Evaluation of SiC Power Devices for a High Power Density Matrix Converter

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Abstract — **With the commercial availability of SiC JFET and MOSFET, their acceptance are expected grows in consideration to the excellent low switching loss, high temperature operation and high voltage rating capabilities of these devices. This paper presents the possibility of building a matrix converter using Normally-off SiC JFET and SiC MOSFET. Firstly, the paper demonstrates a gate drive circuit for Normally-off SiC JFET and SiC MOSFET taking into account the special demands for these devices. Furthermore, a theoretical investigation of the power losses of a matrix converter with Normally-off SiC JFET, SiC MOSFET and Si IGBT is described. The losses estimation indicates that a 7 KW matrix converter would potentially have an efficiency of approximately 96% if equipped with SiC device.**

Keywords — **Normally-off SiC JFET; SiC MOSFET; loss evaluation; matrix converter**

I. INTRODUCTION

Nowadays, one of the vital issues in the development of power electronics converters is power density. Demand for achieving a light weight and low volume power electronics converters is raised along other requirements such as input and output power quality. In fact, due to introducing hybrid electric vehicle and more electric aircraft projects which have a significant impact on decreasing fuel efficiency, the demand for power electronics converter with high power density are increased.

Due to limited switching speed of devices such as SCR and GTO, when power electronic devices have been introduced, the power density was low relatively. By developing high switching frequency and high power devices such as IGBT and MOSFET, the power density of power electronics converter has increased since the 1990s. In addition, also developing fast recovery power diodes has helped to improve power density of converters.

In addition, due to development of Silicon Carbide (SiC) power electronics devices which have some features such as operating in high temperatures, low losses and faster switching speeds, further improvement on power density of power converter is possible to achieve. However, there are some challenges in implementing power converters with SiC devices due to fast switching speed of devices and gate drive requirement of devices.

In recent years, some of research efforts about SiC power converters have concentrated on DC/DC applications which have simple topologies and less complexity[1]. In addition, some efforts have been done in developing three phase power rectifier with switching frequency of 150(KHz)[2]. Furthermore, also there is an effort to develop three phase inverter using only SiC devices.[3] presented an SiC AC/DC/AC converter which consist of a Vienna-type rectifier front end and a two-level voltage source inverter and tested at 10 (KW) with 70 (KHz) switching frequency. Moreover, [4]demonstrated a 100 (KHz), 1.5(KW) SiC sparse matrix converter, but SiC cascade devices which limit the maximum operating temperature of power converter were employed.

It can be stated that attempts for developing and implementing SiC power electronics converters is in the early stages and more researches are required to achieve power converter with high power density.

Among various AC/AC power electronics converters matrix converter has some specific features which makes it more adequate for drive systems. Matrix converter is a preferred choice when the weight and volume are significant factors.

One adequate application for the matrix converter is in more electric aircraft, where power quality and power density demands is more essential in electrical actuators of flight control systems. In order to satisfy various demands of a drive system in more electric aircraft, it can be stated that SiC matrix convert is a suited option. In fact, a SiC matrix converter combines outstanding features of matrix converter and SiC power electronic devices and makes more possible to develop power converter with high power density.

Based on the mentioned contents, a research study has been started to develop a SiC matrix converter. This paper presents investigations and studies about SiC matrix converter which has been done. Firstly, it demonstrates a review about matrix converter. Second section deals with introducing Normally-off SiC JFET, SiC MOSFET and some requirements of them. In the third section, a specific gate drives are developed and tested when normally-off SiC JFET and SiC MOSFET are employed in a bidirectional switch and then a two phase to one phase matrix converter by Normally-off SiC JFET and SiC Schottky diode is

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implemented. Finally results of power losses evaluation and comparison of matrix converters which are implemented by different switching devices will be presented.

II. The Matrix Converter

Matrix converters as a bidirectional direct power electronic converters are able to provide synchronous amplitude and frequency transformation in AC electrical system. They are employed in frequency changers and electrical drives. In compare with Back to Back converters as another kind of AC-AC power converters, there is no energy storage elements in matrix converter topology so it is called an all silicon solution in power conversion. In fact, the weight and volume of the matrix converter due to lack of DC link capacitor is decreased in compare with another kind of ac power converter which has energy storage elements[5].

One of the interested features of matrix converters is sinusoidal input and output currents. Also with suited modulation techniques, the input phase displacement factor can be adjusted then it is possible for matrix converter to achieve unity power factor in any load. They are able to generate load voltage with arbitrary amplitude and frequency, therefore operation under abnormal input voltage conditions is possible for them[5].

The matrix converter consists of an array of controlled bidirectional switches; in fact with matrix converter is possible to connect an m phase voltage source to an n phase load directly. Among different configurations for matrix converter, an array of three by three bidirectional switches is more interest in industry due to it connects a three phase source to a three phase load as shown in Fig. 1.

