High performance, low noise submarine converters: SiC technology

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***Abstract*— One of the major issues for submarines is acoustic discretion. Noise in submarines is partially produced by converters. Converters perform their function through the use of electronic commutation, which by nature creates noise.**

One of the solutions is to increase switching frequency. However, the traditional IGBT (Insulated Gate Bipolar Transistors) do not allow a frequency increase without major losses through heat; hence requiring a larger cooling system. Today's, SiC semiconductors are a real alternative to Silicon IGBTs. This technology has many benefits such as low losses, high operating temperatures, high voltage capability…

***Keywords- SiC MOSFET, SiC driver, acoustic noise, switching frequency, losses*.**

Content

1. Introduction

Wide band-gap materials such as Silicon Carbide (SiC) or Gallium Nitride (GaN) have been subjected to recent intense research in power electronics. This has led to the commercialisation of SiC diodes from the beginning of the 21st century. Recently, SiC controlled switches have also been released. These new devices provide better switching performance than Silicon (Si) components leading to a reduction of losses [1]. This opens new opportunities such as reduced cooling requirements [2,3] and/or an increased switching frequency [4]. These factors play a major role especially when compactness and/or high acoustic discretion is required, such as in submarine applications. However, to get the full potentials of the SiC technology, it is essential not only to use a SiC module but also to couple a dedicated driver in charge of managing its static and dynamic behaviour.

Exail is a company specialised in the design and manufacture of power electronics equipment dedicated to harsh environments. Exail has taken an interest in SiC technology to develop a new range of converters for submarine applications.

This has led to several projects: first, a collaborative project with French Lab Ampère based in Villeurbanne (FRANCE) to study the impact of SiC transistors in power converters; especially in determining semiconductor loss. Secondly, a collaborative project with French Lab IETR (Institut d'Electronique et de Télécommunications de Rennes) based in Nantes (FRANCE) to develop a specific driver to pilot a SiC MOSFET module.

The aim of this study is to evaluate the advantages and drawbacks of using SiC MOSFET and SiC Schottky diodes instead of Si-IGBT in power converters. The converter studied is based on the electrical characteristics of a 60kVA three phase inverter dedicated to embedded systems.

In Section II, we present a quick review of commercialized SiC transistors in a module package. In section III, the driver system in charge of biasing SiC MOSFET is described. This device has to manage the high dv/dt, di/dt switching generated by the SiC devices.

Section IV details the design of a 60kVA system and evaluates the benefits of using the SiC module instead of an IGBT Si module...

2. SiC transistor

The SiC MOSFET has become more and more popular among designers. Their electrical characteristics offer better performance in both switching and conduction losses than classic IGBT. MOSFET is also normally-Off, which ensures safe operation in power converters compared to Normally-On devices (SiC-JFET) requiring complex driver units [5, 6]. This behaviour has led many manufacturers, such has Wolfspeed, [7], Rohm [8], Microsemi [9] ... to produce SiC devices in both discrete packages and power modules. Figure 1 shows different power modules from this manufacturer.

Figure 1: Two SiC MOSFET Modules (left) 62mm package, (right) E package

3. SiC MOSFET driver

To extract the full potential from SiC technology, it is vital to manage the switching behaviour during commutation. Indeed, due to High dv/dt [10], SiC MOSFET is subject to produce EMI/EMC interference and even destructive shoot-through (miller effect). To avoid these undesirable phenomena, it is mandatory to use an electronic system called "driver".

Exail has developed, through collaborative work with the French Research Lab IETR [11], a driver dedicated to SiC MOSFET. Figure 2 presents a view of the Exail SiC driver.

