Enhancement of Transactive Energy Test Bed as Related to Microgrid with Deployment of Synchrophasors for Protection, Monitoring and Control

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Microgrid Testbed Design Overview

The growing need for clean renewable power sources and the technical improvements made to photovoltaic systems and wind turbines have led to the increased deployment of distributed generation (DG) resources on the electrical grid. While this provides numerous benefits, it also requires higher level techniques for controlling, monitoring, and dispatching the dispersed assets. The concept of Transactive Energy made its way to the forefront of discussions regarding the management of the modern grid. Defined as "a set of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using the value as a key operational parameter", Transactive energy provides a solid basis to the future operations of a smart grid. However, as with many emerging technologies, Transactive energy remains largely untested. With a reliable electrical grid being such a critical component of modern life, the implementation of new technology and concepts needs to be thoroughly evaluated to ensure a successful transition to a sophisticated grid. The purpose of the project was to provide a means for testing and perfecting a new set of techniques, as well as developing innovative approaches to oversee the operation of the electrical grid.

Our testbed consists of numerous components that emulate equipment used in electrical generation and distribution systems. A wind turbine and photovoltaic source (PV) serve as the renewable sources for our system. The wind turbine is represented by a doubly-fed induction generator (DFIG) used with an active servo drive simulates a wind profile to spin the generator. The DFIG requires a stable power source in parallel to maintain frequency and voltage requirement. This is done by way of a synchronous generator or a utility source. The utility source feeds power to the microgrid via emulated underground cable. A solar inverter is used in conjunction with a DC power source that emulates a PV array. A solar panel emulator program controls the supply of DC power and represents the variable output of a renewable source. The sources are connected to a load via a double bus bar system that can facilitate automatic and remote switching operations. Loads are represented as static, dynamic and solid-state systems to evaluate considerations that will be needed for each. A Supervisory controls and data acquisition (SCADA) system provides oversite and operation of each of the components. Various Schweitzer Engineering Laboratories (SEL) relays are used to protect the system as well as to provide synchrophasor measurement data to a Human Machine Interface (HMI) for evaluation of system stability and performance. An SEL-300G generator relay facilitates automatic synchronization between the various sub-systems (microgrid and grid).

This project is the second year of a far-reaching experiment intended to become a flexible microgrid testbed with the purpose of emulating modern power systems techniques and providing insight to the numerous requirements of a smart grid.

Our microgrid was constructed using modular components produce by Lucas-Nuelle laboratory equipment. To complete the testbed, the equipment and software has been modified and reconfigured in order to meet the specific needs of the project. Components from other manufactures (SEL) have been integrated into the system to resemble the variability of a practical situation and to use the preferred equipment of utility and facility operators. Our system is modeled at a nominal voltage of 208V, in order to provide a safe working environment.

The design of the microgrid is based around the presence of renewable energy sources. For the testbed, a 1kW doubly-fed induction generator (DFIG) was chosen to emulate a wind turbine. An active servo motor is connected to the input shaft of the generator and emulates the drive force of a wind turbine rotor. This servo is controlled through wind simulation software that varies its output based on either a user defined wind speed or a wind profile. The DFIG can be used in parallel with the utility, or in island mode when a synchronous machine is present. However, the wind turbine is unable to isolate a load without a more stable power source.

For operating the microgrid separate from the utility, a synchronous generator is used. This generator is a 1kW smooth core synchronous machine with its input connected to an active servo drive motor. In this case, the active servo drive represents a stable and predictable mechanical input such as diesel backup generator or a combine heat and power (CHP) generator, which is typical of powering large facilities. This generator serves two main purposes. The first purpose is to provide a stable voltage for the line side of the IGBT converter associated with DFIG. The second purpose is compensating for real and reactive power levels which the DFIG is incapable of producing, dependent on the simulated wind speed. In some cases, the synchronous machine runs as motor to dissipate excess power when used in island mode.

The Microgrid also contains a solar inverter that works in parallel with the wind turbine and generator. The inverter used is a Steca Elektronik StecaGrid model 3203 3.2kW inverter. To avoid situations where the inverter overpowers the rest of the system, the max power output has been limited to approximately 1.4 kW. A DC power source controlled by a solar panel emulator dictates the output of the Inverter. A SCADA system controls the level of power derating, active, and reactive power outputs of the inverter. The inverter is capable of supplying reactive power up to a value of 0.8 lagging or leading.

