Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 15(3), 845-860, 2025
Journal of the Institute of Science and Technology, 15(3), 845-860, 2025
ISSN: 2146-0574, eISSN: 2536-4618
Electrical Electronic Engineering **DOI: 10.21597/jist.1484043**
Research Article
Received: 15.05.2024 **Accepted: 14.02.2025**

To Cite: Tepedelen, H., Eid B. Adak, S., & Cangi, H. (2025). Development of Ultra Fast Gate Driver Board for Silicon Carbide MOSFET Applications. *Journal of the Institute of Science and Technology*, 15(3), 845-860.

Development of Ultra Fast Gate Driver Board for Silicon Carbide MOSFET Applications

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Highlights:
- Mosfet driver board
- SiC Mosfet
- Wide band gap

Keywords:
- SiC MOSFET
- PWM inverters Keyword
- Solar inverter
- Gate Drive Board
- Switching device

ABSTRACT:

Silicon Carbide (SiC) is increasingly utilized in high-temperature, high-power applications due to its exceptional properties, including high-temperature resistance, high electrical conductivity, and a wide bandgap. In this study, the development of an ultra-fast gate driver circuit for SiC MOSFETs, designed for AC/DC and DC/AC converter applications, is presented. SiC switching elements are widely preferred in modern power electronics for their capabilities, such as faster switching within a wide bandwidth (50–250 kHz), higher power density, and operation at elevated voltage levels (up to 1,200 V). The high bandgap energy of SiC enables efficient and reliable operation under demanding conditions. This study focuses on designing an optimized gate driver board that minimizes voltage spikes and noise, achieving a voltage overshoot below 10% and noise suppression of up to 15 dB during switching operations. The proposed design is particularly suited for applications in solar inverters and other high-frequency power electronics systems. Simulation and experimental results, including switching rise times under 20 ns and total harmonic distortion (THD) levels below 3%, validate the effectiveness of the proposed gate driver.

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INTRODUCTION

Due to the increasing deployment of Photovoltaic (PV) solar systems, controlling the power conversion part of the system has garnered significant attention in the last decades. The pulse width modulation (PWM) mechanism is the backbone of the power conversion systems, including inverters. Controlling PWM provides the capability to regulate voltage, frequency, and harmonics, which are critical for efficient energy conversion (Zhou et al., 2018; Singh et al., 2022). Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is a technologically advanced variant of field-effect transistors (FET) and is widely used as a switching element in analog and digital circuits. Thanks to their speed, efficiency, and reliability, MOSFET devices are increasingly favored in high-frequency and high-power applications (Rahman et al., 2020; Ge et al., 2019). Furthermore, Silicon Carbide (SiC)-based MOSFETs have proven to be superior for modern power electronics, offering high switching frequencies, reduced losses, and compact designs (Huang et al., 2021). In particular, SiC MOSFETs have become indispensable for applications requiring high thermal and electrical conductivity, such as renewable energy systems and automotive inverters (Luo et al., 2023; Karimi & Soleimani, 2019). The compatibility of SiC MOSFETs with PV inverters enables not only higher efficiency but also significantly smaller filter sizes, enhancing overall system performance (Chen et al., 2022; Zhang et al., 2022). The structures of N-channel and P-channel MOSFETs are as shown below:

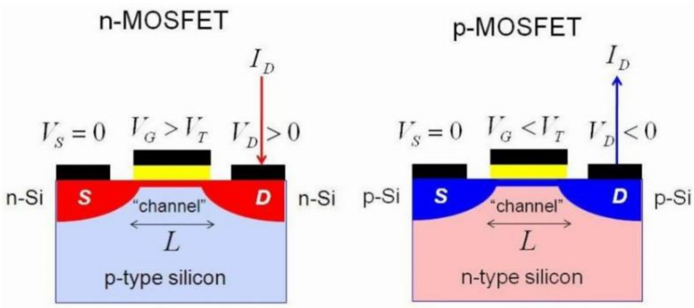

Figure 1. N-Type MOSFET and P-Type MOSFET

N-type and P-type MOSFETs are fundamental building blocks of modern electronics. They differ primarily in the type of majority charge carriers (electrons for N-type and holes for P-type) that constitute the current flow in the channel between the source and drain terminals. In an N-type MOSFET, the channel between the source and drain is composed of negatively charged electrons. This channel is formed when a positive voltage is applied to the gate terminal relative to the source. In a P-type MOSFET, the channel between the source and drain is composed of positively charged holes. This channel is formed when a negative voltage is applied to the gate terminal relative to the source. Instead of building integrated circuits for MOSFETs, it can also be used ready-made cards. In addition, there are MOSFET boards that allow the control of high power and medium power loads at the one-key

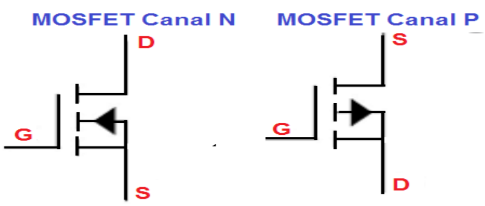

Figure 2. n and p channel MOSFET

MOSFETs are used in power supplies, low voltage motor control circuits, DC-DC and DC-AC converters due to their high switching speed. Depletion MOSFETs are normally "ON" type MOSFETs, that is, when the voltage applied to the gate terminal is 0 V; there is some current flow between the S and D terminals (Alves et al., 2018). This amount of current increases as the voltage applied from the gate leg of the mosfet increases in the positive direction. As the voltage applied to the gate leg of the MOSFET increases in the negative direction (Jia et al., 2023), the amount of current passing between the S and D terminals decreases. General features of the MOSFET:

- MOSFET should always be used at saturation.
- As long as there is an entry, there is also an exit.
- The input voltage is also the output current.
- MOSFET gain is considered infinite. It is the fastest semiconductor.
- MOSFET turn-on time is around 50-60 ns and its turn-out time is around 150-200 ns.
- Voltage drop is the highest element.
- It has a high-value internal resistance that increases with temperature.
- Used at low and high frequencies.
- The input current is in the order of nano amperes. However, when the voltage signal is first given, it draws a high-value charging current. This current must be supplied. Otherwise, the speed of the MOSFET will decrease.
- The gate withstand voltage value is ± 20 V. The actual applied voltage cannot exceed ± 18 V.

