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High Performance SiC MOSFETs for Fault Tolerant Applications

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Abstract 1

Harsh environment applications are characterized by exceptional constraints regarding temperature, volume, fault-tolerance, efficiency, etc. As the introduction of power electronics in such systems is constantly growing, research activities are essential to get more knowledge on the capabilities of available technologies for such applications: aerospace and renewable energies. This paper evaluates the performance of a Silicon Carbide (SiC) MOSFET transistor for a multiphase power converter for fault-tolerant applications. Two methods are carried out in this study: first, the model provided by the manufacturer is used in simulation for a fault-tolerant electric drive application, then in the same operating conditions, the power module is characterized and its performance evaluated. Both methods lead to high system efficiency around 97-98% for a 1200V-400A SiC MOSFET transistor module integrated in a 120kW-100A 6-phase modular inverter.

Research Objective 2

- Evaluation of the dynamic performance and the efficiency of a high power multiphase converter (**120 kW-100A-25kHz**) based on Silicon Carbide (SiC) technology for fault-tolerant applications:
  - Model-based performance analysis of a dual SiC power MOSFET (CREE® HT-3201).
  - Characterization of the power MOSFET module for temperatures varying from 25°C to 150°C.
  - Measurements-based performance study of an H-bridge inverter.

System Description 3

The schematic diagram of the system under consideration is depicted in **Fig. 1**. This configuration is introduced in this paper for aerospace application. The HVDC bus (540V) is interfaced to a hexaphase machine by using multiphase converter and filter. The multiphase power converter is used for power flow control to fulfil power requirements of the machine (120kW). In this application, the power converter is composed of six H-bridge inverters based on SiC MOSFETs. These semiconductors can achieve high performance power conversion as they offer ultra-low losses, and the ability to function at high operating temperatures.

