Attributes and design of composable and modular smart grid test beds

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Workshop on Measurement Challenges & Opportunities in
Developing Smart Grid Testbeds
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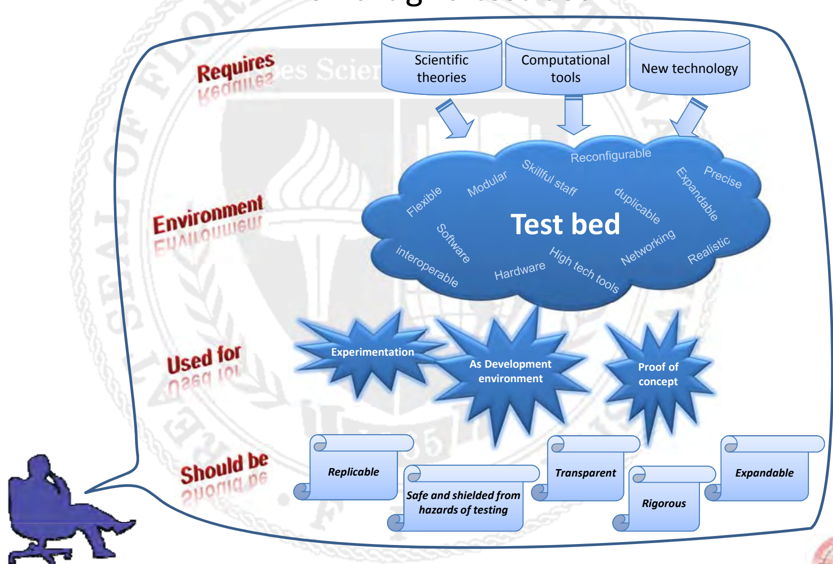
March,13, 2014

Basics for developing a state of the art smart grid test bed



Attributes

- Our main objective here is to use composable modules for developing a smart grid test bed smart grid in a laboratory environment.
- In general a well developed test bed laboratory will provide the following abilities:
  - 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
  - Provide an environment and interface for related fields such as market analysis
  - Enable remote operation (i.e. online or off campus accessibility)

Attributes

– Abilities of the Test Bed from *a technical point of view*:
  - 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 and real-time control

Attributes

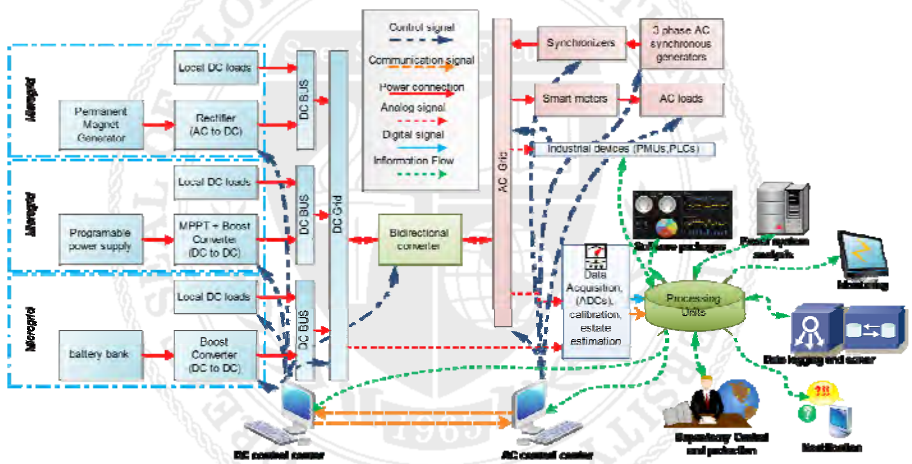
– Abilities of the Test Bed from a technical point of view:
  - Develop and implement wide area Protection System.
  - Study important issues such as real-time voltage stability
  - Develop monitoring and operation strategies using Synchorophasors
  - Conduct experiments on EMS for smart grids including 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

Consequently:

The Test bed needs to have the following components in an integrated platform to provide several capabilities.

- Phasor measurement Units
  - monitoring, protection, and control
- Distributed and renewable energy sources
  - wind, solar, Fuel cells, etc.
- New operational schemes
  - protective digital relaying
  - Wide Area Protection
- Intelligent protection schemes and their application for
  - Prevent cascading outages
  - Islanding situations
  - Grid blackout
- Emulation of Plug-In-Hybrid and Electric Vehicles (PHEVs) and (PEVs)
  - Energy Storage systems, SOC and SOH for batteries
- Integration of Hybrid AC-DC systems
  - micro grid solutions for residential and industrial applications.
  - Enhancement of Energy Efficiency and EMS
- Integration of Multi Agent in an embedded platform
  - Smart meters, HIL

Overview of composable modules integrated in the test bed



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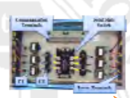
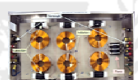
Composing a smart grid test bed at the laboratory scale

- AC Grid Components
  - Bus
  - Synchronizer
  - Generation stations
  - Dynamic brake
  - Transmission line
  - Communication platform
  - Software Platform
    - SCADA
    - Protection module
    - Online monitoring
    - Generation control
    - Data base and archiving
    - Power System analysis
  - Loads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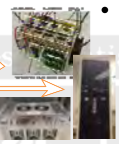
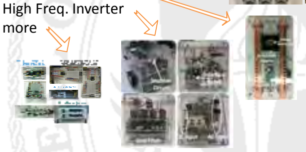
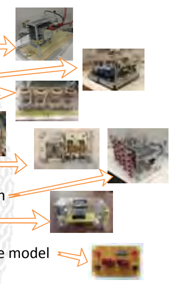
Composing a smart grid test bed at the laboratory scale

- DC Micrograds Components
  - Modular MIBBC
  - Battery Bank
  - Programmable Load emulator
  - DC bus module
  - High Freq. Inverter
  - more

- AC/DC interconnected network components
  - Uncontrolled rectifier
  - Dynamic load emulation
  - AC Filter
  - DC Filter
  - DC/Dc Boost Converter
  - AC/DC Measurements and Protection
  - DC Power Module
  - Medium voltage DC Transmission line model



- Hybrid PEVs Charging system Components
  - RL Filter
  - Bidirectional ac/dc converter
  - Bidirectional dc/dc converter
  - Hardware Overview
  - Lithium-ion Battery
  - Management, Diagnostics Software


Components of Microgrids for pulse load studies
  - Super capacitor bank
  - Bidirectional converter
  - Multi port Boost Converter
  - Lead Acid Battery Bank
  - Programmable DC Load

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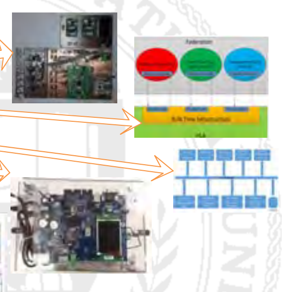
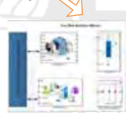
Composing a smart grid test bed at the laboratory scale

- Distributed control components
  - Embedded agent platform
  - HIL simulators
  - DDS infrastructure
  - Smart Meters
  - Developed Interface library

- Phasor measurement Components
  - PMUs
  - PDCs
  - RTACs
  - Interface for control and protection modules
  - Real time phasor data server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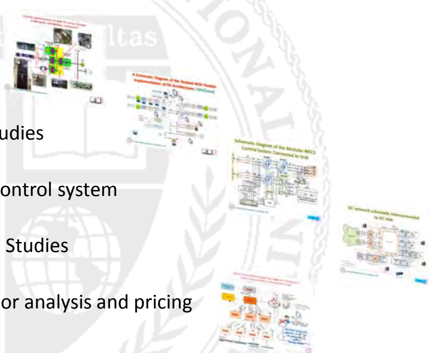
Utilization and Applications of composable modules in the smart grid test bed

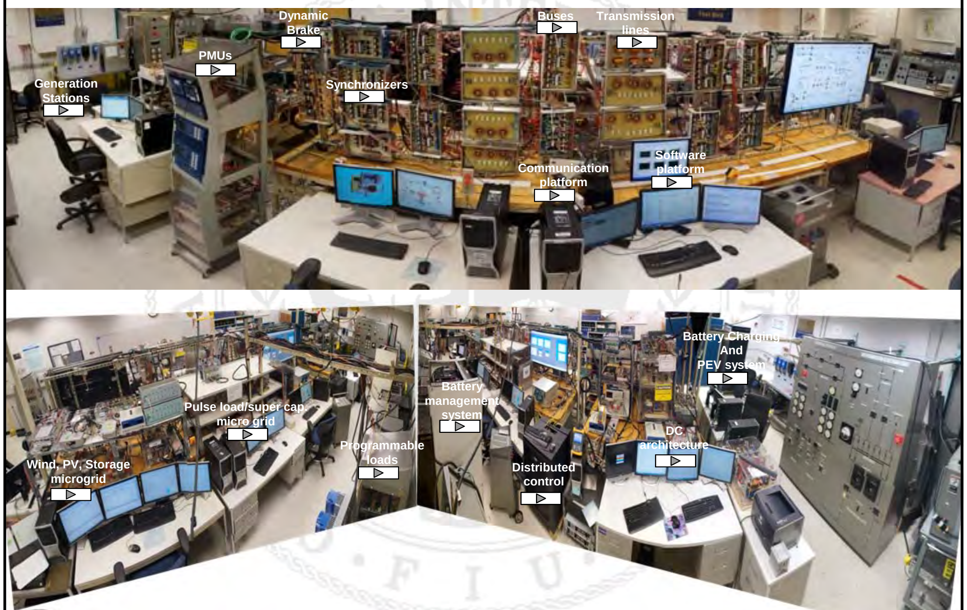
- Steps from design to operation
  - Voltage and current measurement
    - Security analysis
      - Embedded Control architecture

