SIC TECHNOLOGY, A WAY TO IMPROVE AEROSPACE INVERTER EFFICIENCY

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Abstract

Silicone carbide (SiC) components are now becoming commonly known from electrical power designers, but what is the real interest of a such technology for airframer ? In this paper we discuss and argue the potential benefit for aeronautical application to use or not SiC component. A first trade off based on Safran Power results on MOET project will be done with SiC diode and a second one with full SiC components.

1. Introduction

Five years ago, first generation of commercially available SiC diodes has been launched. Through demonstrators and prototypes, Safran Power has evaluated the potential benefit of this diode. Comparisons have been performed through a focus on inverter for different types of applications. Then an overview of the interests/benefits of full SiC inverter will be discussed.

2. Rough results on SiC diode use

Before MOET project, 600 V SiC diodes have been evaluated through Safran Power Electronic Center self founded programs. Results have shown an improvement on efficiency as demonstrated in [1]. As MOET distribution voltage baseline is +/- 270 VDC, the evaluation for SiC has been extended to 1200 V Schottky diodes with IGBT from the last available generation.

2.1 Inverter description

The inverter is made in only one module. This module is made for motor drive applications from 1 to 5 kW with a 540 V dc bus voltage. The module is designed to withstand base plate temperature from –55°C up to 150°C, 20 g of vibration amplitude, 95% of humidity and 0.1 atm of pressure. All of these environmental constraints impact the size of the power converter. The high ambient temperature explains the need for a maximum die temperature over the standard limit of 150°C (generally due to the silicium).

Fig1 MOET Power Module

The power module, developed by Semelab (Fig1), has been integrated in a power core with PCB and its complete driver board (Fig2).

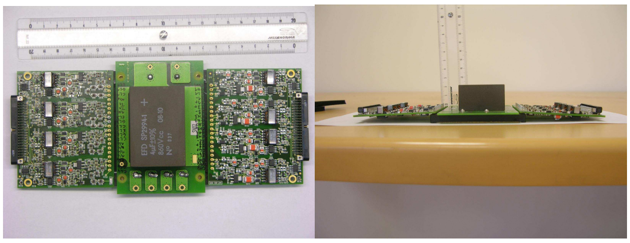

Fig 2 MOET Power Core

The characterization has been done following the picture set-up presented on figure1. Current and voltage (Vce and Vf) measurements are acquired directly on the scope and registered to allow an accurate losses calculation through a software program.

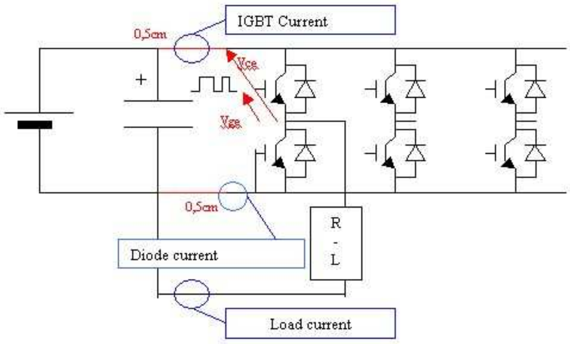

Fig3 Set Up scheme of the one shot test bench

The main benefit to characterize in such a way is that the switching losses measurement is completely representative of the real use of the module. Indeed, the module is mounted with its final busbar and capacitor design. An other advantage is to prevent breakdown of the component thanks to only one or two command signals.

2.2 Switching performances

For first assessment, the foreseen benefit of the switching losses was between 30 and 40% on the total losses. This assessment was based on the idea that we would have the same improvement than seen with the 600 V module [1].

However the comparison was not so simple. To well understand and compare the technology, the switching results are compared with 2 other power modules that are almost identical (Package, layout, IGBT dies …), the only difference is that the first one has the Emcon diodes recommended with the IGBT die used and the second one has 2 SiC Schottky diodes in parallel.

Indeed, two diodes are used in parallel to reduce the drop voltage that can degrade the overall efficiency of the inverter and to mitigate in the same way the cost of an expensive SiC die having a too big surface.

Hereunder the following curves and table summarize the results and the comparison:

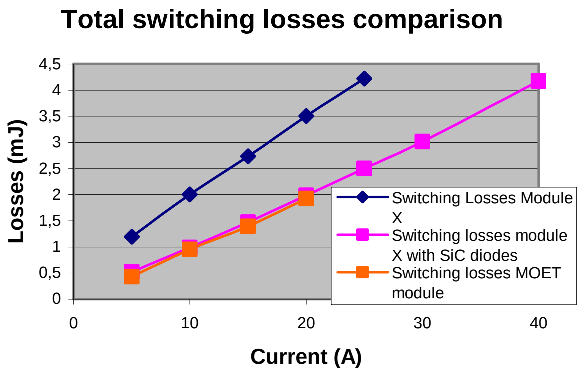

Fig4 Switching losses results

Current (A)	Total switching losses reduction
5	56%
10	51%
15	46%
20	43%
25	41%

Fig5 Losses summary table

All the comparisons are done at room temperature, the benefits will be higher at higher junction temperature (due to the increasing of the Si diode Qrr).

