Hybrid Modular Multilevel Converters for High-AC/Low-DC Medium Voltage Applications

With ever-increasing power density requirements, technologies such as energy storage systems and electric vehicles can benefit greatly from interfacing directly with medium voltage (MV) AC grids like 13.8 kV or 30 kV using high-AC/low-DC voltage converters. One such high-AC/low-DC system architecture is shown in Fig. 1. Here the MVAC grid is interfaced with a high-AC/low-DC voltage active front end that develops an intermediate DC bus. The DC voltage can then be brought to the required 400 V to 1kV voltage using a conventional isolated input-series-output-parallel converter. Such architectures eliminate the need for low frequency transformers, while also being cost-effective compared to solid-state transformer (SST) based systems. Additionally, the whole system can be maintained modular, ensuring ease of repairability. This paper will discuss alternatives for first stage active front-end (AFE) converter.

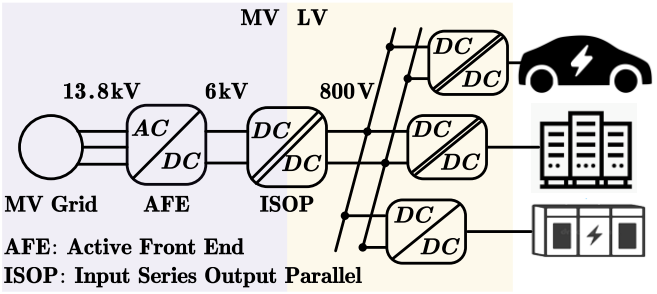

Fig.1. Recently proposed MVAC-LVDC architecture

Full-bridge modular multilevel converters (FB-MMC) and SST are existing solutions for such operations but suffer from limitations of high semiconductor requirements, large submodule capacitors, and/or many high frequency transformers. This research introduces three new hybrid-MMC (HMMC) topologies for such high-AC/low-DC voltage operations. Each of the three developed HMMCs utilizes a unique combination of high voltage switches and low voltage switch-based submodules to generate multilevel AC voltage.

One promising HMMC, HMMC-Three ($HMMC_3$) is shown in Fig. 2. As observed, it comprises devices S_1-S_4, which are line-frequency switching, high voltage insulated-gate bipolar transistors (IGBTs), like conventional three-level converters. Additionally, $HMMC_3$ also comprises fast-switching device-based submodules (SM). A series stacking of SMs and inductors is commonly referred to as chain-link (CL) and each phase of HMMC comprises of two such CLs.

The three proposed HMMCs are compared extensively to state-of-the-art FB-MMC, and $HMMC_3$ is shown to have the best performance. $HMMC_3$ introduces semiconductor savings of about 27%, 38% lower submodule capacitor size, and 53% lower losses for 13.8 kV-AC/6 kV-DC operation compared to conventional FB-MMC. Compared to SST-based architecture for the same operation, $HMMC_3$ uses 30% fewer devices and 81% fewer high frequency transformers.

In conclusion, this paper explores a recently proposed MVAC-LVDC architecture and proposes a new topology well suited for high-AC/low-DC voltage operation. HMMCs can be an

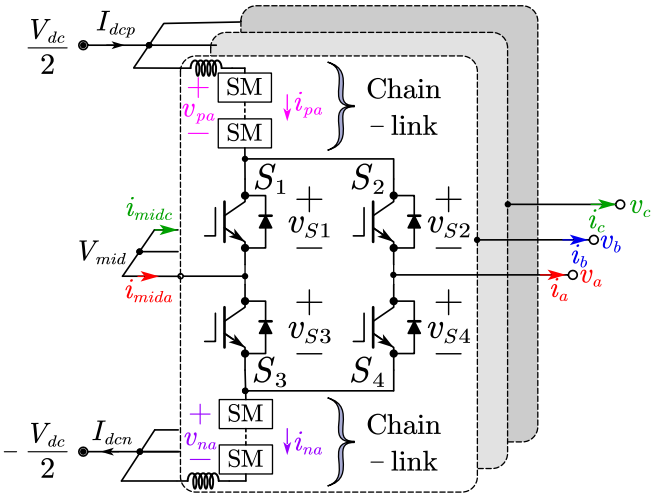

Fig. 2. Hybrid Modular Multilevel Converter-Three

excellent option for high-AC/low-DC applications. Practical considerations like snubber and DC split-capacitor requirements are also elaborated for developing and commercializing HMMCs. Comparison results are verified using a 17.5 kW three-phase MV laboratory prototype.