- PMUs and RTAC
  - Hybrid PEV charging station
    - Pulse load studies
      - DC System monitoring and protection

Utilization and Applications of composable modules in smart grid test bed

- Wind, PV and Energy storage integration
  - Implementation of DC architecture studies
    - Modular interconnected WECS Control system
      - AC/DC Interconnection Grid Studies
- Multi Agent Environment and Social behavior analysis and pricing





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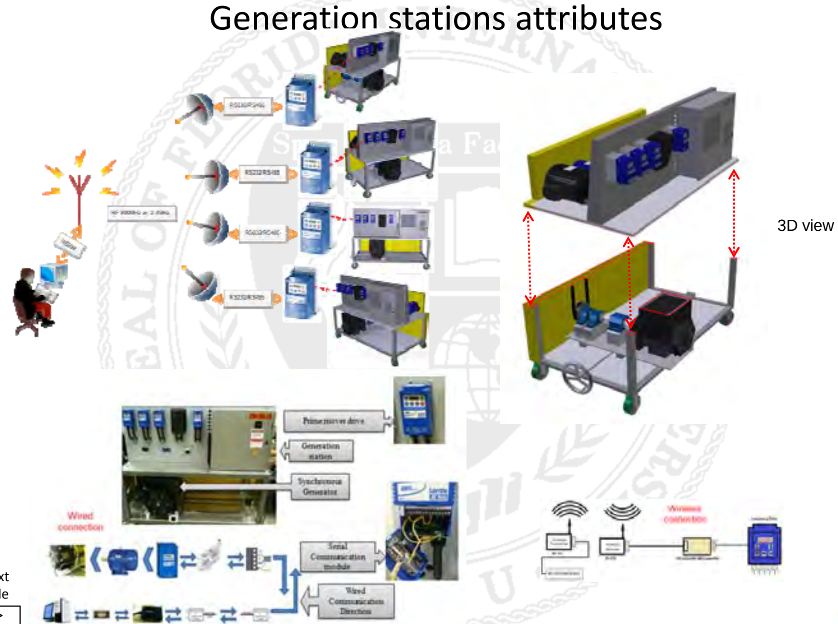
Generation stations attributes



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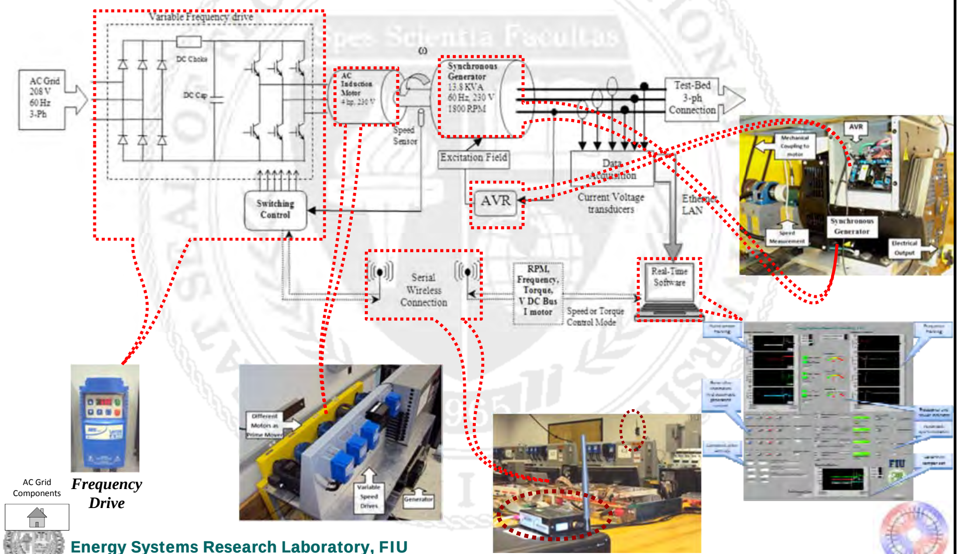
Generation Stations



AC Grid Components

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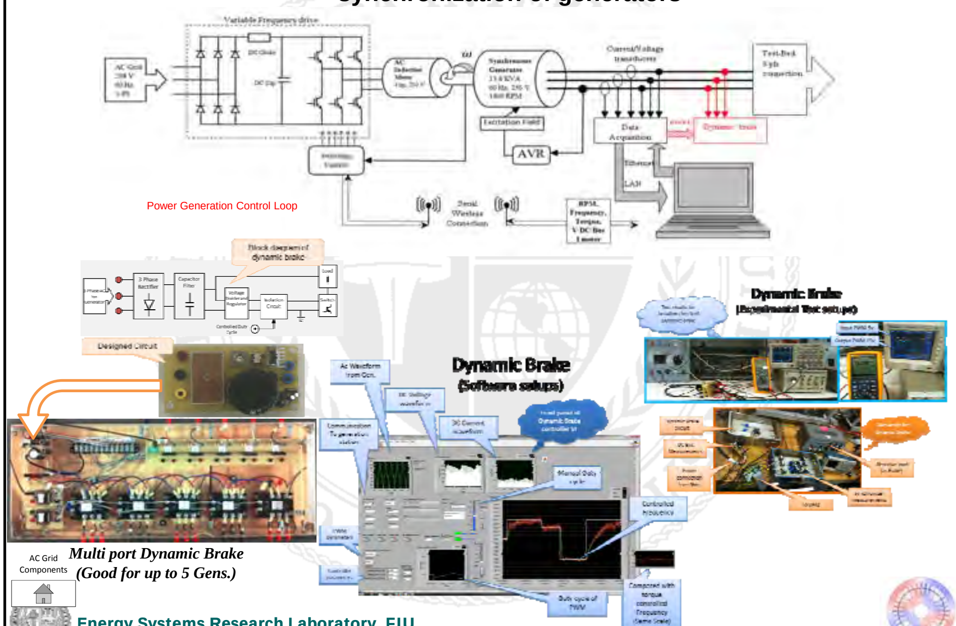
Dynamic brake for quick synchronization of generators



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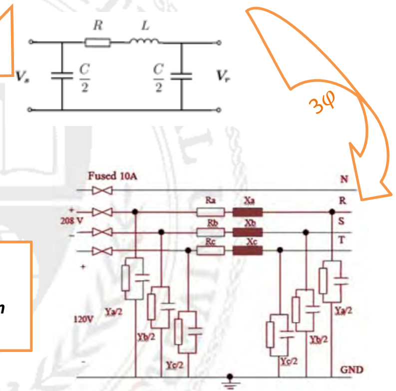
Transmission lines

OR

π Model !



Hardware implementation

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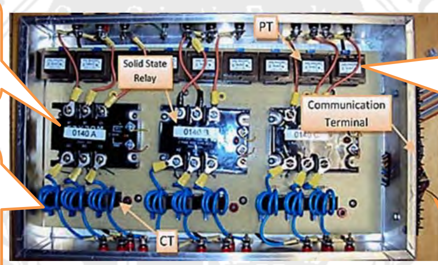
Switching and measurement buses

Solid state switches:
- *High current capability*
- *Low consumption*
- *Fast response, symmetrical*
- *Indication LED*

CTs:
- *1% to 100% current range*
- *Overcurrent capability*
- *Low impact on measurement*
- *Calibrable*
- *Adjustable range and output range*
- *Voltage convertable*

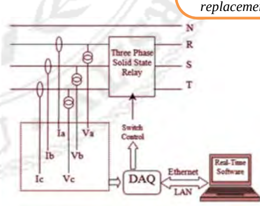


PTs:
- *Over voltage capability*
- *Low impact on measurement (efficient)*
- *Calibrable*
- *Adjustable range and output range*
- *Linear response*

Connection Terminals:
- *Standard wiring for analog outputs*
- *Optimized & Compatible with DAQs*
- *Flat cable for quick replacement*

Line parameters for some line boxes

Transmission Line Box #	RL (Ohm)	L (mH)	C (uF)	Rc (Ohm)
0060	2.261	24.11	6.689	0.16
0080	0.627	2.685	3.287	0.24
0090	0.614	2.703	6.581	0.11
0150	0.643	2.728	2.228	0.326
0170	1.246	5.4	6.67	0.16
0180	0.64	2.715	2.195	0.303
0190	0.646	2.724	2.194	0.3
0200	2.246	11.78	2.224	0.36



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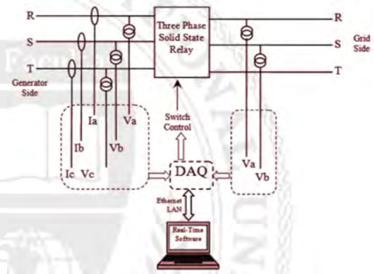
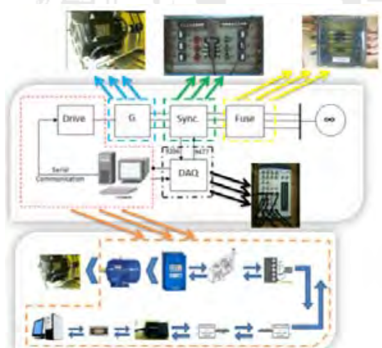
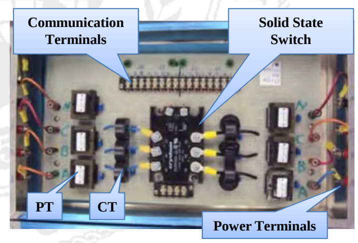
Synchronizer Module