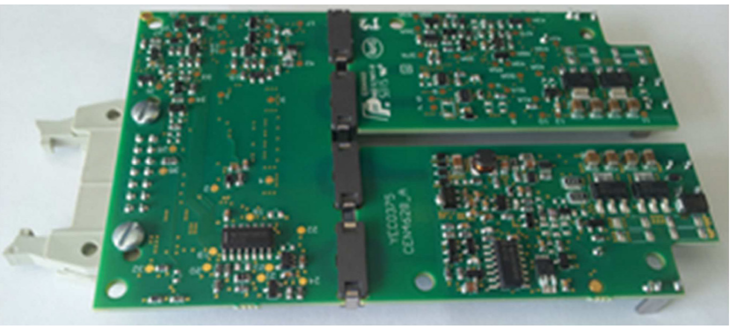

Figure 2: Exail driver for SiC MOSFET module

The Exail SiC driver possesses dedicated features such as:

BIASING VOLTAGE SWING:

Even if, the MOSFET gate is similar to IGBT, biasing voltage of SiC MOSFET has not been yet standardised among manufacturers (see Table 1). Therefore, it has to be adapted to avoid extra losses in the transistor which can lead to thermal runaway. This is a major difference compared to a classic IGBT driver.

SiC MOSFET module	VGS on (V)	VGS off (V)
CAS300M12CM2 (1200V/293A @Tc = 90°C)	20	-5
BSM300D12P2E001 (1200V/300A @ Tc = 60°C)	18	0
IGBT module	**VGE on (V)**	**VGE off (V)**
SKM300GB12E4 (1200V/324A @ Tc = 80°C)	15	-15

Table 1: Recommended gate voltage biasing for SiC MOSFET and Si IGBT

ACCURATE DEAD TIME

It is common thing to add a dead time between transistor commutations to avoid direct shoot-through. Exail SiC drivers employ a RC network, window comparator (LMV7219) and a precision voltage reference. These devices generate precise dead time on each driver channel compared to classic RC networks with logic gates and insure the driver reproducibility.

MASTER/SLAVE CONFIGURATION

The input command can be synchronised between parallel drivers to bias power modules. It avoids delays and unbalanced dynamic losses inside modules which can lead to thermal runaway.

LOW CAPACITIVE INSULATION

Insulation is achieved via planar transformers which produce low capacitive parasitic coupling. This critera is essential to limit the EMC/EMC interference and to allow high speed switching to limit switching losses.

Exail SiC driver has classic protection:

UNDER-VOLTAGE LOCK OUT:

The driver stops when input supply voltage is too low. It avoids excessive conduction losses and thermal runaway for the devices.

SHOOT-THROUGH PROTECTION + SOFT SHUT DOWN:

The driver detects an over-current due to shoot-through and opens with dedicated dynamics behaviour to avoid a destructive overvoltage.

4. 60kVA SiC converter

Currently, a SiC 60kVA (see FIGURE 3) converter is being manufactured by Exail based on the loss relations presented in previous SIA publications [12].

Figure 3: View of the current 60KVA converter

Among the SiC modules on the market, a 1200V/300A halfbridge module has been selected. To reduce static losses, two modules per phase are put in parallel. SiC Modules are coupled with a SiC driver developed by Exail. These devices symbolize the heart of the converter and are called the "Power Bridge". The converter also includes:

- LC Input and output filter to reduce parasitic harmonics.
- Power Transformer to provide electrical insulation safety.
- Control command to ensure regulation and proper behavior.
- Cooling system to evacuate calories produced by every power loss source (semiconductor, cables, transformer, capacitor...). Figure 4 presents schematics of the 60kVA converter.

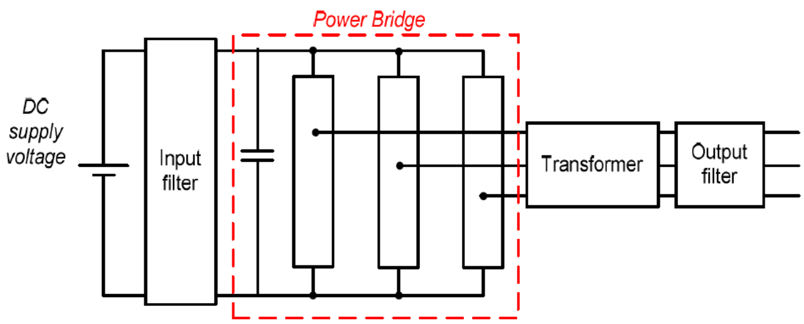

Figure 4: Schematics of the 60kVA converter

This converter is designed to complement the actual Si 60kVA converter embedded in a submarine. Table II details the main characteristic of the SiC 60kVA converter.