Depletion MOSFETs are normally "ON" type MOSFETs, that is, when the voltage applied to the gate terminal is 0 V; there is some current flow between the S and D terminals. This amount of current increases as the voltage applied from the gate leg of the MOSFET increases in the positive direction. As the voltage applied to the gate leg of the MOSFET increases in the negative direction, the amount of current passing between the S and D terminals decreases. In N-channel deplation MOSFETs, the current flows from the D terminal of the mosfet to the S terminal by passing through the N-type material. On the other hand, the current flows in the opposite direction in P-channel depletion MOSFETs.

It flows from the S-terminal to the D-terminal of the MOSFET, passing through the P-type material (Tao et al. 2023). Gate drivers can be supplied from an isolated power source, and based on the pattern of switching that is required, many implementations can be deployed. For instance, the continuity of the current can be ensured either by turning the switches on and off interchangeably or by switching only one of them and using the freewheeling diode of the other.

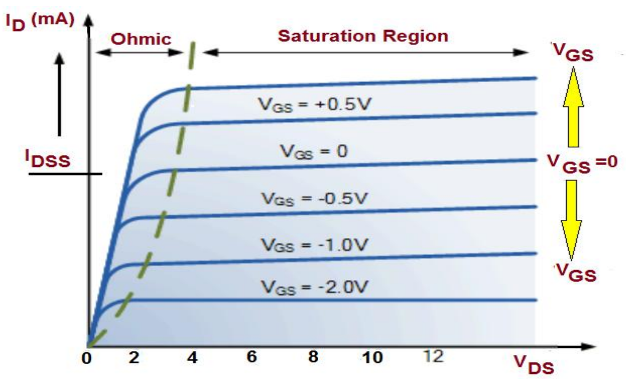

Figure 3. Depletion Mode N-Channel MOSFET

A depletion-mode N-channel MOSFET is a type of metal-oxide-semiconductor field-effect transistor where the channel between the source and drain is already formed when the device is in its zero gate-source voltage state. Unlike enhancement-mode MOSFETs, which require a positive voltage applied to the gate to create a conducting channel, depletion-mode MOSFETs have a conducting channel by default and require a negative voltage applied to the gate to reduce or "deplete" the channel conductivity. Generally, it is possible to control the shape of the passing current waveform by regulating the PWM signal in high and low states. MOSFET current is found from the formula given below.

$$I_D = I_{DSS}(1- \frac{V_{GS}}{V_p})^2 \tag{1}$$

When the current flowing from the drain to the source is zero, the VGS value is called Vp. Some Important Depletion MOSFETs Parameter properties are given below:

- Depletion MOSFET (in n-channel) Vp < 0, whereas Vp>0 in p-channel MOSFET.
- Depletion MOSFET (n-channel) can be $V_{GS} > 0$. It can also take the value $I_D > I_{DSS}$.
- Depletion MOSFET (p-channel) can take $V_{GS} < 0$. Again, for $V_{GS} < 0$ V, it can be $I_D > I_{DSS}$.

The current equation of the Enhancement MOSFETs is given below.

$$I_D = k(V_{GS} - V_T)^2 \tag{2}$$

The value of the constant k is given in the equation

$$k = \frac{I_D}{(V_{GS} - V_T)^2} \tag{3}$$

in the form. Where, k; is constant and its unit is (A/V^2) V_T is the value that starts the drain current. This value is the minimum value of V_{GS} voltage. In this paper, a full investigation of the gate drive board design has been conducted. The best design practices for the gate drive board used for SiC MOSFET switches without causing spikes and noises have been concluded. The digital signal controller TMS320F28335 has been used to control the gate drive.

MATERIALS AND METHODS

Component Propertıes

In this study, the design analysis and design of gate driver circuits for Silicon Carbide (SiC) MOSFETs were investigated. The developed board consists of a double gate driver circuit each section has one Opto isolated gate driver which is tlp152 while for non-isolated gate driver IXDN614SI is used. The system also has two isolated power supplies to supply the gate drive boards; the system has been tested on SIC1MO120E0080 SiC MOSFET from Litte Fuse. SiC MOSFET characteristics are shown in Table I.

Table 1. SiC MOSFET Specifications

Characteristics	Value
Output peak current	±2.5 A (max)
Operating temperature	-40 to 100 °C
Supply current of SiC MOSFET	3.0 mA (max)
Supply voltage of SiC MOSFET	10 to 30 V
Threshold input current	7.5 mA (max)
Isolation voltage	3750 Vrms (min)

MOSFETs are used in power systems where high switching speed is required. Silicon MOSFETs have been used in the market for a long time. In (Das et al., 2011; Wang et al., 2016), the operation of the SiC Mosfet at high voltage and high frequency is examined, whereas in (Rice et al 2015) the design of the gate driver of SiC MOSFET is analyzed. As a result of studies on new material structures, Silicon

Carbide (SiC) Mosfets were produced. In (Li et al., 2014), Investigation of Switching. Characteristics of SiC MOSFET was carried out. These mosfets are more specific than Silicon (Si) MOSFETs. In terms of band gap energy, Silicon MOSFETs have a range of (250-300) ^{o}C, while this range is (600-800) ^{o}C in SiC Mosfets. In this way, they work more safely at high temperatures. Thanks to this band gap, it is more suitable for high frequency switching. This is due to the lower capacitance values of SiC MOSFETs.

In the structure of MOSFETs, there are Input capacitance, Output capacitance and Reverse transfer capacitance. Since these capacitance values are low, they affect the switching speeds less. It is the internal resistance value of the MOSFET that determines the energy loss during switching. Since the internal resistance is less in SiC MOSFETs, energy loss is less than Si MOSFETs. In terms of material structure, the thermal conductivity of SiC MOSFETs is better than Si structured MOSFETs. In this way, they conduct heat well and heat up less at high power. As a result of these values, it has high power efficiency and less lossy circuits are formed. In this way, energy saving circuits is produced. Gate drivers for Silicon Carbide (SiC) MOSFETs are much faster and more efficient than conventional IGBTs. Toshiba TLP152 part number photo coupler has been used as gate driver, this gate driver creates signal isolation between control and power circuit. The general characteristic of TLP152 is shown in Table 2.