Synchronizing conditions

$$|V_{right}| - |V_{left}| < 3V$$
$$f_{right} - f_{left} < 0.1Hz$$
$$\angle V_{A\text{-}right} - V_{A\text{-}left} < 2\deg$$
$$|\angle V_{AB\text{-}right} - V_{AB\text{-}left}| < 5\deg$$







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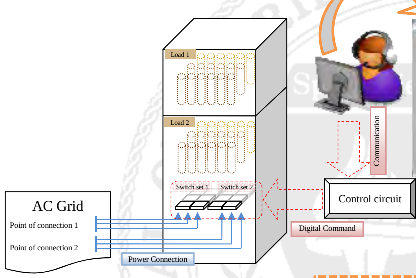
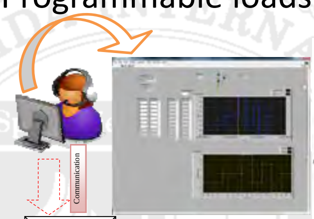
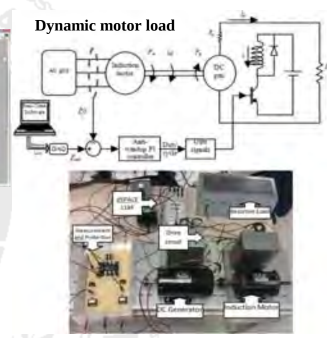
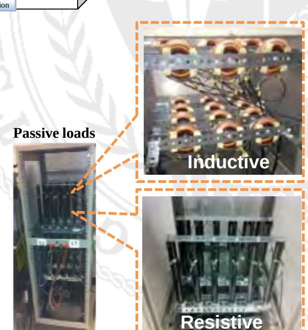
Programmable loads









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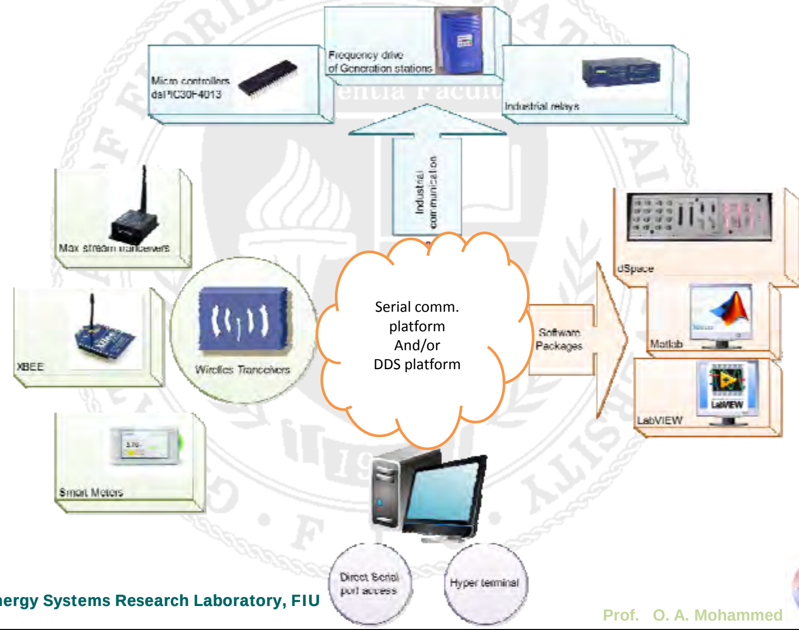
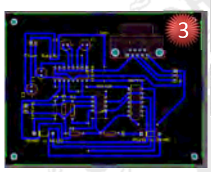
Communication Infrastructure



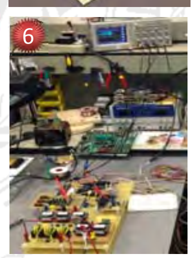
AC Grid Components

Steps From Design to complete operation of a composable module

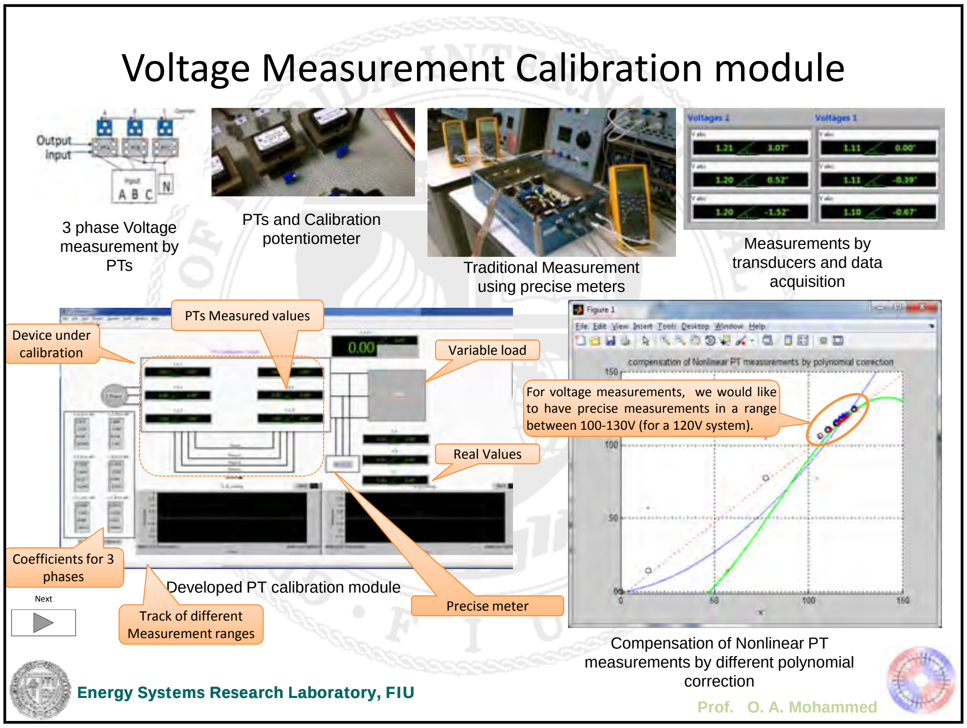
Example:
Serial RS232 to RS485 converter



1. Electric standards
2. Design circuit
3. Design PCB
4. Fabrication constraints
5. Prototyping
6. Testing and calibration
7. Evaluation and results
8. On site test and full Operation



Applications


Voltage Measurement Calibration module
Output
Input
3 phase Voltage measurement by PTs
PTs and Calibration potentiometer
Traditional Measurement using precise meters
Voltages 2
Voltages 1
Measurements by transducers and data acquisition
Device under calibration
PTs Measured values
Variable load
Real Values
Coefficients for 3 phases
Developed PT calibration module
Track of different Measurement ranges
Precise meter
Next
compensation of Nonlinear PT measurements by polynomial correction
For voltage measurements, we would like to have precise measurements in a range between 100-130V (for a 120V system).
Compensation of Nonlinear PT measurements by different polynomial correction
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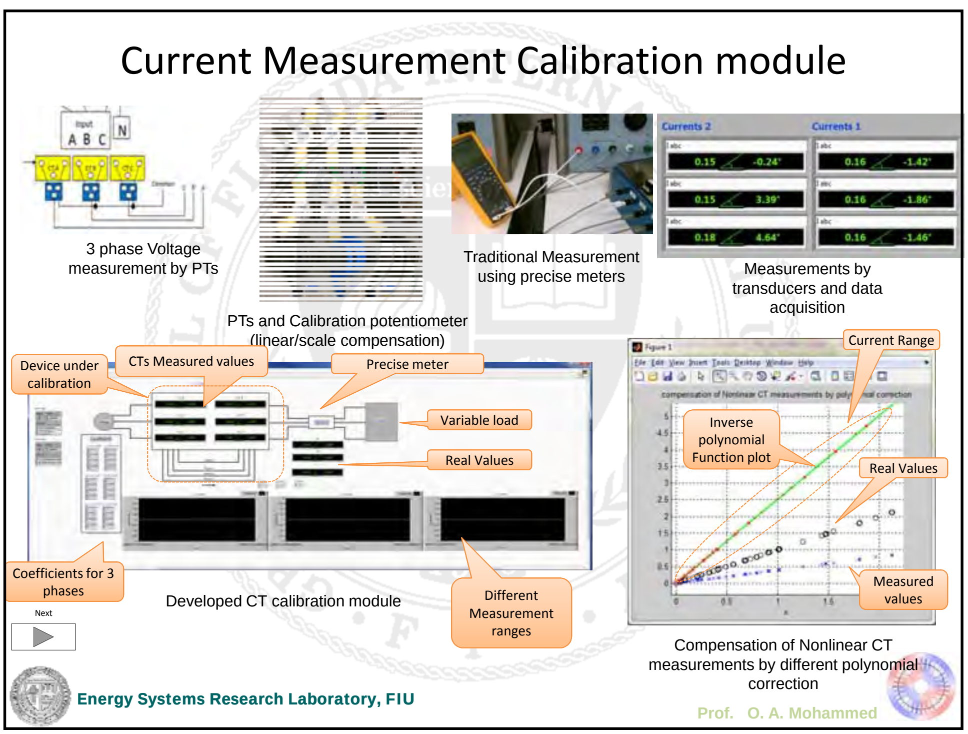
Current Measurement Calibration module
3 phase Voltage measurement by PTs
PTs and Calibration potentiometer (linear/scale compensation)
Traditional Measurement using precise meters
Currents 2
Currents 1
Measurements by transducers and data acquisition
Device under calibration
CTs Measured values
Precise meter
Variable load
Real Values
Coefficients for 3 phases
Developed CT calibration module
Different Measurement ranges
Next
Current Range
Inverse polynomial Function plot
Real Values
Measured values
Compensation of Nonlinear CT measurements by different polynomial correction
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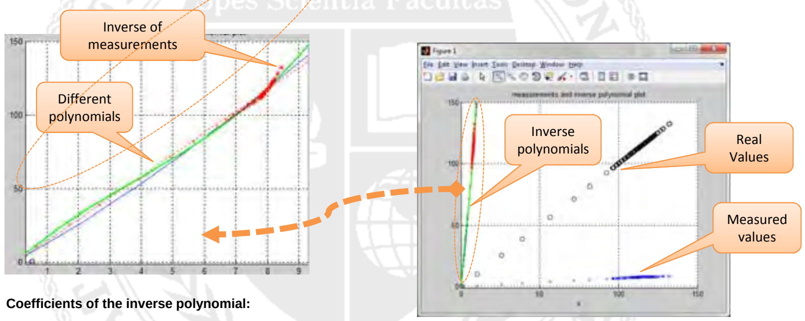
Post design requirement checks:

Measurement Calibration
&
Measurement linearization



Coefficients of the inverse polynomial:

- *q1* = 0.0680 0.0240
- *q2* = -0.0001 0.0812 -0.0209
- *q3* = -0.0000 0.0005 0.0499 0.0127

(Red Graph) $f=c1*x^1+c0$

(Green Graph) $f_{\text{Real Value}}(\text{Measured } x)=c3*x^3+c2*x^2+c1*x^1+c0$

Applications

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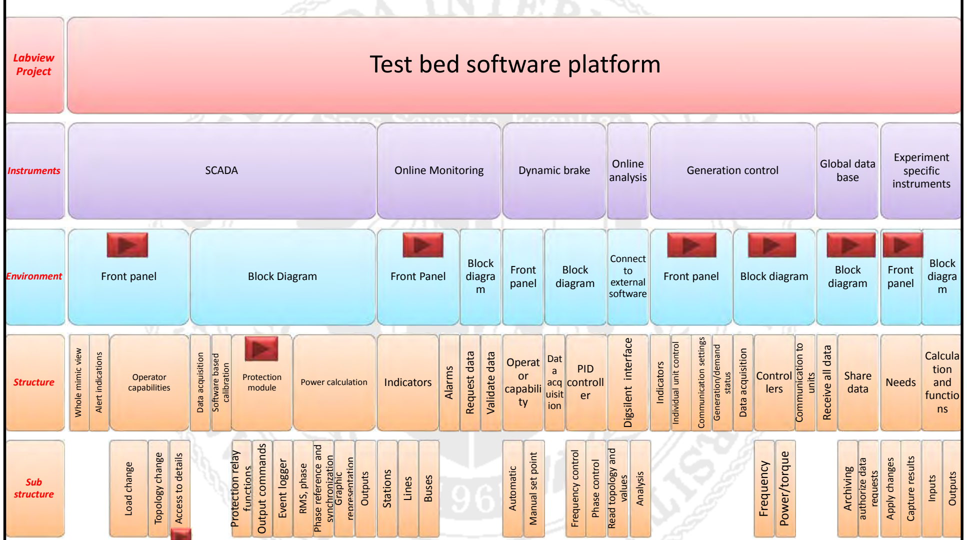

Return to AC Grid Components

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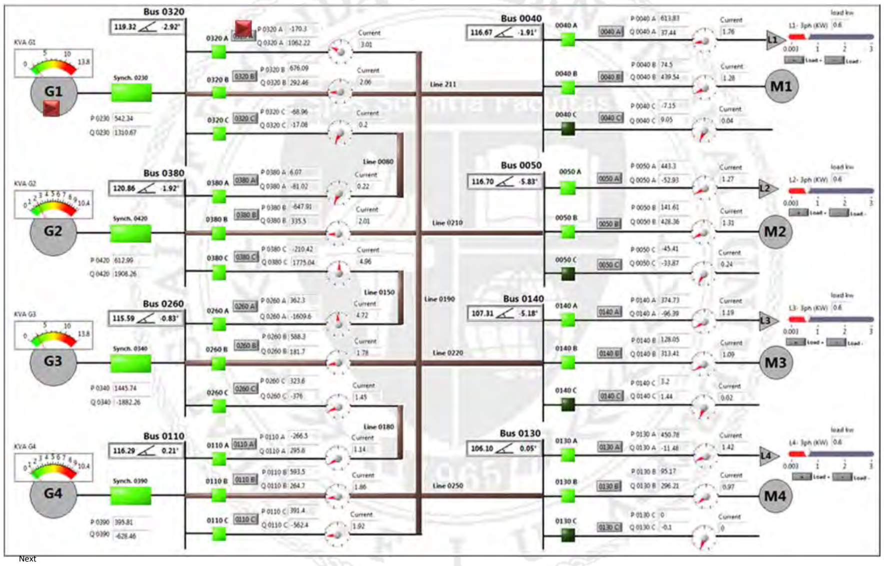
Real Time SCADA



Next

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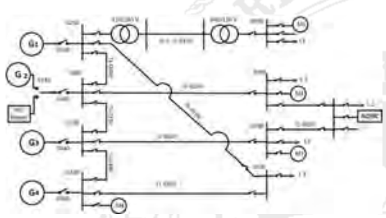
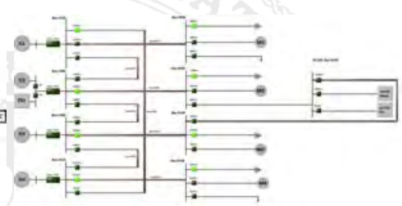
SCADA

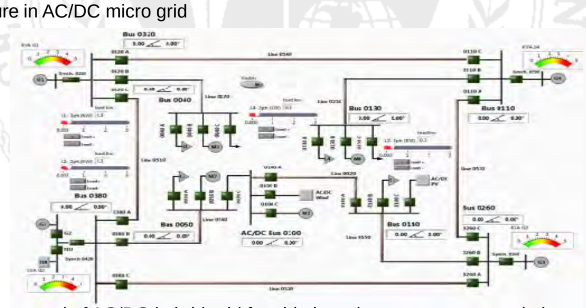
Several architectures, overview of hardware setups and load management



Single line diagram with different architecture in AC/DC micro grid



Simple front panel of AC/DC micro grid



panel of AC/DC hybrid grid for ship board power system emulations

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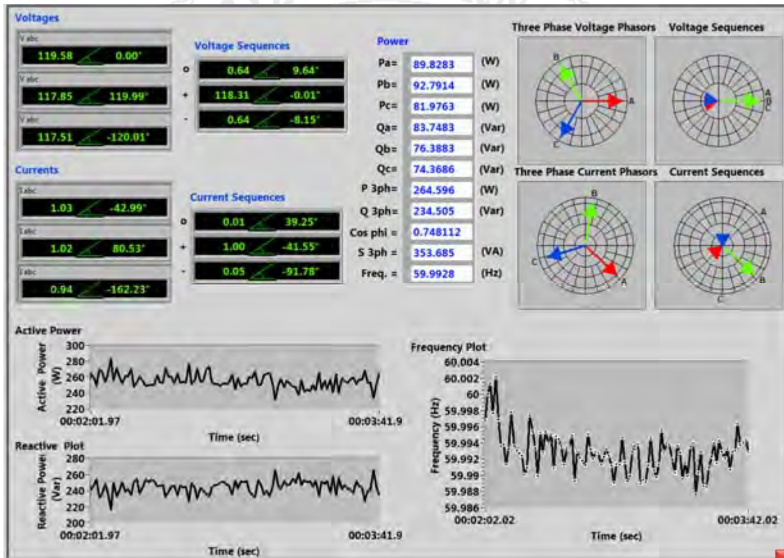
Return to Software platform

Real Time Monitoring



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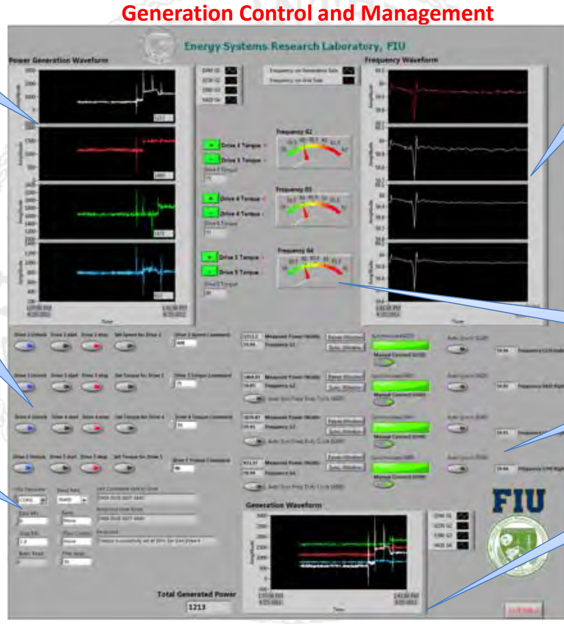
Generation Control and Management

