Modeling and Simulation of PMU based Wide Area Measurement Systems using a Global Event Scheduling Technique

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The modern power systems are becoming more complex and hard to predict with the deployment of advanced information technologies and communication technologies. As a result, system engineers must gradually pay more attention to the impacts of underlying communication networks. They must pay close attention to both the power system itself and the characteristics of the communication infrastructure and their influence on relevant applications running on it. The existing cyber-attacks such as the Stuxnet worm have indicated that any malicious cyber-attack will not just cause harm to the cyber system, but will also severely affect the normal operation of physical systems under the control of the cyber system being attacked. Therefore, research efforts related to constructing a co-simulation platform for power systems and the corresponding communication systems have become a new research direction.

To accurately model and simulate the interactive behavior between a power system and a communication network, we have to construct an appropriate co-simulation platform. Owing to the uniqueness and complexity of each individual system, there are only a few co-simulators developed specifically for power system applications. EPOCHS developed by Hopkinson, pioneers the efforts to integrate a power system-modeling tool with underlying communication network simulator as an integral platform. A similar work by Nutaro et al, improves the synchronization mechanism based on DEVS formalism and integrated with NS2. Zhu, et al make an effort by integrating MATLAB Simulink and OPNET to study the reliability of wide area measurement system (WAMS) under information and communication architecture. An integration of virtual test bed software and OPNET in Li is proposed to simulate distributed power electronic devices in a small-scale application.

Co-simulation platform is also used as a test bed for assessing the vulnerabilities and cyber security issues in SCADA systems. Davis, et al integrate PowerWorld and RINSE to construct a SCADA security test bed. All the proposed co-simulation platforms are designed for the traditional power system applications so that it is reasonable to ignore the possible synchronization errors.

However, the Phasor Measurement Unit (PMU) based WAMS applications are more sensitive to the co-simulation errors that may be introduced by the two-simulator interaction. This is because of the time resolution in WAMS data collection and state estimation are in the order of 30ms. Synchronizing two simulators at that granularity would solve the synchronization error problems but would slow down the co-simulation too much.

In order to combine a power system simulator (Dynamic Simulation for Power Systems) and a network simulator (Event-Driven Simulation for Communication Networks) into an integral co-simulation framework, the co-simulation platform has to synchronize the simulation time from two distinct simulation models.

According to the power flow characteristics, a power system dynamic simulation that exhibits the dynamic behaviors of power systems can be modeled as a continuous time system simulation. System state variables such as voltages, currents, and phasors change in a continuous manner. Typically, the system dynamic variables can be expressed by a set of differential equations. For numerical analysis and simulation, the differential equations are discretized and the time base is evenly divided into small steps. When simulating, the next system state will be derived from current system state. In addition, small variations of the state variables are integrated to approximate the system trajectory. The discretized time step is around 5ms, which is often very small, so that system variables do not have an abrupt transition within the time step.

While on the other hand, the most common method for network simulation is the discrete event-driven simulation. Discrete event-driven simulation is used for systems whose operating state is only subject to changes due to discrete events. In reality, the discrete events usually are unevenly distributed with respect to time. The method of time discretization into small-time intervals cannot be applied to discrete event systems since it is difficult to choose the time step. Selecting either too small or too long of a time step will decrease the simulation efficiency.

Therefore, the discrete event-driven simulation method with a dedicated event scheduler and an event list queue is applied. An event list is a queue that stores system events with timestamps in a chronological order.

The most challenging hurdle for designing a co-simulation platform is to schedule a synchronization mechanism for two distinct simulators. There are existing methods to provide an intuitive way that predefines explicit time-stepped for hybrid simulator synchronization. In those methods, several synchronization points have to be predefined. When the co-simulator starts to execute, the individual simulators run independently until both of them reach the predefined synchronization point. At this point, the two simulators pause and exchange information reciprocally. After that, two simulators restart and repeat the synchronization procedure. These methods may generate errors that cause unexpected time errors that may accumulate over time.

To prevent the synchronization errors and increase the simulation accuracy, we propose to use a global event synchronization method. Our co-simulation runs globally in a discrete event-driven manner. Since the power system dynamic simulation is in fact implemented in a discrete form, we consider each of the simulation round as a special discrete event in this framework. A global event queue is designated as a global time reference and coordinator. The global event queue is designed through sequencing the iteration events of power system and communication network events according to the event timestamps. By checking the content of the global event queue, the co-simulator knows whether the next event is a power system event or a communication network event. In addition, the entire simulation procedure is capable of suspending each event and yield a control back to the simulator. This method can effectively prevent the time delay errors introduced by synchronizations.

In this position statement, we will elaborate on a Global Event-driven CO-simulation (GECO) framework and analyze how to eliminate the synchronization errors using a global event scheduling technique. Then we will illustrate with two WAMS applications based on this framework. All PMU state estimation and PMU-based out-of-step (OOS) protection are selected to demonstrate our methodology. Since the communication requirements of these two WAMS applications are different, we apply different co-simulation scenarios and study the cyber impacts on these two power systems.

Bio: Yi Deng is a Research Scientist of Hume Center, Electrical and Computer Engineering at Virginia Tech. His research interests are cyber-physical security, modeling and simulation for embedded systems, software modeling and metamodeling, etc. He is currently working on projects of Smart Grid security, SCADA security, and establishing a virtual SCADA lab in Virginia Tech.