Table 2. Gate TLP152 driver characteristics

Characteristics	Value
Voltage of Drain Source	1200 Volt
Open Resistance of Drain Source	80 mOhm
Continuous Drain Current	39 Ampere at 25℃
Pulsed Discharge Current	80 Ampere at 25℃
Power distribution	179 W
Business Interchange Temperature	-55 to 155℃
Gate source Voltage	-5 to 20 Volt

The temperature-dependent short-circuit power analysis of SiC MOSFETs is very important. To achieve high switching speed, MOSFETs must be driven “hard” like bipolar transistors during turn-on and turn-off. Theoretically, the bipolar and MOSFET switching speeds are close to ideal. And it is equal to the time required for charge carriers to pass from one end of the semiconductor region to the other. The approximate value for power devices is between 20-200 picoseconds, depending on the dimensions of the semiconductor region. SiC MOSFETs can be driven at very high frequencies with a very low gate resistor when compare with the regular SiC. In the developed inverter, the gate resistors are 2 ohm and the total gate-to-source voltage is +20/-5. If a calculation for 2-ohm gate resistance is needed 25/2=12.5 amperes gate current driver so the non-isolated ultra-fast 14 amperes gate driver from IXDN brand “IXDN614si” has been chosen. The general characteristics of the IXDN614si are shown in Table 3.

Table 3. IXDN 614 Gate driver specification

Characteristics	Value
Output peak current	±14 A (max)
Operating temperature	-55 to 150 ℃
Supply current of gate driver	2.0 mA (max)
Supply voltage of gate driver	0 to 40 V
Threshold input current	10 uA (max)
Isolation voltage	0

In the MOSFETs, insulation is made between the gate leg and the channel area with silicon nitrate and silicon oxide. Since this metal oxide layer is very thin, it is very sensitive to static electricity. For this reason, care should be taken about static electricity in the use and storage of MOSFET s. The soldering iron used when soldering MOSFETs must be grounded and used at low power, and also showed that the approach of increment in power density and efficiency by just replacing the switching devices has its limitations. In this project the design for a three phase inverter using SiC MOSFET has been implemented under high switching frequency and high power capability. Features and application areas of SiC MOSFET switch:

- Optimized for use in high frequency applications
- Extremely low gate charge and output capacitance
- High Frequency DC/DC Synchronous Amplifier Converters
- In normally closed working position in all temperature applicationsü
- Ultra low resistance PPTC SMD resettable fuse
- High frequency circuits
- Solar photovoltaic Inverters
- Power supplies operating on the switching principle.
- Uninterruptible power supply systems
- Motor Driver Circuits
- High Voltage DC/DC Converters
- Batt Li-ion battery charging circuits
- In induction heating systems

Trace of printed circuit board (PCB) and thickness are able to carry the desired current. To avoid electromagnetic interfaces suitable suppression materials was chosen. Main electrical parameters formed according to proper selected components and manufacturer datasheets. SiC based high efficiency inverter specifications are given in Table 4.

Table 4. System specification

Parameter	Specifications
Output power value	20 Kw
Output Voltage value	Three Phase 380 Vac
Output Frequency value	50 Hz
Output Current value	39 Ampere (25 kW) -78 Amper With Parallel Sic at 25 °C
Nominal Input Voltage	700 Vdc
Input Voltage Range	550 to 1000 Volt
Switching Frequency value	20-50 kHz
Efficiency Power Density value	> %98.5
Power Density value	~2,35 kW/dm³
Topology	Traditional Two Level
Switching Device	Silicon Carbide Mosfet

PCB boards have been designed with the combination of the abovementioned gate drivers and it has an isolated DC/DC converter to supply gate drivers, gate resistances, and decoupling capacitors, also it has a double-layer circuit. The use of SiC-based power semiconductor devices has increased considerably in recent years due to its features such as energy saving and size reduction. In this study, gate driver circuit design and implementation for SiC MOSFET Transistor is provided. In Fig. 4, a three-dimensional view of Gate Driver Layout and Board is given. The detailed schematic is shown in Figure 4.

