Cyber Physical Structure

This testbed is a Cyber Physical System (CPS). It not only includes the power system components and infrastructures, but also involves a cyber infrastructure consisting of communication networks, database structures, metering, intelligent agents, and data distribution services.

Communication Network and Integrated Protocols

- The testbed is utilizing DAQs for general applications regarding control and operation of the test setup.
- A realistic power system, industrial protocols and media have been extensively integrated within this testbed.

Phasor Measurement Units (PMUs)

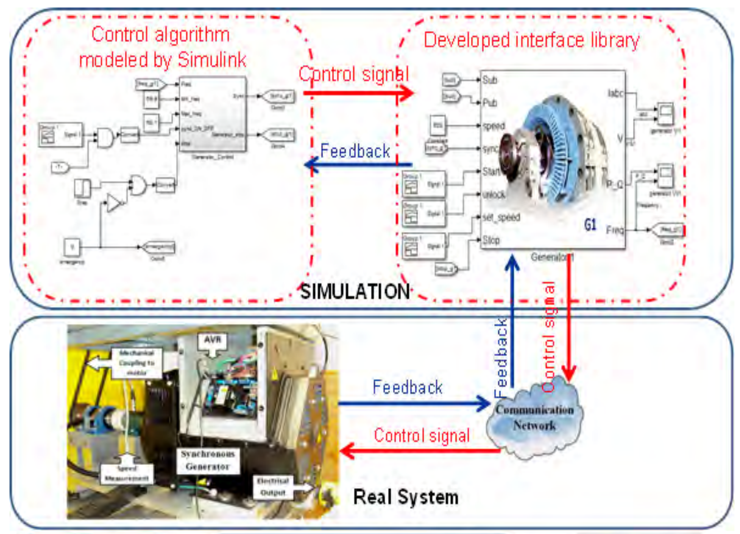
- Two PMUs with total input of 6 voltage and current measurements are time-stamped with a real time GPS clock.
- PMU measurements are published and available in a Phasor Data Concentrator (PDC) through the IEEE C37.118 synchrophasor protocol.
- A real time automation controller is integrated to exchange information in various communication protocols.
- DNP3, Modbus, IEC 61850 GOOSE, IEC 60870-5-101/104, LG 8979, SES-92, IEEE C37.118 protocols are in use.
- This real-time controller provides communication protocols and control logic features on top of physical layer of the testbed.

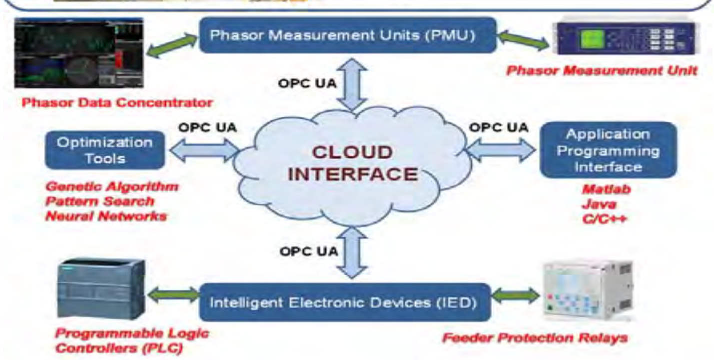
Intelligent Electronic Devices (IEDs)

- Intelligent Electronic Devices (IEDs) are installed on the testbed.
- The IEC 61850 capability is to form a distribution or protection for distribution automation.
- Protocols are merged through the OPC middleware while a gateway is established for interconnection and interfacing of the field devices with external applications.
- External applications includes: Computational intelligence, optimization, hardware-in-the-loop simulation, HMI and SCADA.
- The middleware is also implemented on a cloud interface via the Internet.
- The cloud interface has a read/ write capability in order to enable remote data access and control of the IED field devices.

DDS, Cloud Interface and Remote Connection

- A secondary middleware provides the test bed with a real-time monitoring, control and remote connection scheme.
- It includes the RTPS protocol with different quality of service profiles to meet control requirements.
- This interface is based on a real-time publisher.
- Capable of exchanging information between different software packages such as MATLAB and LabVIEW.
- The Data Distribution Service enables connectivity of remote operators 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.
- A Cloud Interface provides remote monitoring, utilization of optimization tools and an application programming interface.