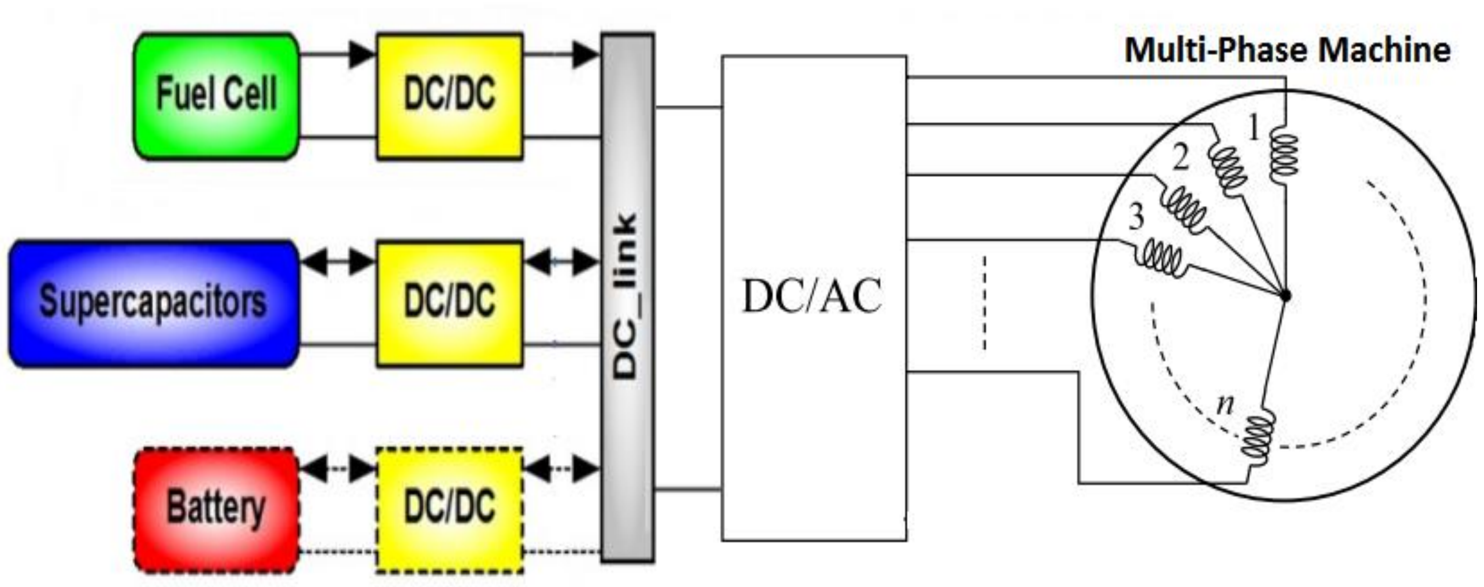

Fig. 1. System description showing power drive train for electric traction

Model-based Performance Evaluation 4

With the availability of the SiC MOSFET HT-3201 model ((**Fig. 2**) on LTSpice®, there is the possibility to assess its performance in a specified application. The model represents a half-bridge module composed of detailed models of SiC switches, schottky diodes and parasitic inductances of the package included by the manufacturer: from the inner drain, source and gate of each switch to the outer connections. Parasitic inductances between two switches are also included.

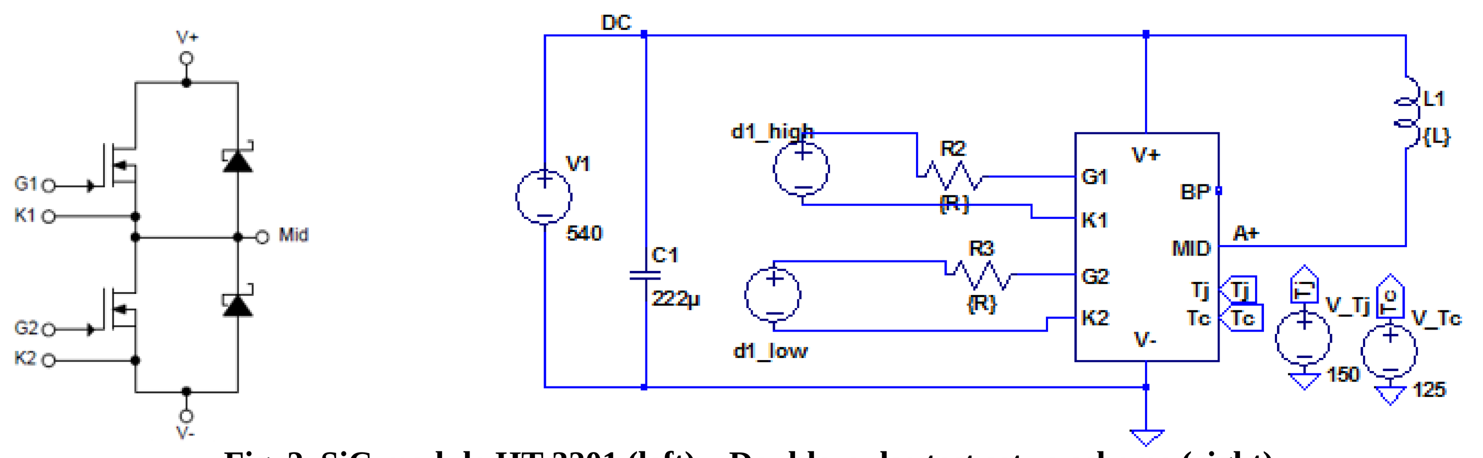

Fig. 2. SiC module HT-3201 (left) – Double-pulse test setup scheme (right)

Results of this simulation show some good performance in the switching behavior (**Fig. 3**). In fact, the overvoltage in the turn-off operation is very low (about 5%) and the total switching losses computed is around 5mJ (turn-on and turn-off). But the current overshoot at turn-on is quite high (more than the double of the 100A objective), but is still below the 400 A rating of the device.