System characteristics	Value	Unit
Maximum Input voltage, V_{DC}	504	V_{DC}
Ouput voltage, U_{OUT}	115	V_{RMS}
Ouput current, I_{OUT}	250	A_{RMS}
Power Factor, PF = cos (φ)	0.8	
Switching frequency, F_{SW}	10 → 24	kHz
Ambient temperature, Tamb	60	°C

Table 2: Electrical characteristic of the SiC 60kVA converter

Due to the superior performance of SiC devices, switching frequency is increased from 10 to 24 kHz in order to evaluate the change on loss, acoustic discretion and cooling system.

LOSSES REDUCTION IN THE SAME OPERATING CONDITIONS (10KHZ)

Using SiC MOSFET instead of Si-IGBT has increased efficiency up to 2.9% which represents 30% loss reductions by a converter. It opens new possibilities, such as a smaller cooling system or even the use of a free air-cooling system instead of forced air system. The absence of an air fan is a real benefit due to noise/vibration and the reduction in maintenance.

INCREASE SWITCHING FREQUENCY FROM 10 TO 24KHZ

A 24 kHz switching frequency generates low acoustic noise especially in the audible bandwidth. In addition, the LC output filter's size can be reduced thanks to the higher cut-off frequency. Therefore, the magnetic elements will create less noise. However, increasing frequency from 10 to 24 kHz increases power losses. There is an optimal configuration to get maximum benefit from the SiC technology. Figure 5 illustrates this optimal configuration with converter losses in different configurations. The SiC converter loss is still below the IGBT converter loss, despite the increase of switching frequency to 24 kHz (out of audible bandwidth).

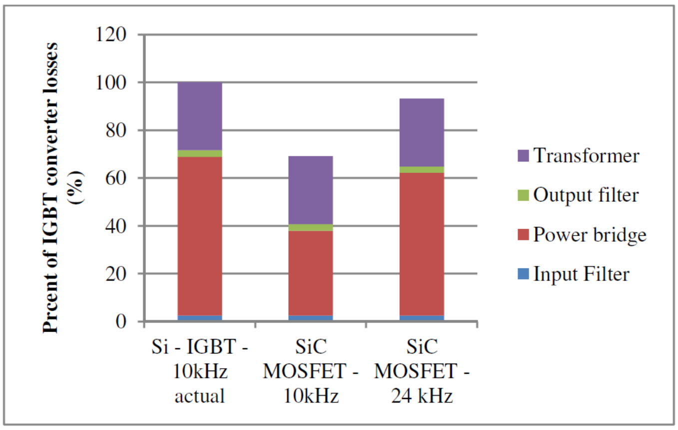

Figure 5. SiC 60kVA converter losses for different configuration

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5. Conclusion

This paper details the development a SiC converter. Namely, the development of the power bridge. A specific SiC driver has been designed by Exail to manage the behavior of the SiC MOSFET module and extract its full potential.

Measurement shows a loss reduction of 30% overall for the converter, compared to the classic IGBT. This gain can be exploited by designing a specific converter:

- High efficiency converter (low switching frequency) to reduce loss and increase battery autonomy. According to a submarine manufacturer, one watt can be assimilated to a 2kg Pb battery.
- High acoustic discretion converter (optimal switching frequency) to be less detectable by nearby vessels.

6. Future work

Exail is currently developing a communication printed circuit board for the SiC driver [13]. This electronic card monitors critical signals for SiC transistors such as temperature, voltage and current in order to perform a checkup. Using this card allows the designers to anticipate destructive failure modes and allows the converters to operate in derating mode. This electronic card is plug and play with the SiC driver and gives a full compact solution.

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