Multi Agent Control Platform

- This testbed uses an embedded Linux and JADE platform in a multi agent control firmware securely and privately for distributed control features.
- This provides operational experiments including faults, attacks, and scenarios for the investigation of vulnerabilities in the modern power grid as a cyber and physical system.
- The control system is very sensitive to communication and cyber-attack issues.

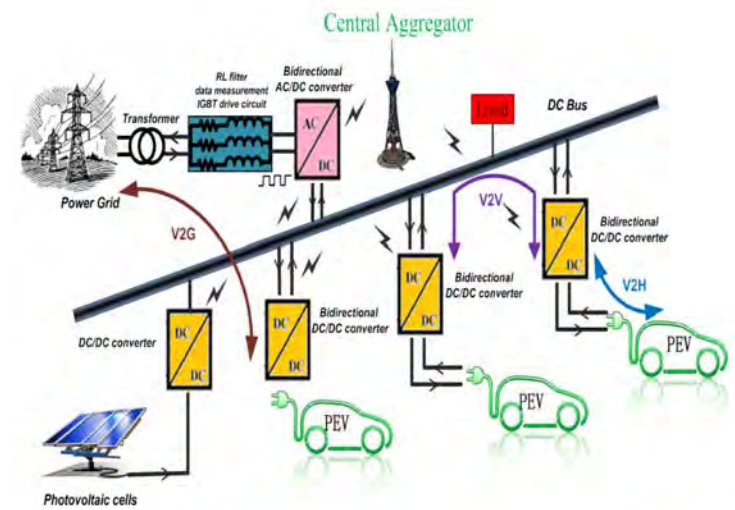
Advanced Metering Infrastructure

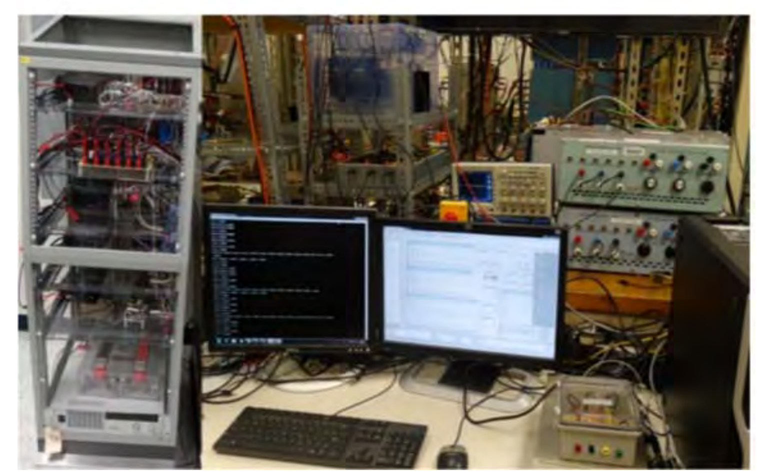
- A combination of smart meters are available on the testbed.
- A communication network and head-end software platform provides an advanced metering infrastructure.
- A variety of communication methods such as power line carrier (PLC), Wi-Fi, and ZigBee are being used.
- Allows the implementation and testing of different issues including energy management.
- This method provides security, privacy and interoperability of components.

Integration of vehicular Technologies

Hybrid AC-DC Plug-in Electric Vehicle Car Park Emulator

- On the Smart Grid testbed, operation, implementation, control and energy management case studies can be conducted on plug-in electric vehicles (PEV) using the smart charging station emulator.
- Smart energy management algorithms are implemented considering commercially sustainable energy resources.
- A combination of energy storage, power electronics and a power system emulator allows for the design and implementation of high efficient components for future PEV car parks.
- This enables the study of the utility grid reaction in terms of voltage, loss, and loading issues.
- Vehicle-to-vehicle (V2V) and vehicle-to-grid (V2G) services provides voltage assessments, frequency regulations and economics for future parking garages.





