase displacement between inverter outputs. The fast-switching capability of the SiC MOSFETs improves waveform quality and switching response during inverter operation

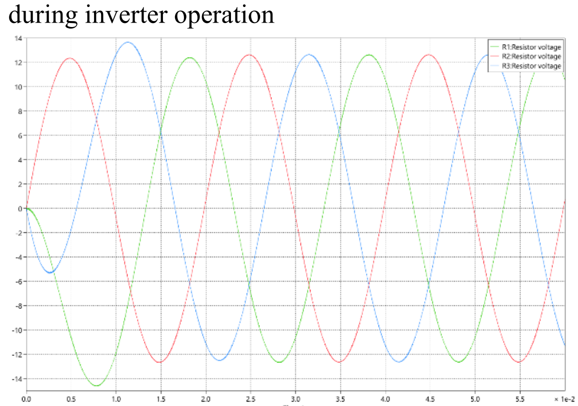


Fig. 7 Simulated three-phase inverter output voltage waveform

*D. Current Waveform Analysis*

The current characteristics of the proposed inverter system were analyzed using PLECS simulation under SPWM switching control. Both the input DC current and inverter output phase current waveforms were observed during simulation.

Fig. 7 shows the simulated input DC current waveform of the inverter system, while Fig. 8 illustrates the simulated inverter output phase current waveform. The obtained waveforms indicate stable inverter operation and proper switching performance of the proposed SiC MOSFET-based inverter system.

The SPWM control technique provides smoother current characteristics with reduced switching distortion suitable for electric two-wheeler motor drive applications

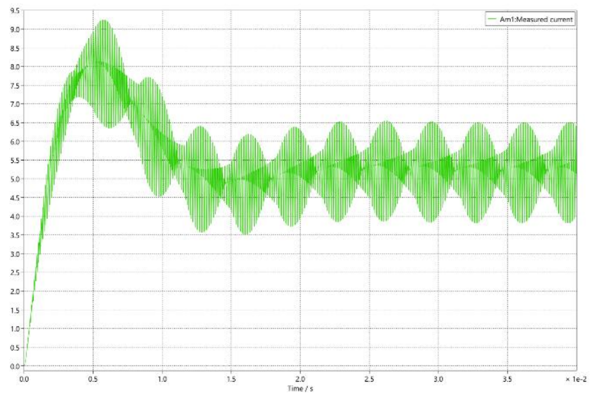
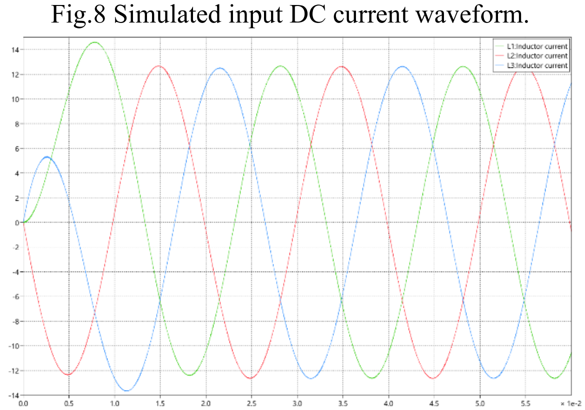



Fig.8 Simulated input DC current waveform.




.Fig.9 Simulated inverter output phase current waveform.

*E. Simulation Performance Discussion*

The simulation results demonstrate that the proposed SiC MOSFET-based inverter system operates successfully under SPWM switching control. The inverter produces balanced three-phase output voltages and stable current waveforms suitable for electric vehicle motor drive applications.

The fast switching characteristics and lower switching losses of SiC MOSFETs improve inverter switching performance and reduce thermal stress during operation. The obtained simulation results verify the effectiveness of the proposed inverter topology and SPWM control strategy for electric two-wheeler propulsion systems.

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