The Smart Grid Testbed

Energy Systems Research Laboratory, ECE Department
Florida International University

The FIU Smart Grid Testbed at the Energy Systems Research Laboratory gives researchers the ability to:

Achieve full potential for testing practical issues in smart grid research

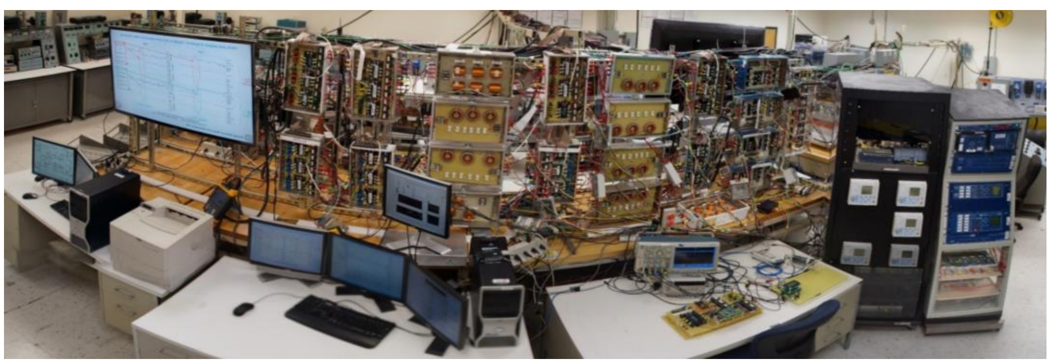
Investigate and validate the performance in an isolated platform

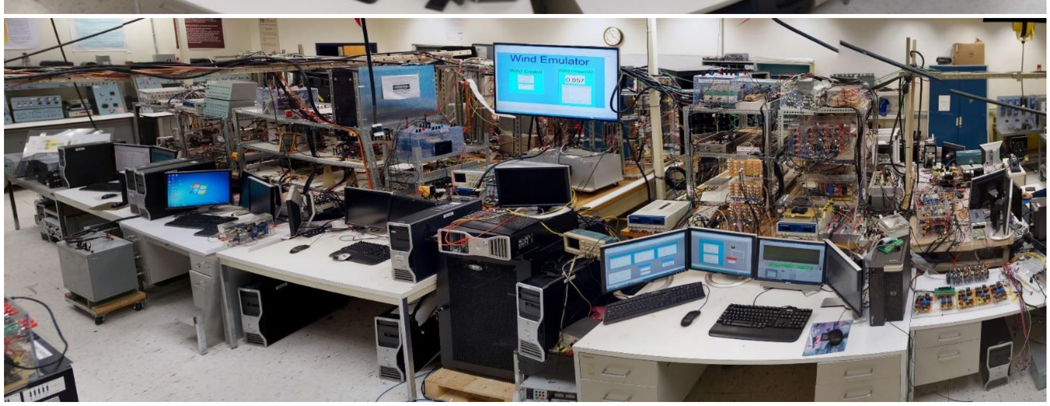
Characterize the components, equipment's and systems in flexible architectures

Develop, integrate and verify new ideas and techniques

Capabilities to practically use, test and enhance modern standards

The Smart Grid Test-bed laboratory at the department of Electrical and Computer Engineering, Florida International University (FIU), is a unique contemporary research facility which was developed as an integrated hardware based AC/DC system. This cutting-edge hardware/software/communication based system includes capabilities for conceptualizing a holistic Cyber-Physical Smart Grid framework. In fact, our Energy Systems team's efforts interleave the interdisciplinary and interrelated research areas of Power System Operation and Control, Communication Infrastructure in the Smart Grid, and Cyber Security of the Smart Grid. This reduced scale power system was created and built to implement new technologies and products required for Smart grid development according to established national and international standards. The new technologies evaluated are related to power generation, renewable energy resource utilization, automation, distributed control, energy management, and wide area protection. Also, technologies related to increased electric vehicles penetration, micro grid implementations, advanced metering, communication and security and cyber physical systems are featured on this testbed. One of the main focuses in building this testbed is the communications and distributed real-time control issues. This testbed features capabilities for studying real-time smart control and operation issues related generation, transmission and distribution as well as microgrid operations in islanded and grid-connected modes. One of the major features is the capability to connect this testbed to other governmental, industrial or research facilities for the purpose of testing and verifying tools developed by others.





