Development of a Multi-User Network Testbed for Wide-Area Monitoring and Control of Power Systems Using Distributed Synchrophasors

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Collaborators: Duke Energy (utility), Southern California Edison (utility), ABB Inc. (vendor), Renaissance Computing Institute at UNC Chapel Hill (network provider)

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Project Overview

The objective of this 2-year DOE project is to develop an integrated research and teaching laboratory at the FREEDM Systems Center at NC State University to advance ongoing research and education in wide-area monitoring and control of power systems using Synchrophasors. Over the past one year, the PI and his research group at NC State have already done the groundwork to achieve a major part of this objective by setting up a laboratory infrastructure for hardware-in-loop simulations using multiple Phasor Measurement Units (PMU) integrated with three racks of Real-time Digital Simulators (RTDS). This facility will now be extended to develop a multi-port, multi-user, and multi-vendor network of PMUs spread across the three campuses of NC State, Duke University and UNC Chapel Hill through an existing metro-scale fiber optic network called the Breakable Experimental Network (BEN), hosted by the Renaissance Computing Institute (RENCI) at UNC Chapel Hill. This PMU network will allow multiple users at various points of the network to process and communicate PMU data between each other, and collaboratively use them for critical Synchrophasor applications such as power oscillation monitoring, wide-area protection and damping control. The PI and the co-PIs will collaborate with local utility company Duke Energy as well as with long-standing collaborator Southern California Edison, ABB Inc., and RENCI to realize this network testbed.

Expected Research Outcomes

Once constructed, this testbed will be a tremendously useful resource for testing, validation and demonstration of real-life power system operations using PMU data in a human-centric network environment. For example, local users in this PMU network can access artificial PMU data generated by RTDS simulations in real-time, apply their individual local algorithms on these data, and then communicate the results to neighboring users until the loop reaches a global consensus over time. The network will also allow a detailed investigation of the sensitivity of these distributed algorithms on network latencies, jitters, and data loss. Four critical applications of Synchrophasors will be tested over the project period, namely:

1. Oscillation monitoring via estimation of damping, mode frequencies and mode shapes
2. Transient stability assessment
3. Voltage stability assessment
4. Wide-area PSS design for oscillation damping

All four applications will be validated via WAMS-ExoGENI testbed at NC State using a cloud-computing based distributed communication infrastructure connecting the three campuses of NC State, Duke University and UNC Chapel Hill.

Expected Educational Outcomes

A professional engineering course extending over four semesters (Fall 2013, Spring 2014, Fall 2014 and Spring 2015) will be offered through the Electrical & Computer Engineering department at NC State to accomplish the above four tasks. The course will be referred to as the WAMS-MS program (or, $WAMS^2$ in short). It will be a hands-on experimental course, and mostly geared towards Masters-degree students, who are interested in pursuing professional careers in power systems engineering. The course will be integrated as a part of our ongoing course curriculum in the FREEDM center called MS-EPSE (Masters in Electric Power Systems Engineering), which is a DOE-funded education program focused on distribution systems, substation automation and renewable energy integration. The proposed 4-semester course will greatly enhance the scope of the EPSE program to encompass advanced applications of Synchrophasors in transmission-level power systems, and impart more industrial exposure to the enrolled students. Upon completion of their accelerated MS degree students will have the opportunity to pursue internship and full-time employment opportunities with our industry collaborators Duke Energy, SCE and ABB. Students who are interested in academic careers will be encouraged to pursue PhD degrees in the FREEDM center in collaboration with these industry members leading to further collaborations on Synchrophasor research. Chakrabortty and Baran will work with two PhD students and mentor them on the four above-listed topics on wide-are monitoring and control throughout the project period. These PhD students, in turn, will serve as group leaders and team champions for the course projects, and work with the MS students, in consultation with the PIs and the industry members, to advance their research. Dr. Carpenter, who is the education program manager for the MS-EPSE program and also a co-PI for this project, will oversee the overall coordination of the course, and administer student evaluation at the end of each semester. She will also provide administrative support through report writing and online presentations to SCE, Duke and RENCI.

