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Simulation Study of Silicon On Insulator MOSFET based inverter for Electric Vehicle Application using MATLAB

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Abstract: Silicon-On-insulator (SOI) complementary metal oxide semiconductor (CMOS) technology has matured after beginning as a niche market. The technology first appeared in the early 1980s, with applications in rad-hard (military) and power. SOI structures are made up of a top single-crystal silicon layer that is either separated from the bulk substrate by an insulating layer (such as SiO2) or supported directly by an insulating substrate. The purpose of this paper is to analyse and compare the performance of silicon-on-insulator and silicon-carbide-based inverters. The experimental procedure for obtaining those two semiconductors will be entirely based on MATLAB simulation software. The switching and conduction losses of each semiconductor are used in the comparison. As a result of this paper, SOI outperforms in terms of lowering each loss and the total loss for SOI-based inverter is 3.94 %.

Keywords: Silicon on Insulator, MOSFET, Electric Vehicle

1. Introduction

Electrical vehicles have a lot of advantages over conventional vehicles. EVs use electricity as a domestic energy source so it will reduce energy dependence. Conventionally powered vehicles (petrol and diesel) are one of the biggest sources of pollution in congested city centers in automobiles, and one of the main benefits of electric cars is that they minimise pollution [1].

An inverter is a device that transforms DC power into AC power, which is used in the motor of an electric vehicle. By modifying the frequency of the alternating current, the inverter can change the motor's rotational speed. The inverter is vital for the performance of the vehicle as it recognizes how the vehicle drives and the end client perceives the vehicle. Inverters form critical parts as it is one of the vital parts of the electric vehicle framework [2]. Over the past decade, silicon-on-insulator (SOI) material has become the leading semiconductor platform for high-performance devices and integrated circuits. Silicon-On-Insulator (SOI) technology compared with a bulk circuit, an obvious improvement in power consumption and speed is always observed for the corresponding SOI circuit. The goal of the

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research is to show how to model and simulate SOI MOSFET-based inverters, as well as conduct reliability tests on the system, in order to improve the performance of EV applications. As a result, the system is studied and built with MATLAB software.

1.1 Silicon On Insulator technology

A thin silicon layer (less than 100 nm) is deposited on top of a silicon dioxide layer known as a buried oxide to create silicon-on-insulator transistors. The majority of the parasitic effects present in bulk silicon transistors are eliminated by this oxide layer's total dielectric isolation for the transistor. The bulk transistor's structure and that of the SOI transistor are quite similar. The key distinction is the existence of buried oxide, which bestows desirable characteristics on the SOI transistor. Power has emerged as one of the most significant paradigms of design convergence for multi gigahertz communication, including optical data lines, wireless products, and microprocessor ASIC/SOC designs. The bottleneck in microprocessor design is low power consumption. For more than three decades, researchers have been trying to find ways to speed up computer performance by enhancing current silicon technology. This recent achievement in utilizing SOI technology will lead to quicker and more energy-efficient computer chips, which is essential for prolonging the battery life of small, portable gadgets, which will be used more frequently in the future. Because SOI is one to two years ahead of traditional bulk silicon, it represents a substantial improvement in the chip manufacturing industry [3].

2. Materials and Methods

This part contains an in-depth discussion of the simulation produced using MATLAB for the model development of SOI and SiC MOSFET-based inverter, as well as the chosen materials, software, and methods used in the project work.

2.1 Silicon On Insulator (SOI) and Silicon Carbide (SiC)

Table 1 shows electrical characteristics between both Silicon and Silicon Carbide MOSFET under a junction temperature at 25℃ and these parameters were taken from data sheets for Silicon On Insulator [4] and Silicon Carbide [5].

Table 1: Parameter specification for SOI and SiC MOSFET

Parameter	SOI MOSFET	SiC MOSFET
Static drain-source on-state resistance, $R_{DS(ON)}$	0.15 Ω	0.156 Ω
Drain current, $I_{(ON)}$	10.00 A	10.00 A
Gate-source voltage, V_{GS}	10.00 V	18.00 V
Turn-on energy, E_{ON}	12.1875 µJ	61.00 µJ
Turn-off energy, E_{OFF}	47.125 µJ	41.00 µJ
Input Capacitance, C_{iss}	1400 pF	1200 pF
Output Capacitance, C_{oss}	40 pF	90 pF
Reverse Transfer Capacitance, C_{rss}	0.5 pF	13 pF