Synchronizing the generators with the rest of the system is achieved with a Schweitzer Engineering Laboratories (SEL) model SEL-300G generator relay. This device was chosen due to SEL’s status in the protective device industry. SEL relays are commonly found in low, medium, and high voltage power systems and are used throughout our testbed. The relay achieves synchronization by performing a frequency and voltage check before a breaker is closed. With this setup, the relay acts as a pass through for a breaker close signal. When the command to close the breaker is received, the relay verifies that the microgrid is in phase with the utility before allowing the breaker to close. If the system does not pass the synchronism check, the relay will send a signal back to the system to adjust its frequency until the system is in sync.

A utility connection is provided by an AC power source that operates at 208V. Power is supplied through emulated 93-mile transmission line. This line is protected using SEL-411L relays. The line is protected using instantaneous and time overcurrent, as well as directional overcurrent and differential protection (ANSI designations 50/51, 67, 87). The relays contain a reclose function (ANSI 79) when the relays operate on differential protection. The transmission line terminates at a double busbar substation. This substation serves the microgrid through emulated underground feeder, as well serves other loads. The underground feeder is 7.8 miles long and has overcurrent protection (ANSI 50/51) from SEL-751 feeder protection relays. The SEL-751 relays has overcurrent protection settings that selectively coordinate with the SEL-411L relays.

The phasor measurement unit functions of the SEL-411L and SEL-751 are used to provide synchrophasor measurements to a human machine interface (HMI). The data are taken and evaluated during normal operation and fault conditions in order to optimize the design and control of our system. Measurements of voltage, current, and frequency are taken by the relays. An SEL-2407 satellite synchronized clock provides an external time source to the relays via fiber optic cables. This allows the data to be time stamped and exported for comparison at a central location. The data are collected at the initial point of the transmission line, at the substation and at our microgrid.

Each of the power sources and the loads are connected through double busbar switching modules, which can switch between preferred power sources. Each module contains two switches that select between two busses and a circuit breaker to connect or disconnect the load or generator. This has the capability to be controlled remotely through SCADA.

The current SCADA updated in this project includes real time switching capabilities of all power sources. The current double-busbar system allows for switching through SCADA. The double-busbar allows for opening and closing of the contacts within the busbar module, for a switching operation which can be done remotely at a computer.

Multiple methods are used to acquire data, including synchrophasor measurement from the SEL relays, Siemens model PAC 4200 smart meters and utility industry test equipment. The data collected will be used to optimize the eventual automation of our microgrid.

All SCADA systems are configured by Lucas-Nuelle and operate using Structured Text embedded in a soft PLC. The code is open for modification and addition, which has been utilized to interface with and control additional components.