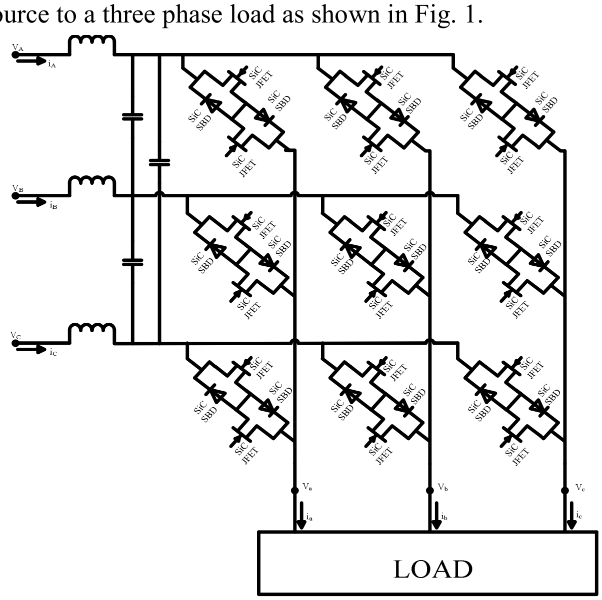

Fig. 1. The basic structure of a SiC matrix converter

However, due to lack of energy storage element, voltage transfer ratio of matrix converter is limited to 0.866 and this is a main disadvantage of matrix converter. Also due to high number of power electronic switches, the switching loss of matrix converter is higher than other AC-AC power converters.

The EMI filter capacitor of matrix converter which is put in the input of matrix converter requires being a small value for the application of matrix converter with high input frequency (for example from 360 to 800 Hz) in contrast to standard 50/60 Hz mains application in order to keep the reactive power low and to satisfy the power factor requirement. However, it is needed a large input capacitance to keep input voltage ripple and harmonic distortion low especially for such application with high peak output power. Thus this is not applicable because of reactive power limitation. The main solution for this problem is to raise frequency of switching but it depends on performance, efficiency, volume and weight requirements.

III. The SiC Power Electronic Devices

Nowadays SiC power electronic device is known as a high voltage and high switching frequency device in contrast with Silicon device. In fact, the SiC power semiconductors possess intrinsic advantages as high voltage blocking capability, low on-state voltage drop, high switching speed and low thermal resistance. Thus the conduction and switching losses of SiC power devices could be decreased and the operating temperature could be increased in compare by Si power devices. Based on the SiC power devices, achieving highly compact converter systems with lower conduction and switching losses and high voltage is possible.

Moreover, due to high thermal conductivity and wide band gap energy of SiC, operation in high temperature is allowed to SiC devices which make them more preferred for harsh environment applications.

Recently, two classes of SiC power electronic devices are commercially available, namely Schottky diodes and field effect transistors. SiC Schottky diodes are available from several manufacturers, including Infineon, Cree, IXYS, Microsemi, and STMicroelectronics, etc. The high voltage ratings to 1200 V and the near zero reverse recovery time of these devices, make them excellent choices for many other hard switching applications. Also SiC controllable switching devices in a variety of voltage and current levels are available as engineering samples such as JFETs from SemiSouth, MOSFETs from Cree, and BJTs from TranSiC.

A. *Normally-off SiC JFET*

One of the most successful and promising device to replace Si-MOSFET and IGBT is the normally-off SiC JFET. The SiC JFET is the controlled turn on-off SiC device which is close to commercialization and is available as restricted samples. The SiC JFET is a majority carrier device and its active device structure presents only with P-N junctions. It can be stated that its surge current capability is better than Si power MOSFET, also its on resistance is lower than 10 mΩcm^2 and it has very high switching speed due to small intrinsic capacitances, thus it is suitable for high switching frequency high power density application.

In fact, there is a channel in the n-drift region of SiC JFET structure which allows current can flow in n-drift region in both directions by applying no negative voltage between the gate and source of the SiC JFET. However, the n-drift channel will be blocked by applying enough negative voltage between gate and source. Also there is a normal P-N junction in the JFET structure which can be operated as a body diode. In compare with SiC Schottky diode, body diode of the SiC JFET suffers from reverse recovery and high forward voltage. Thus performance of the SiC JFET with body diode is decreased especially when operation temperature is increased. Therefore the switching performance of the SiC JFET can be improved by paralleling a SiC schottky diode by the SiC JFET.

