Cost Benefits on High Frequency Converter system based on SiC MOSFET approach

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The Power Point Presentation will be available after the conference.

Abstract

Silicon Carbide (SiC) offers many advantages over silicon in the 1200V switches arena representing the best choice for those designers who look for increased power density, safer thermal operation, better efficiency, reduced system form factor as well as a significant reduction of the size and cost of passive components.
In this paper it will be shown how the SiC MOSFET can help to maximize the overall performance of a high frequency converter by lowering the overall system cost.
The most relevant aspect of this work consists in exploiting the SiC MOSFET capability to work at high frequency through its extremely low switching losses, therefore, the possibility to reduce size, weight and cost of the system with some remarks about logistic cost.

1. Introduction

The demand for increasing efficiency is becoming more relevant in Power electronics new designs as well as the possibility to have lighter and smaller systems. In the 1200V device range, SiC is becoming an excellent alternative to the currently used silicon technologies. SiC MOSFET guarantee R_{ON}*Area values far lower than the latest silicon 1200V MOSFET super-Junction technology while moving the operative frequency limit well beyond the one achievable by the state-of-the-art IGBTs available on the market.
Thanks to the above properties the efficiency achievable through a SiC MOSFET in a boost converter is significantly higher versus silicon IGBT based solution especially at high frequency.
In order to demonstrate the SiC MOSFET performance, ST had developed a 5 kW DC/DC CCM boost converter reference design using ST's new silicon carbide 1200V 45A MOSFET, SCT30N120. The use of high performance silicon carbide power device showed a significant improving of the efficiency vs. the IGBT enabling higher frequency operation (up to 125kHz).
In this paper a further step forward will be done: to evaluate the overall system cost with a SiC MOSFET approach against the use of conventional IGBT. For such purpose 2 dedicated boost converters have been built tailored to 2 different switching frequency (25kHz for the IGBT and 100kHz for the SiC MOSFET) while the cost analysis is based on the cost of heat-sink and passive components.

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2. SiC MOSFET: the right choice to cut cost and losses

2.1. SiC MOSFET enables higher efficiency versus IGBT

The silicon IGBT power losses are much higher than SiC MOSFET one and this is mainly due to the weight of switching losses, as confirmed by the total losses calculation reported in Table n.1

DEVICES	Driving	Total power losses [W] (P_{COND}+ P_{SW}) @5KW,25kHz
SiC MOSFET	R_{GON}=R_{GOFF}=2.2Ω, V_{GSOFF}= -4V	6.2+4.9=11.1
Si IGBT		8.1+17.5=25.6

Fig.1. Power losses in ST 5kW Boost converter reference design

Consequently at high frequency SiC MOSFET represents the “ideal” solution by taking also into account the very light switching losses dependence on temperature.
The figure below shows the efficiency vs. switching frequency (at given load of 5kW) for both SiC MOSFET (SCT30N120) and a 1200V/25A Trench Field-stop IGBT.
It’s worth noticing that SiC MOSFET gives the same efficiency as the IGBT with much higher frequency (around 4 times). These results are referred to a pin-to-pin replacement that means the same Boost inductor and heat-sink have been used in both cases.