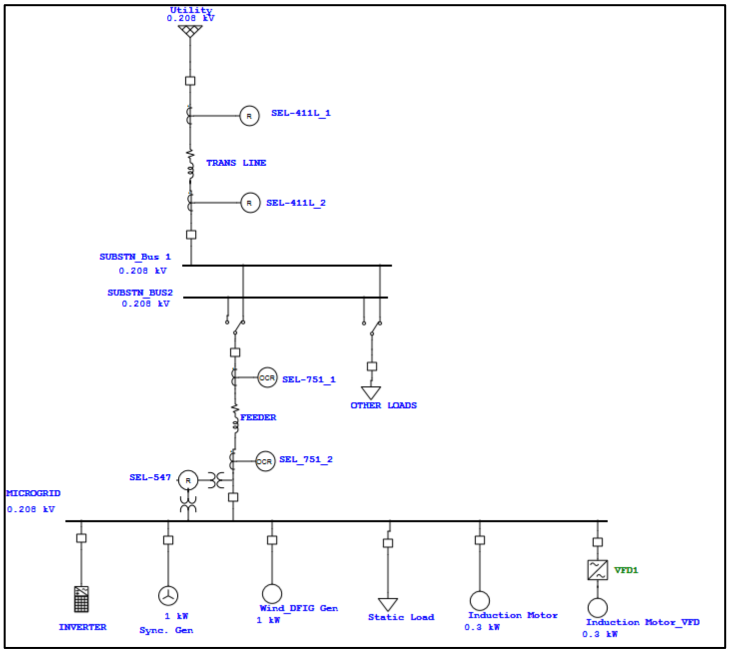

Figure 1: One-Line Electrical Distribution Diagram

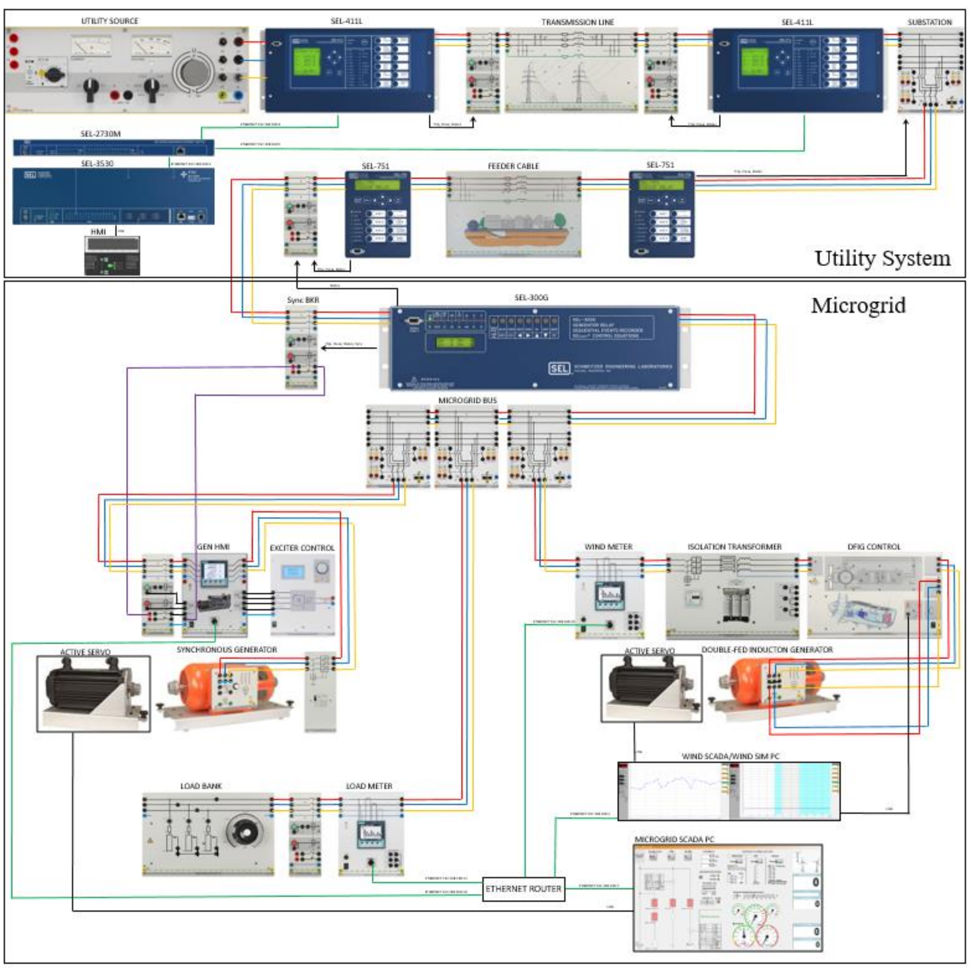

Figure 2: System overview

Fig. 3. Microgrid Test Bed Layout

Development of SCADA / HMI for Solar Microgrid with Transactive Energy Controls

To Facilitate operation of the solar section of the test bed, Lucas-Nulle components and SCADA/HMI were combined into one single SCADA and HMI. The PLC code was developed with proper input/output variables and addresses as necessary. In addition, several unique control panels, slide bars, panel/indicator sections were added to facilitate transactive energy experiments in the solar microgrid. The following figure shows the new SCADA HMI created using Lucas-Nulle SCADA Designer and Panel Designer.