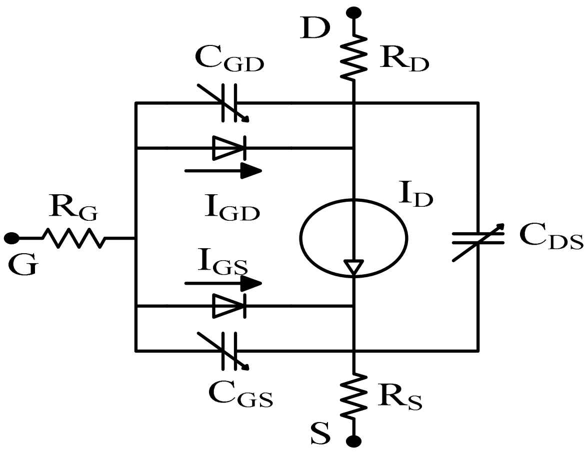

Fig. 2. Equivalent schematic model of the normally-off SiC JFET

Figure 2 shows the equivalent schematic model of the Normally-off SiC JFET. It reveals that at the gate-source junction, a variable capacitance appears which resembles a classical MOSFET's gate-source capacitance. The value of this capacitance is lower though compared to a MOSFET. Moreover, a P-N diode also appears at the gate-source Junction same as a BJT. This layout sets the basic gate requirement to deliver a dynamic charge to the gate capacitance during the turn-on and rapidly remove this charge to ensure a fast turn-off process. Apart from dynamic charge/discharge requirement another vital gate requirement is the maintenance of the gate-source diode on by keeping it forward biased during the on-state. Due to SiC P-N diode's typical built-in potential of around 3 V at 25 °C the drive voltage must thus be kept at 3 V. The gate driver circuit should also maintain the diode forward current during the on-state.

B. SiC MOSFET

Recently, SiC MOSFETs have become available and some of its advantages have demonstrated. Because the higher doping and current densities of SiC material, the SiC MOSFETs have smaller area and capacitance, therefore they are more efficient than Si MOSFETs. The fall time of SiC MOSFET current is smaller, hence switching loss and on state resistance of it is lower than Si MOSFET[6].

The Cree has introduced a 1200 V SiC MOSFET with extremely low on-state resistance R_{ds}(on) of 80 mΩ, thus removing the upper voltage limit of silicon MOSFETs. It should be noted that high voltage (>1000 V) Si MOSFETs can be manufactured, but due to fairly high R_{ds}(on) their application is considered unpractical. Figure 3 shows the equivalent schematic model of the SiC MOSFET. It reveals that three variable capacitances appear on the MOSFET model. The switching performance of the MOSFET transistor is determined by how quickly the voltages can be changed across these capacitors. Therefore, in high speed switching applications, the most important parameters are the parasitic capacitances of the device. The variable gate capacitances set the gate requirement to deliver a dynamic charge during the turn-on and rapidly remove this charge to ensure a fast turn-off process. Unlike SiC JFET, there is no requirement of providing the on-state current for the gate of SiC MOSFET, since the gate is isolated as already mentioned before.

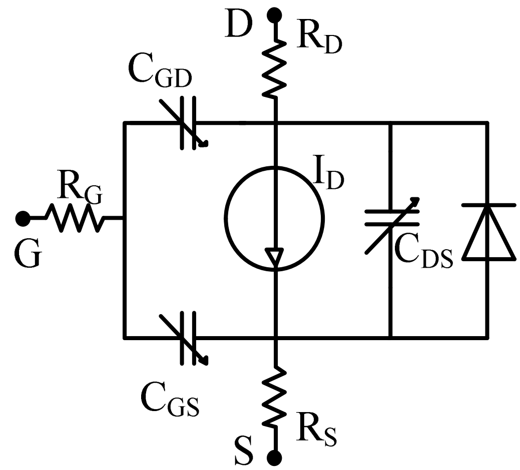

Fig. 3. Equivalent schematic model of the SiC MOSFET

IV. GATE DRIVE DESIGN

The need to develop suitable gate drives in pursue of full utilization of the SiC JFET and MOSFET high speed capabilities has hence become apparent, where the major obstacle faced has been the parasitic components. To solve this problem, several researches have been done to consider special attention which is required [7-11].

A. Normally-off SiC JFET Gate Drive

Normally-off SiC JFET makes special demands on the gate driver circuit compared to other unipolar SiC or Si devices. To fully exploit the potential of normally-off SiC JFETs, conventional gate driver circuits for unipolar switches need to be adapted for use with these switches. During on-state the gate-source voltage must not exceed 3 V, while a current of around 300 mA (depending on the desired on-resistance) must be fed into the gate, during switching operation the transient gate voltage should be around ±15 V and the low threshold voltage of less than 0.7 V requires a high noise immunity which is a severe challenge as the device has a comparably low gate-source but high gate-drain capacitance.

In the existing two stage gate drive[12], one stage supplies a short pulse with a high voltage for turn-on and a second stage delivers the dc gate current for the on-state. Although the performance of this kind of gate drive is suitable, it still features high circuit complexity, a high part count, and a large printed circuit board footprint.

A gate driver is developed in order to overcome the current limitations while still having a low circuit complexity using one gate driver IC and passive components only is used for driving Normally-off SiC JFET. The proposed gate drive circuit is indicated in Fig. 4, and is designed to control a 1.2 kV- 30 A normally-off SiC JFET (SJEP120R063) from the Semisouth.

In the proposed gate drive, a standard gate driver IC is supplied with a differential voltage V_{CC}-V_{EE} with the midpoint (0 V) connected to the source of the JFET, V_{cc} is equal to the suitable gate-source voltage $V_{GS} \approx 3$ V and V_{EE} is -24 V. The 0.2 Ω resistor and Schottky diode provide a path for the applying V_{CC} to the gate of JFET during the on-state of switch. In the other hand during the off-state of switch, the output of the gate drive IC is at -24 V, however the zener diode determines the required voltage which is -15 V. Also during turn-on of the switch the voltage of the capacitor is added to V_{CC}, in order to make sure that a high positive voltage is applied to the gate terminal of JFET for fast charging of the JFET's input capacitance.

