Synthesis and Design of a Medium-to-Low Voltage, High Step-Down Coaxial DC-DC Converter

In recent years, the demand for power distribution has experienced a persistent surge driven by various factors, such as escalating infrastructure requirements for electric vehicle (EV) charging stations, heightened real estate costs due to rapid urbanization, an increase in distributed renewable energy sources, a growing need for efficient energy storage solutions, and an augmented frequency of severe weather events. To address the challenges posed by these evolving demands, there has been a notable rise in the demand for solid-state modular and redundant power conversion stages, driven by the enhanced reliability of power electronics systems. Existing high step-down medium voltage ac (MVac) to low voltage ac (LVac) transformers, commonly found in substation settings (as shown in the top half of Fig. 1 (a)) typically exhibit a power density of 0.3 MW/m^3. The evolution of modular power electronics for MV applications has demonstrated significantly higher power densities, reaching up to 10 MW/m^3. These systems offer bidirectional power flow control, along with sophisticated protection and diagnostics. The MVac cables used in power distribution exhibit a power density of 40 MW/m^3, making them ideal for integrating with these solid-state power converters.

In LV dc-dc converters, as processed power increases, the energy density of capacitors dominates that of inductors. This trend advocates for a capacitance-based isolation approach, rather than the conventional magnetic isolation of the converter for achieving solid-state insulation.

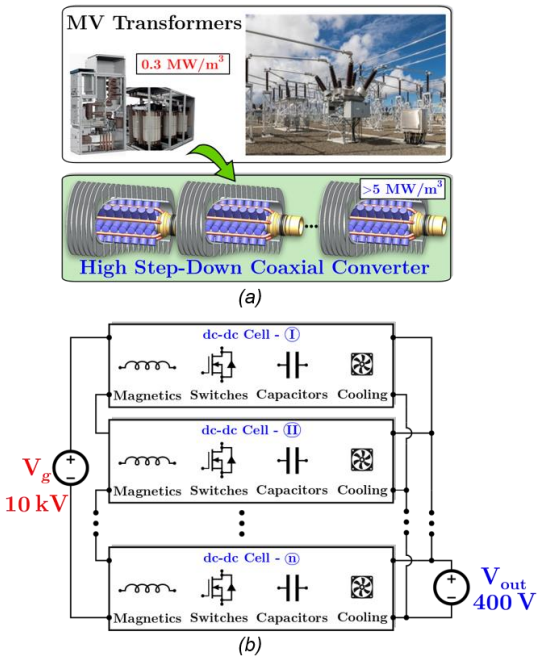

Fig. 1. (a) High step-down coaxial converter as an alternative to MV transformers, and (b) Input-series output-parallel (ISOP) architecture.

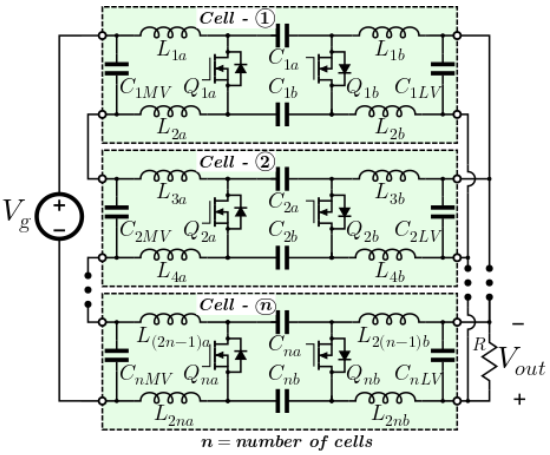

Fig. 2. The isolated-stacked ćuk (iSĆuk) converter utilizes several capacitively isolated ćuk dc-dc cells connected in an ISOP fashion.

Leveraging the maturity of dc-dc converter synthesis for power conversion, the input-series, output-parallel architecture is adopted for processing the MV differentially, as shown in Fig. 1 (b). The novel isolated-stacked ćuk converter (iSĆuk) shown in Fig. 2 with capacitive isolation is synthesized and designed to effectively absorb parasitics, a manifestation of the coaxial packaging of components. Additionally, this work demonstrates how the size of the components is reduced to achieve zero-voltage switching (ZVS) in all cells to achieve 10 kV – 400 V at 250 kW.