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Smart Grid TestBed

Energy Systems Research Laboratory

Florida International University

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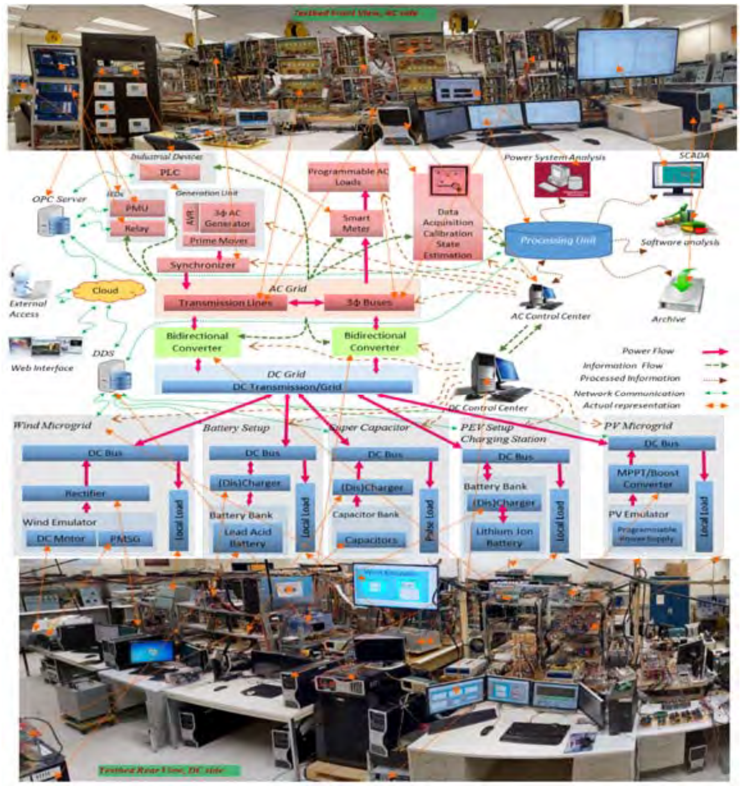
Smart Grid Testbed



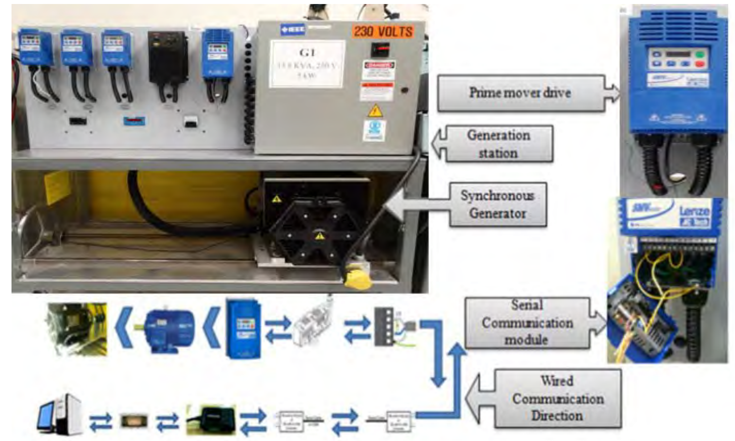
The FIU Smart Grid Testbed is located at the facility of the Energy Systems Research Laboratory in the Department of Electrical Engineering, College of Engineering and Computing at Florida International University in Miami, Florida. It is a state of the art hardware -software platform for research and development, component evaluation, as well as educational activities.

- This reduced-scale power system was created and built to implement new technologies and products required for Smart Grid development.
- Technologies related to increased electric vehicle penetration, microgrid implementations, advanced metering, communication and security, and cyber physical systems are featured on this testbed.
- This Smart Grid testbed has the capabilities to emulate bulk generation, distributed generation, energy storage of different types, and study their utilization.
- The Smart Grid Testbed has several layers including physical, data, network communication and security.
- One of the main focuses in building this testbed is on the communication and distributed real-time control issues.
- The communication infrastructure allows the connection of all components to control points.