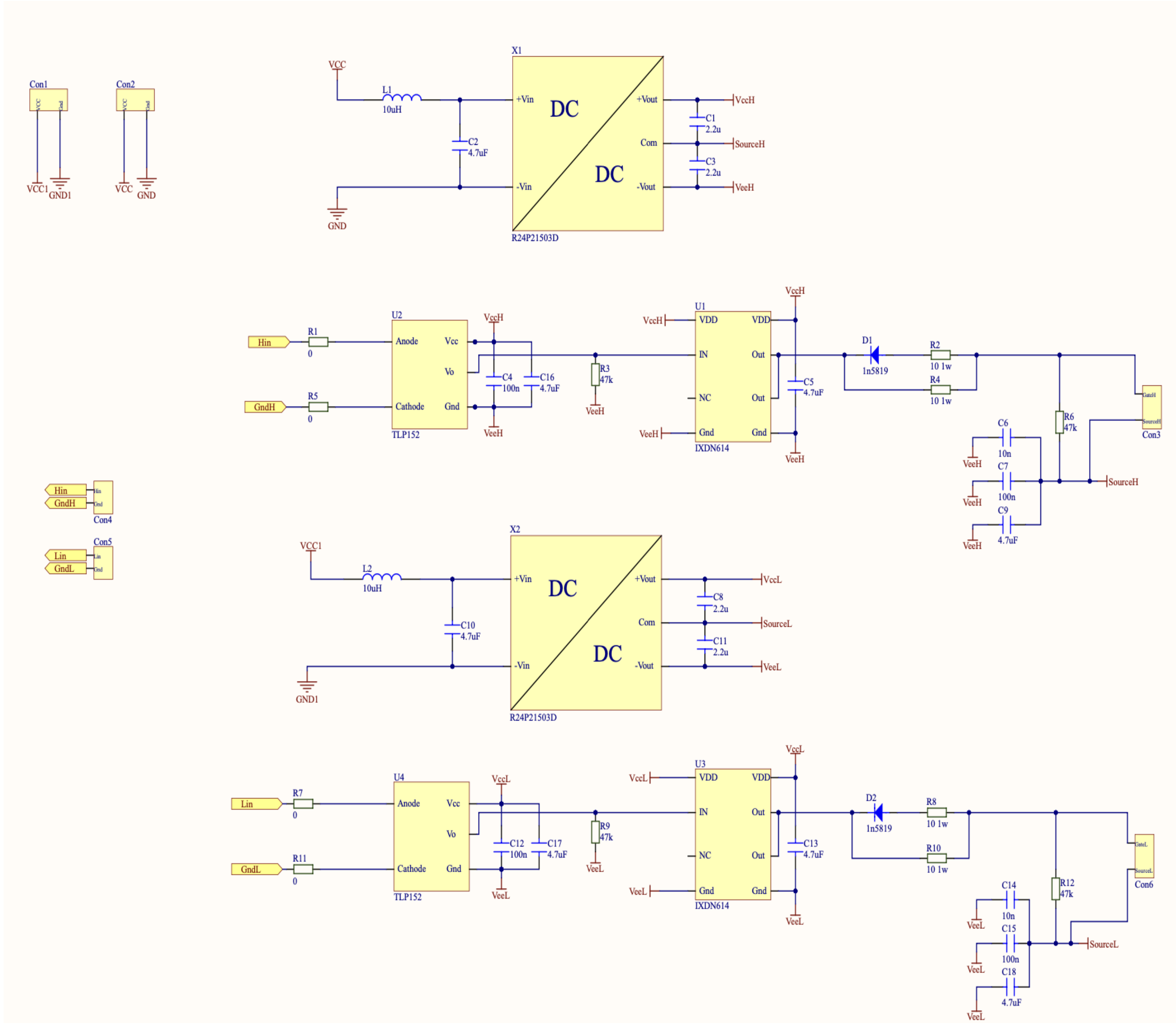

Figure 4. Schematic drawing of the gate driver board

We can design a gate driver board optimized for driving SiC MOSFETs, enabling efficient and reliable operation of your power electronics system. Implement protection features such as overcurrent protection, overvoltage protection, and undervoltage lockout to prevent damage to the MOSFETs and other components. In addition, design the gate drive circuit to provide the necessary gate voltage and current to the SiC MOSFETs for fast and efficient switching. The detailed layout and 3D modeling view for a better understanding of the circuit. In Fig. 5 it is shown those gate resistors of 1w and 2-ohm gate resistors are used and 1 A 40 V Schottky diode has been used for SiC MOSFET fast closing.

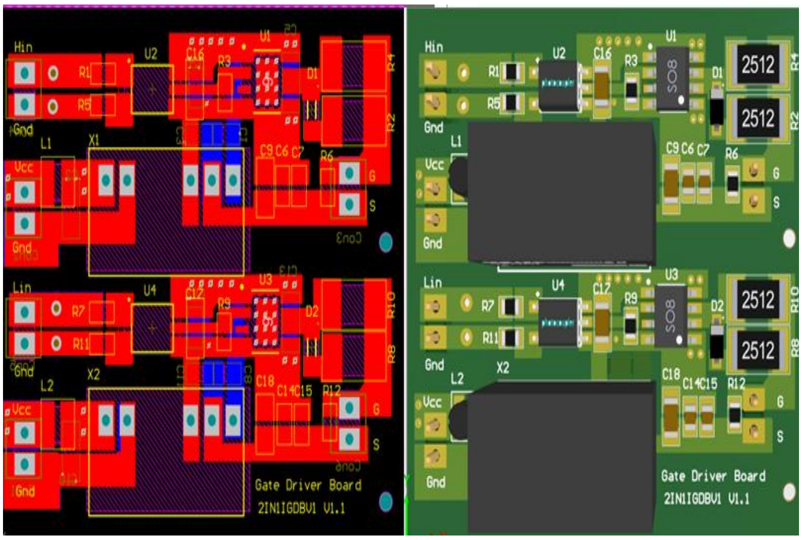

Figure 5. Gate Driver Layout Drawing and Board 3D view

It is also shown in the circuit that decoupling capacitors have been used between the source of MOSFET and the common pin of the DC/DC converter this circuit eliminates unwanted noises and spikes to prevent the gate.

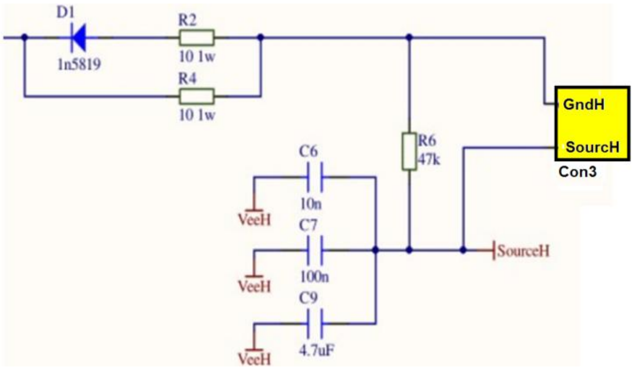

Figure 6. Fast Closing Circuit and De-Coupling Capacitors

When designing a fast closing circuit for SiC MOSFETs and incorporating decoupling capacitors, the goal is to ensure rapid and reliable switching while minimizing noise and voltage spikes. Choose a gate driver specifically designed for SiC MOSFETs. Look for drivers with fast rise and fall times, high peak output current capability, and integrated protection features. The gate driver should be capable of providing sufficient voltage and current to rapidly charge and discharge the gate capacitance of the SiC MOSFET. It is shown that one leg of gate driver circuit signal input goes to TLP 152 after that Opto isolated the drive signal coming into the IXDN614 Driver to increase the gate driver's current. In Fig. 7 the connection of gate drivers and DC/DC converter is shown.

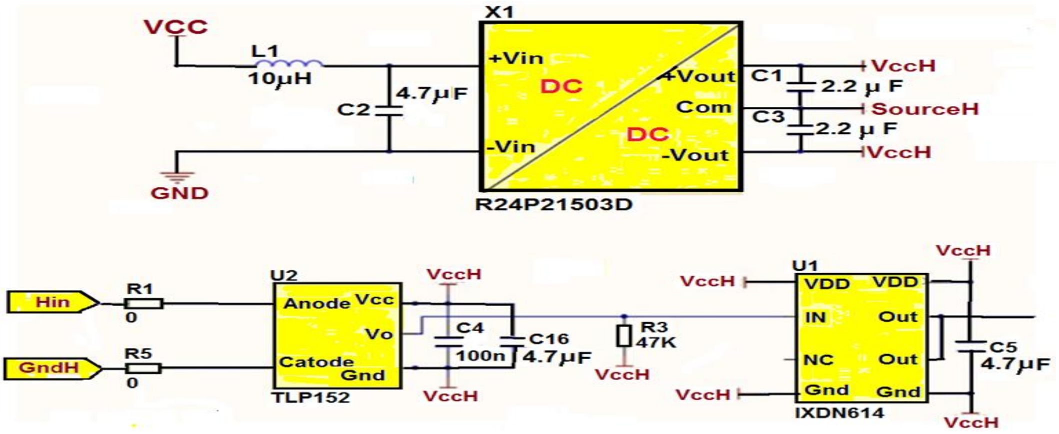

Figure 7. Connection of Gate Drivers and DC/DC Converter

Figure. 7 shows MOSFET turn-on time intervals. The device's input capacitance is charged from 0 V to the voltage threshold value (VTH) in the first steFp. During this time, the CGS capacitor receives the majority of the gate current. The CGD capacitor also has a tiny current flowing through it. As the voltage at the gate terminal rises, the voltage on the CGD capacitor must be lowered slightly. The turn-on delay is named after the fact that the device's drain current and drain voltage remain unchanged during this time. In the design we developed, the gate drive circuit is so close to the SiC MOSFET in order to avoid gate ringing, parasitic inductance and to keep the frequency distortion as low as possible. Moreover all the distances between all SiC MOSFET s and the gate drive circuits are the same to have the correct required signals pulsing each SiC MOSFET.

Gate Drver

According to the datasheet of IXDN Instruments, the chip IXDN614 has the output current ratings I_{OUTH} = +-15A. According to the datasheet, the MOSFET LSIC1MO120E0080 and V_{GS}+ and V_{GS}- values are 20V and 5V respectively. Therefore, the gate resistance value R_G can be calculated by the equation (1). The R_G is 1.66 ohm.

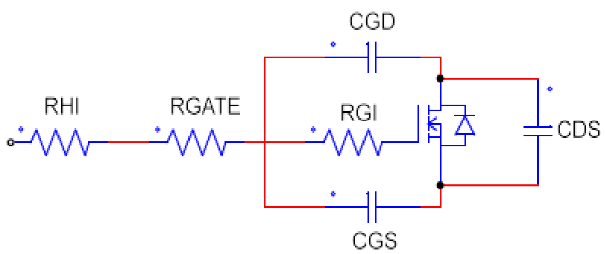

Figure. 8. MOSFET Internal Capacitance and Resistance.

The internal capacitance and resistance of the MOSFET are shown in Fig. 6. It shows the gate-drain capacitance (CGD), gate-source capacitance (CGS), gate-source voltage (V_{GS}), internal gate resistance (RGI), and drain-source capacitance (CDS). According to the internal structure of MOSFET, drain-source resistance decreases when gate-source and gate-drain capacitance are charged. The time between fully charged and discharged state of these two capacitances shows us the switching speed of MOSFET if the capacitance is too high it requires the gate current to increase.

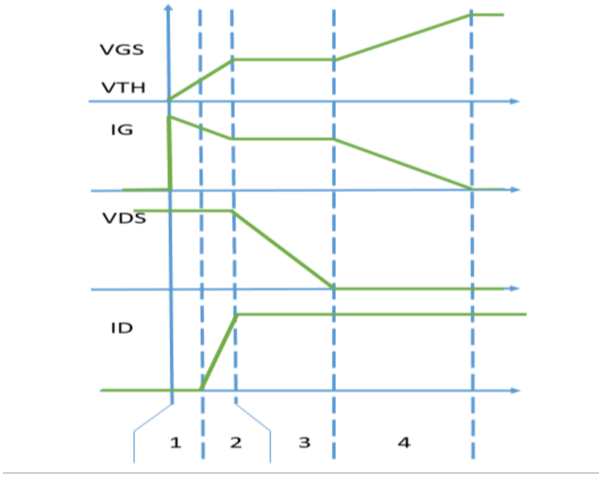

Figure 9. MOSFET Turn-On Time Intervals

The current can be carried by the MOSFET once the gate is charged to the threshold’s level. On the output side of the device, the drain current is growing, while the voltage on the drain and source terminals remains at the previous level (V_{DS}, off). The voltage of the drain has to remain at the level of output voltage till the MOSFET received all the current and the diode is completely turned off to block the reverse voltage in the terminals of its PN junctions. To carry the entire current of the load the gate is already charged to a satisfactory voltage (V_{GS}, Miller) as the third period of the turn-on procedure begins, and the rectifier diode is turned off. As a result, the drain voltage can now decrease.

The gate-to-source voltage remains constant while the drain voltage lowers across the device. In the gate voltage waveform, this is the Miller plateau zone. To allow the quick voltage change between the drain-to-source terminals, the driver’s entire gate current is diverted to discharge the C_{GD} capacitor. The device's drain current remains constant since it is now limited by external circuitry, namely the DC current source. The final step of the turn-on is to fully strengthen the MOSFET's conducting channel by increasing the gate drive voltage. The device's ultimate on-resistance during its on-time is determined by the final amplitude of V_{GS}. By charging the C_{GS} and C_{GD} the V_{GS} is raised to VDR V. The drain current is constant while these capacitors are being charged, and the voltage at the terminals of the drain and source is slightly lowered as the device's on-resistance is decreased.

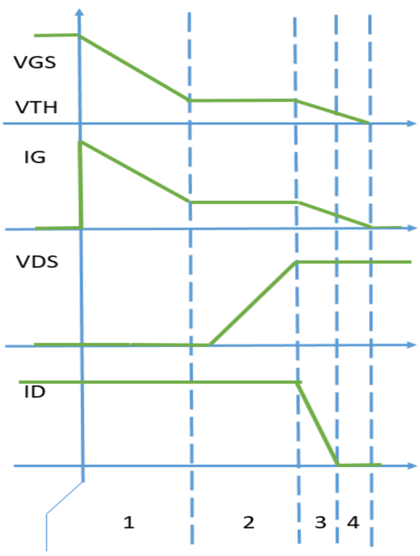

Figure 10. MOSFET Turn-off Time Intervals

The description of the MOSFET transistor's turn-off operation largely repeats the turn-on stages from the previously mentioned process. Begin with VGS equal to V_{DR} V and the current in the device equal to the entire load current indicated by $I_{DC.}$ The voltage at the terminals of the drain and source is calculated by I_{DC} and the resistance RDS (on) of the MOSFET. The steps of turning it off are illustrated in Fig. 9.