Active power tracking

Frequency tracking



Generation commands And automatic generation control

Frequency and power indicator

Automatic synchronization

Communication settings

Generation comparison

Return to Software platform

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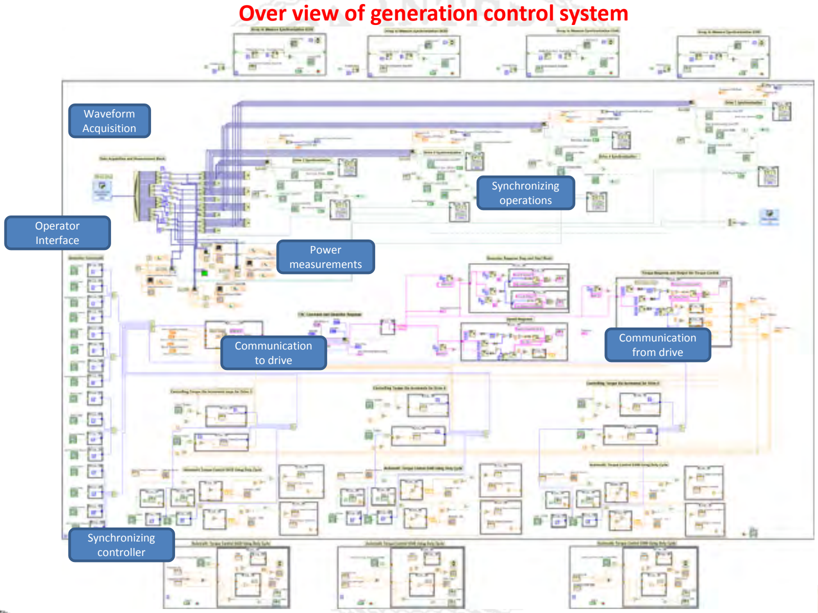
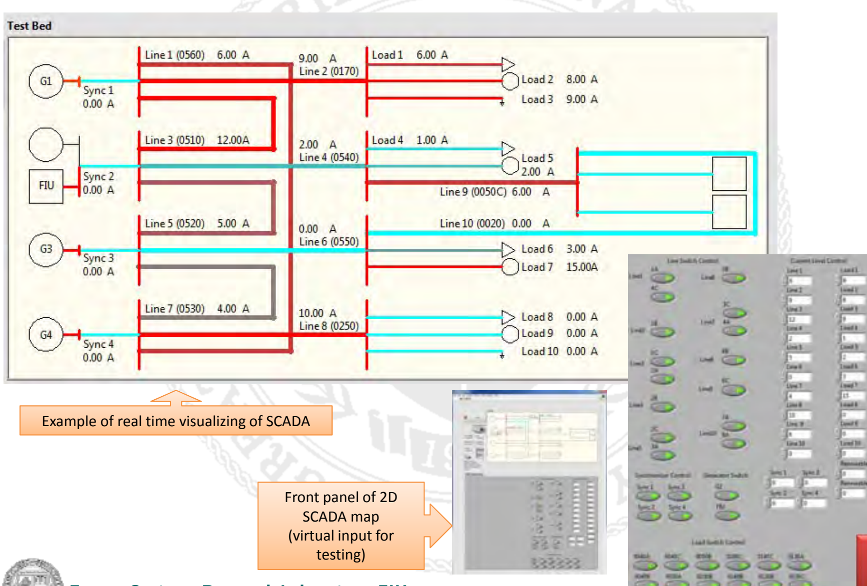
Over view of generation control system



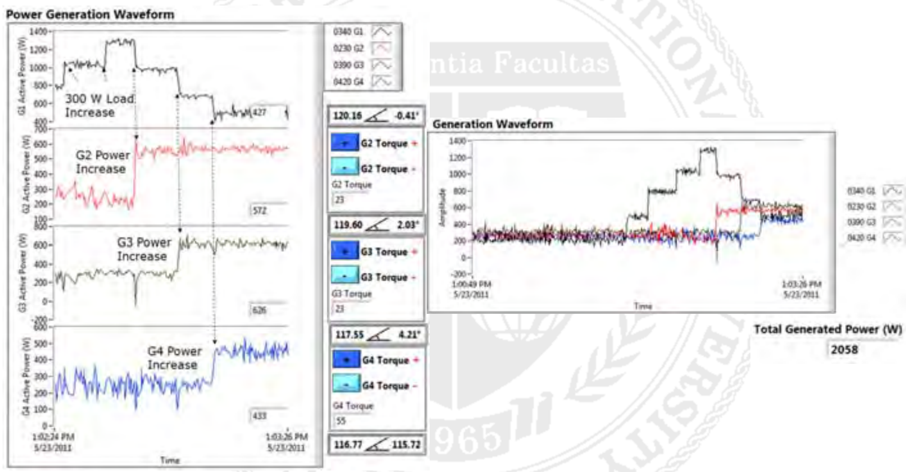
Return to Software platform

Real time monitoring



Return to Software platform

Experiments in Real time



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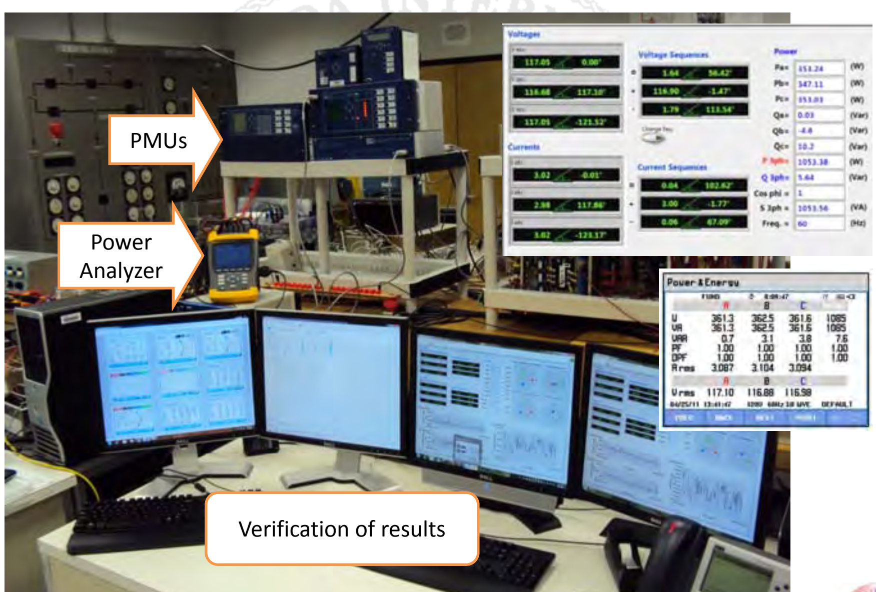
Verification of Synchrophasors