Detailed Project Description

Each year of the project will be divided into 3 distinct phases following the academic calendar of NC State– namely, Spring semester, Summer semester, and Fall semester. The overall project will, therefore, comprised of 6 semesters, each of which will have the following dedicated tasks:

1. Students will work on the collection, organization, database management, software installation and other bookkeeping of the PMU data sets obtained from Duke Energy and SCE, as well as on enhancing the existing hardware-in-loop facility by adding two new PMUs from ABB to the RTDS system. Two PMUs from National Instruments that are currently being used for other purposes will also be added to this facility to create a multi-vendor PMU set up.
2. The $WAMS^2$ program will be launched in summer 2014. Assuming about 8-10 MS students to enroll in in the first semester, they will be divided into two groups, each headed by one PhD student. The students in each group will work with their group leader to use the PMU data from SCE and Duke Energy to develop wide-area oscillation models for the WECC and Duke System, and implement these models in RTDS.
3. The summer of 2014 will be devoted to the connection of the PMU-RTDS set up with the BEN network of RENCI. Students will work with RENCI to develop the necessary software and communication interfaces for this wide-area network.
4. Student groups will carry out detailed experiments using the Duke and WECC models created in RTDS in the second semester. Various types of disturbances will be simulated, and the responses will be captured using PMUs from SEL, ABB and NI, and distributed to remote computers using the BEN network. Algorithms will be installed at each virtual computer operating in the BEN network, and used in a distributed fashion for power oscillation monitoring and damping calculations for the two system models.
5. In Spring 2015, the WECC and the Duke models in RTDS will be used for testing two critical Synchrophasor applications – transient stability assessment and voltage stability assessment. The students will be divided in two groups for these two tasks. PMU data will be distributed across the BEN network to collectively assess these stability requirements for the WECC and Duke models.

6. In summer 2015, the PhD students will set up the lab infrastructure for closed-loop control using a Real-time Automation Controller (RTAC) donated recently to NC State by SEL, and integrate it with the Duke and WECC model. Detailed models of AVR and PSS will now be developed in RSCAD for various subcomponents of this model, and detailed closed-loop simulations will be carried out to validate the response with actual PMU data by proper tuning of the controllers.
7. The project will conclude with every student writing a detailed project report summarizing his/her experimental observations. These reports will be shared with our industry collaborators followed by a one-day group workshop to promote student-industry interaction and further DOE collaborations.

Possible Collaboration with other projects

This project has a strong collaborative aspect with many other Synchrophasor based monitoring and control projects dedicated towards:

- FACTS and HVDC driven transmission grids, especially grids with high penetration of wind/solar power
- Distributed voltage control using Synchrophasors in distribution systems
- Coordinated voltage-source-converter (VSC) based synchronization control in micro-grids using local Synchrophasor data

All of the above monitoring and control application, when executed over a geographically dispersed wide-area communication network, will face similar research and implementation challenges as being addressed in this project. Therefore, one of the critical contributions of this project will be in establishing an explicit functional relationship between the communication, computing and control requirements for any real-time data-driven monitoring and control application in transmission-level and distribution-level power systems. Our primary goal, for example, is to investigate how these distributed PMU data processing strategies can be cast on top of series FACTS devices such as Thyristor-controlled Series Compensators (TCSC) and Static VAr Compensators (SVC) for oscillation damping and power flow regulation control in grids with significant amount of renewables. Both TCSC and SVC have been shown to be an effective supplementary damping control agent in previous literature on WAMS, and, therefore, will be a natural choice for implementing damping controllers for wind and solar infested grids. Real-time validation of these algorithms in presence of communication delays and network uncertainties need to be demonstrated using realistic WAMS communication networks such as GENI. Results of decentralized control where every TCSC/SVC receives remote or wide-area PMU feedback must be compared to the case where they take a control action based on its local PMU data only. Impact of malicious malware, GPS spoofing and Byzantine attacks on distributed computing nodes spread across the WAMS cyber-architecture also need to be thoroughly tested in order to make the spatially and temporally coupled wide-area control loops resilient and robust.