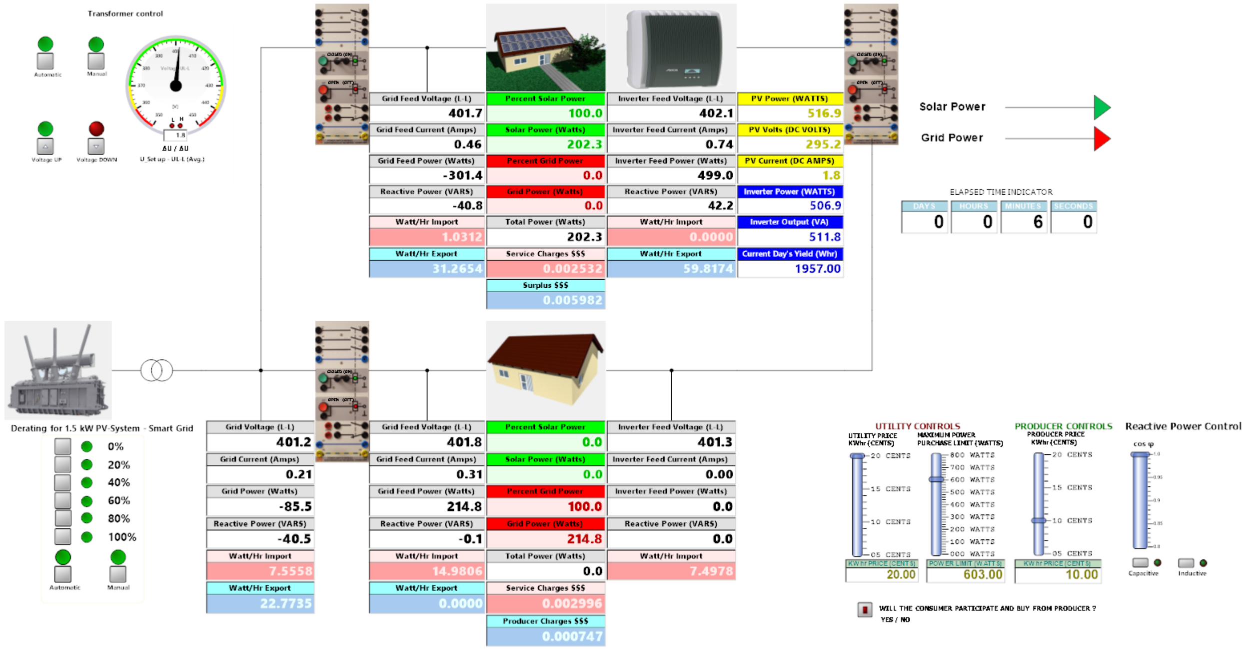

Figure 3. Solar Microgrid SCADA / HMI with Transactive Energy Controls

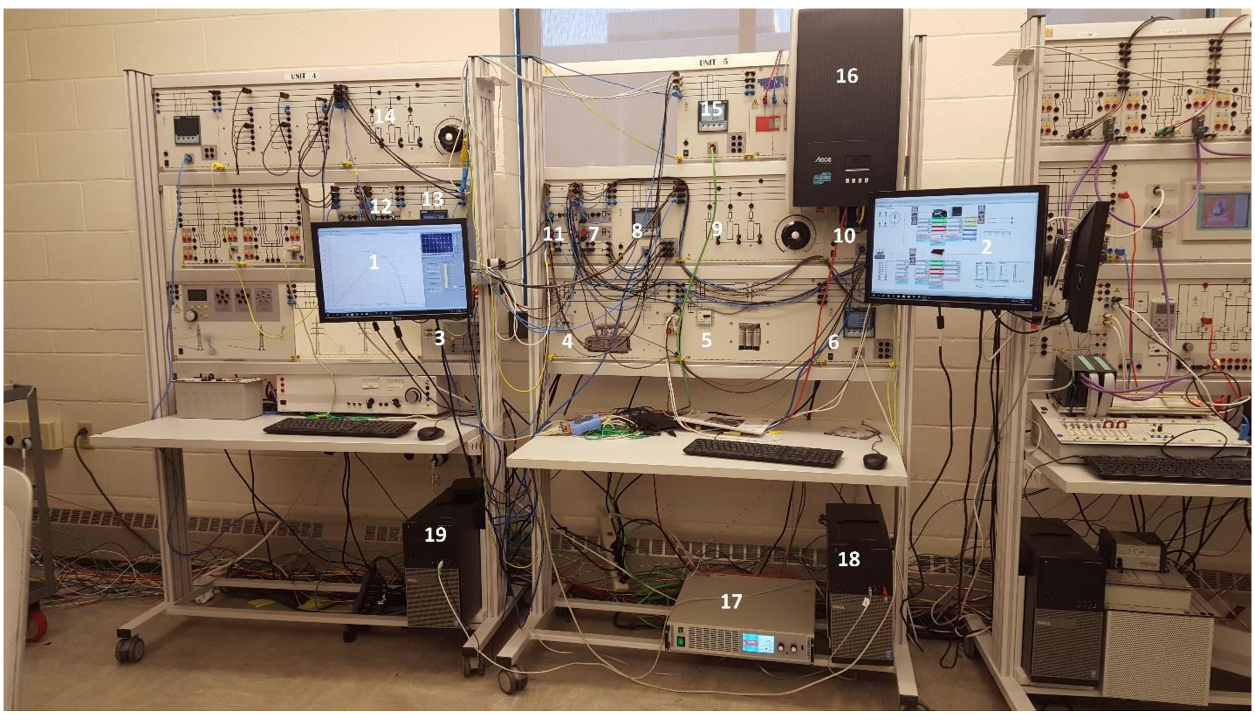

Figure 4. Layout of Photovoltaic/Transactive Energy Component of the Test Bed

Acknowledgements

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Dr. Ilya Grinberg, Professor and Coordinator of Electrical Engineering Technology at SUNY Buffalo State

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The team acknowledges financial and technical support from the following institutions: