DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

PhD Public Defence

Title:	Mission Profile based Control and Reliability Improvement Strategies of Modular Multi-level Converter
Location:	Pontoppidanstræde 111, auditorium
Time:	Tuesday 10 December at 13.00
PhD defendant:	Zhongxu Wang
Supervisor:	Professor Huai Wang
Moderator:	Associate Professor Sanjay Kumar Chaudhary
Opponents:	Associate Professor Sanjay Kumar Chaudhary, Dept. of Energy Technology, Aalborg University (Chairman) Associate Professor Maryam Saeedifard, Georgia Institute of Technology, USA Principal Scientist Nan Chen, ABB Corporate Research, Sweden

All are welcome. The defence will be in English.

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Abstract:

Modular multilevel converters (MMCs) are typically composed of hundreds of power devices and capacitors. Its fast-growing application and complexity call for much more attention and research need on its reliability performance. Given its different topology from conventional two- or three-level converters, how to effectively improve the reliability of the MMC has not been sufficiently studied. In order to cope with these issues, this thesis firstly studies a sub-module (SM) based reliability testing scheme of the MMC and then proposes reliability improvement strategies from a control perspective. Two condition monitoring strategies for SM capacitors are also introduced and validated experimentally.

In order to illustrate the limitations of existing SM based testing schemes, an overview of existing testing emulators is given. Based on the challenges, this Ph.D. project proposes a mission profile emulator for power modules in the MMC. By integrating an auxiliary SM based voltage stabilizer, the testing scheme is applicable to mimic practical current profiles and switching profiles. Meanwhile, due to the decoupling between the voltage of DC power supply and the high voltage of SM capacitors, the power rating and voltage rating of the used power supply in the current source are both significantly reduced. In order to facilitate the implementation of this setup, a guideline regarding the selection of control parameters and hardware parameters is provided. Simulation and experiment results validate the effectiveness of the proposed mission profile emulator.

Capacitor voltage balancing control offers an internal conduction loss balancing mechanism among SMs. An analytical evaluation validates that the balanced conduction loss distribution is independent of the control, modulation and loading conditions of the MMC. However, due to parameter mismatch and the low switching frequency operation of the MMC, switching losses are not evenly distributed among SMs. Thus, a power loss balancing control is proposed in this project. The switching loss differences among SMs can be reduced to less than 25%.

For MMCs connected to the grid, stringent grid codes are supposed to be fulfilled during the operation. In order to limit the output current THD within a specific range, a relatively high switching frequency has to be employed for MMCs with a relatively small number of SMs considering conventionally fixed carrier frequency. Large switching losses can be generated for heavy loading conditions for high voltage rating power devices. In this regard, this Ph.D. project proposed an adaptive control to dynamically adjust the carrier frequency according to the loading conditions of the MMC. The carrier frequency boundaries regarding the output current THD and SM capacitor voltage ripple are first explored. Based on the results, the lowest allowable switching frequency can be applied to the MMC while meeting the requirements of output current THD and SM capacitor voltage ripple. A mission profile-based reliability evaluation is conducted to illustrate the impact of the proposed method on the efficiency, thermal stress, and lifetime of the MMC. A case scenario based on a 15 kVA three-phase MMC is also studied experimentally. The observed power loss reduction of power devices validates the effectiveness of the proposed method.

Capacitors are one of the components prone to failure in power electronic converters. When it comes to the MMC, the reliability concern about SM capacitors is much more serious since they typically account for over 50% and 80% of the volume and weight of one SM, respectively. Since the capacitor ages with time, as one of the means to improve reliability, condition monitoring of SM capacitors is important regarding the reliable operation of the MMC. Due to the high voltage rating, film capacitors are typically applied in the MMC. One of the end-of-life criteria of film capacitors is typically 5-10% capacitance drop. The tiny capacitance change poses a challenge for the condition monitoring (CM) of film capacitors. In order to enhance the monitoring accuracy, two CM methods are proposed in this Ph.D. project. Firstly, it is based on the DC-side start-up of the MMC. An RC charging circuit formed

during the start-up process can be utilized to extract the capacitance values. The impacts of diode tolerance and degradation, bleeding resistor tolerance and time delay are discussed. Experimental validation is provided in the end.

The second condition monitoring method takes full advantage of the SM voltage sensor range. Monitoring accuracy can be significantly improved. The precondition is that the capacitance of the reference SM should be known beforehand by applying existing CM methods but with more accurate sensors or extra measurement circuits. For comparison, an accuracy analysis is conducted. Practical considerations regarding the implementation of these proposed methods are discussed, namely the detection of reference SM capacitance and the impact of the proposed method on the operation of the MMC. Experiments based on capacitors with small capacitance differences (e.g., from 0% to 3.2%) show that the proposed method can achieve the objective of capacitor monitoring with enhanced accuracy, less computational burden, and loading-independent characteristics.