2.2 Loss calculation for SOI and SiC based inverter

The inverter is a critical component of a renewable energy system, and its performance has an impact on the system's overall performance. In many electric drive applications, an inverter is applied to convert the DC power to AC power for electric machines. Conduction and switching phenomena generate losses in inverters for electric vehicle applications, raising the operating temperature of the devices and changing their performance [6]. Switching and conduction loss for SiC MOSFET and SOI based inverters can be calculated as the following:

$$P_{TOTAL} = P_{SWITCHING} + P_{CONDUCTION} \quad [3]$$

$$P_{TOTAL} = 6\,(P_{SWITCHING} + P_{CONDUCTION}) \quad [3]$$

The power loss of one MOSFET is the sum of the conduction and switching losses, and the total of the inverter is provided by six times the power loss of one MOSFET because six MOSFETs were used in the three-phase inverter circuit.

$$P_{SWITCHING} = fs\,(E_{M,ON} + E_{M,OFF}) \quad [3]$$

The inverter's switching loss is calculated by multiplying the switching frequency by the total of the turn-on and turn-off switching losses.

$$P_{CONDUCTION} = R_{DS(ON)} \text{ x } I^2{}_{ON} \quad [3]$$

The product of static drain-source on-state resistance, $R_{DS(ON)}$, and the square of drain current, $I^2{}_{ON}$, generates the inverter conduction loss.

3. Results and Discussion

The simulation results for the materials used for this research, including SOI and SiC MOSFET, are shown in the results and discussion section. Simulink is used to model SiC and SOI MOSFETs, and the output and transfer characteristics are simulated using the parameters taken from each datasheet for a range of voltages. The inverter circuit is configured to monitor the switching pulse and output waveforms and to verify their distinction. In order to quantify the power wasted in SOI and SiC MOSFET-based inverters by analyzing the results, loss estimates for switching and conduction are thus done using MATLAB code.

3.1 Output and transfer characteristic of SOI and SiC MOSFET

At a junction temperature of 25 degrees Celsius, the drain current is plotted against the drain-source voltage. At 18 Volts, the drain current, I_D, was measured vs. the drain-source voltage, V_{DS}, to assess the output characteristics of SOI and SiC MOSFETs. Figure 1 shows the comparison of the output characteristics between the SOI curve (blue line) and the Silicon Carbide curve (orange line) at 18 Volts of voltage gate. From the observation based on the figure shown, for example, when the voltage at 18 Volts, V_g the difference between SOI and SiC MOSFET at 40 Volts, V_{DS} for drain current, I_D are 75.42 A.

