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Ultra-Efficient Power Module for MVDC Solid-State Circuit Breakers

Abstract:

MVDC distribution systems are an emerging solution to integrate renewable and electrified energy sources and loads with high efficiency, high density, and high performance. In these systems, DC circuit breakers act as vital protection devices to promptly isolate faulty subsystems caused by severe environmental or human intervention and recover soon after the faults are cleared. The fully electrified SSCB, compared to its mechanical and hybrid counterparts, excels with no arc, shorter breaking time, longer lifetime, higher density and simplicity, and infinite possibilities of intelligence. Yet, the SSCB's low efficiency and bulky cooling system remain its Achilles' heel because of limited semiconductor technologies. The widely used silicon (Si) IGCT and IGBT mod-ules with an inborn offset voltage generate inevitable high conduction losses. Conversely, the emerging SiC FET modules have no such limitations, but they are continually optimized for high-switching-frequency operations other than SSCBs with constant conduction and occasional switching. This preproposal addresses the SSCB's efficiency and bulky cooling system problems by proposing the development of a bidirectional SiC FET module (ηPak) optimized for MVDC SSCBs, capable of achieving: 1) efficiency > 99.988%; 2) power density > 300 kW/L; 3) passive cooling; 4) systematically enhanced robustness; and 5) unrestricted voltage and current scaling. Such striking performance can be attained by adopting the proposed: 1) back-to-back press-pack of enormous-scale SiC FET dies; 2) fault-tolerant designs; and 3) multiphysics optimization. The project targets the delivery of one 1.7 kV, 167 A, 600 μΩ, ηPak submodule. The successful de-velopment of the proposed technologies will remove up to 90% of the power losses from the best-in-class SSCB products, posing a disruptive techno-economic impact in the current and future MVDC areas, such as electric vehicle supercharger stations, utility-scale energy storage units, shipboard and aviation DC systems, and fusion energy systems.