



Hybrid Time Domain Simulation: Application to Fault Induced Delayed Voltage Recovery

Final Project Report

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Power Systems Engineering Research Center

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Power Systems Engineering Research Center

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Executive Summary

This project develops two complementary hybrid simulation approaches that electromechanical transient stability analysis and electromagnetic transient analysis (time domain analysis). One approach is electromagnetic transient (EMT)-transient stability (TS) hybrid simulation, the other is quadratic integration method based quasi-dynamic domain and time-domain hybrid simulation. The developed capabilities provide the ability to represent desired portions of the system in greater detail, while the rest of the system is adequately modeled in phasor modeling detail and the dynamic responses are well-represented without simplification. Such an ability is of great importance to better understand the dynamics of increasing number of power electronic devices and single-phase induction motors, such as residential air conditioner motors, and their impacts on power systems.

The project consists of two parts. Part 1 deals with the development of a new EMT-TS hybrid simulation tool, named OpenHybridSim, and its applications to fault-induced delayed voltage recovery (FIVDR) studies on the Western Electricity Coordinating Council (WECC) system as well as dynamic simulation of power systems interfaced with high voltage direct current (HVDC) systems. Part 2 develops an approach for hybrid time domain simulation that combines electromechanical transient stability analysis (quasi-dynamic domain) and electromagnetic transient analysis (time domain analysis). Some details of each part are provided below.

Part 1: Electromagnetic Transient and Electromechanical Transient Stability Hybrid Simulation: Design, Development and its Applications

Two significant trends of recent power system evolution are: (1) increasing installation of dynamic loads and distributed generation resources in distribution systems; (2) large-scale renewable energy integration at the transmission system level. A majority of these devices interface with power systems through power electronic converters. However, existing TS simulators are inadequate to represent the dynamic behavior of these devices accurately. On the other hand, simulating a large system using an EMT simulator is computationally impractical. EMT-TS hybrid simulation approach is an alternative to address these challenges. Furthermore, to thoroughly analyze the increased interactions among the transmission and distribution systems, an integrated modeling and simulation approach is essential.

Firstly, an improved hybrid simulation approach is proposed and a tool named OpenHybridSim is developed based on the proposed approach. Compared to the previous work, the proposed approach has three salient features: three-sequence TS simulation algorithm, three-phase/three-sequence network equivalencing and flexible switching of the serial and parallel interaction protocols.

The second part of the work concentrates on the applications of the hybrid simulation tool. The developed platform is first applied to conduct a detailed fault-induced delayed voltage recovery (FIDVR) study on the Western Electricity Coordinating Council (WECC) system. This study uncovers that after a normally cleared single line to ground fault at the transmission system could cause air conditioner motors to stall in the distribution systems, and the motor stalling could further propagate to an unfaulted phase under certain conditions. The developed tool is also applied to

simulate power systems interfaced with HVDC systems, including classical HVDC and the new generation voltage source converter (VSC)-HVDC system.

The third part centers on the development of integrated transmission and distribution system simulation and an advanced hybrid simulation algorithm with a capability of switching from hybrid simulation mode to TS simulation. Firstly, a modeling framework suitable for integrated transmission and distribution systems is proposed. Secondly, a power flow algorithm and a diakoptics based dynamic simulation algorithm for the integrated transmission and distribution system are developed. Lastly, the EMT-TS hybrid simulation algorithm is combined with the diakoptics based dynamic simulation algorithm to realize flexible simulation mode switching to increase the simulation efficiency.

Part 2: Hybrid Time Domain Simulation: Quadratic Integration Approach

This project develops an approach for hybrid time domain simulation that combines electromechanical transient stability analysis (quasi-dynamic domain) and electromagnetic transient analysis (time domain analysis). This capability makes it possible to represent desired portions of the system in greater detail and enable the analysis of phenomena associated with switching of power electronic systems, unbalance in phases, unsymmetrical faults, single phase devices and many more detailed analysis for large power systems in an efficient manner. While the project was initially conceived to demonstrate the hybrid method for the study of Fault Induced Delayed Voltage Recovery phenomena, the proposed method is general and applicable to several problems that require variable detail at different parts of the system such as Geomagnetically Induced Currents, HV ACDC systems, and inverter interfaced generation. It enables electromagnetic transient analysis at selected parts of the system, while utilizing the entire model of the systems and therefore the effect of the entire system in this studies.

The advantage of the hybrid approach is that it can combine two different systems discretized over two different scales in time. The quasi-dynamic domain uses ms resolution while the time-domain uses microsecond resolution. The hybrid system achieves a simultaneous solution with reduced computational burden while preserving the ability to observe nonlinearities and fast switching transients. The Georgia Tech work resulted in a hybrid simulation method that allows arbitrary placement of an interface boundary to separate the system into two subsystems, one to be modeled and simulated with the quasi-dynamic method and the other subsystem to be modeled and simulated in the time domain while obtaining simultaneous solution at the interface.

An example of this method is presented in the report.

Project Publications:

- [1] Q. Huang, V. Vittal, – Arizona State University – “OpenHybridSim: an open source tool for EMT and phasor domain hybrid simulation,” IEEE PES General Meeting, Boston, MA, United States, July. 2016.
- [2] Q. Huang, V. Vittal, – Arizona State University – “Application of Electromagnetic Transient-Transient Stability Hybrid Simulation to FIDVR Study,” *IEEE Transactions on Power Systems*, Vol. 31, No. 4, PP. 2634-2646, July 2016.

- [3] Q. Huang, V. Vittal, – Arizona State University – “Integrated Transmission and Distribution Modeling and Simulation with three-sequence/three-phase mixed modeling,” *IEEE Transactions on Power Systems*, under review.

Student Theses:

- [1] Qiuhua Huang. *Electromagnetic Transient and Electromechanical Transient Stability Hybrid Simulation: Design, Development and its Applications*. PhD Dissertation, Arizona State University, May2016.