



Hybrid simulation for large-scale MMC-MTDC embedded power systems

Final Project Report

S-83G

Power Systems Engineering Research Center
*Empowering Minds to Engineer
the Future Electric Energy System*



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Power Systems Engineering Research Center

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Executive Summary

Modular multilevel converter (MMC) has become the most attractive converter topology for voltage-sourced converter high-voltage direct current (VSC-HVDC) transmission systems due to its salient features, e.g., modularity, scalability, inherent redundancy, and high efficiency. MMC based multi-terminal high voltage dc (MTDC) system is a promising technology in grid integration of various renewable energy resources, interconnection of asynchronous ac grids, long-distance power transmission, and enhancement of ac networks. To analyze and understand the dynamics of large-scale MMC-MTDC hybrid ac and dc systems, simulation-based study is commonly used. However, high-efficient simulation for such complex systems is difficult to be achieved due to large amount of mixed power electronic switches, electromagnetics devices, and electromechanical components. In this report, the primary goal is to investigate techniques for highly efficient modeling and simulation of MMC-MTDC systems. The report is presented in three parts.

Part I: A general equivalent circuit model for MMCs and simulation performance analysis

Modelling and simulation of a high voltage-level modular multilevel converter (MMC) is challenging due to large amount of semiconductor switches, various submodule (SM) circuits, and different operating conditions. Several equivalent models have been proposed for modelling and simulation in system level, which did not consider an industrial or digital controller. To accelerate MMC simulation, a highly efficient model is needed with considering control parameters/strategies and accurate dynamics of voltage/current. In Part I, a general equivalent circuit model (ECM) is developed for large-scale system simulation and MMC station design. The proposed ECM considers the MMCs based on various SM circuits under different operating conditions. It can generate bipolar arm voltage and simulate static compensator under dc fault condition. Based on the proposed ECM, the influences of simulation time step on simulation accuracy/efficiency are investigated by considering the sample period and voltage balancing strategies. This research is conducted based on an MMC-HVDC system in the PSCAD/ EMTDC software platform. The study results demonstrate the effectiveness of the proposed ECM and show the relationship between simulation accuracy/efficiency and control/simulation parameters for determining simulation time step. Based on study results, it is found that the computational efficiency of proposed model is not significantly affected by the complexity of SM circuit.

Part II: Modeling of MMC-MTDC Systems

With the increasing demand on renewable energy integration and bulk power transmission, the MMC-MTDC system with droop control and intricate dc network develops into a complicated nonlinear system. Modeling of such complex system is challenging due to multiple coupled controllers and complicated dc networks. In particular, modeling of dc network in the previous research is insufficient, which only considers the simple topology of dc network, e.g., common-bus, three-, or four-terminal systems. In Part II, a systematic method for modeling the MMC-MTDC system will be developed with considering the general topology of dc network, the model of transmission lines or cables, dq control, and droop control. The edge-node incidence matrix is introduced for modeling the dc network with arbitrary topology. The transmission lines or cables

are modeled as two-port networks without knowing their inner structures. In addition, a uniform matrix structure is developed for easily scaling the model of the MMC-MTDC system when the number of converter stations and controllers changes. To verify the developed model, two study systems, i.e., a 4-terminal and 14-terminal MMC-MTDC systems, are employed. A comparison of dynamic responses between the calculations of the developed nonlinear state-space models in MATLAB and the EMT simulations in PSCAD/EMTDC is conducted, which demonstrates the accuracy and correctness of the developed model.

Part III: MATLAB/Simulink-Based Electromagnetic Transient-Transient Stability Hybrid Simulation

The dynamics of power electronic converters are best represented accurately by electromagnetic transient (EMT) simulation tools. However, in these programs, the simulation time step size is usually very small and the presence of frequencies other than the fundamental frequency, such as harmonics and switching frequencies, necessitate the use of instantaneous, three phase quantities. Therefore, they require large computation times. On the other hand, transient stability (TS) simulation programs generally use comparatively large integration time steps. It can be assumed that the fundamental power frequency is maintained throughout the system under most conditions and phasors of the electrical quantities are therefore sufficient to model these systems. They have a much smaller computation time, but are not adequate to represent the dynamic response under many conditions. Therefore, to study power electronics based power systems, hybrid simulation methods and tools have been proposed and developed which combine two different software platforms to run the EMT and TS simulations separately. However, there are complexities, inconsistencies and inaccuracies involved when interfacing two different simulation platforms. Matlab/Simulink has the capacity to run EMT as well as phasor domain simulations. Thus, it serves as a suitable platform to integrate both simulation domains to build a hybrid simulation. In Part III, a hybrid EMT-TS simulation method is developed in the MATLAB/Simulink environment for modeling and simulation of power electronics based power systems. The purpose of selecting MATLAB/Simulink over individual software for EMT and TS simulation is to deliver a more general simulation environment, to test the hybrid simulation algorithm and procedure, particularly the interface between the EMT and TS simulations. It also ensures improved and less complex interfacing, communication and compatibility between the EMT and TS simulation models.

Project Publications:

- [1] L. Zhang, J. Qin, D. Shi, and Z. Wang, "Improved equivalent circuit model of MMC and influence analysis of simulation time step, " *IET Power Electronics*, vol. 13, no. 11, pp. 2212-2221, 2020.
- [2] D. Athaide, J. Qin and Y. Zou, "MATLAB/Simulink-Based Electromagnetic Transient-Transient Stability Hybrid Simulation for Electric Power Systems with Converter Interfaced Generation," 2019 *IEEE Texas Power and Energy Conference (TPEC)*, College Station, TX, USA, 2019, pp. 1-6.

Student Theses:

- [1] Lei Zhang. *Modeling, Control, and Design of Modular Multilevel Converters for High Power Applications*. PhD thesis, Arizona State University, December 2020.
- [2] Yuntao Zou. *Modeling, Control and Stability Analysis of MMC-based MTDC System*. PhD thesis, Arizona State University, expected in May 2021.
- [3] Denise Athaide. *Electromagnetic Transient - Transient Stability Hybrid Simulation for Electric Power Systems with Converter Interfaced Generation*. Master's thesis, Arizona State University, November 2018.