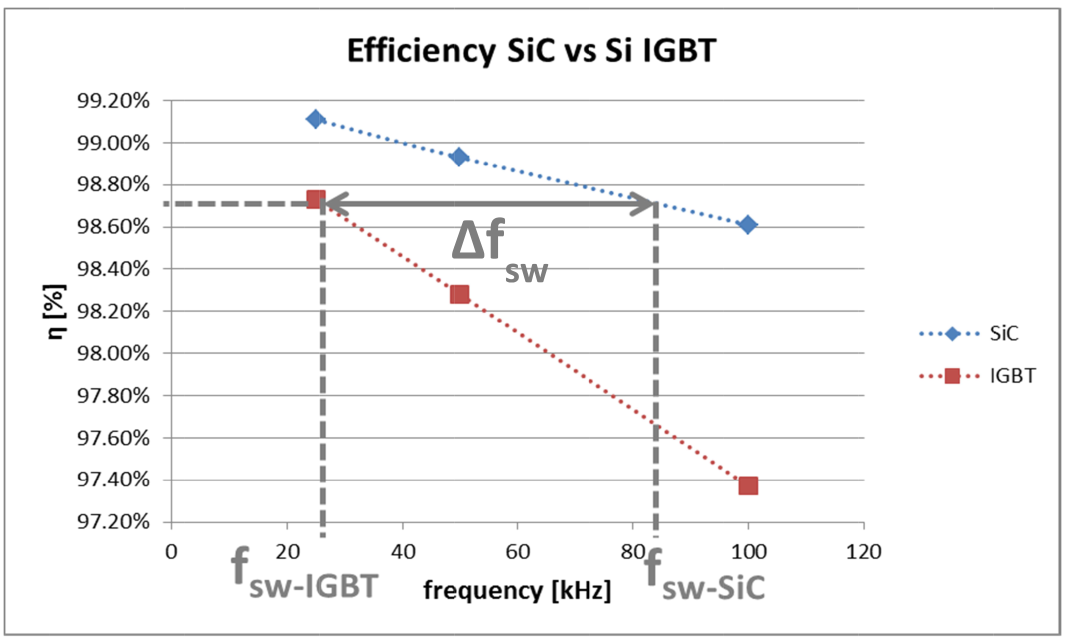

Fig.2. Efficiency vs switching frequency in ST 5kW Boost converter reference design

2.2. Cost saving in passive components

Increasing the switching frequency in a Boost converter gives benefits in terms of inductor and/or output capacitor downsizing. Let’s assume that the output voltage (V_{OUT}), the output power (P_{OUT}) and output voltage ripple (ΔV_{RIPPLE}) are provided as input design specs. The highest value of current ripple (ΔI_{RIPPLE}) occurs at V_{IN}=V_{OUT}/2 and it is typically chosen

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according to the max average inductor current (I_{L_MAX}). Two different strategies are typically implemented:

a) For a typical ΔI_{RIPPLE} value (let's say 20% of $I_{L\_AVG\text{-}max}$), the higher is the switching frequency the lower is the inductance value according to the law:

$$L = \frac{0.5 \cdot V_{IN}}{\Delta I_{RIPPLE}} \cdot \frac{1}{f_{sw}}$$

b) Keep the same inductance value chosen for low frequency operation with IGBT and then minimize the current ripple by increasing the frequency. As a consequence the output electrolytic capacitor can be down-sized according to the law:

$$C = \frac{0.5 \cdot V_{IN} \cdot 80 \cdot 10\hat{} - 6}{\Delta V_{RIPPLE} \cdot L} \cdot \frac{1}{f_{sw}}$$

where ESR*C=80*10^-6 and it has been assumed that the capacitive component of the output ripple is much smaller than the resistive one.
The third option consists in choosing a trade-off between a) and b) in order to achieve both lower inductance and capacitance. By following the a) option the relevant inductor cost reduction can be given by lowering size of the inductance value thanks to the higher switching frequency. Fig. 3 shows the typical cost trend of the inductor versus frequency in a DC-DC Boost converter.

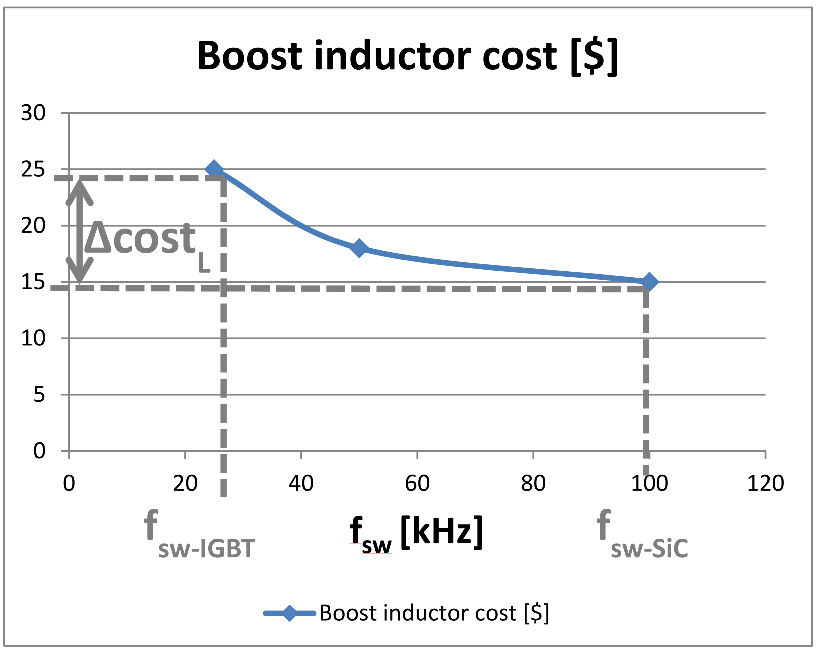

Fig.3. Typical cost of the inductor vs switching frequency

2.3. Cost saving in the cooling system

Thanks to the higher maximum junction temperature (200°C) allowed by SiC MOSFET as well as its inherent high thermal conductivity, in the application the case operative temperature of 125°C has been adopted for the SiC MOSFET vs. the 100°C of the IGBT. The relevant safety margin in terms of temperature is required to ensure high reliability. Due to the similar losses level (SiC MOSFET roughly dissipates the same power as Si IGBT at 4

