Hybrid Modular Multilevel Converters for Medium-Voltage Variable Speed Motor Drives

It is well established that Modular Multilevel Converters (MMC) are suited for high power, Medium-Voltage (MV) applications, owing to their modular and scalable design, high power density, reliability and fault-tolerance. However, their adoption for variable-frequency motor drives (VFD) has been especially hindered by the high sub-module (SM) capacitance requirement for applications where a large and constant torque is required at startup and low-frequency operation, ultimately increasing converter size and cost.

This research evaluates Hybrid MMC (HMMC), a combination of IGBT based ANPC converter and MMC, as an alternate solution for motor drives application. Two HMMC topologies, $HMMC_1$ and $HMMC_3$ (as illustrated in Fig. 1) are selected for comparative analysis across the low/high voltage

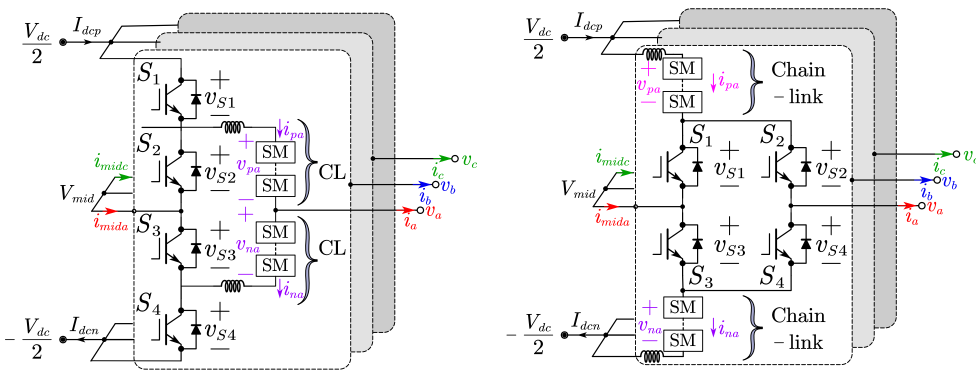

Fig. 1 (a) $HMMC_1$ *Fig. 1 (b) MMC_3*

range of DC (5 kV, 10 kV, 20 kV) and AC (3.3 kV, 6.6 kV, 13.8 kV).

The IGBT S1 – S4 switches at close to motor frequency whereas the SMs – modular units of low-voltage (LV) semiconductors – operate at high switching frequency to produce a sinusoidal output. The series stacked SMs form an arm, and together with an inductor are referred to as a chain-link (CL). The inherent structure of HMMC results in a maximum arm voltage of $0.5\,V_{dc}$, as opposed to V_{dc} in conventional MMC, leading to about 30% reduction in the total semiconductor count. The SM capacitance is a measure of total buffered energy (AC + DC) by the arms, which in turn is a factor of arm voltage, current, and motor frequency. Building upon the reduced arm voltage in HMMC, the total buffered energy (and consequently the converter energy storage requirement) is further reduced through novel modulation techniques introduced in this paper. These are based on reducing the peak-peak AC ripple component of arm energy (ΔE_{arm}), as shown in Fig. 2. As observed, the net energy ripple (balance of charge and discharge) is proportional to the SM voltage ripple and SM capacitance i.e., $\Delta E_{SM}\ (= \Delta E_{arm}/N_{SM}) \propto \Delta V_{SM}$. For a fixed peak-peak SM voltage ripple spec, $\Delta E_{SM} \propto C_{SM}$.

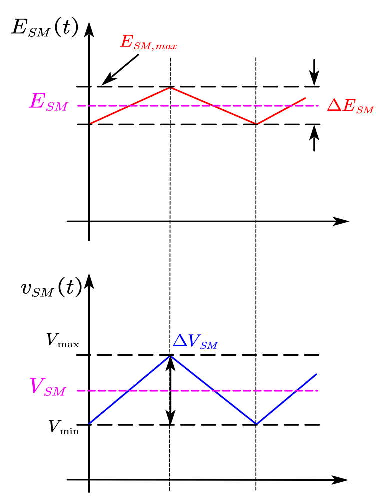

Fig. 2 (a) SM energy ripple (top)
Fig. 2 (b) SM voltage ripple (bottom)

The utilized approach for reducing ΔE_{arm} is distinct for $HMMC_1$ and $HMMC_3$. Numerical analysis and simulation results show that HMMC-based inverters for motor drives can provide 27% lower semiconductor devices, 42% lower SM capacitor size, and 50% lower losses at rated power. Furthermore, it is identified that $HMMC_1$ is better suited for high-DC/low-AC applications, while for low-DC/high-AC, both $HMMC_1$ and $HMMC_3$ can be utilized.