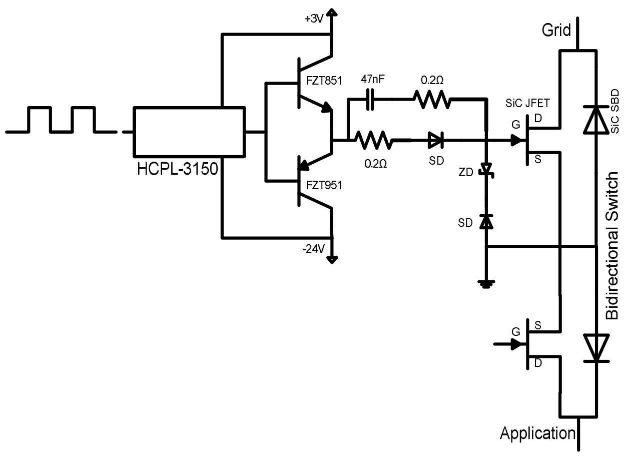

Fig. 4. A schematic diagram of gate drive for normally-off SiC JFET

In order to implement the gate drive circuit for normally-off SiC JFET, a standard NPN/PNP totem pole driver was employed to drive the device and as it is mentioned a specific AC coupling circuit is employed to compensate for varying turn on and off voltages of JFETs and also to limit the gate terminal current.

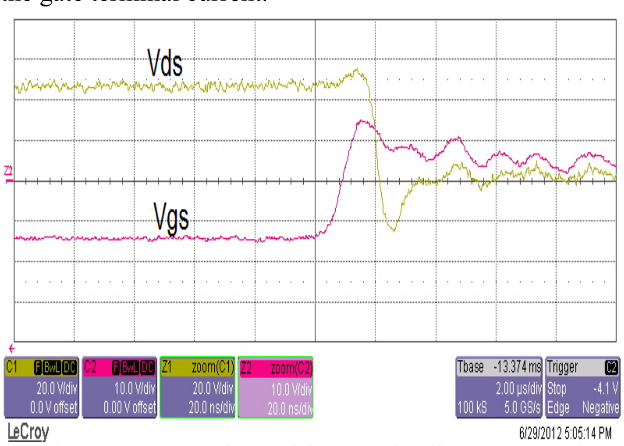

Fig. 5. Turn-on waveforms of the normally-off SiC JFET which is employed in a bidirectional switch

The waveforms of gate drive voltage and drain-source voltage for turning on the normally-off SiC JFET in a bidirectional switch in matrix converter is shown in Fig.5. It is obvious that the switching turn on time is slightly more than 20 ns.

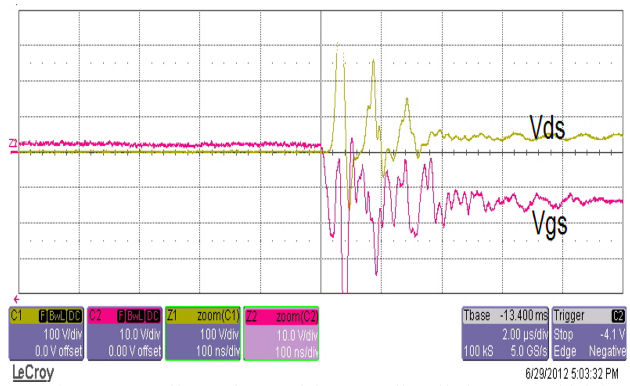

Fig. 6. Turn-off waveforms of the normally-off SiC JFET which is employed in a bidirectional switch

In addition, the waveforms of gate drive voltage and drain to source voltage for turning off the normally-off SiC JFET in a bidirectional switch in matrix converter is indicated in Fig.6. It is clear that the switching turn off time is slightly more than 100 ns and it is due to the oscillation in the gate drive voltage in turning off time and it is needed to reduce it.

B. SiC MOSFET Gate Drive

The proposed gate drive circuit for SiC MOSFET is indicated in Fig. 7, and is designed to control a 1.2 kV- 24 A SiC MOSFET (CMF10120D) from CREE. The main component of the circuit is a PMOS-NMOS totem-pole arrangement. The totem-pole arrangement can provide 28V output swing and up to 9A of current with a typical output resistance of 0.8 Ω. The optoisolator, the Avago HCPL-3150, has high common mode transient immunity (30 kV/µsec) and can operate from 4.5 to 30 V.