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times larger switching frequency) the different operative temperature can be translated into a smaller heat-sink for 100kHz operation.

3. A real case: ST 5kW Boost converter (25kHz vs 100kHz)

In power applications mainly magnetic components benefit of higher switching frequency. Once the frequency has been chosen for both SiC and IGBT approaches, it's easy calculating the Boost LC values. As already cited in section 2.2, the preferred strategy pursues the inductance reduction and consequently the down-sizing of the choke in terms of cost, weight and volume. The main features of ST's 5 kW DC/DC CCM boost converter evaluation board are below reported:

- P_{OUT}=5kW
- V_{IN}=400-600V_{dc}, V_{OUT}=800V_{dc}
- Active fan cooling and over temperature protection
- Built in auxiliary flyback with +20V; +5V; -5V power supply

The two implemented versions and the relevant gains in terms of money are descripted in the following table.

Main switch	**Si IGBT**	**SiC MOSFET**
Frequency	**25kHz**	**100kHz**
Efficiency (%)	98.69	98.73
Boost inductor (USD)	24.6	13.7
Heat-sink (USD)	8.1	5.4

Fig.4. Cost savings given by high frequency operation

It's worth noticing that the main benefit comes from the minimization of the magnetic component. Moreover, thanks to the use of an optimized choke for high frequency operation, the overall losses at 100kHz slightly decrease in comparison with Fig. 2, thus meaning a small efficiency advantage for SiC solution. A similar cost evaluation can be performed in other topologies where magnetic transformers, chokes, coupling inductors are used in the power conversion process.

4. Cost saving in logistics

The logistical costs of transporting and storing products can eat into the profits of a company. These costs strongly depend on the overall size and weight of the products.
Both volumetric density (W/l) and gravimetric density (W/kg) have an impact on the following logistic variable costs:

a) Warehouse
b) Labour
c) Gasoline
d) Shipment

By following a simplified approach, the saved money can be calculated in terms of saved size and weight when the frequency is boosted up thanks to the use of SiC MOSFET according to the qualitative law ΔPrice($)=f(ΔPower Density).

Finally, the above benefits will add value on the overall production chain from the semiconductor maker till to the end users as showed in Fig.5.

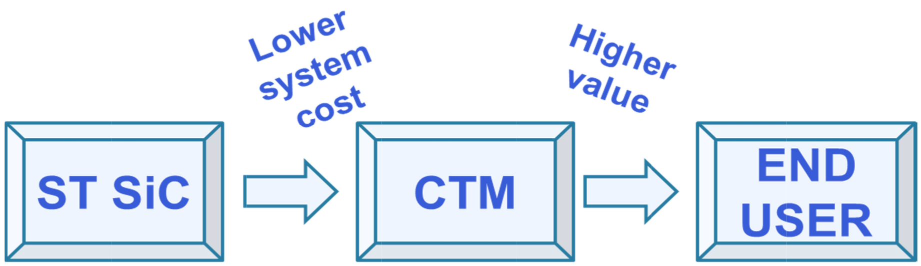

Fig.5. Added value in the supply chain

5. Conclusions and future work

SiC MOSFET allows increasing the switching frequency, efficiency and power density of power electronics applications. Despite of the higher cost of SiC MOSFET itself, these advantages can be converted in a lower overall system cost.
In order to gain the cost cutting, several strategies can be pursued. The best trade-off among all the potential benefits (magnetics minimization, increasing efficiency and/or power density, etc..) depends on the application, the output power and other factors. In the present paper an example on how to reduce the overall cost of a 5kW Boost converter moving from an IGBT based solution to a SiC based one has been showed. The main focus has been dedicated to the magnetics downsizing. The present analysis has to be continued in three main directions: a) investigating any constraint to the frequency increase in power applications, b) calculating the potential advantage in other topologies c) deepening the benefit analysis linked to logistics.

6. Reference

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