At least the improvement on switching losses is 40 %. However, the most important point is the benefit that you have at the inverter level.

2.3 Benefit at inverter level

In this paragraph will be shown the benefit at the inverter level depending of the application and the way to drive it.

The benefit has been evaluated through comparison between sinus/trapezoidal motor drive for actuator and pump type applications.

(A RMS)	Module X	Module MOET	Gain
5	66	37	44%
10	116	80	31%
15	171	129	25%
20	228	186	18%

Fig6 Inverter losses using a sinus drive at a high duty cycle.

The figure 6 evaluates the benefit from the SiC diode in an inverter where the motor drive is sinusoidal at a high speed. It corresponds to application like pump, fans that needs a high level of torque accuracy.

Inverter losses sinus @ 15 kHz, Low duty cycle			
Current (A RMS)	Module X	Module MOET	Gain
5	66	40	39%
10	116	93	20%
15	171	161	6%
20	228	242	-6%

Fig7Inverter losses using a sinus drive at a high duty cycle.

The figure 7 evaluates the benefit from the SiC diode in an inverter where the motor drive is sinusoidal at a low speed. It corresponds to application like actuators controller where the speed is variable.

Inverter losses trapezoid @ 15 kHz			
Current (A pk)	Module X	Module MOET	Gain
5	30	19	37%
10	55	41	25%
15	83	68	18%
20	114	98	14%

Fig8 Inverter losses using a trapezoidal drive at a high duty cycle.

The figure 8 evaluates the benefit from the SiC diode in an inverter where the motor drive is trapezoidal at a high speed. It corresponds to application like pump, fans that don't need a high level of torque accuracy.

All these tables enable us to understand some strong trends. Losses are reduced at least per 25% when used for high duty cycle application where the diodes do not conduct too much. Indeed, after a certain current the benefit obtained on the switching losses is cancelled by the extra losses obtained during the conduction phase of the diode. The table 3 shows us how a bad use of this module can cancel all the benefit from the SiC diode use.

To really take advantage of the SiC diode use, the temptation to use the smallest possible die shall be avoided by doing a complete trade off between losses and cost.

2.4 Conclusion on SIC diode use

These previous paragraphs show that for inverters in various type of applications with different way to drive them, the use of SiC diode for +/-270 VDC bus voltage can be a way to reduce at least from 25 % the losses seen on the converter.

Higher reduction can be expected but the good optimization shall be done at system level by challenging overall system cost and weight.

The use and the know-how obtained from the use of this type of today's components can bring Safran equipment the good approach to optimize the various electrical functions of the aircraft.

However an higher step can be achieved by introducing the use of full SiC inverter.

3. Possible benefit from a full SiC inverter

Semi conductor industries have never been so close to introduce commercially available commanded SiC power component.

The SiC has three main theoretical benefits: the higher switching speed, the higher maximum junction temperature [Fig9] and the lower specific on resistance [Fig 10].

