Feasibility study of a Medium Voltage DC/DC Converter adopting WBG devices

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Abstract

A collaboration between Politecnico di Torino and IKOS Lab, the innovation sector of IKOS Consulting, represents the starting point of this work. The railway innovation related to the concept of the ultra-fast vacuum-tube train, known as Hyperloop, is the environment in which this PhD thesis moves. One of the worldwide Hyperloop projects is TRANSPOD, in which IKOS is one of the Canadian company partners. This manuscript aims to provide a technical solution to one of the TRANSPOD research topics. The TRANSPOD innovative power transmission eliminates the need for an accumulation system inside the capsule (POD). Because of the low space availability, lightness and reduced size, the medium voltage power conversion inside the POD is the topic that this thesis faces.

The power required by the POD is about 2MW with a nominal voltage of 6kV DC. The Medium Voltage Converter (MVC) that steps down the voltage from 6kV to 800V regulates the power flow between the medium voltage and the low voltage side. Modularity and galvanic insulation are the key points of the MVC structure design, the research topic focuses on the opportunity to include the Wide Band-Gap (WBG) devices in medium voltage applications with the intent to increase the MVC power density. After a brief state of the art concerning the DC/DC MVC topologies and the state of the art of the Medium Frequency Transformers (MFT), the work focuses on three MVC aspects: structure identification, insulated AC link for SST converter concluding with a Three-Phase Dual Active Bridge (TP-DAB) prototype.

The MVC structure analysis considers the Input Series Output Parallel (ISOP) modular structure that meets the TRANSPOD specification using the WBG technologies available on the market. The ISOP adopts eight SST converters as a single cell to guarantee the galvanic insulation between MV and LV sides. The state of the arts in medium voltage DC/DC converter consider the Single Phase DAB (SP-DAB) as the principal solution. However, the mechanical constraints (weight and volume) force to increase the converter power density. The power density improvement leads to a change in the SST structure and ISOP control through the interleaving between the SST connected to the ISOP. The SST structure passed from an SP-DAB to a TP-DAB, reducing the capacitor filter as well as the ISOP filters. The final ISOP with TP-DAB then interleaved, represents the MVC structure to adopt inside the POD for the power flow regulation.

The state of the arts considers the axial transformer as the solution to guarantee galvanic insulation into SSTs. This thesis study moved towards the use of planar transformers to improve the AC link compactness. The planar transformer technology ensures the low deviation standard among the MFT parameters allowing the connection between two or more transformers. The adopted multi transformer structure is the Input Parallel Output Series (IPOS) made by ten 20kW planar MFTs. The adoption of a multi transformer structure instead of a single 200kW axial transformer increases the SST and thus the MVC compactness and efficiency.

The adopted 1.7kV, 325A SiC devices allow to operate at switching frequency up to 115 kHz at full power. The opportunity to increase the operating SST frequency provided by WBG devices results in a filter and a converter size reduction. The AC-link is a three-phase structure made by three IPOS multi transformer structure (TP-MFT) with a star-to-star connection. Thanks to this structure, the 650V voltage rated MFTs have been employed in a converter with a DC-link voltage level of 800V. This because the maximum voltage applied to the single IPOS in a star connection is 2/3 V_{DC}. The TP-DAB efficiency evaluated at 200kW and 1kV, achieves an efficiency equal to 96.5% resulting higher than 92% the typical TP-DAB converter.

In addition to the discussed work, the collaboration between IKOS consulting and Politecnico di Torino leads to a patent-pending idea on the cooling system and the power electronics integration.