Can Flying Capacitor Multilevel Converter with Natural Voltage Balancing be Good for Practical Applications?

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The presentation demonstrates the power of time domain averaging methods applied to multilevel converter PWM voltage quality evaluation (theoretical lower bound) and Flying Capacitor (FC) converter natural voltage balancing dynamics analysis.

The contribution to the understanding of FC converter natural voltage balancing mechanisms is made by emphasizing the fact that voltage balancing process is driven by Flying Capacitors unbalance energy dissipation by switched current harmonics. Single-leg and H-bridge FC converters with Phase Shifted (PS) DC and AC PWM are extensively analyzed. PS PWM is shown to be optimal in voltage balancing sense only for 3-level and 4-level single-leg FC converters because there are no switching state redundancies. For all other converters, PS PWM does not make optimal use of switching redundancies. This results in poor voltage balancing for small voltage commands (modulation indices). Theoretically predicted poor voltage balancing performance for small voltage commands / modulation indices for PS PWM explains practically observed voltage divergences due to non-idealities like switching delays, voltage drops, leakage currents etc. Some recent publications suggest active voltage balancing control approaches. However, active balancing requires capacitor voltage measurements or estimation and may compromise optimal voltage quality of nearest level / nearest space vector PWM. That would result in increased converter switching which causes electrical machine / coupling inductor / feeding transformer loss.

The authors believe that a remedy may be a different modulation strategy that provides good self-balancing properties for small voltage commands (modulation indices). Faster natural voltage balancing dynamics occurs due to higher unbalance energy dissipation rate by current switching harmonics delivered by an improved PWM switching patterns. Better self-balancing means larger stability margins to cope with non-idealities and disturbances.

Good natural voltage balancing for small voltage commands is a key that allows to resolve what is considered by engineering community "one of the most serious drawbacks of this type of converters" – flying capacitors initialization at power-up. Indeed, given DC bus voltage ramp-up control at power-up, capacitors initialization is easily achieved at virtually no cost due to natural voltage balancing while keeping load current zero on average (self-precharge).

Using simple 3-level H-bridge FC converter example, it is demonstrated that different from PS PWM modulation strategy can dramatically improve self-balancing properties and provide self-precharge capability. Though three- and multiphase FC converters are not considered in detail, all the major ideas, approaches, and conclusions are applicable as is.

So, finally, the answer to the question “Can Flying Capacitor Multilevel Converter with Natural Voltage Balancing be Good for Practical Applications?” is hopefully positive and future research effort must focus on finding “optimal” PWM strategies that assumes optimal voltage quality of “nearest switching”, fastest possible natural voltage balancing dynamics, and minimal switching loss.