DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

PhD Public Defence

Title: Small-Signal and Transient Stability Analysis of Voltage-Source Converters

Location: Online defence

Time: Friday June 12th. 13.00 - 16.00

PhD defendant: Heng Wu

Supervisor: Professor Xiongfei Wang

Moderator: Professor Frede Blaabjerg, Dept. of Energy Technology, Aalborg

Opponents: Professor Francesco Iannuzzo, Dept. of Energy Technology, Aalborg University (Chairman)
Professor Paolo Mattavelli, University of Padova, Italy
Professor Tim Green, Imperial College London, UK

All are welcome. The defence will be in English.

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Abstract:

Voltage-source converters (VSCs) have been widely used with power generation, transmission, distribution and consumption. The full power controllability of VSCs enables to modernize the electric power grid with more flexibility, yet it also poses new challenges to the stable operation of power systems.

In the low-voltage distribution network, VSCs with capacitors centralized in the DC-link, e.g., two-/three-level VSCs, are commonly used. In contrast, modular multilevel converters (MMCs) with capacitors distributed in each submodule, are typically adopted in the high-voltage transmission grid. Differing from two-/three-level VSCs, whose small-signal stability has been extensively investigated in the literature, less research works can be found on the small-signal stability of MMCs. The internal dynamics of the MMC, i.e., capacitor voltage variations of submodules, tends to affect its external ac dynamics and leads to the frequency-coupling behavior, which not only complicates its small-signal model, but also brings in new challenges for the stability analysis and the controller design of the MMC system.

To cope with these issues, a systematic modeling framework of the MMC is developed in this PhD project based on the harmonic state space modeling theory and complex space vectors, which is capable of capturing the frequency-coupling dynamics of the MMC. The small-signal models for MMCs with grid-forming (GFM) control and grid-following (GFL) control are developed, based on which, the differences and similarities between the models of MMCs and two-/three-level VSCs are highlighted, and root causes of different instability phenomena of MMCs are revealed. Lastly, perspectives on control methods and design recommendations for stabilizing MMCs in different operating scenarios are given.

Besides the small-signal stability, the transient stability of grid-connected VSCs, i.e., the synchronization stability under large disturbances, is also addressed in this thesis. The transient stability analysis is more challenging, due to the necessity of considering the large-signal nonlinear dynamics of synchronization loops, e.g., the active power loop (APL) for GFM-VSCs and the phase-locked loop (PLL) for GFL-VSCs. To tackle these challenges, the phase portrait is employed for a design-oriented analysis on the transient stability of GFM- and GFL-VSCs, with which, the main cause for the loss of synchronization of VSCs under large disturbances is identified. Further, it is found that the transient stability of VSCs can be guaranteed by using the first-order synchronization loop, i.e., the first-order APL for GFM-VSCs or the first-order PLL for GFL-VSCs, provided that the equilibrium points exist after disturbances. When there are no equilibrium points during the faults, the VSC with the first-order synchronization loop can still be re-synchronized with the power grid, even if the fault clearing time is beyond the critical clearing time, which reduces the risk of system collapse caused by the delayed fault clearance.