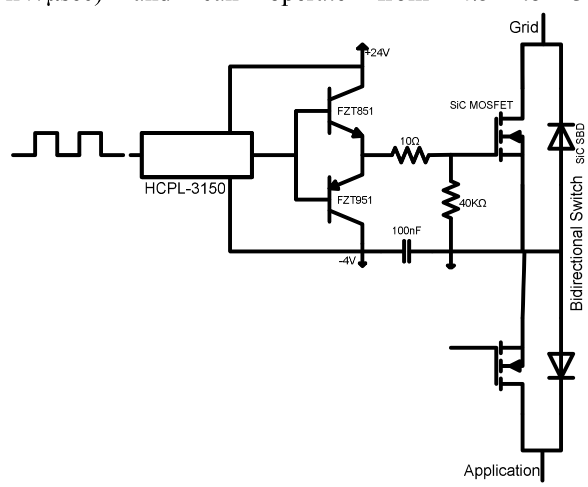

Fig. 7. A schematic diagram of gate drive for SiC MOSFET

The waveforms of gate drive voltage and drain-source voltage for turning on the SiC MOSFET in a bidirectional switch in matrix converter is shown in Fig.8. It is obvious that the switching turn on time is slightly more than 50 ns.

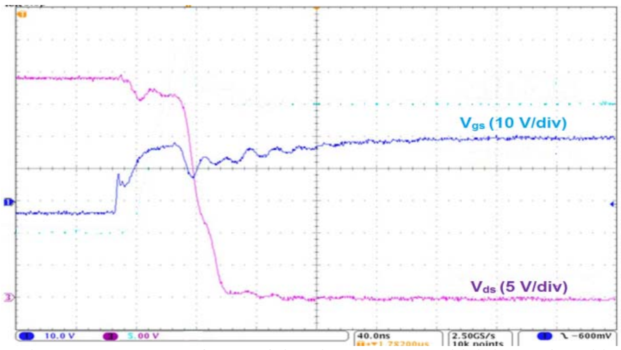

Fig. 8. Turn-on waveforms of the SiC MOSFET which is employed in a bidirectional switch

In addition, the waveforms of gate drive voltage and drain to source voltage for turning off the SiC MOSFET in a bidirectional switch in matrix converter is indicated in Fig.9. It is clear that the switching turn off time is slightly more than 40 ns. So in compare with normally-off SiC JFET, it has lower turn-off time and higher turn-on time.

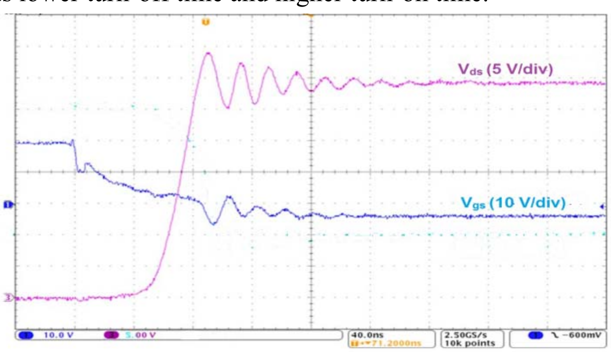

Fig. 9. Turn-off waveforms of the SiC MOSFET which is employed in a bidirectional switch

V. EPRIMENTS AND SIC MATRIX CONVERTER

In order to investigate the developed gate drive circuit of normally-off SiC JFET and also application of SiC power device in converters, a two phase to one phase matrix converter is implemented. A schematic of experimental rig is shown in Fig. 10.

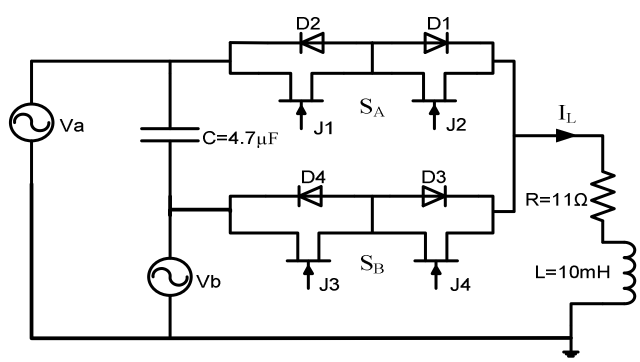

Fig. 10. A schematic of two phase to single phase matrix converter

Two bidirectional switches were constructed using four 23A, 1200V normally-off SiC JFET and four 16A, 1200V SiC Schottky Diode TO-247-3 packages and arranged as a two phase to single phase matrix converter. To control the switch sequencing using a four step commutation strategy an FPGA is employed. The switching frequency of converter is set on 20 KHz and fixed duty cycle switching is used to give equal input and output frequencies. The supply is variable from 0-230Vrms, 50Hz in each phase and the output current is controlled by adjusting the load resistance. A large inductance in the load ensures a smooth current. There is a simple capacitive filter which is constructed from ultra-low inductance metalized polypropylene capacitor at the input side which connected directly to the power plants. Figure 11 shows the gate voltage and the drain to source voltage of a normally-off SiC JFET in matrix converter when the input voltage of converter is equal 20 Vrms. In addition, Fig. 12 demonstrates the output current and voltage of a SiC JFET matrix converter. The output frequency of converter is 50 Hz due to duty cycle of converter is set to 50%.

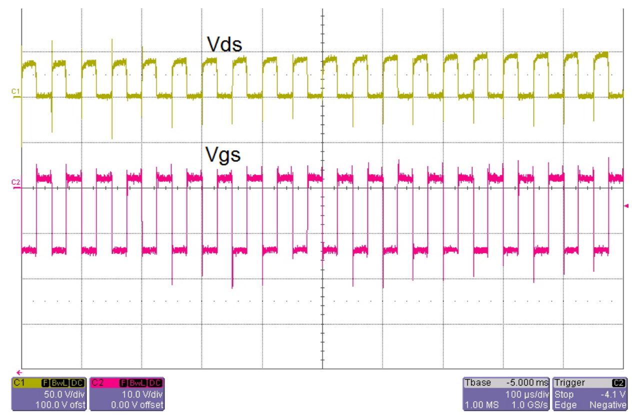

Fig. 11. Gate voltage and Drain to Source voltage of normally-off SiC JFET in matrix converter

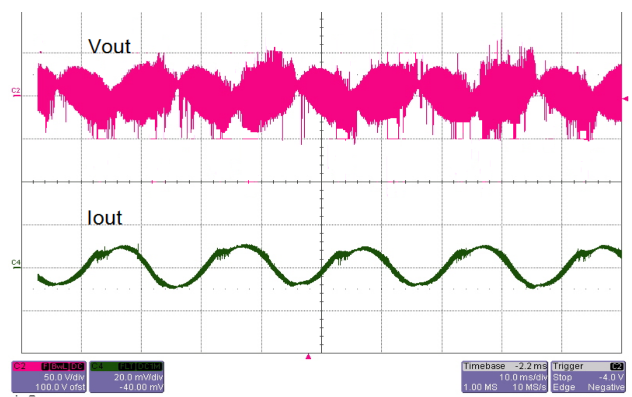

Fig. 12. Experimental waveform of Output voltage and current of normally-off SiC JFET matrix converter

VI. POWER LOSSES EVALUATION

One of the basic steps for evaluation of the reliability of matrix converter is power loss analysis. Due to converting AC utility voltages into variable voltage outputs in matrix converter by nine bidirectional switches, the drain-source voltage of JFET switches are not constant at each switching instant. Also due to rotation of voltage angle of utility grid, the current distributions in each JFET or MOSFET switch changes.

This part of paper presents an analysis method for evaluating power losses of matrix converter with Si and SiC devices and then comparison of them. Power device losses of matrix converter consist of conduction and switching losses of diodes and switch devices such as Si IGBTs and SiC JFET or MOSFET.

A. Conduction Losses

Conduction losses of switching devices in matrix converter have been covered in [13, 14]. In fact, the output current flow through one switch such as JFET or IGBT and one diode at any instant, thus based on the balanced three phase output currents some equations have been derived to determine conduction losses with depend on the model of switch. By assuming a sinusoidal output current of rms magnitude I_o, the average conduction losses for three phase matrix converter for different switch devices has been given by:

For Si IGBT: $$P_{con-ph} = \frac{6\sqrt{2}}{\pi} V_{ce} I_o + 3 r_{ce} I_o^2 \quad (1)$$

For SiC JFET and MOSFET: $$P_{con-ph} = 3 r_{ds} I_o^2 \quad (2)$$

For Diode (Si or SiC): $$P_{con-ph} = \frac{6\sqrt{2}}{\pi} V_f I_o + 3 r_d I_o^2 \quad (3)$$

In the above equation, V_{ce} and r_{ce} are the on-state collector-emitter voltage and on-state resistance of IGBT switch respectively. Also r_{ds} is on-state resistance of normally-off SiC JFET or SiC MOSFET and V_f and r_d are the diode forward voltage drop at zero current and the on-state resistance of diode respectively.

It is obvious that the conduction loss is only calculated by the rms value of the output current and the operation conditions such as modulation index or switching frequency do not have any effect.

B. Switching Losses

Evaluation of switching losses in matrix converter requires conceptual understanding of switching rules and physical characteristics of switches and diodes.

The turn-on and turn-off energy losses for a power electronic switch can be assumed to vary linearly with the change in voltage across the power electronic switch during the switching transient. Also, it is reasonable to assume that the turn-on and turn-off energies vary linearly with the blocking voltage and the conducting current of power electronic switch at the instant of switching event. Hence, the turn on and turn off JFET or MOSFET energy losses at the reference voltage and current are computed using the equations:

Turn-on energy loss, $$E_{on} = \frac{e_{on}}{V_R I_R} \quad (4)$$

Turn-off energy loss, $$E_{off} = \frac{e_{off}}{V_R I_R} \quad (5)$$

In the above equations, e_{on} and e_{off} are the turn-on and turn-off losses of JFET and MOSFET or IGBT respectively. V_R is the reference voltage in the drain-source or collector-emitter of JFET and MOSFET or IGBT respectively. I_R is the current reference in the drain or collector of JFET and MOSFET or IGBT respectively.

