AC 2012-3487: MULTI-INSTITUTIONAL SMART GRID LABORATORY

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Multi-Institutional Smart Grid Laboratory

Recent years saw an unprecedented growth of awareness in aging utilities infrastructure and workforce. Significant Government and industry funding is being targeted towards implementation of Smart Grid as well as other activities to modernize existing electric power system. These efforts are critical to achieving renewable energy development, electric vehicle adoption, and energy efficiency improvements. Existing skills shortage and aging workforce in power industry makes it critical to reinvent commitment to training of current workforce and educating new cadre of power engineering professionals. Such education and training requires close cooperation of constituents including academia, power utilities, and manufacturers of electrical equipment.

Smart Grid laboratory has been established at Buffalo State College as a collaborative effort of two academic institutions (Buffalo State and University at Buffalo). It is equipped with state-of –the-art equipment and serves as a hands-on teaching tool for undergraduates, as well as a research lab for graduate students.

This paper describes the development of the lab, covers curriculum areas affected, and elaborates on multiple activities to engage students in active learning and research.

As part of the Department of Energy (DOE) funding of Strategic Training and Education in Power Systems (STEPS), under the ARRA, a consortium of six institutions in New York State was formed to address curriculum development and laboratory enhancements to address critical need in education and training of power industry professionals[1]. Two of these institutions are located in close proximity and it became apparent that depleting resources for laboratory equipment between two campuses is not advisable. The decision was made to concentrate all equipment related to Smart Grid laboratory at one facility, specifically at Buffalo State College. The rational for that was based on the fact that the above-mentioned institution already had substantial amount of power system equipment and expertise using and maintaining it.

Both institutions committed to the idea that a joint laboratory placed in a single location would allow easy access to students of both institutions, as well as to other participants of the consortium.

Such equipment was purchased in fall of 2011 and commissioned within several weeks. It consists of the following subsystems.

- Conventional Generation Systems
- Transmission Systems
- Distribution Systems
- Complex loads
- Renewable Generation Systems
- Energy Management Systems
- Protection & Control Systems

Figure 1. Laboratory layout

Generation System Components

Generation component includes 300W and 1kW synchronous generators and means of manual and automatic synchronization.

Electrical power is mainly produced by three-phase generators. This applies to power stations as well as to standby power supplies and wind generators. In addition to the basic experiments dealing with three-phase synchronous generators, the experiments involving manual and automatic synchronizing circuits as well as experiments on the automatic power factor control and power control can be carried out. Thus, the generation component is used to simulate power station operation in stand-alone (isolated) or interconnected operation.

Transmission System Components

Transmission component includes modules of transmission lines (medium length of 150 km and long lines of 300 km). It allows experiments with line parameters, all types of faults, and parallel lines.

380-kV transmission lines are investigated and connected at a low-voltage level without detracting from the characteristics of a real high-voltage line. Emulation of a 380-kV transmission line switches over automatically between line lengths of 300 km and 150 km once the overlay mask has been put into place. Joint use of several line modules connected in parallel or series permits complex networks to be assembled.

Distribution System Components

Distribution system includes double bus-bar system to provide experiments with switching and reconfiguring distribution system. Electrical power at large switching stations is distributed almost exclusively using double busbar systems. These stations incorporate switching matrices for connecting the two busbars, the incoming and outgoing feeder cubicles as well as the measurement fields. The incoming and outgoing feeder cubicles as well as the switching matrices are furnished with circuit breakers and one disconnector for each busbar terminal. For safety reasons, a particular switching logic must be strictly adhered to. Integrated instruments for measuring currents and voltages permit direct analyses of switching operations.

Complex Loads

Experiments on reducing peak loads through measurements with active-current and maximum-demand meters demonstrate how the load on a supply network can be reduced and evenly distributed over a 24-hour period. An analysis of the grid and connected loads is necessary for effective use of the measurement techniques involved. Accordingly, each experiment permits a detailed investigation of static, dynamic, symmetric and asymmetric loads.

A three-phase induction motor coupled with the servo machine test stand is used as a dynamic load. The active and reactive powers depend on the motor load and are therefore not constant. The servo machine test stand is used to drive the induction motor, consuming active power. Reactive power compensation reduces undesirable reactive current. In this process, capacitive loads are connected via a central feed point.

Renewable Generation Systems

Wind Power Plants

This equipment set is used to investigate the design and operation of modern wind power stations. The effect of wind force and the mechanical design of wind power stations is emulated using the servo machine testing stand and the WindSim software. The control unit for the double-fed induction machine allows user-friendly operation and visualization during the experiments. The corresponding software provides interactive support for the experiment set-up and allows for computer-assisted evaluation of the measured data.

Advanced Photovoltaic Plant

The advanced photovoltaic component enables realistic emulation of the progression of the sun. Emulators make it possible to carry out the experiments in the laboratory without the sun.

Energy Management Systems

One of the main features of Smart Grid is integration of traditional power engineering components with communication and information technologies. TCP/IP-enabled smart meters and sensors are an integral part of the laboratory. SCADA Power Engineering Lab software for the intelligent control and evaluation of the Smart Grid provides visualization and control of switching operations both manually and automatically as well as display of all grid parameters and load variation curve.

Protection & Control System

System protection is being utilized by using available SEL microprocessor relays and provides generator protection, time-overcurrent protection, distance protection, and differential protection schemes for the components and the entire system.

Experimental content

Experimental content for available components is presented in Table 1.