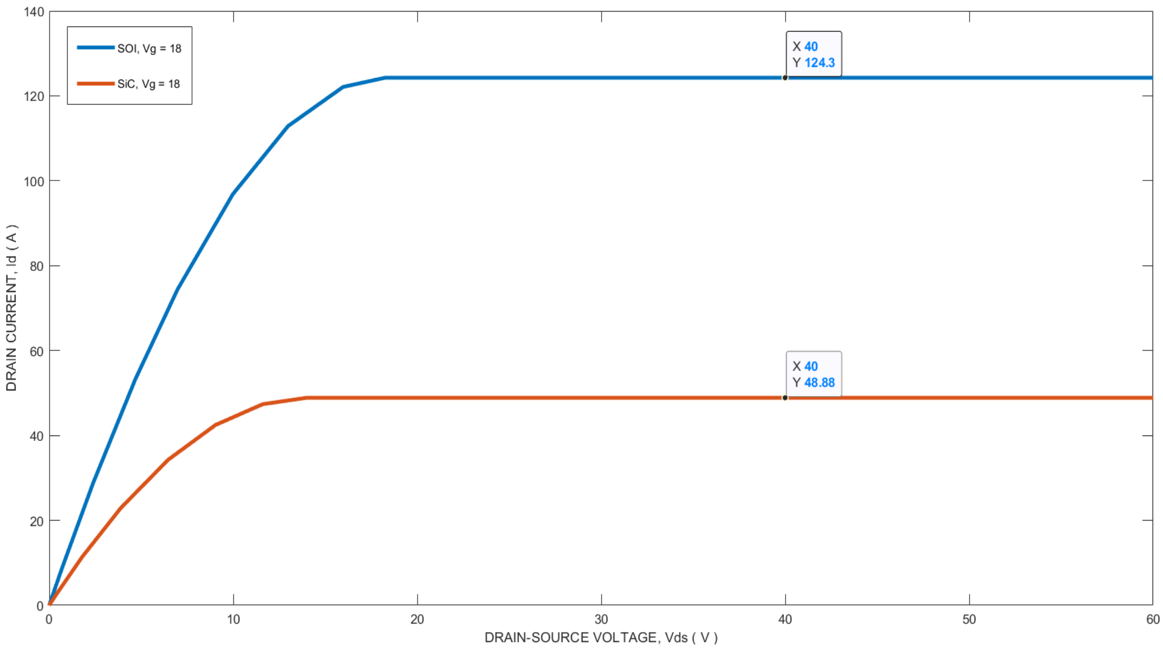

Figure 1: The comparison of output characteristics between SOI and SiC MOSFET

The curves of the simulation models match the datasheet curves really well. Figure 2 shows a comparison of the datasheet-based transfer characteristic curve to the simulation curve of the presented Silicon on Insulator and Silicon Carbide model. From the observation based on the figure shown, for example, when voltage at 10 Volts, Vg the difference between SOI and SiC MOSFET at 800.8 Volts, V_{GS} for drain current, I_D are 630.6 A. The legend indicates two different line styles. The blue line shows the SOI MOSFET while the voltage at 10 Volts, Vg and orange line illustrates the SiC MOSFET while the voltage at 10 Volts, Vg.

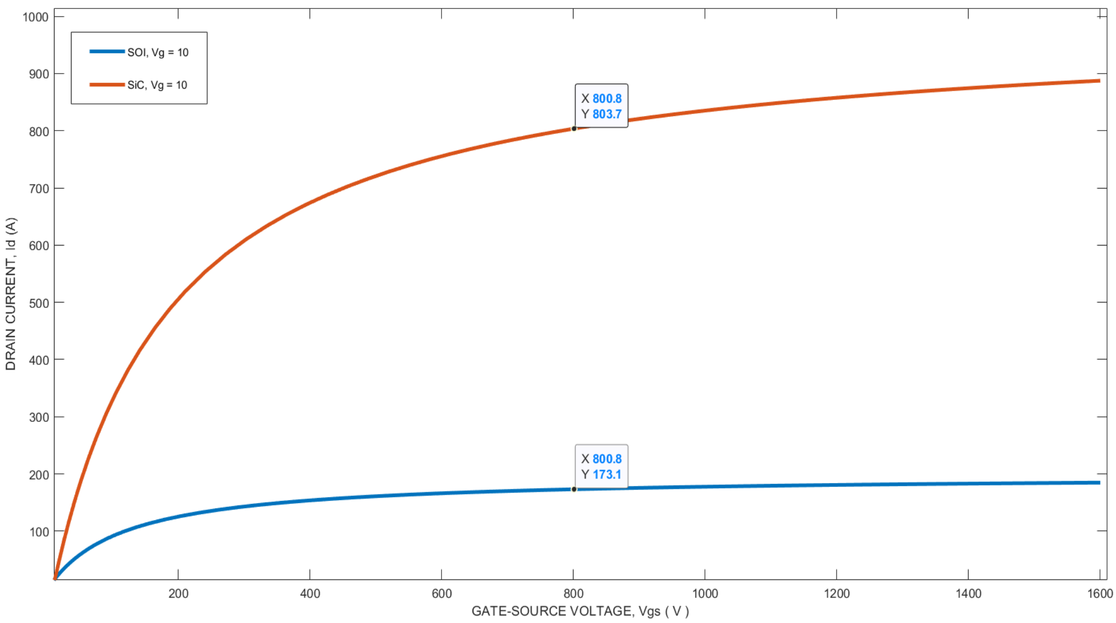

Figure 2: The comparison of transfer characteristic between SOI and SiC MOSFET

3.2 Gate pulse and output waveforms of SOI and SiC based inverter

Figure 3 shows the circuit design of the inverter using MATLAB software. The circuit design is a three-phase inverter circuit with a 180-degree conduction mode.

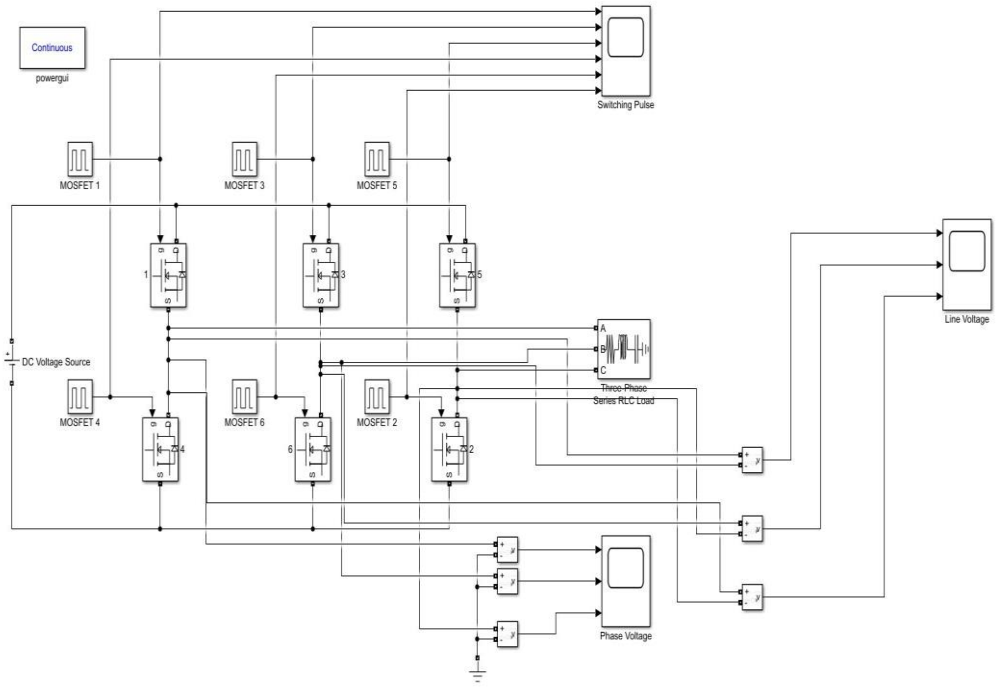

Figure 3: Simulink model of a full circuit inverter

Figure 4 shows an inverter's gate pulse to show the amplitude at 5 Volts vs the period at 20 milliseconds. Each pulse generator is connected to six MOSFET switches, the properties of which vary depending on whether Silicon on Insulator or Silicon Carbide is used. As a result, the pulse width is set to 50% of the period and the switching frequency, fs, is set to 50% of the period. When the upper switch of a phase is in conduction mode, the output shows the positive half cycle of that phase (ON). When the lower switch of a phase is in conduction mode, the output shows the negative half cycle of that phase (ON). In one arm, there are two switches that will never be activated at the same moment.

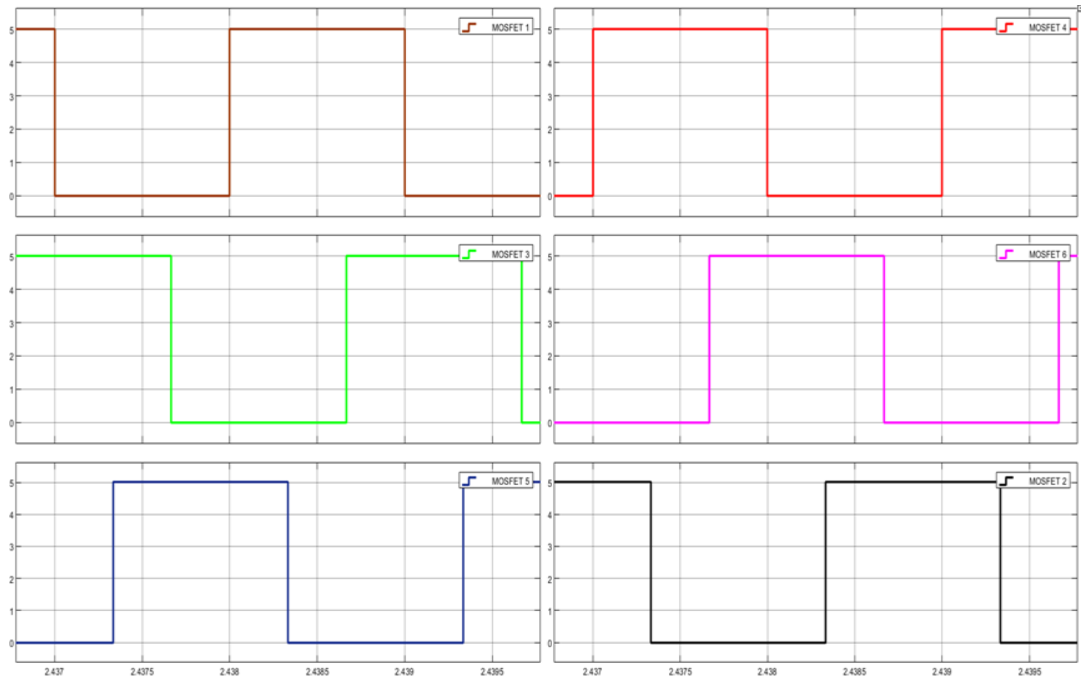

Figure 4: The gate pulse of a full circuit inverter for SOI and SiC

In this mode of operation, the switching pulses 1 and 4, 3 and 6, and 5 and 2 are designed to be completely opposite to each other [7]. MOSFET-4, for example, is turned off when MOSFET-1 is switched on. The phase-to-phase voltage of a SOI and SiC MOSFET based inverter is shown in Figure 5 as a function of line voltage, V, and time, s, revealing that the peak line voltage is about 250 Volts.

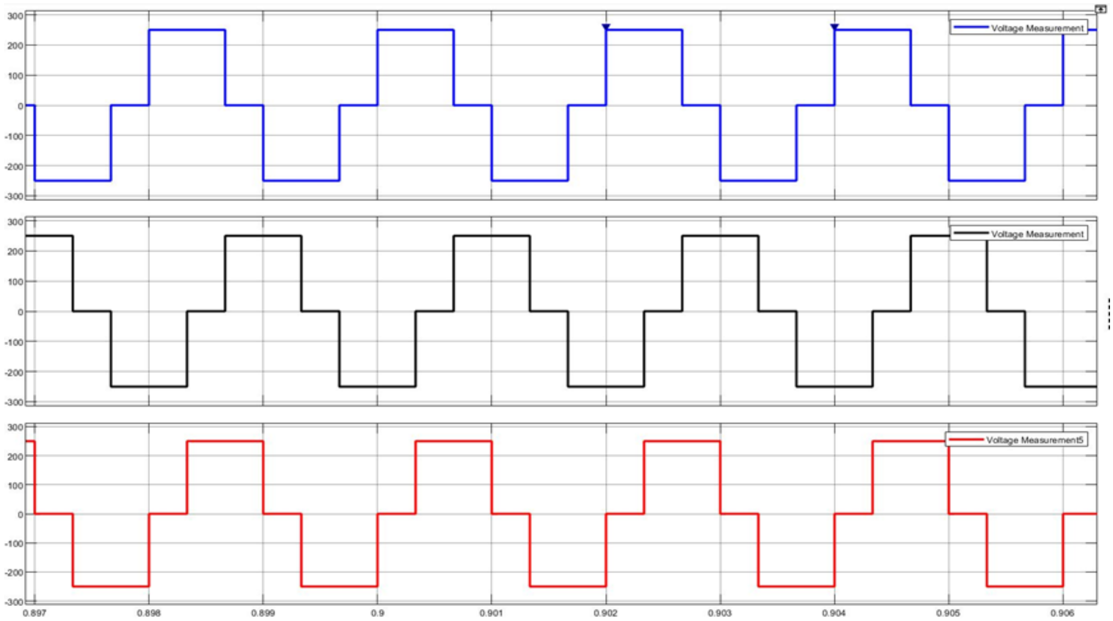

Figure 5: Line voltage of an inverter

Figure 6 shows the phase-to-ground voltage of an SOI and SiC MOSFET-based inverter as the phase voltage, V, varies with time, s, demonstrating that the peak phase voltage is around 166.5 Volts.