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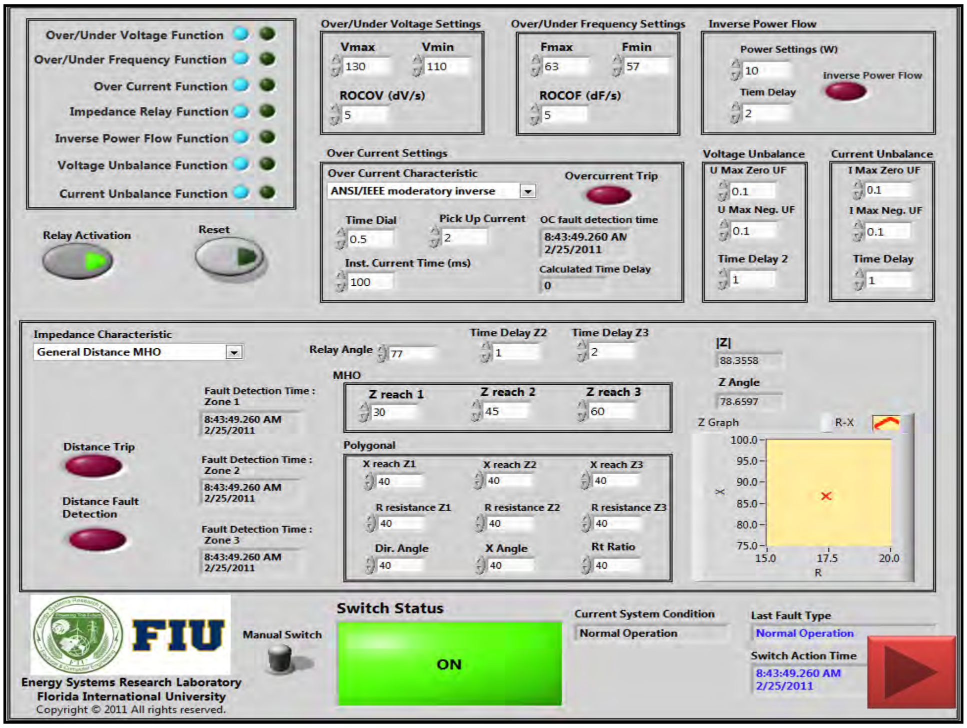
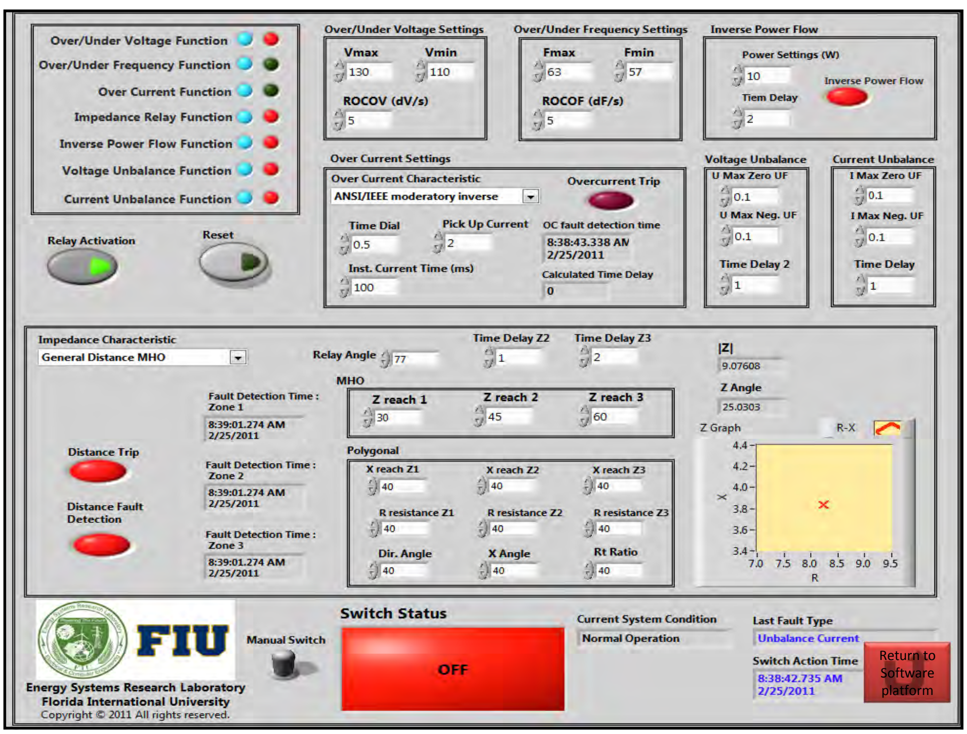
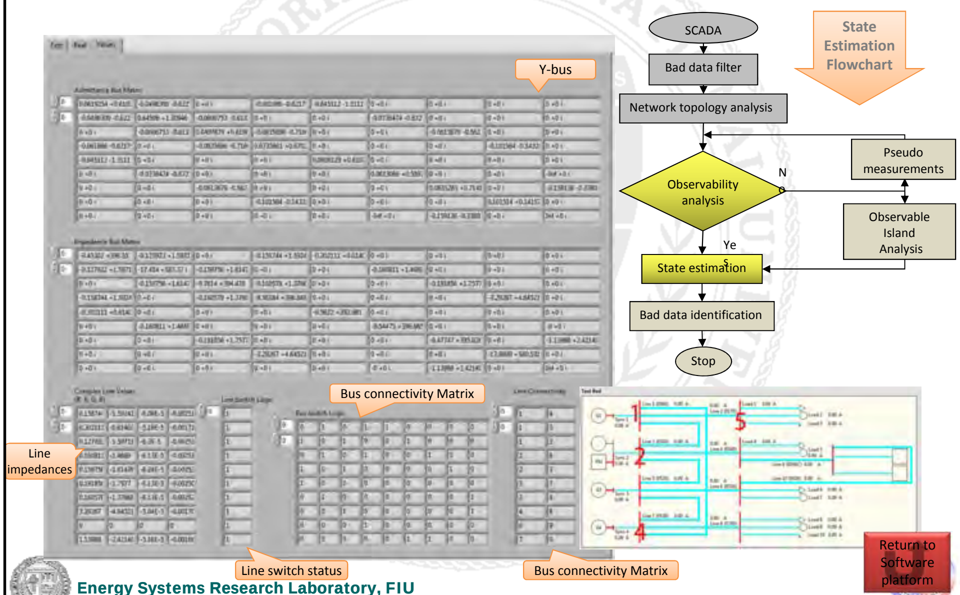

Over/Under Voltage Function
Over/Under Frequency Function
Over Current Function
Impedance Relay Function
Inverse Power Flow Function
Voltage Unbalance Function
Current Unbalance Function
Relay Activation
Reset
Over/Under Voltage Settings
Vmax
Vmin
130
110
ROCOV (dV/s)
5
Over/Under Frequency Settings
Fmax
Fmin
63
57
ROCOF (dF/s)
5
Inverse Power Flow
Power Settings (W)
10
Inverse Power Flow
Tiem Delay
2
Over Current Settings
Over Current Characteristic
ANSI/IEEE moderatory inverse
Overcurrent Trip
Time Dial
0.5
Pick Up Current
2
OC fault detection time
8:43:49.260 AM
2/25/2011
Inst. Current Time (ms)
100
Calculated Time Delay
0
Voltage Unbalance
U Max Zero UF
0.1
U Max Neg. UF
0.1
Time Delay 2
1
Current Unbalance
I Max Zero UF
0.1
I Max Neg. UF
0.1
Time Delay
1
Impedance Characteristic
General Distance MHO
Relay Angle
77
Time Delay Z2
1
Time Delay Z3
2
|Z|
88.3558
Z Angle
78.6597
MHO
Z reach 1
30
Z reach 2
45
Z reach 3
60
Fault Detection Time : Zone 1
8:43:49.260 AM
2/25/2011
Distance Trip
Fault Detection Time : Zone 2
8:43:49.260 AM
2/25/2011
Distance Fault Detection
Fault Detection Time : Zone 3
8:43:49.260 AM
2/25/2011
Polygonal
X reach Z1
X reach Z2
X reach Z3
R resistance Z1
R resistance Z2
R resistance Z3
Dir. Angle
X Angle
Rt Ratio
Z Graph
R-X
X
R
FIU
Manual Switch
Energy Systems Research Laboratory
Florida International University
Copyright © 2011 All rights reserved.
Switch Status
ON
Current System Condition
Normal Operation
Last Fault Type
Normal Operation
Switch Action Time
8:43:49.260 AM
2/25/2011


Over/Under Voltage Function
Over/Under Frequency Function
Over Current Function
Impedance Relay Function
Inverse Power Flow Function
Voltage Unbalance Function
Current Unbalance Function
Relay Activation
Reset
Over/Under Voltage Settings
Vmax
Vmin
130
110
ROCOV (dV/s)
5
Over/Under Frequency Settings
Fmax
Fmin
63
57
ROCOF (dF/s)
5
Inverse Power Flow
Power Settings (W)
10
Inverse Power Flow
Tiem Delay
2
Over Current Settings
Over Current Characteristic
ANSI/IEEE moderatory inverse
Overcurrent Trip
Time Dial
0.5
Pick Up Current
2
OC fault detection time
8:38:43.338 AM
2/25/2011
Inst. Current Time (ms)
100
Calculated Time Delay
0
Voltage Unbalance
U Max Zero UF
0.1
U Max Neg. UF
0.1
Time Delay 2
1
Current Unbalance
I Max Zero UF
0.1
I Max Neg. UF
0.1
Time Delay
1
Impedance Characteristic
General Distance MHO
Relay Angle
77
Time Delay Z2
1
Time Delay Z3
2
|Z|
9.07608
Z Angle
25.0303
MHO
Z reach 1
30
Z reach 2
45
Z reach 3
60
Fault Detection Time : Zone 1
8:39:01.274 AM
2/25/2011
Distance Trip
Fault Detection Time : Zone 2
8:39:01.274 AM
2/25/2011
Distance Fault Detection
Fault Detection Time : Zone 3
8:39:01.274 AM
2/25/2011
Polygonal
X reach Z1
X reach Z2
X reach Z3
R resistance Z1
R resistance Z2
R resistance Z3
Dir. Angle
X Angle
Rt Ratio
Z Graph
R-X
X
R
FIU
Manual Switch
Energy Systems Research Laboratory
Florida International University
Copyright © 2011 All rights reserved.
Switch Status
OFF
Current System Condition
Normal Operation
Last Fault Type
Unbalance Current
Switch Action Time
8:38:42.735 AM
2/25/2011
Return to Software platform

Data base and archiving for real time analysis of the power system



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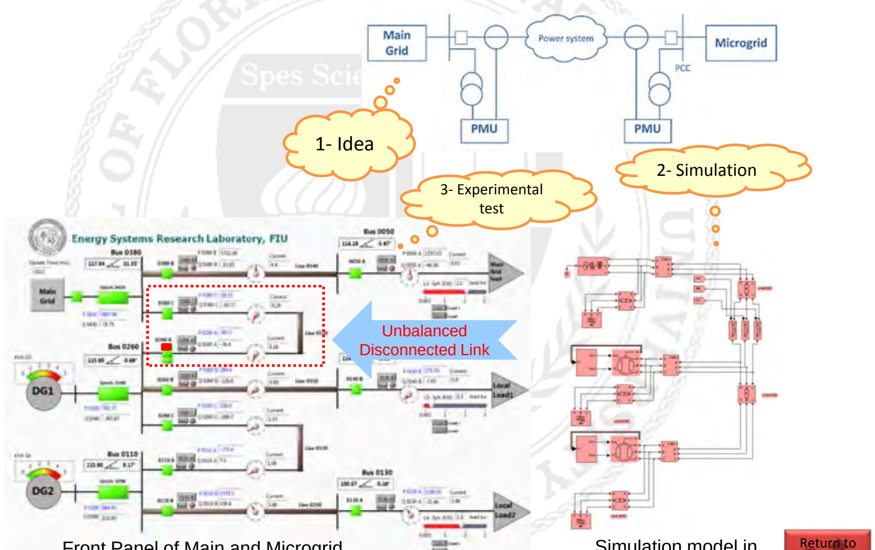
Islanding Detection Using Synchronized Measurements and Sequential Vectors (+,-,o)