Here under are the following tables that

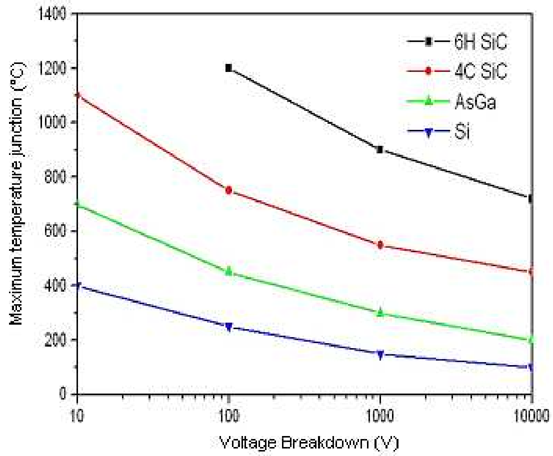

Fig 9: Voltage breakdown versus max junction temperature

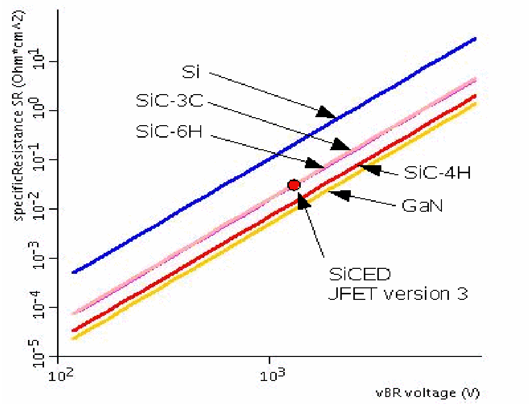

Fig 10: Specific resistance against voltage breakdown

Today, 2 types of components are competing, JFETs and MOSFETs. They are the most advanced SiC power components. The MOSFET is the simplest one due to its normally off behavior. The JFET has the disadvantage to be normally on but its maturity seems to be largely better. Safran Power through programs like SEFORA introduces its use in inverter application for extremely high ambient temperature (200°C).

The use of normally on JFET tested in Safran facilities seems to be quite promising and the last generation component from SiCed has once time more improved the Ron performance [Fig11].

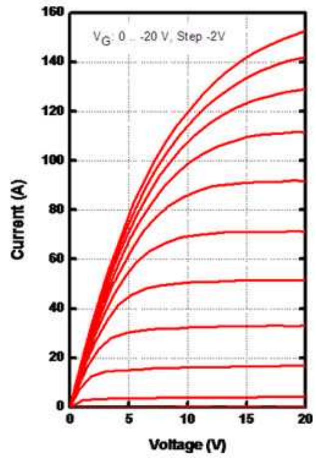

Fig11 Characterization curve from SiCed [3]

Indeed, the Ron value of this component is about 60 mOhms for a surface of 23.5 mm² (about 16 mΩ/cm² in comparison to CoolMOS at 150 mΩ/cm²). Moreover, JFET performance is far from its theoretical limits as JFET is still a "young" product.

In the same way, the high switching speed enables to have lower switching losses than Si component (Fig 12 and 13).

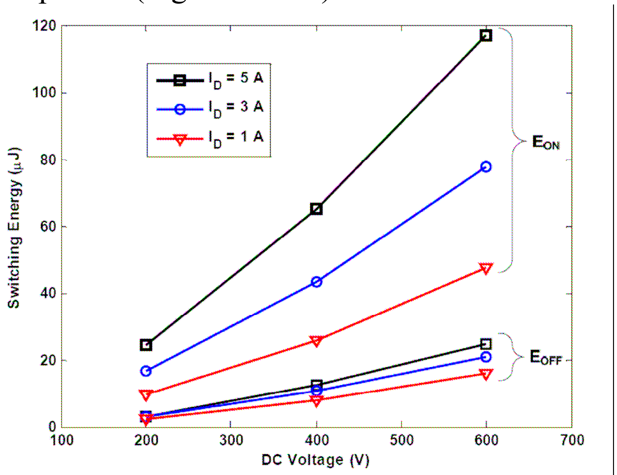

Fig 12: Switching losses measurements [2]

		Si IGBT (IRG4PH20K)	Si MOSFET (IRFPG50)	SiC JFET (SiCED)
Rating		1200 V, 5 A	1000V, 6.1 A	1200 V, 5 A
C-E Saturation Voltage (V)		3.2	–	–
On-resistance (Ω)		–	2	0.41
Switching Energy (µJ) @ 600 V, 5 A	E_{on}	234 *(153*)*	97*	113
	E_{off}	229 *(650*)*	74*	37
	E_{tot}	***463 (803*)***	***171****	***150***

Fig 13: Switching losses comparison [2]

To assess the benefit of the SiC devices, a comparison table has been done between MOET module and a JFET inverter that are driven in trapezoidal current a motor.

Inverter losses trapezoid @ 15 kHz			
Current (A pk)	Module MOET	Module JFET	Gain
5	19	5	74%
10	41	16	61%
15	68	35	49%
20	98	60	39%

Fig 14 Inverter losses using a trapezoidal drive at a high duty cycle.

The calculation has been done by using the last generation dies from SiCed @25°C. All the calculations are done with a single die per switch.

In this figure 14, we see possible improvement above 50 % on the best inverter of today's technology. The gain is decreased at too high current. To improve efficiency at these currents, the solution is to add dies in parallel. In the same way, a trade off between cost and efficiency save shall be done.

4. Conclusion

This papers through inverter type applications example has shown the tremendous possible improvement brought by the SiC component in short and in medium term.

Full SiC inverter will bring a huge gap in power electronic development for future aircraft development and that's the reason of the investment from Safran in technological research project.

5. Acknowledgments

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