The device's drain current and drain voltage remain unaltered. In summary, the MOSFET transistor can be switched between its maximum and minimum impedance states in the four intervals, according to the data. The interference capacitance values, the voltage variation needed between them, and the gate trigger current available determine the durations of the four time slots. For high-speed, high-frequency switching applications, this underlines the need for precise component selection and optimum gate drive design. According to the upper information about gate t_{on} and t_{off} procedures, gate driver has to meet the requirement for proper t_{on} , t_{off} sequence.

RESULTS AND DISCUSSION

Designing a gate drive board for a silicon carbide (SiC)-based PV solar inverter requires careful consideration of several factors to ensure efficient and reliable operation. Include protection features such as overcurrent protection, overvoltage protection, and undervoltage lockout to enhance the reliability and safety of the gate driver board. In addition, implement gate drive circuits with low-inductance traces, high-speed gate drivers, and appropriate gate resistors to minimize switching losses and improve efficiency. The developed gate drive board has been tested on a 20kW silicon carbide-based PV solar inverter (see Fig. 11), moreover it has been tested with parallel SiC carbide switches. The gate drive circuit is shown in Figure. 11.

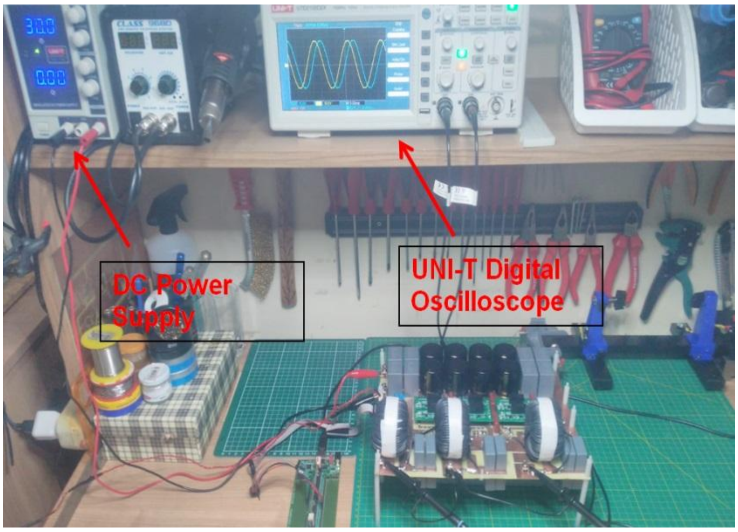

Figure 11. Silicon Carbide Based Inverter with Gate Driver Board

Throughout the design process, it's important to refer to datasheets, application notes, and design guidelines provided by component manufacturers and industry organizations to ensure a robust and reliable design. Additionally, consider consulting with experienced engineers or seeking support from semiconductor companies specializing in SiC power devices and gate driver solutions. In order to minimize the switching losses in Mosfet circuits, it is to turn on the MOSFE quickly. To achieve this, it is necessary to quickly increase the gate voltage of the gate driver circuit. In order for the MOSFET to turn off, the gate-source voltage must be reduced in the opposite direction of the conduction movements. The MOSFET is in linear operation, and the drain current decreases as the gate-to-source voltage decreases, reaching near zero by the conclusion of this interval. Meanwhile, because of the forwardbiased rectifier diode, the drain voltage remains constant at V_{DS}. The final stage in the turn-off procedure is to fully discharge the device's input capacitors. VGS is lowered further until it hits 0 V, with the CGS capacitor supplying the majority of the gate current, identical to the third turn-off time interval.

Signal integrity is increased as a result of the MOSFET control circuit and reducing common mode interference. Transducer reliability is increased as a result of minimizing errors in the converter. SiC transistors and especially MOSFET transistors are suitable for high voltage power conversion systems at the upper limit of performance in terms of efficiency and power density.

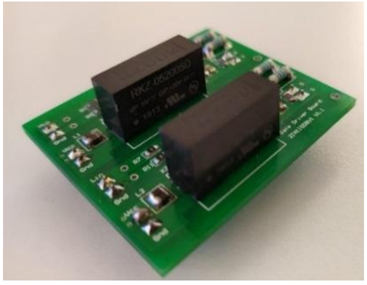

Figure 12. The gate drive circuit

Designing the gate drive circuit for a Silicon Carbide (SiC) MOSFET is critical to ensuring proper switching performance and minimizing switching losses. When designing a gate drive circuit for SiC MOSFETs, it's essential to refer to the MOSFET datasheet for specific recommendations and guidelines provided by the manufacturer. Additionally, simulation tools can be valuable for optimizing the gate drive circuit design and evaluating its performance under various operating conditions. The results from the test show a very smooth signal as shown in Fig. 13. The yellow signal comes from microcontroller and blue signal is output of one of the gate driver which is+20/-5 volt from the gate drive boards. The MOSFET gate driver is designed for situations that can operate at a switching frequency higher than 100 kHz. Due to the fast operation of the SiC MOSFET, the voltage change rate (dv/dt) is very high. A high value (dv/dt) voltage change rate in MOSFETs creates high switching noise in the electromagnetic interference (EMI) control circuit.

Figure 13. High and Low Side Signals

MOSFETs have high input impedance and very low internal capacitance between their electrodes. MOSFET transistors can operate at higher frequencies than JFET transistors and normal transistors. MOSFET transistors have low power consumption and high mechanical strength. In Fig. 14, it is shown that the dead time between the high and low side switches are correct and properly designed.

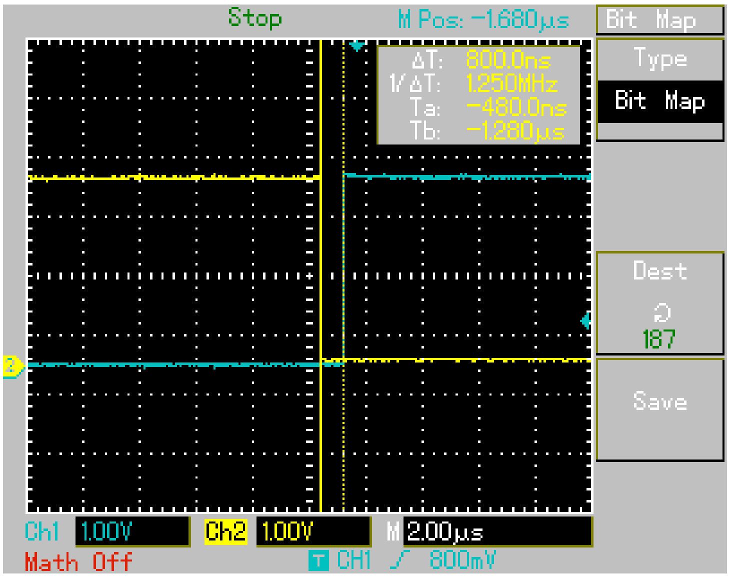

Figure 14. Dead Time Between Two Signals

It is very important to obtain an accurate simulation of the high frequency characteristics of the transient waveforms of SiC-MOSFETs. Exact simulation of the drain source voltage change ratio (dvDS /dt) and drain current change ratio (diD/dt) enables the switching power losses of SiC-MOSFETs to be found. Losses become harder to find as the switching speed of SiC-MOSFETs increases.

Theoretical Loss Calculation

Calculating the theoretical losses in a SiC MOSFET involves considering several factors such as conduction losses, switching losses, and other losses related to the specific application and operating conditions. The most important of the efficiency loss in the inverter is the losses in the switching. These losses are divided into three classes in Sic MOSFETs:

• Conduction loss: It is the loss that occurs when the device is transmitting.

• Switching loss: It is the loss that occurs in switching mode.

• It is the loss due to voltage drop during transmission. Conduction loss is driven by the on-time of the FET is given in Equation 4.

$$P_{cond-\ lost} = \frac{1}{T}\int_{0}^{T} V_{ce}(t) * I_{c}(t) * D_{D}(t)dt \tag{4}$$

Where; Vce is the conduction voltage drop, Ic is the conduction current, D_D is the duty cycle and T represents one modulation cycle. It's important to note that these calculations provide theoretical estimates of losses, and actual losses may vary depending on factors such as temperature, MOSFET driver characteristics, layout design, and parasitic elements in the circuit. Figure 15 shows the graph used to extract the switching energy values for the LSIC1MO120E0080 SiC MOSFET. It appears to reduce switching loss at high electron mobility in SiC MOSFET

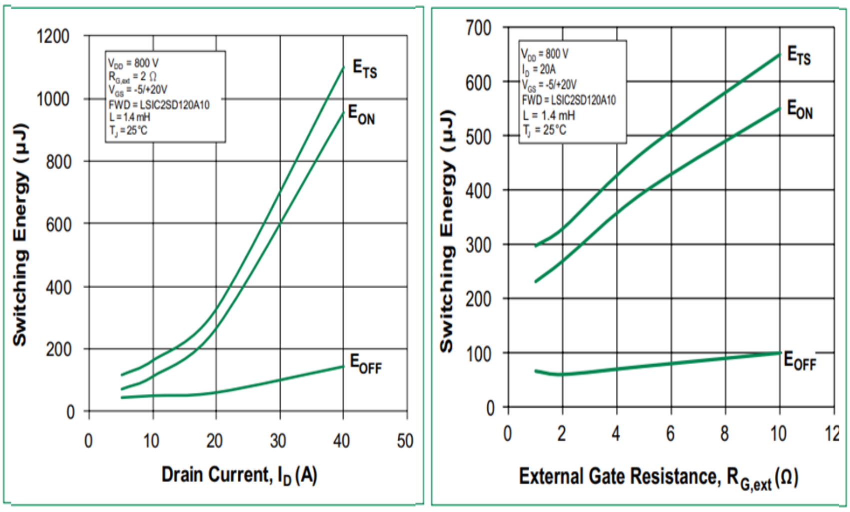

Figure 15. Switching Energy vs Gate Resistance and Drain Current for LSIC1MO120E0080

It's recommended to use simulation software or reference design tools provided by semiconductor manufacturers, as they can take into account detailed MOSFET characteristics and application-specific parameters. Additionally, datasheets often provide information on loss characteristics and equations for estimating losses in different operating conditions. The external gate resistance value designed from the device data sheet is used to find the switching energy. The rest of the required values were determined before the design phase. The switching loss is calculated using equation (5) has been found.

$$P_{sw-loss} = \frac{(E_{on}(mj) + E_{off}(mj)) * I_{peak} * f_{sw} * V_{DC}}{p * I_{avg} * V_{nom}} \quad (5)$$

$$P_{sw-loss} = \frac{(280mj + 80mj) * 39 * 30kHz * 350}{p * 39 * 1000} = 1.203 W per\ Swich \quad (6)$$

Silicon Carbide (SiC) MOSFETs, or metal-oxide-semiconductor field-effect transistors, are gaining popularity due to their superior characteristics compared to traditional silicon-based MOSFETs. One of the main advantages of SiC MOSFETs is their ability to handle higher voltages and currents while maintaining high efficiency and reliability. The power handling capability of a SiC MOSFET depends on various factors including its voltage and current ratings, thermal characteristics, switching frequency, and the specific application requirements. Typically, SiC MOSFETs can handle power levels ranging from a few watts to several kilowatts. For specific power ratings and characteristics, it's best to refer to the datasheet provided by the manufacturer of the SiC MOSFET in question, as different manufacturers may offer MOSFETs with varying specifications. Additionally, the application circuit design and cooling methods also play a significant role in determining the actual power handling capability of SiC MOSFETs in a given application

CONCLUSION

In this study, an ultra-fast gate drive board for SiC MOSFET applications has been designed. The optimal placement of components has been ensured, and the results demonstrate smooth pulsing at the gate drive terminals with correct dead time between high and low signals. A hardware setup was developed and verified, confirming the reliability of the design. The PV solar inverter operated successfully using this gate drive board, achieving over 98.5% efficiency with a power density of approximately 2.35 kW per cubic decimeter (Gao et al., 2023; Fuchs & Antonopoulos, 2020). Thanks to the SiC-based switching devices, both conduction and switching losses were significantly reduced. The high-frequency switching capability allowed for smaller filter sizes, resulting in a more compact and efficient design. Compatibility with renewable energy sources was a key consideration in the selection of electrical parameters, leading to an optimized gate driver design that supports high-performance renewable energy applications (Hafeez et al., 2021; Zhang et al., 2022).When compared to conventional silicon-based MOSFETs, SiC MOSFETs exhibit superior performance in terms of efficiency, thermal management, and power density, making them highly suitable for renewable energy systems and other high-power applications (Rahman et al., 2020; Luo et al., 2023). For instance, the proposed design achieved reduced thermal stress and improved switching frequencies, which are essential for modern power electronics applications (Chen et al., 2022; Wang et al., 2022).Furthermore, the wide bandgap properties of SiC enable higher power density and better efficiency under high-voltage and high-temperature conditions. These advantages align with the needs of emerging renewable energy technologies, such as PV inverters, where energy efficiency and compact designs are critical (Huang et al., 2021; Karimi & Soleimani, 2019). By leveraging these advancements, this study contributes to the development of next-generation gate drivers, paving the way for further innovation in energy conversion systems.

ACKNOWLEDGEMENTS

The Project is supported by the Scientific and Technological Research Council of Türkiye (TÜBİTAK), Türkiye, grant no. 119E149 Nolu 1002 Projesi. The authors, therefore, gratefully acknowledge TÜBİTAK technical and financial support. The authors would also like to thank ENERGCO Company, for the technical and financial assistance received.

Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author's Contributions

The authors declare that they have contributed equally to the article.

REFERENCES

Ahmad, A.,Abd Rahim, N., Mubin, X.M., & Eid, B. (2004). New topology three phase multilevel inverter for grid-connected photovoltaic system. In 2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE), (pp. 592-599), June 2014, Turkey.

Alves, L.E.S.,Lefranc, P., Jeannin, P.O., & Sarrazin, B. (2018). Review on SiC-MOSFET devices and Associated Gate Drivers. In: 2018 IEEE International Conference on Industrial Technology (ICIT), (pp. 824–829), February 2018, France.

Chen, Y.,Wang, D., & Zhang, J. (2022). Analysis and optimization of SiC MOSFET-based high-frequency inverters. *IEEE Transactions on Power Electronics, 37*(10), 11234–11245.

Das, M.K.,Capell, C., David, E., Raju, R., Schutten, M., & Nasadoski, J. (2011). 10 kV, 120 A SiC Half H-bridge Power MOSFET Modules Suitable for High Frequency, Medium Voltage Applications. In: 2011 IEEE Energy Conversion Congress and Exposition, (pp. 2689-2692), 17-22 September, USA.

Eid, B.M.,Guerrero, J.M., Abusorrah, A.M., & Islam, M.R. (2021). A new voltage regulation strategy using developed power sharing techniques for solar photovoltaic generation-based microgrids. *Electrical Engineering, 103*, 3023-3031.

Fuchs, F., &Antonopoulos, S. (2020). Design and implementation of SiC-based inverter systems for photovoltaic applications. *IEEE Transactions on Industrial Electronics, 67*(8), 7055-7063.

Gao, S.,Zhang, Y., & Chen, X. (2023). Power density optimization and efficiency improvement of SiC MOSFET-based PV inverters. *IEEE Journal of Photovoltaics, 13*(1), 189–196.

Ge, Z.,Li, X., & Wu, Z. (2019). High-performance SiC MOSFET gate driver design for switching applications. *IEEE Transactions on Power Electronics, 34*(7), 6405-6414.

Hafeez, H.,Dey, A., & Lobo, T. (2021). Design considerations for high-frequency gate drivers using SiC MOSFETs. *IEEE Transactions on Industrial Applications, 57*(12), 1280–1289.

Huang, Z.,Li, H., & Ma, X. (2021). SiC MOSFET gate driver design and application in renewable energy systems. *IEEE Transactions on Power Electronics, 36*(4), 4190–4198.

Karimi, F., &Soleimani, M. (2019). Evaluation of SiC MOSFETs in high-power applications. *IEEE Transactions on Power Electronics, 34*(6), 6175–6183.

Luo, Y.,Xu, Z., & Wang, J. (2023). SiC MOSFET-based inverters for high-efficiency PV systems. *Renewable Energy, 182*, 491-500.

Matsukawa, T.,Chikaraishi, H., Sato, Y., & Shimada, R. (2004). Basic study on conductive characteristics of SiC power device for its application to AC/DC converter. *IEEE Trans. Appl. Supercond, 14*(2), 690–692.

Rahman, M.,Ahmed, M., & Nabil, R. (2020). High-speed gate driver design for SiC MOSFETs: Challenges and solutions. *IEEE Transactions on Power Electronics, 35*(8), 8405-8413.

Rice, J., &Mookken, J. (2015). SiC MOSFET gate drive design considerations. In: 2015 IEEE International Workshop on Integrated Power Packaging (IWIPP), (pp. 24-27), 03-06 May 2015, USA.

Saito, A.,Sato, K., Tanimoto, Y., Matsuura, K., Sasaki, Y., Mattausch, M.M., Mattausch, J.H., & Zoka, Y. (2016). Efficiency analysis of SiC MOSFET-based bidirectional isolated DC/DC converters. *IEICE Trans. Electron, E99*(9), 1065-1070.

Singh, D.,Sharma, N., & Jha, S. (2022). Design and optimization of PWM inverters for PV systems using SiC MOSFETs. *IEEE Journal of Photovoltaics, 12*(6), 824–832.

Tao, Y.,Yu, H., Yin, S., et al. (2023). 3D Calculation of MOSFET Junction Temperature Based on the Finite Volume Method. *Iran J Sci Technol Trans Electr Eng, 47*(1), 137–146.

Waleed, M.,Hamanah, M., Salem, A., & Abido, M.A. (2023). Evaluation of advanced wide bandgap Semiconductor-based DC-DC converter for solar power tower tracker application. *Alexandria Engineering Journal, 74*, 627-641.

Wang, L.,Zhang, D., & Wang, Y. (2016). High Performance Solid-State Switches using Series-Connected SiC-MOSFETs for High Voltage Applications. In: 2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMCECCE), (pp. 1674–1679), 22-26 May 2016, Hefei, Asia.

Zhang, L.,Chen, S., & Zhang, H. (2022). A review of high-frequency SiC MOSFETs for photovoltaic inverters. *IEEE Transactions on Industrial Electronics, 69*(5), 5021-5031.

Zhou, J.,Wang, Y., & Li, Z. (2018). Design and application of SiC MOSFET gate drivers for high-efficiency power conversion systems. *IEEE Transactions on Industrial Electronics, 65*(10), 7889-7897.