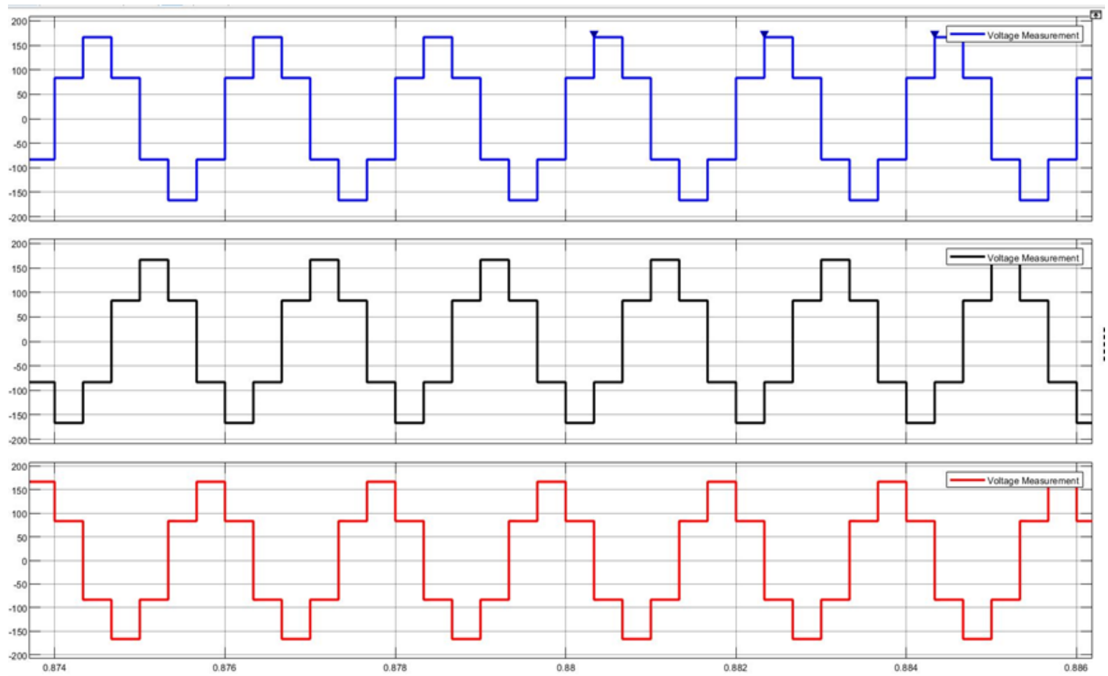

Figure 6: Phase voltage of an inverter

3.3 Loss calculation of switching and conduction for SOI and SiMOSFET-baseded inverter

The loss calculation comparison between SOI and SiMOSFET-baseded inverters in Table 2 shows that the use of Silicon On Insulator can reduce more losses in the operation of an inverter than Silicon Carbide.

Table 2: Comparison of loss calculation between SOI and SiC MOSFET based inverter

Parameter	SOI MOSFET (W)	SiC MOSFET (W)	Loss reduce (%)
Conduction loss	15.00	15.60	3.85
Switching loss	2965.63 µ	15599.00 µ	81.00
Total loss inverter	90	93.69	3.94

A smaller value in static drain-source on-state resistance used in SOI MOSFETs than in SiC MOSFETs may influence total loss in SOI MOSFET inverters. Figure 7 shows a comparison of SiC and SOI MOSFET-based inverters with switching frequency variations in Hertz versus inverter loss in Watt. As a result, it was discovered that using SOI MOSFETs for inverters can reduce losses when compared to SiC MOSFETs. When comparing SiC MOSFET inverters to SOI MOSFET inverters, the higher the switching frequency, the higher the losses produced.

Figure 7: Switching frequency versus inverter loss in SOI and SiC MOSFET based inverter

At 250 DC Volts, SiC MOSFET-based inverters clearly outperform SOI MOSFET-based inverters in terms of power loss. SOI MOSFET devices will help to reduce power loss and increase inverter efficiency in EV applications. This can lead to improved inverter design optimization while allowing for high operating frequency and voltage ratings. The EV application is the best example of silicon on insulator over silicon carbide implementation. When driving an electric vehicle, the hardware system is designed to accommodate the vehicle's full power capability, as is required in both silicon on insulator and silicon carbide-based designs.

4. Conclusion

Simulating and realizing the model in MATLAB allowed the experimental evaluation of an SOI MOSFET-based inverter for electric vehicle applications. The analysis result proves the SOI-based inverter has a higher potential in terms of reducing the switching loss when operating in a high frequency and reducing conduction loss with a lower drain current. According to both loss observations, the SOI MOSFET based inverter has a significantly lower overall total loss than SiC MOSFET based inverter. SOI body devices have a body factor near unity, which minimizes their subthreshold slope, making them appealing for switching applications. However, SOI devices have the following disadvantages. The floating body effect in partly depleted SOI MOSFETs causes kink in direct current circuits and drain-current overshoot in switching circuits. Fully depleted devices Ultra-films are challenging to produce. The buried oxide-silicon interface must be of high quality. However, the advantages that SOI technology provides, particularly at lower power. As a result of this paper, SOI outperforms in terms of lowering each loss and the total loss for SOI-based inverter is 3.94 %.

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