Testbed Features

- Capable of standalone operation and isolation from the campus electrical network.
- This system is in a 3-phase scheme and can provide unsymmetrical operation features.
- The frequency can be independently varied to work in a wide range.
- There is complete monitoring of all points on the real-time system through more than 200 sensors extracting numerous data samples.
- The total power scale of generation/transmission/consumption is more than 120 KVA.
- This platform has been merged with industrial components, such as IEDs, PMUs, PLCs, protection relays, and smart meters.
- The testbed has the capability to connect to external sites for the purpose of testing and verifying tools developed by others for the control and operation of Smart Grid through Cloud and VPN Interfaces.

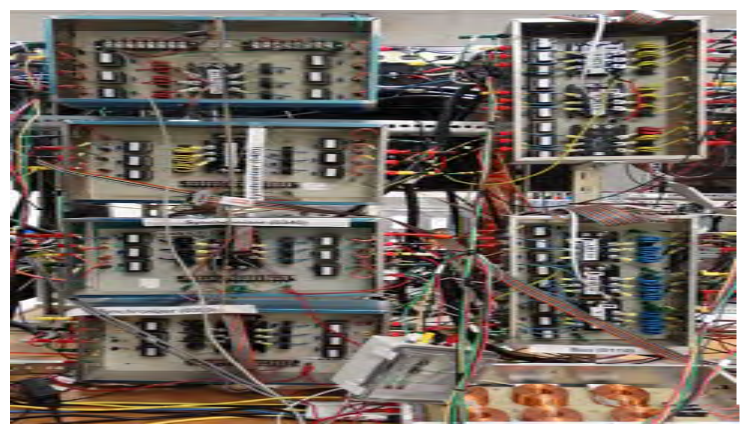
Generating Stations



- The power for the main grid is supplied by these 4 AC generating stations. Each station has a 13-15 KVA generation capacity.
- Automatic voltage regulators (AVR) are used to control the voltage amplitude with 5 different prime movers.
- The prime movers are controlled through frequency drives.

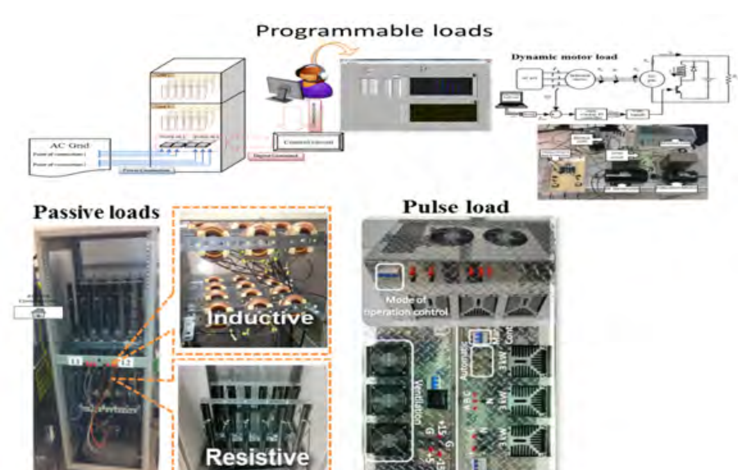
Synchronizers and Buses

- AC generators are connected through synchronizers for a proper connection to the main grid.
- Buses have 3 power terminals each with switching capability to measure the voltage and current independently.



Loads

- More than 10 programmable loads are built and located at multiple locations on the grid.
- Resistive, inductive, dynamic, and pulsed loads are available.
- Capable of automated operation to follow a predefined scenario based on a programmable load profile.

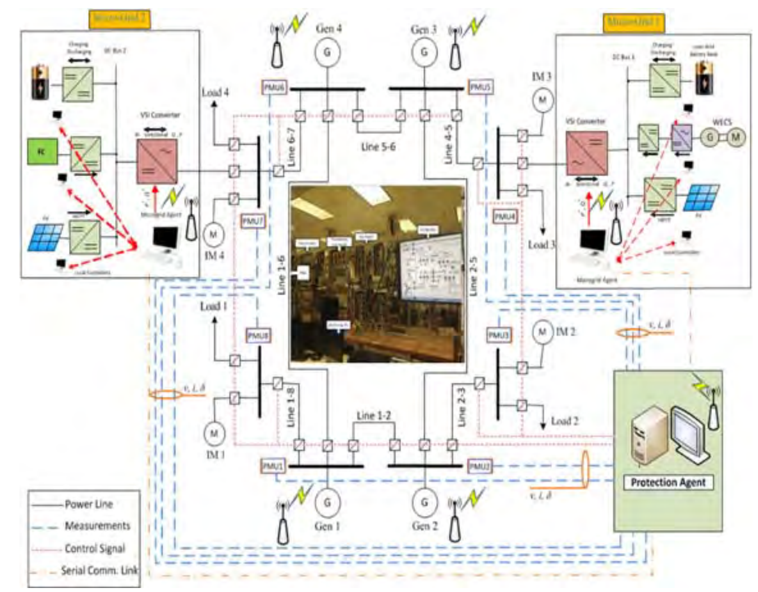


Measurements and Data Acquisition

- Control of the grid is achieved through raw data collection from all points on the grid.
- National Instruments Data Acquisition (DAQ) is the main hardware interface while the software-based SCADA system is via Labview.
- Each A/D module has at least 6 kHz sampling rate with 12-16 bit resolution.

Microgrids and Renewable Energy Integration

The testbed employs several microgrids to incorporate the integration of wind, solar, and energy storage systems. Renewable energy is a complimentary source which is implemented on the testbed in the form of 3 DC microgrids.



DC Microgrids

- Utilizes state of the art techniques in power electronics and control.
- Techniques are used to investigate operational issues of futuristic power systems.
- These include generator behavior studies, power sharing and control techniques, DC-bus voltage management, control and protection, etc.

PV Emulators

- Photovoltaics are deployed through 5 programmable power supplies with a maximum power of 6 kW each.
- Solar panels are connected along with maximum power point tracking (MPPT) modules and boost converters to a DC bus.
- The DC Bus is accompanied by other modules to transfer energy to and from the AC grid.

Wind Emulator

- A wind generation unit has been implemented through a wind emulator with a PMSG coupled to a controllable DC prime mover as a turbine.
- Generated AC power will be injected into the DC bus through rectifiers and a bidirectional converter connected to the AC grid.
- System can be configured to create, control and follow different wind patterns.

DC Zones and Architectures

- This platform has several zones for each generation unit.
- One zone includes a hybrid energy storage array to implement different DC distribution architectures.
- Special pulsed loads have been integrated for specific research requirements.

Energy Storage Systems

This testbed includes the latest technologies for energy storage systems, mainly batteries, supercapacitors/ultracapacitors and flywheels.

Battery Storage System

- The lead acid battery bank has been equipped with a unique battery management system (BMS).
- Individual management, balancing, and a method to conduct diagnostics on each battery module using hall-effect sensors to obtain voltage and current is in place.
- The BMS monitors the batteries and can also extract a defective battery and compensate for its loss.
- This system is expandable to any chemistry/quantity of batteries based on its modular characteristics.
- A High fidelity data logging and advanced protection is included to limit the current and voltage of each battery.

Supercapacitor/Ultracapacitor Bank

- Integration of supercapacitors/ultracapacitors to improve the performance and efficiency of unpredictable renewable energy resources.
- Currently 2- 2.9 F supercapacitors can be utilized in a series or parallel architecture, with 1.45 F at 650 V or 5.8 F at 320 V.
- A supercapacitor at the DC bus can stabilize all the converters to work in current control mode.
- One has been deployed to stabilize the voltage and power quality indices on the DC bus.


Flywheel Energy Storage System

- A large rotating mass coupled to a DC machine has created a laboratory Flywheel Energy Storage System.
- Works under 3 operating modes: charge, stand-by and discharge.
- This setup studies the power failures, outages, the mitigation of pulsed loads and also the design and performance of flywheel systems.