Similarly the diode recovery loss is determined using:

Recovery energy loss, $$E_{rec} = \frac{e_{rec}}{V_R I_R} \quad (6)$$

In the above equation, e_{rec} is the diode recovery energy loss. V_R is the reference voltage across the diode and I_R is the reference current of the diode.

In the other hand, for calculating switching losses, it is important to know the mechanisms of commutation due to its effect on switching. Commutation in matrix converter is not as straightforward as in conventional inverters since there are no natural free-wheeling paths. In a matrix converter, the commutation between two bidirectional switches is dependent on both the direction of the output current and the input voltage across the switches undergoing commutation.

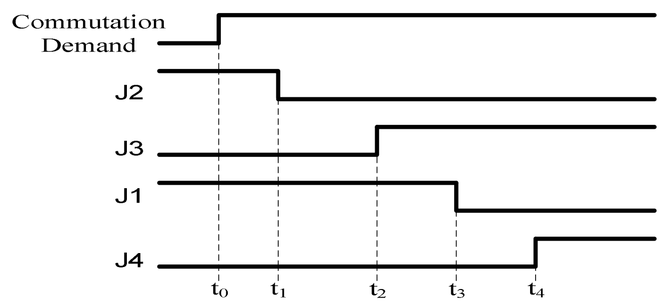

Fig. 13. Timing diagram indicting typical device sequencing when using a four step commutation strategy

Different commutation schemes are possible depending on the direction of the load current, and the relative potentials of input voltage. The device gate timings for a four step commutation strategy when commutating from S_A to S_B with the load current, I_L in the direction indicated in Fig.10 is shown in Fig. 13. If input voltage is positive, commutation will occur at t_3 resulting in a hard turn-off in S_A (J1) and a soft turn-on in S_B (J3). Conversely, if input voltage is negative, commutation takes place at t_2 resulting in a hard turn-on in S_B (J3) and a soft turn-off in S_A (J1). It is worth to note that, there is no switching loss at all in J2 and J4 for either situation, since neither conduct current when I_L is positive. A similar, but different sequence of events to that above occurs for negative I_L. The soft commutations are not completely lossless, but the energy involved is at least an order of magnitude less than for the hard commutations.

The observation from the four step commutation scheme can be generalized that there are one turn-on loss transient, and one turn-off loss transient for the switches and also one reverse recovery energy loss for diode in each commutation event. So by considering symmetry of the balance three phase systems at the input and output terminals of three phase matrix converter, the total switching energy loss of one phase in one switching cycle can be determined by:

$$E_{sw} = (E_{on} + E_{off} + E_{rec})(|V_{12}| + |V_{23}|)|i_{o1}| \quad (7)$$

In the above equation, V_{12} and V_{23} are phase to phase voltage and i_{o1} is the output current of matrix converter.

By considering that the switching frequency is much higher than the fundamental frequency of input voltage and output current and also a typical double sided space vector modulation, the total switching loss of the three phase converter can be calculated by:

$$P_{sw} = \frac{24\sqrt{3}}{\pi^2} f_s (E_{on} + E_{off} + E_{rec}) V_i I_o \quad (8)$$

In the above equation, f_s is the switching frequency of matrix converter and also V_i and i_o are peak value of input voltage and output current of matrix converter respectively.

C. Comparison of Power Losses in Matrix Converter with various power electronic switches

To determine and evaluate power losses in matrix converter with various devices three phase matrix converter is considered and four-step commutation strategy is applied. Also, it is considered three cases of matrix converter with three different switching devices for calculating and comparing the power losses of matrix converter. Three different switch devices which are used in simulation of matrix converter are listed in table I. Peak voltage and frequency of input of matrix converter is 230 (V) and 50(Hz) respectively and the peak voltage and frequency of output of matrix converter is set 150 (V) and 400(Hz). The value of the resistance and inductance of the load which are supplied by matrix converter are 10 Ω and 1.3 mH respectively.

Table I

DIFFERENT SWITCH DEVICES WHICH ARE USED IN LOSSES EVALUATION

Switch	Model	Manufacturer	Voltage (V)	Current (A)
Si IGBT+ diode	SK20GB123	Semikron	1200	23
SiC JFET	SJEP120R063	Semisouth	1200	30
SiC MOSFET	CMF10120D	CREE	1200	24
SiC Diode	C4D20120D	CREE	1200	32

Based on the mentioned equations for calculating conduction losses and a simple MATLAB program to calculate the switching losses from provided data with SABER software, the switching and conduction losses of matrix converter for various switching devices are determined. Figure 14 shows the comparison of the conduction loss and switching loss between Si IGBTs, SiC MOSFET and SiC JFETs in three phase matrix converter when switching frequency and output power of converter are 80 KHz and 7 KW respectively. It can be stated that there is a significant decreasing in switching losses of SiC matrix converter due low switching energy losses of SiC JFET and MOSFET in compare with Si IGBT. Also there is no on-state voltage across drain-source of JFET, so conduction loss in JFET is lower than IGBT. It is worth to mention that due to on resistance of SiC MOSFET is ten times more than Si IGBT, the total conduction loss of SiC MOSFETs are more than Si IGBTs in matrix converter, although there is no on state voltage across drain-source of SiC MOSFET.

