Performances evaluation of electric vehicles recharging systems implementing Silicon Carbide and Gallium Nitride switches

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Abstract. The recent improvement in semiconductor devices has led to higher efficiency and power density. SiC and GaN offer higher switching frequencies and lower losses; however, the knowledge of the behavior of these devices is not mature. In this paper, a system for fast charging of batteries for electric vehicles based on an isolated DC-DC converter equipped with both SiC and GaN devices is presented, and an experimental comparison among these two technologies will be given in terms of dynamic performances, electromagnetic compatibility, stability, efficiency.

Keywords: Power Electronics, Silicon Carbide, Gallium Nitride, Fast-Recharging, DC-DC Converter.

1 Introduction

There is a keen interest in developing alternative semiconductor materials to standard silicon to achieve a new generation of high-performance devices; among these, silicon carbide (SiC) and gallium nitride (GaN) are promising materials for power electronics. The systems involving SiC and GaN-based devices achieved interesting values of efficiency, power density, and switching speed, making them a preferred choice for high-performance power electronics applications [1, 2, 3]. SiC MOSFETs present a series of advantages to traditional silicon devices, i.e., higher thermal conductivity, higher breakdown voltage, and lower switching losses, allowing for high-frequency and high-temperature operations, which are particularly favorable for automotive applications. Besides, using GaN MOSFETs allows for higher performance than SiC devices in terms of power density and switching speed. GaN presents a lower gate charge than

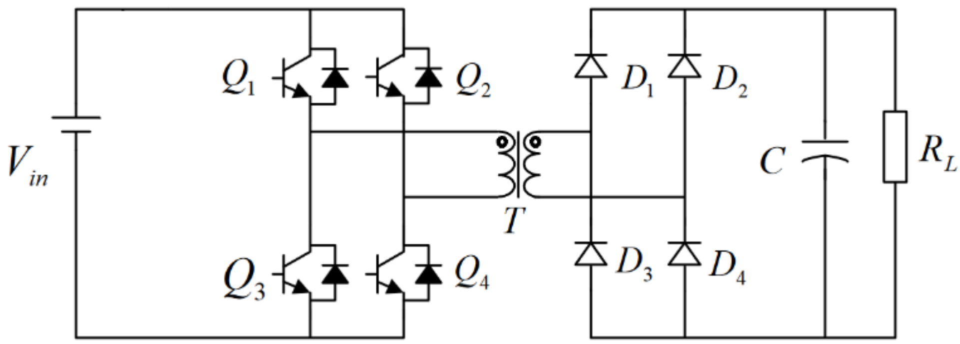
SiC MOSFETs, which have even lower switching losses and allows for achieving higher operating frequencies, which are essential in applications with a target of high power density and high efficiency [1, 2, 3].

On the other hand, the availability of SiC and GaN-based devices is still limited, and the knowledge of the designers on these devices is not fully mature as there are many challenges in terms of losses, reliability, and electromagnetic compatibility. To better understand the behavior of these devices, we developed a fast-charging system for electric vehicles based on an isolated DC-DC converter made with SiC devices and tested inside a semi-anechoic chamber at high DC voltage levels. A subsequent study involving the same converter equipped with the GaN-based devices will be presented in the extended version of this contribution and the comparisons.

2 Experimental section

Fig. 1a shows the schematic of the DC-DC isolated converter realized for the switching operation verification. The electrical insulation is implemented by employing a high-frequency transformer. The converter consists of a full-bridge inverter (DC-AC converter) based on SiC MOSFETs connected to the primary side of the transformer and a passive rectifier (AC-DC converter) based on SiC diodes connected to the secondary side. From Fig. 1, the switches Q1~Q4 constitute the full bridge circuit, T is the isolated transformer whose ratio is N, diodes D1~D4 constitute the rectifying circuit, and C is the output filter capacitor. The converter provides an output DC voltage equal to 800 V starting from an input DC voltage of 1000 V. The control board implements the timing logic and the control system, which allows for regulating the converter's output voltage through a voltage and current loop. Fig. 1b shows the experimental setup arranged in the semi-anechoic chamber, reporting the different components. Experimental tests have proven the proper operation of the DC-DC converter. The investigated input DC voltage level is 1000 V, whereas the switching frequency is 100 kHz. Figure 2 compares the measured voltage waveforms across the primary and secondary sides with the SiC and GaN devices. Figure 2a shows the rising edge of the output voltage of the full bridge implementing the SiC MOSFETs and the rectified voltage.

Similarly, Fig. 2b shows the rising edge of the output voltage of the full bridge with the GaN MOSFETs. Both measurements show similar performances. Afterward, the EMI compatibility analysis of the converter was analyzed in a semi-anechoic chamber through the measurements of the near field using an antenna placed close to the MOSFETs. Results shown in Fig. 3 report that the use of a GaN (Fig. 3b) switch introduces a ringing with twice the amplitude with respect to the SiC MOSFET (Fig. 3a) and a frequency of 35 MHz against the 15 MHz measured when employing the SiC switch. Therefore, a complete EMI analysis should be evaluated to address the combability of the whole converter when employing faster switches.



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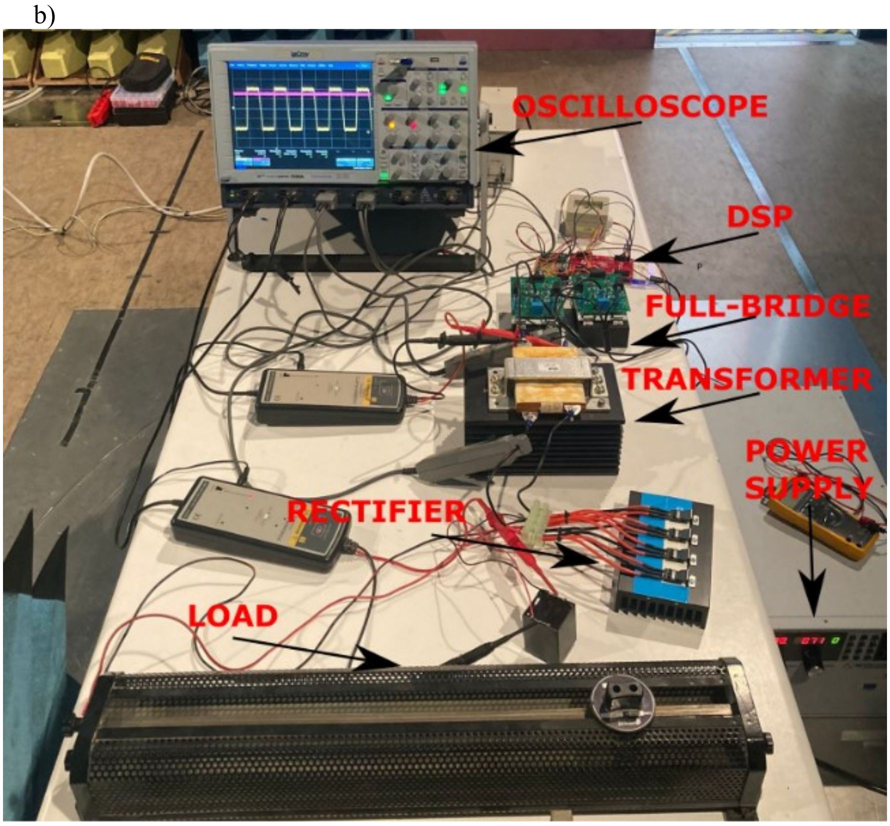
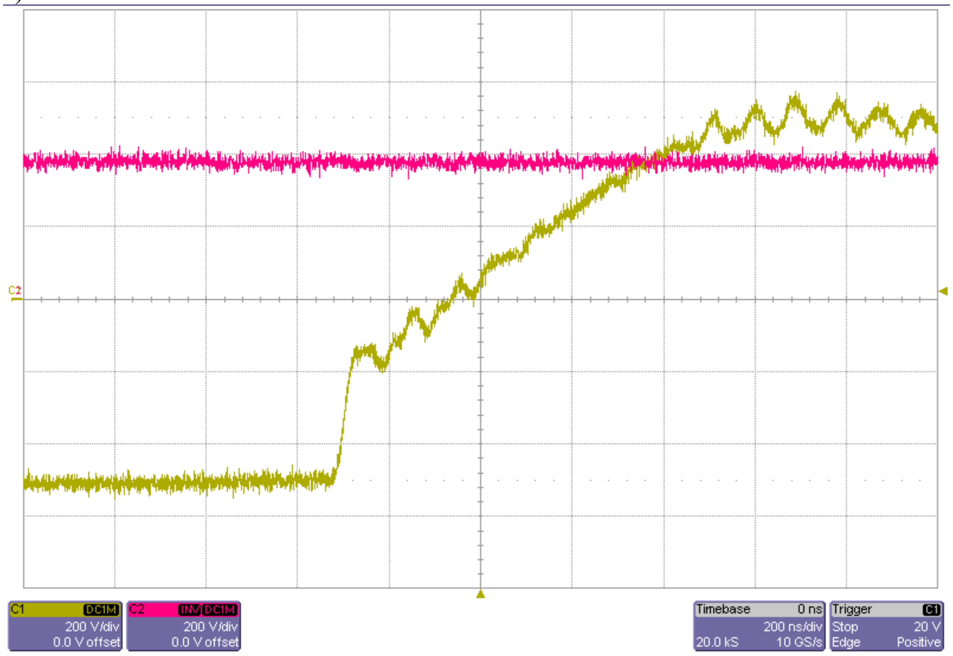


Fig 1. a) schematic of the isolated DC-DC converter, b) experimental setup arranged inside the semi-anechoic chamber.

a)



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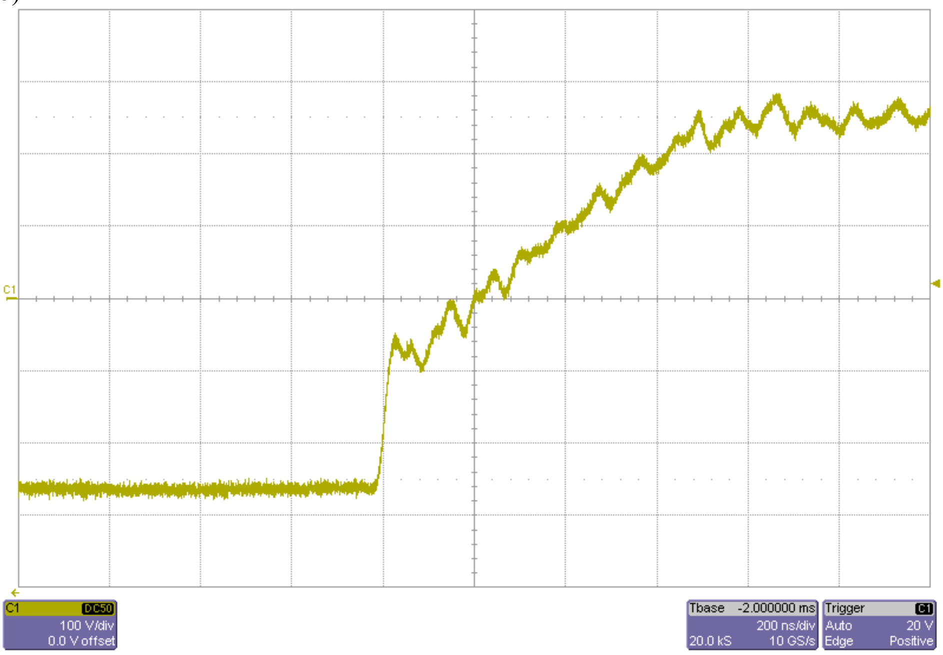

Fig 2. a) full bridge output voltage (yellow) and rectified DC voltage (pink) with SiC MOSFETS, b) full bridge output voltage (yellow) with GaN MOSFET.

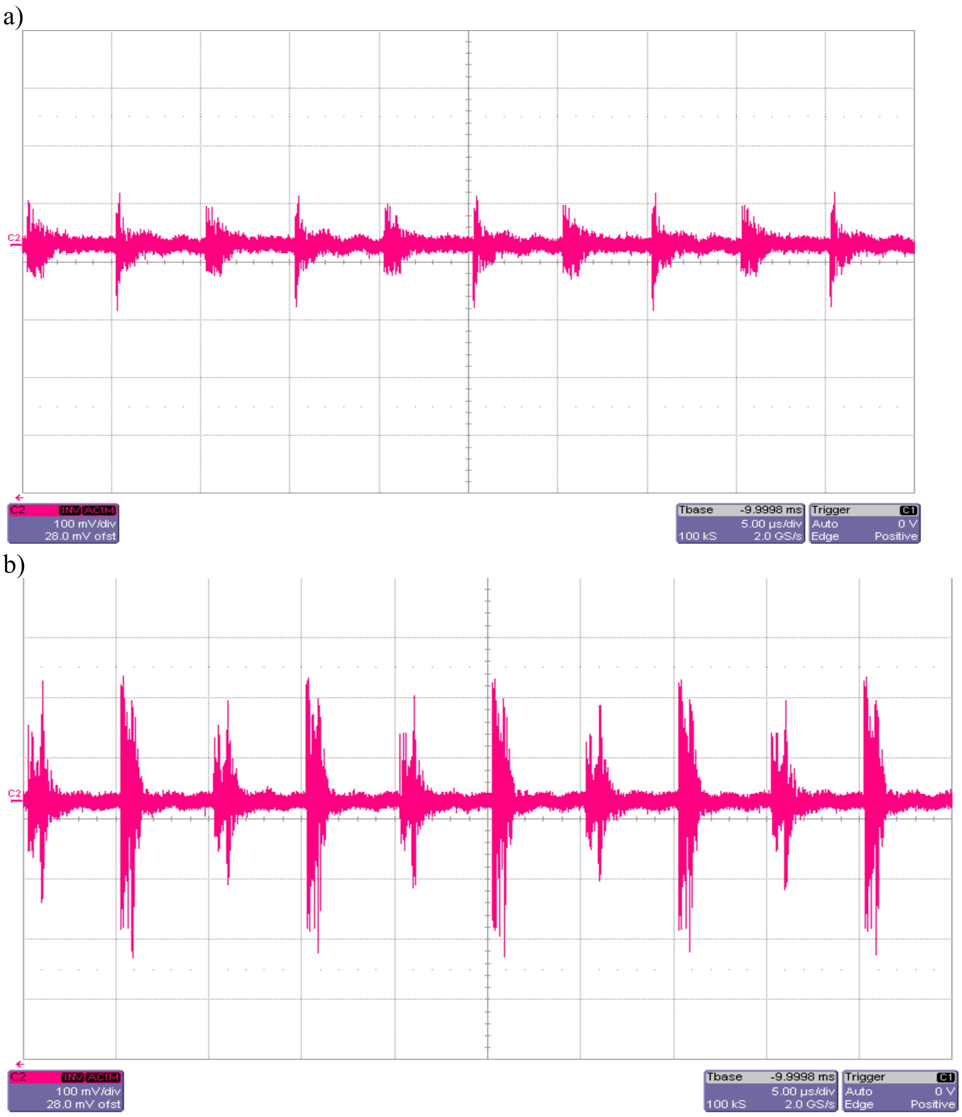

Fig 3. Close field signal captured with an antenna placed close to the switches a) Silicon Carbide MOSFETs, b) Gallium Nitride MOSFETs.

3 Conclusions

A power electronic system for fast charging of batteries for electric vehicles equipped with SiC and GaN devices is presented to analyze the behavior of the wide band-gap device. A series of measurements has been produced to analyze the converter's performance, resulting in an output voltage with a reduced ripple thanks to the fast-switching frequencies obtained with the SiC and GaN devices. The effect of the different devices was analyzed by means of the measurements of the close field, showing that the use of GaN switches introduces more harmonics with higher amplitude in the close field; therefore, a complete analysis of the EMI combability should be evaluated when employing GaN devices.

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