Contribution ID: **170** Type: **Poster**

High precision scalable power converter for accelerator magnets

Tuesday 21 September 2021 17:29 (3 minutes)

The lower conduction power losses and the positive temperature coefficient that favours parallel connections, make Silicon Carbide (SiC) metal oxide semiconductor field-effect transistors (MOSFETs) to be an excellent replacement of existing Silicon insulated gate bipolar transistors (IGBTs) technology. These characteristics combined with high switching frequency operation, enables the design of high-accuracy DC-DC converters with minimised filtering requirements. This paper compares two designs for a converter with high-accuracy current (0.9ppm) supplying a 0.05H electromagnetic load; one design with the topology and filter for a typical IGBT-based full-bridge and a second one with a SiC MOSFET based topology without filter.

Summary (500 words)

A primary objective of the powering in particle accelerator is the precision and reproducibility of the experiments. Scalable converters enable sub-ppm current precision with minimal filtering requirements by using multiple modules in interleaved operation [1]. In order to reach the 1ppm level which is required for some applications active filters are often used [2]. However, they require relatively large reactors and their control is not trivial. With the introduction of SiC MOSFETs as a commercial alternative for switch-mode converters, it is now feasible to utilise this semiconductor technology in the world of high-particle physics as well. This paper demonstrates a case study for a 0.05H electromagnet with high accuracy requirement of 0.9ppm and investigates the performance improvements to the design and operation of such converters when using SiC MOSFETs compared to IGBTs. The benefits of the SiC MOSFET are two-fold. Firstly, the reduced conduction on-state losses and positive on-state temperature coefficient and secondly, the reduced switching losses, enabling higher switching frequencies. And with the technology emerging with lower current ratings than the IGBTs, parallel connection is necessary to take advantage of the advantages that the SiC can offer.

The reduced on-state losses of SiC MOSFETs enables high-efficiency operation. Besides, their positive temperature coefficient facilitates a robust and more reliable parallel connection, as the positive temperature coefficient leads to natural balance of the current. Introducing a number of parallel connected DC-DC converter enables the use of interleaving to achieve a lower current ripple.

The current ripple form a single converter can be approximated by Eq. 1, where the ripple is inversely proportional to the switching frequency of the DC-DC converter. By using SiC MOSFETs it becomes possible to increase the switching frequency from 5kHz that is currently used, up to 60kHz and beyond. This gives an increase in accuracy by an order of magnitude or more. In addition, higher switching frequency results in a higher frequency on the ripple, reducing the size of any filters if they are still required. Thus, the anticipated cost and losses of filters are reduced. It is also possible to consider 3-level modulation (unipolar switching), reducing the ripple even further.

Introducing parallel connected devices leads to an increased investment cost for the devices, but it can reduce the device losses, cooling requirements, filter requirements and filter losses. In addition to having the benefit of being a more scalable topology to cover a large range of loads with minimal overcapacity, redundancy, and introducing more segmentation for the storage in the case of pulsed loads with storage requirements for the DC-DC converter. By taking a complete view and considering lifetime costs, SiC MOSFETs seem to be very suitable technology for this application [3]. The final paper will present the design and operation of a topology to satisfy sub-ppm accuracy without filters and will show the advantages and disadvantages of such a design compared to a conventional converter with IGBTs and active filters.

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Session Classification: Posters Power, Grounding and Shielding

Track Classification: Power, Grounding and Shielding