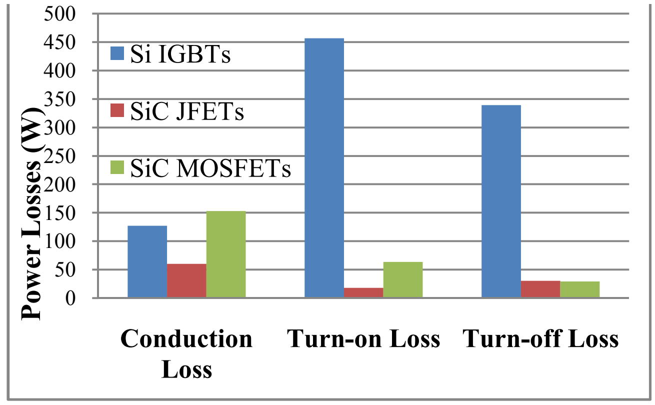

Fig. 14. Conduction and switching losses of Si IGBTs and SiC JFETs and MOSFETs in a 7 KW three phase matrix converter when switching frequency is 80 kHz

In addition, Fig. 15 shows the comparison of the conduction and turn-off losses between Si diode and SiC Schottky diodes which are used in three phase matrix converter. The most significant difference between Si diode and SiC Schottky diode is in turn-off loss due to there is no reverse recovery current in SiC schottky diode in compare with Si diode.

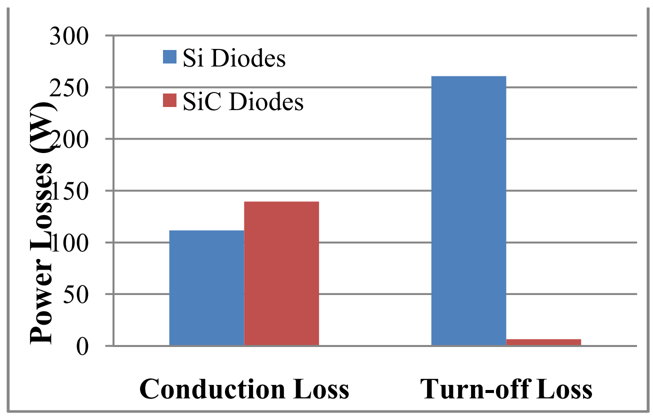

Fig. 15. Conduction and switching losses of Si diode and SiC schottky diode in a 7 KW three phase Matrix converter when switching frequency is 80 kHz

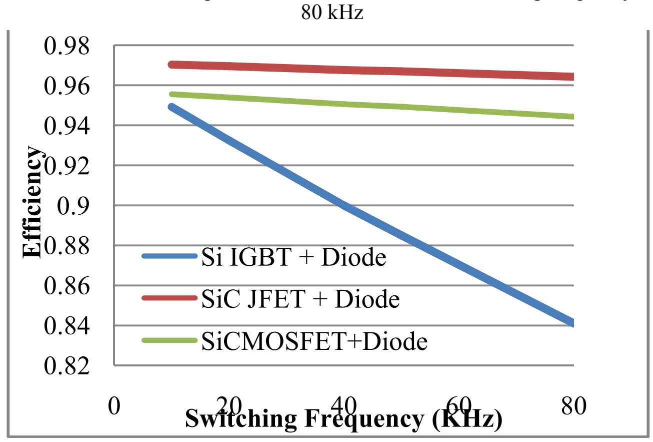

Fig. 16. Efficiency of 7 KW Matrix converter for various devices in different frequencies

The efficiency of the Si and SiC matrix converter with different switching frequencies when the load that supplied by matrix converter is 7 KW is also studied. The calculation results are shown in Fig. 16. It is obvious that efficiency of a three phase matrix converter which is built by SiC JFET or MOSFET is not reduced rapidly by increasing the switching frequency in compare a Si matrix converter. This calculation also shows that high power SiC matrix converter would approximately have an efficiency that exceeds 94% in high switching frequency when is built by SiC MOSFET or even it can have 96% when is implemented by normally-off SiC JFET.

VII. CONCLUSION

This paper has presented the design of normally-off SiC JFET and SiC MOSFET gate drive circuits and their applications in matrix converter. It has been shown that by the developed gate drives, it is possible to turn on a normally-off SiC JFET and SiC MOSFET in less than 25 and 55 ns respectively. Moreover, a turn off time about 40 ns has been achieved for SiC MOSFET by the proposed gate drive Circuit.

In addition a two phase to one phase matrix converter has been implemented based on the developed gate drive in order to investigate the switching waveform in a SiC matrix converter.

Moreover, mathematical descriptions for calculating power losses in matrix converter are presented and then power losses of Si and SiC matrix converter are determined in various frequencies. It has been shown that high power SiC matrix converter would approximately have an efficiency that exceeds 96%.

To sum up, the power electronic switches realized with SiC are respectable devices which will ensure the loss reduction and the improvement of power density in future.

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