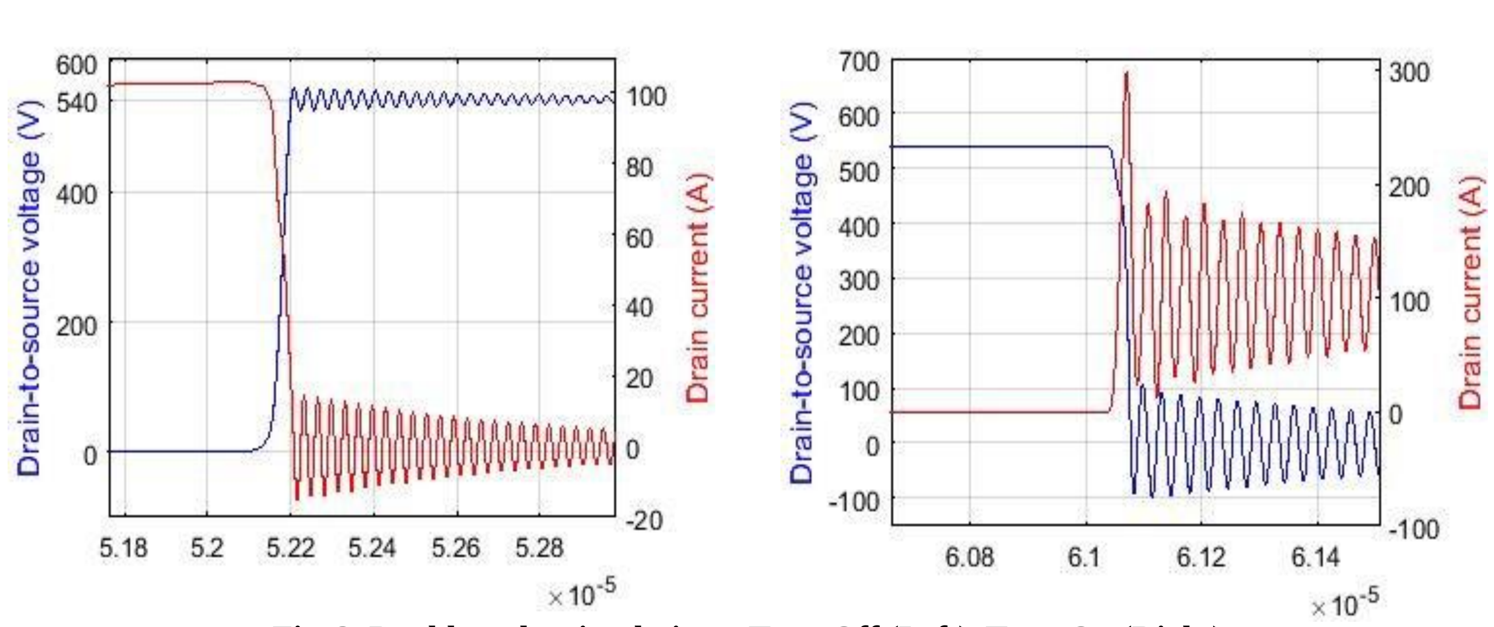

Fig. 3. Double-pulse simulation – Turn-Off (Left), Turn-On (Right)

SiC MOSFET Switching Characterization 5

The complete test setup of one module is shown in **Fig. 4**. The layout of the setup encompasses an aluminum hot plate which is used to heat the power module, a DC bus capacitor, the SiC power module and the gate driver, ITGD2-3001 from CREE®. As it can be seen, the assembly achieved is very compact to limit additional parasitic inductances. Switching results are depicted in **Fig. 5**.

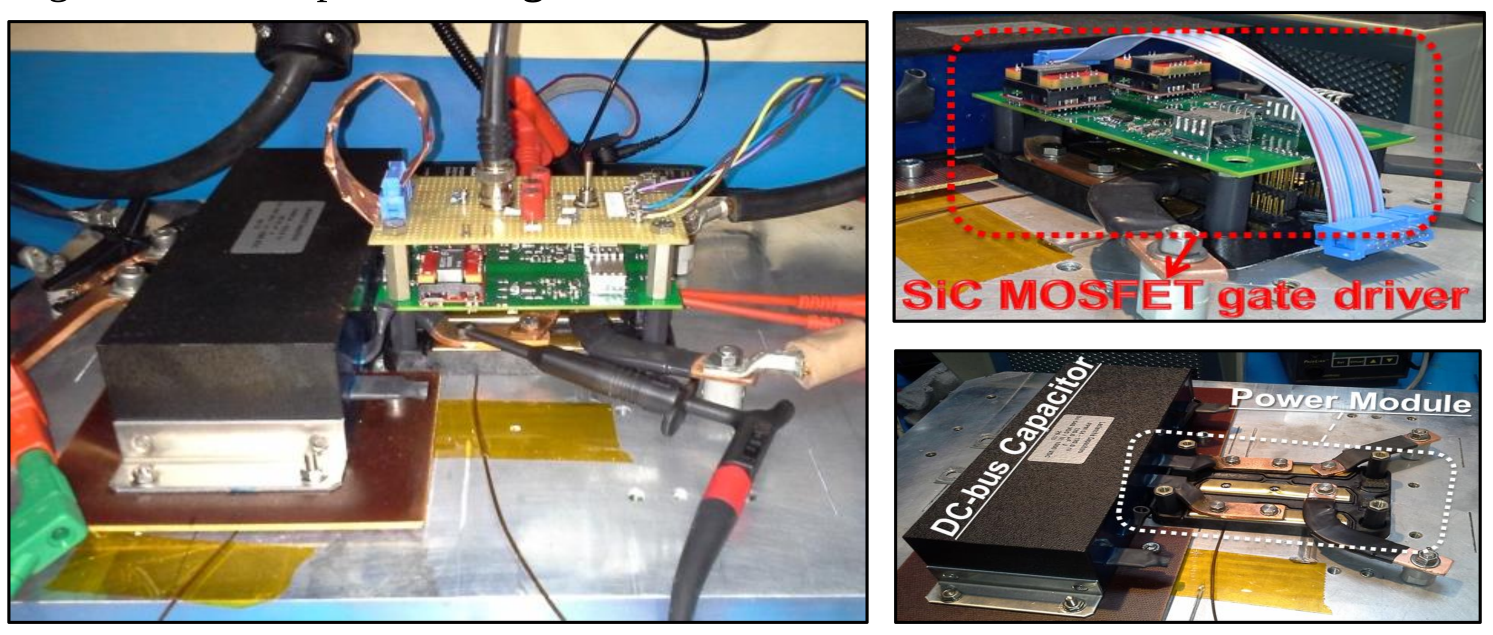

Fig. 4 Left: Characterization layout– Right: SiC power module connected to gate driver and DC-bus capacitor

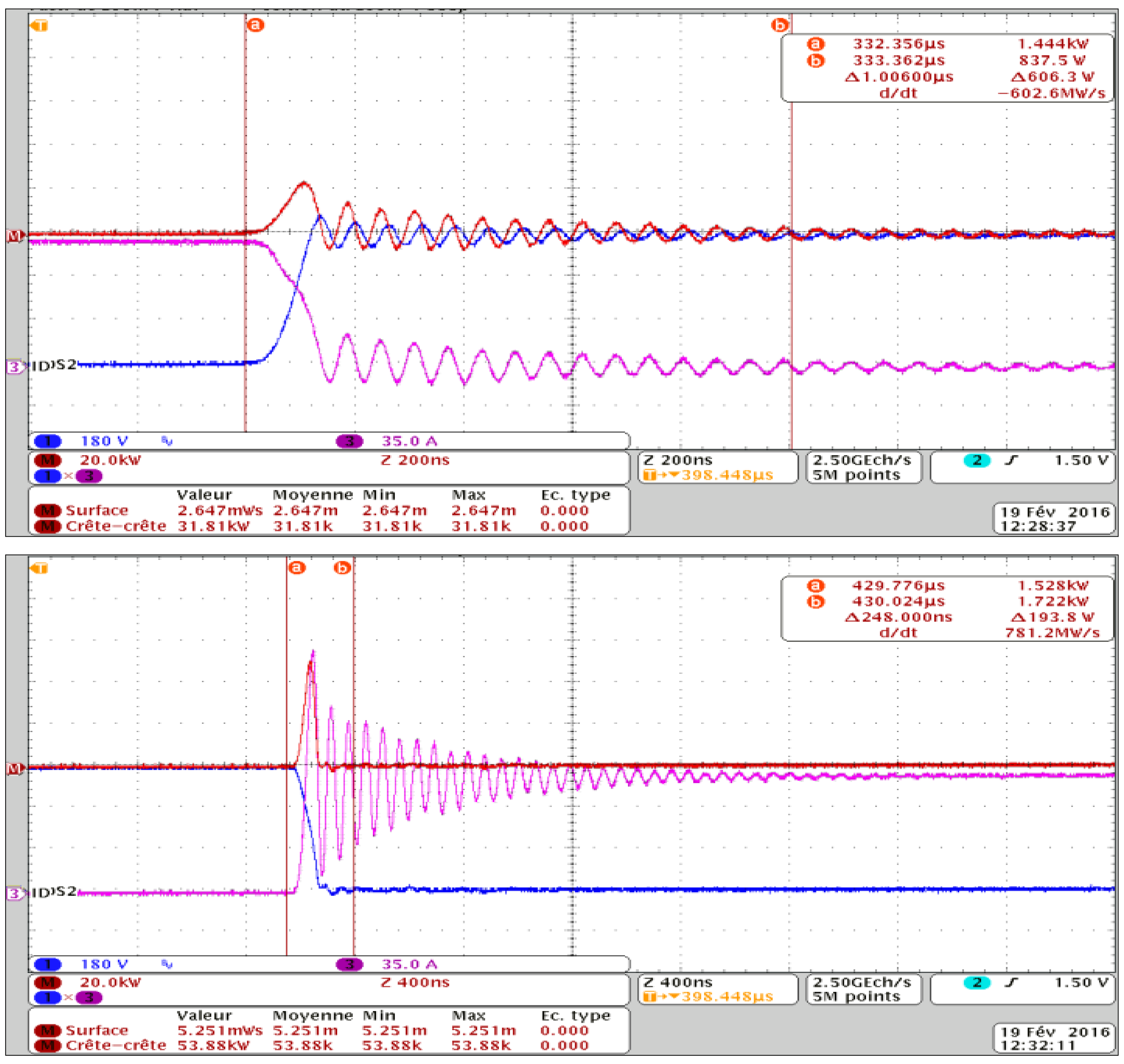

Fig. 5. Double-pulse experimentation – Turn-Off (Top), Turn-On (Bottom)

Measurements-based Performance 6

To evaluate the performance of the SiC module, a full-bridge inverter is modeled in Simulink® environment, as shown in **Fig. 6**. Also, the efficiency curve is given in function of the switching frequency. The efficiency achieved for the converter is around 97%, at a switching frequency of 25 kHz, and 98% at a switching frequency of 12.5 kHz.

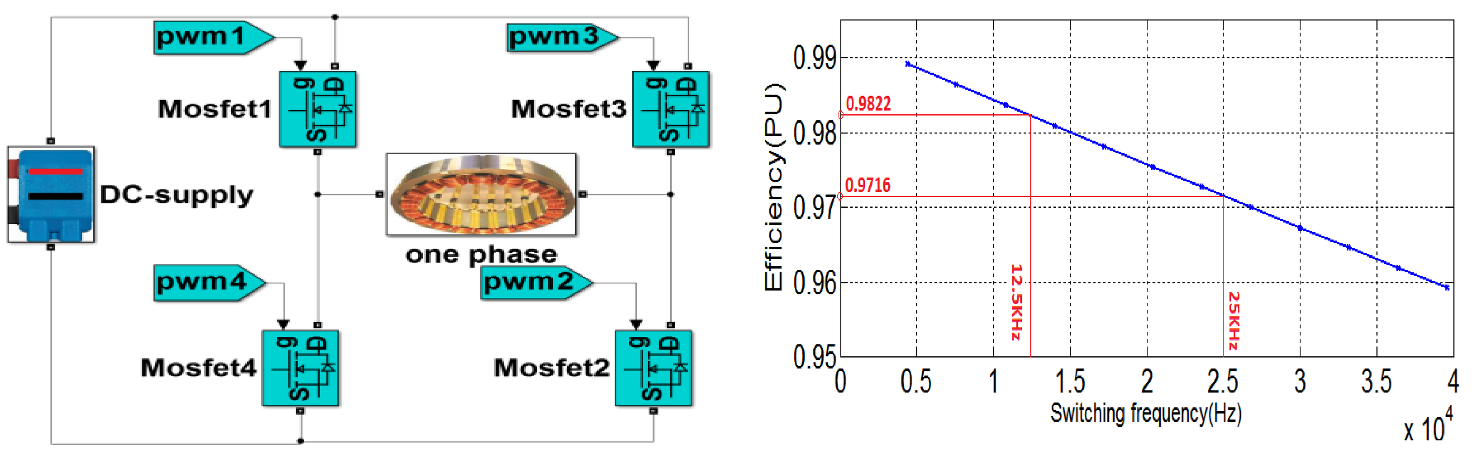

Fig. 6. Left: Independent phase powered in H-bridge configuration simulated in MATLAB/Simulink® - Right: Efficiency in function of switching frequency

Conclusions 7

System efficiency has been computed using LTSpice model provided by the vendor and measurements with the actual power module to validate the model behavior and its results. Based on the double-pulse test method, the characterization of the switches was carried out. The converter efficiency achieved is around 97-98 % for a switching frequency around 12.5-25 kHz, for a current of 100 A peak value.

Acknowledgements 8

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