Table 1. Experimental Content

Components	Experimental Content
Generation	
Manual synchronization	• “Dark” synchronizing circuit, “light” synchronizing circuit • “Cyclic“ synchronizing circuit • Active power generation • Inductive reactive power generation • Capacitive reactive power generation.
Automatic synchronization and control	• Operation and parameterization of the automation unit • Synchronization in test mode • Synchronization to the real power grid • Response of the automation unit to faulty programming • Automatic power factor control • Response of power controller to changes in control variable and disturbance variable • Power controller sensitivity and direction of action.
Transmission	• Voltage increases on open-circuit lines • Voltage drop as a function of line length • Voltage drop as a function of power factor variations • Capacitive and inductive power losses on a line as a function of voltage and current • Phase shift on a line.

Distribution	• Basic circuits of a three-pole, double busbar system • Three-phase double busbar system with load • Busbar changeover without interruption of the branch • Investigation of algorithms for various switching operations • Busbar coupling.
Complex loads	• Power consumption measurement and peak load monitoring of three-phase loads with Y and delta connections (R, L, C, RL, RC and RLC loads) • Measurement with active and reactive energy meters • Determination of the first and second power maxima • Determination of the power maximum in the event of an asymmetric load • Automatic recording of load profiles • Manual compensation of reactive power • Automatic compensation of reactive power.
Renewable generation	
Wind power plants	• Setting up and commissioning a double-feed induction wind generator • Operation of the generator with varying wind force levels and regulation of the output voltage and frequency • Determination of optimum operating points under changing wind conditions • Investigation of the operating response during fault ride through allows exploring symmetrical fault scenarios • Adjustment of controller parameters • Representation of variables in the dynamic range as well as with positive phase sequence and negative phase sequence, and compensation for the negative sequence components.
Advanced photovoltaic	• Testing the optimum alignment of solar modules • Recording the characteristics of solar modules

	• Investigating the module's response to shadow formation • Investigating operations of bypass diodes • Exposure to various types of wiring and connection configurations for solar modules • Determining efficiency of the grid-connected inverter • Investigating response of a PV system to the grid failure.

Student project activities

In spring 2012 semester undergraduate and graduate students from both institutions were involved in a series of projects utilizing individual components of the lab as well as integrating these components into the system.

These projects and activities are described below.

The first activity concentrated on automatic generator synchronization and control and involved study of a power relay (Woodward GCP-30), software package for visualization of the relay actions (LeoPC1), establishing of communication between the relay and a PC, and performing generator (1 kW) synchronization and control according to experimental content. The outcome of this activity is used in preparation of training module for a local power utility company.

The second activity was focused on automatic power factor correction using reactive power controller RM9606 for fine adjustments of power factor. Besides other numerous routine experiments as outlined in Table 1, students were involved in integrating components in a system, running the entire system as a micro-grid, operating SCADA with monitoring of parameters and switching operations, and most importantly, programming SCADA for automatic operations for selected contingencies based on sensors and smart meter outputs.

Students were also engaged in calibration of smart meters designed and developed by a local company ESensors of Amherst, NY. Calibration was performed in the lab using existing smart meters and specialized stabilized 3-phase power supply.

Future activities planned for summer and fall 2012 will concentrate on integration of SEL microprocessor-based relays with lab subsystems and deployment of synchrophasor technology.

Educational importance and student feedback

During the course of the work on the senior design projects using joint Smart Grid laboratory, students reflected on their educational experience:

- This project offers a deep understanding of how the micro-grid works, by providing educational knowledge through a theoretical approach, as well as hands on approach working with the equipment directly.
- This equipment provides real- life scenarios that will give the Buffalo State Electrical Engineering Technology students a situational learning environment that provides a better understanding of what to expect once in a career; one such example is generator synchronization.
- These experiments, though performed in the school learning environment, provide students the opportunity to discuss scenarios with industry personnel on a higher level of understanding than those who are only learning in a strictly theoretical or computer modeling situation; we are using a real life connection schedule, wiring diagrams, dynamic loads, and SCADA software to monitor the various modules and make engineering decisions based on the readings.
- We expect that this experience will provide an advantage for us graduating from this program over the rest of recent grads who do not have access to such equipment.
- My personal career path is going in a manufacturing operation and maintenance direction. And the power system, distribution knowledge that is gained from the performance of experiments with this equipment will provide me the ability to contribute to a company's bottom line in the form of energy savings, power quality, and environmental stewardship.
- The smart grid equipment uses state of the art automation equipment relating to the power industry, encompassing all power industry aspects ranging from various green-power generating systems through power distribution to various types of customer loads.
- The automation hardware and software that controls the micro smart grid reflects the future in technology for the power industry and allows me to gain the experience needed for potential employment in the power industry.

- With the future of the power industry moving towards a smart grid solution, this equipment and program allows students to become educated and trained beyond the bounds of anything else in Western New York.
- As I am getting firm understanding of the hardware and software controls of this smart grid system, the company I work for will have an advantage when bidding on control integration opportunities for the power industry that they did not have prior to my entering into this program and experience with this equipment.
- Working on the smart grid system has encouraged me to look into continuing my education at a graduate level with a focus on power systems, ranging from protective equipment to various types of automation equipment controlled using a Supervisory Control and Data Acquisition (SCADA) interface.

Conclusions

Academia ignored the electrical power systems field in their curricula for decades in pursuit of other emerging disciplines such as computers, IT, nanotechnology etc. Now that the energy, in general and electric power, in particular, has the highest priority globally, the academia needs to make up for the lost time, while financially constrained at the same time. Not only government-industry-university partnership is the only option, but also collaborations between academic institutions are indispensable, if we are to answer the call of duty.

Bibliography

1. Ilya Grinberg, Mohammed Safiuddin, Chilukuri K. Mohan, and Steve Macho. Multi-Institutional Approach to Engineering Education. *Proceedings of 2010 Annual Conference of the American Society for Engineering Education,* Louisville, KY, June 20 -23, 2010