Testbed Features:

1. **Generating Stations**

The power for the main grid is delivered through 4 AC generation units (two 13.8KVA and two 10.4KVA generators) using 3 phase synchronous machines as generators each equipped with 4 induction machines as prime movers. Each station has an AVR to control the voltage amplitude or reactive power of the generating unit.

2. **Synchronizers and Buses**

AC generations are connected through synchronizers for proper connection to the main grid, and also for measuring electrical parameters at the point of connection. Generated power is delivered and distributed through more than 14 transmission lines to more than 24 feeders located on 8 buses. The developed transmission lines are 3 phase 5 wire, with Pi model structure, reflecting series and parallel characteristics of actual overhead lines or cables. Developed buses have 3 power terminals (feeders) and each not only has the switching capability (breaker emulation through solid state relays) but also measures the voltage and current independently (through PTs and CTs)

3. **Loads**

More than 10 programmable/controllable loads are built and located on the multiple locations on the grid. They include resistive, inductive, dynamic motor, and pulse loads, and are capable of automated operation to follow a predefined scenario based on a programmed load profile.

4. **Measurement and Data Acquisition**

This is done through the National Instruments Data Acquisition (DAQ) as the main hardware (connected through PCI, PCI-express, USB, Ethernet or Wi-Fi) and LabVIEW as the software, which are the junction for acquiring and interpreting the data from the test bed, as well as the junction to send control commands to the testbed itself. So this combination is creating the backbone of the system operation through data acquisition and actuators, communication capabilities, processing and calculation schemes, and human machine interface. More than 200 voltage and current sensors are capturing the power signals and this information is published and archived to be used by real-time applications for control, operation or monitoring purposes.

5. **Microgrids and Renewable Energy Integration**

The testbed includes several micro grids, to incorporate the recent integration of wind, solar, and energy storage systems. Renewable energy is a complimentary source which is implemented on the test bed in the form of 3 DC microgrids which are connected to the main AC grid through power electronic components. They utilize state of the art techniques in power electronics and control to investigate operational issues of futuristic power systems. These research topics include generator behavior study, power sharing and control techniques, dc-bus voltage management, design and improvement of bidirectional converters, demand side management, and secure and stable operation of islanded microgrids.

   a. **PV Emulators**

   Nonlinear behavior of DC resources such as photo voltaic and solar panels are deployed through 5 programmable power supplies with a maximum power of 6KW. PV solar panels are connected along with Maximum Power Point Tracking

The FIU Smart Grid Testbed at the Energy Systems Research Laboratory gives researchers the ability to:

Provide an environment and interface for related fields such as market analysis

Provide a platform for multiple microgrids connections, Electric Vehicle penetration and resiliency analysis

Provide a platform for testing and evaluating cyber physical system development

Provide a platform for testing distributed control, optimization studies and multi agent-communication

Enable remote operation (i.e. online or off campus accessibility)

The FIU Smart Grid Testbed Provides the Following Technical Abilities:

Develop a communication infrastructure

Develop real time monitoring of the hybrid system

Implement a variety of architectures and connectivity to emulate different systems and microgrids

Involve trainees in the development and building the various test bed components

Develop and evaluate hardware/software solutions by hand and experiment with it

Study Cyber Physical Systems by developing measures for data handling energy flow and real-time control

(MPPT) modules and boost converters to a DC bus. They are accompanied by voltage regulators, energy storages, protection modules, and bidirectional grid tied converters to transfer energy to/from AC grid.

b. Wind Emulator

A wind generation unit is implemented through a wind emulator with a Permanent Magnet Synchronous Generator (PMSG) coupled to controllable DC prime mover as the turbine. This system can be configured to create, control, and follow a wind pattern through controllable wind speed emulator.

c. Battery Storage System

The lead acid battery bank storage has a 10-110 Ah capacity and is equipped with a unique battery management system (BMS) which individually manages, balances, and conducts diagnostics on each battery module using hall-effect sensors of voltage and current. The BMS not only monitors the batteries, but also extracts the defective battery and compensate its loss through the distribution of the load on other resources using power electronic converters (buck/boost).

d. Super Capacitor Bank

An energy management system improves the performance and efficiency of unpredictable renewable energy resources through integration of super capacitor energy storage systems in the testbed with two 2.9F super capacitors in series or parallel architecture with 1.45F-650V or 5.8F-320V. A super capacitor at the DC bus will stabilize all the converters to work in current control mode, and one will be used to stabilize the voltage and power quality indices on the DC bus, especially in the presence of pulse loads.

e. Flywheel Storage System

A large rotating mass coupled to a DC machine constitutes a Flywheel Energy Storage System which works under 3 operating modes: charging mode, stand-by mode, and discharging mode. This setup is used to perform several studies. To name some: the power failures and outages, mitigation of pulse loads, power quality improvements, and design and performance of flywheel systems.

6. Cyber Physical Structure of the Testbed

Similar to actual power grids, the FIU testbed is a Cyber-Physical System (CPS). Along with the power system components, it involves a cyber-infrastructure consisting of communication networks, database structure, metering, intelligent agents, and data distribution service. Industrial protocols and media have been extensively integrated within this testbed.

a. Phasor Measurement Units

The setup utilizes 2 Phasor Measurement Units (PMUs) from Schweitzer Engineering Laboratories (SEL) with inputs of 5 voltage and current measurements which are time stamped by a real time GPS clock. PMU measurements are published and are available in a Phasor Data Concentrator (PDC) through c37.118 synchrophasor protocol. A real time automation controller from SEL exchanges information in DNP3, Modbus, IEC 61850 GOOSE, IEC 60870-5-101/104, LG 8979, SES-92, IEEE C37.118 protocols. It also provides control logic features on top of the physical layer of the testbed.

b. Intelligent Electronic Devices

Intelligent Electronic Devices (IEDs) (5 ABB 615 Relion series protection relays) with IEC61850 capability are integrated into the system to form a distribution or substation network. The setup also covers Modbus protocol to provide industrial communication and control features. The above-mentioned protocols are merged through an OPC server as a middleware and the gateway for interconnection within the protocols in order to interface measured data and issued commands with external organizations such as computational intelligence, HMI, SCADA, etc.

c. Data Distribution Service (DDS) Remote Connection

DDS is a data-centric middleware having an API interface that provides the test bed with a real-time monitoring, control, and remote connection scheme. This interface is based on a real-time publisher and subscriber (RTPS) protocol with different quality-of-service (QoS) profiles to meet the control requirements. One of the main advantages of this system is the capability of exchanging information between different software packages such as MATLAB and LabVIEW, or any integrated/embedded application using a C++ or a JAVA API. The unique features of DDS enables connectivity of remote operators and end users to the testbed to use, configure, operate, and control the system remotely. This feature is merged with a cloud service to provide web-based attributes for the above-mentioned purposes.

d. Multi Agent Control Platform

The testbed is using embedded Linux and JADE platforms in a multi agent control firmware securely and privately for distributed control features. This provides operational experiments including faults, attacks, and scenarios for investigation of vulnerabilities in modern power grids as a cyber and physical systems.

e. Advanced Metering Infrastructure

A combination of smart meters, a communication network, and head end software is providing an advanced metering infrastructure. A variety of communication methods in an embedded platform such as power line carrier, Wi-Fi, and ZigBee allows the implementation and testing energy management cases in addition to security, privacy, and interoperability of components.

7. Integration of vehicular technologies: Hybrid AC-DC plug-in electric vehicle car park emulator

In the smart grid testbed, Operation, implementation, control and energy management case studies on plug-in electric vehicles has been wisely taken into account through designing a PEVs smart charging station emulator. Smart energy management algorithms by considering commercial sustainable energy resources, efficiency and utilization limitations on charging system are controlling the operation of this microgrid and its connectivity to main grid. The combination of energy storage, power electronics and power system emulator allows for the design and implementation of high efficient components for PEVs car parks, and the study of utility grid reaction in terms of voltage, loss, and loading. In addition, V2V and V2G investigates voltage assessment, frequency regulations, spin reserve and load shaping technically as well as economically for parking garages.

The FIU Smart Grid Testbed Provides the Following Technical Abilities:

Develop and implement wide area Protection System

Develop monitoring and operation strategies using Synchorophasors

Conduct experiments on EMS for smart grids including alternate and sustainable sources

Integrate embedded architecture and distributed control through intelligent agents

Perform market analysis, economic studies and social behavior.

Link to other Infrastructures at other Universities and National Labs