Front Panel of Main and Micrgrid

Simulation model in MATLAB/Simulink

Return to Software platform

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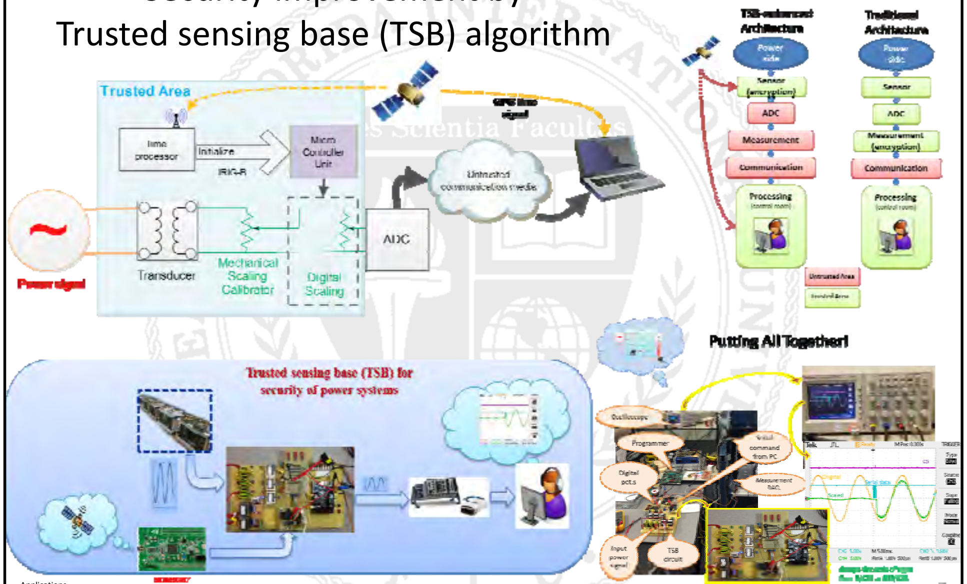
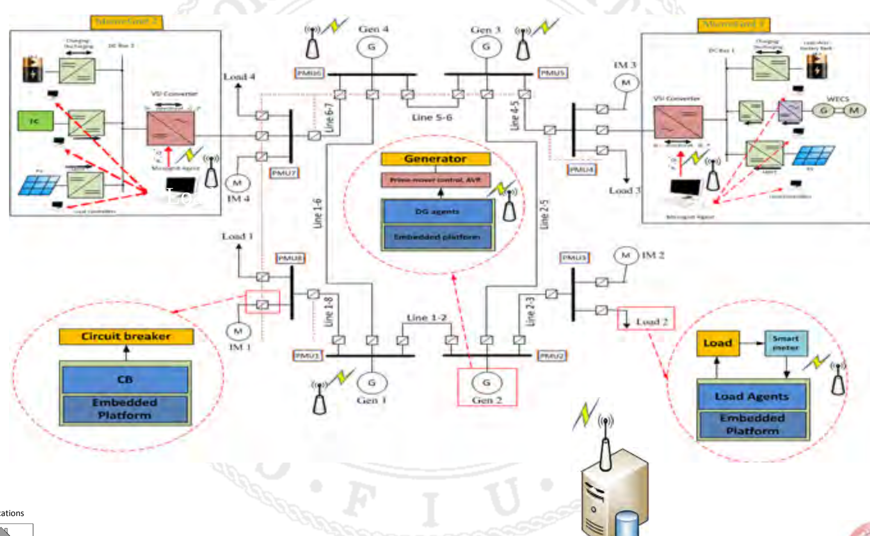
Security improvement by Trusted sensing base (TSB) algorithm



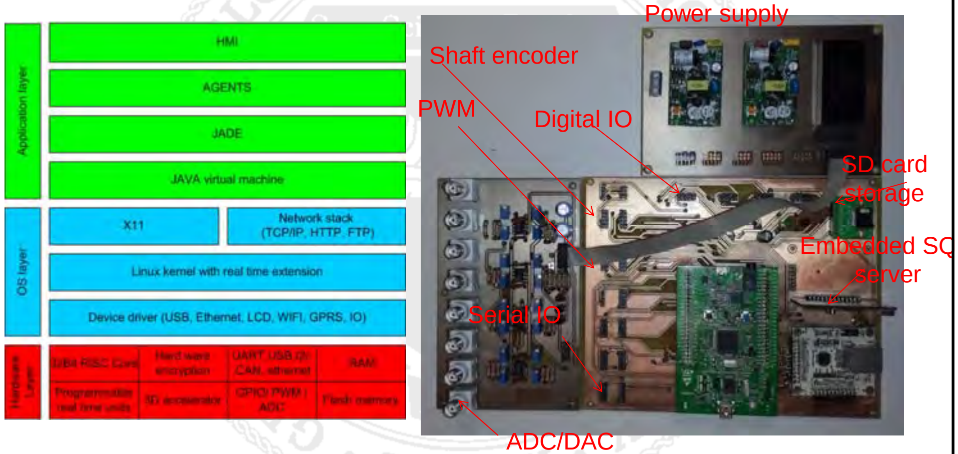
Applications

Distributed control architecture



Applications

Embedded Agent platform



Embedded Platform

Distributed control, and PMU

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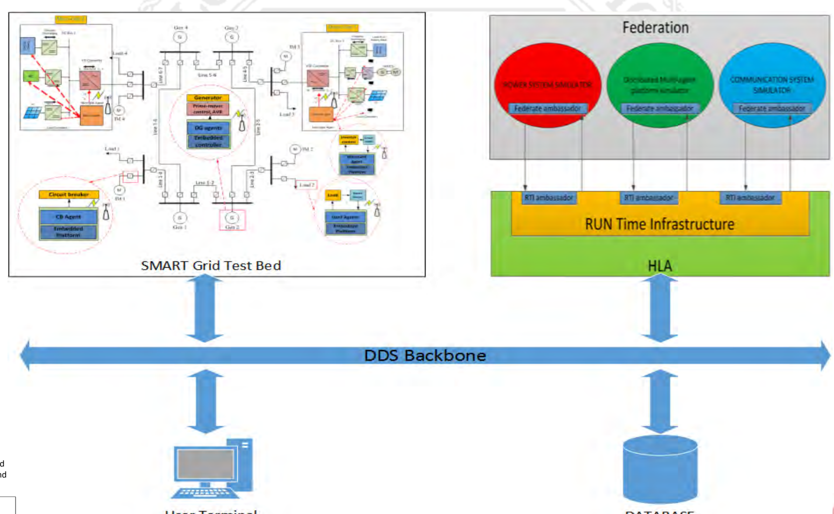
HIL simulation



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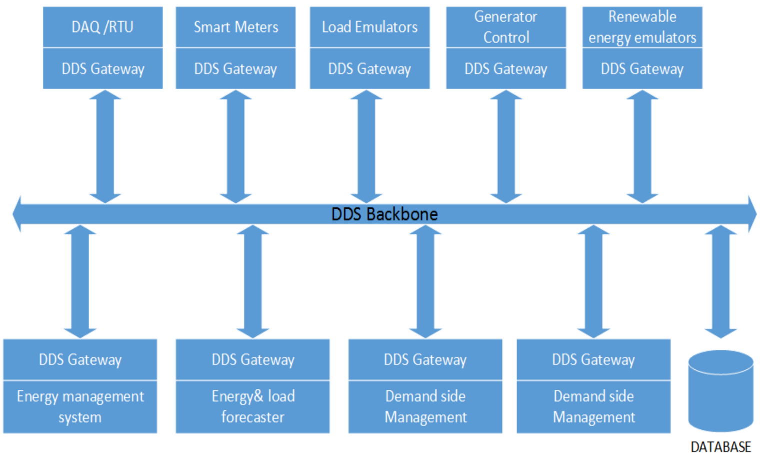
DDS infrastructure



Distributed control, and PMU

Data Distribution service DDS Infrastructure

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Smart meter

- Smart meter Based on ARM processor
- Integrated power line carrier Modem (PLCM)
- Customized firmware
- Real time measurement of P,Q
- Support zigbee, serial, USB and power line communication

Smart Meter

Distributed control, and PMU

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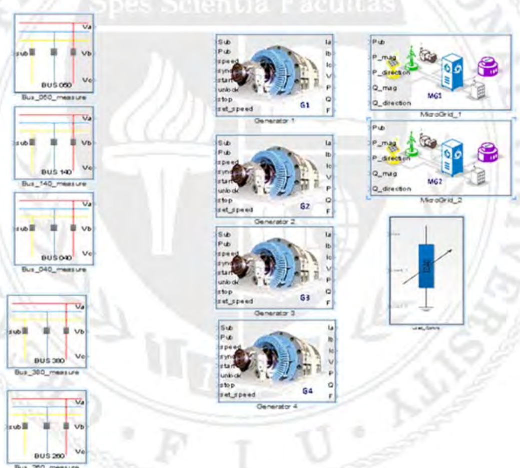
Test Bed Interface Library

- Standard interface Library provide control function and data collection capability from local and remote network
- Real time publisher subscriber protocol (RTPS) insure interoperability
- Provide Flexible environment for Distributed control test and validation
- Currently available interface for generators, Microgrids, CB, measurement nodes, PMU, Load emulators and renewable energy emulators

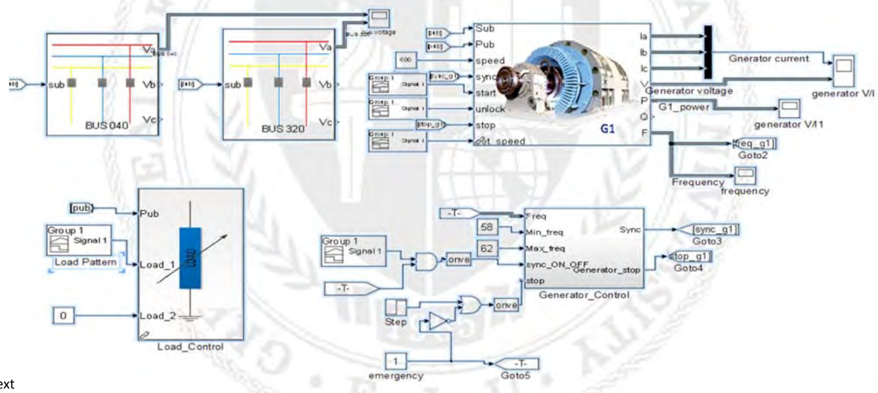
Next slide

Smart Grid Test Bed Interface Toolbox



Next slide

Interface Example



Next slide

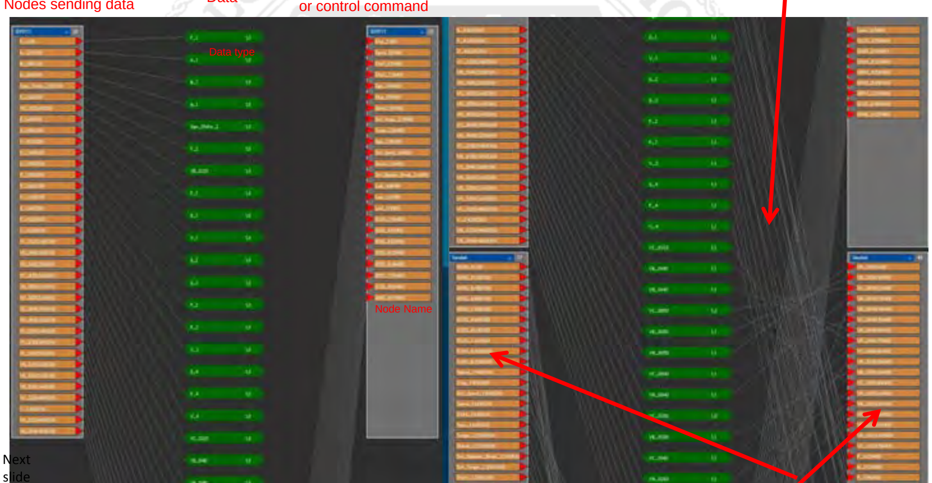
Logical Connection Diagram between Different Test bed Nodes (Updated In Real Time)

Nodes sending data

Data

Nodes Receiving Data or control command

Data connection between Simulation Model and Physical system



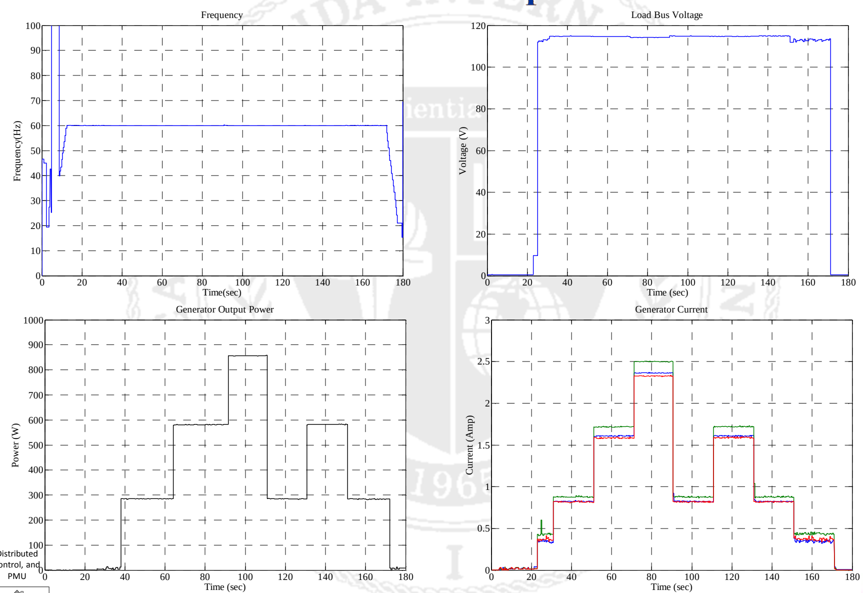
Next slide

Simulation Models

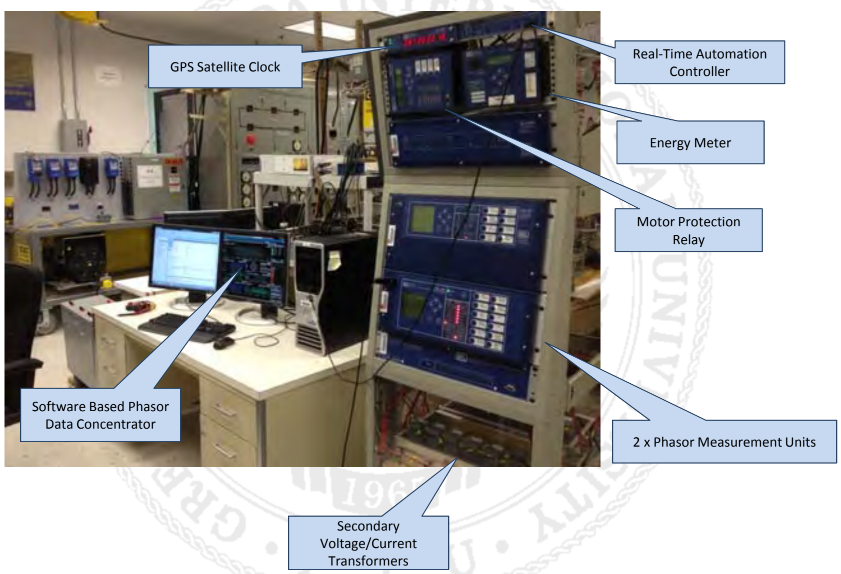
Logical Connection Before running HIL Simulation

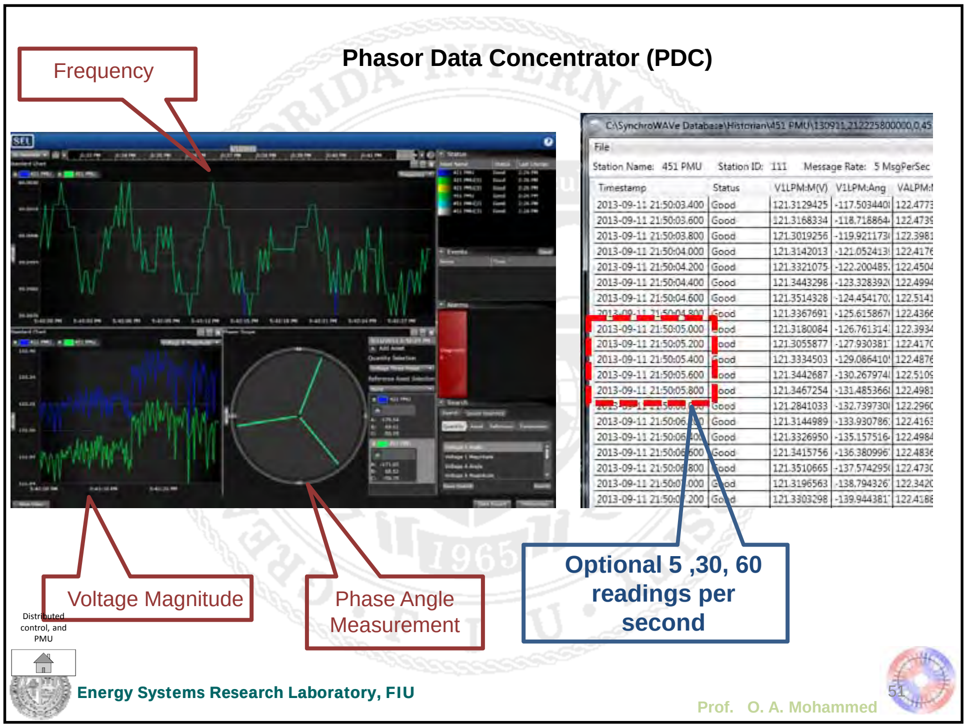
Logical Connection and data exchange during HIL Simulation

HIL Example



PMUs and Complimentaries




Phasor Data Concentrator (PDC)
Frequency
Voltage Magnitude
Phase Angle Measurement
Optional 5 ,30, 60 readings per second
Distributed control, and PMU
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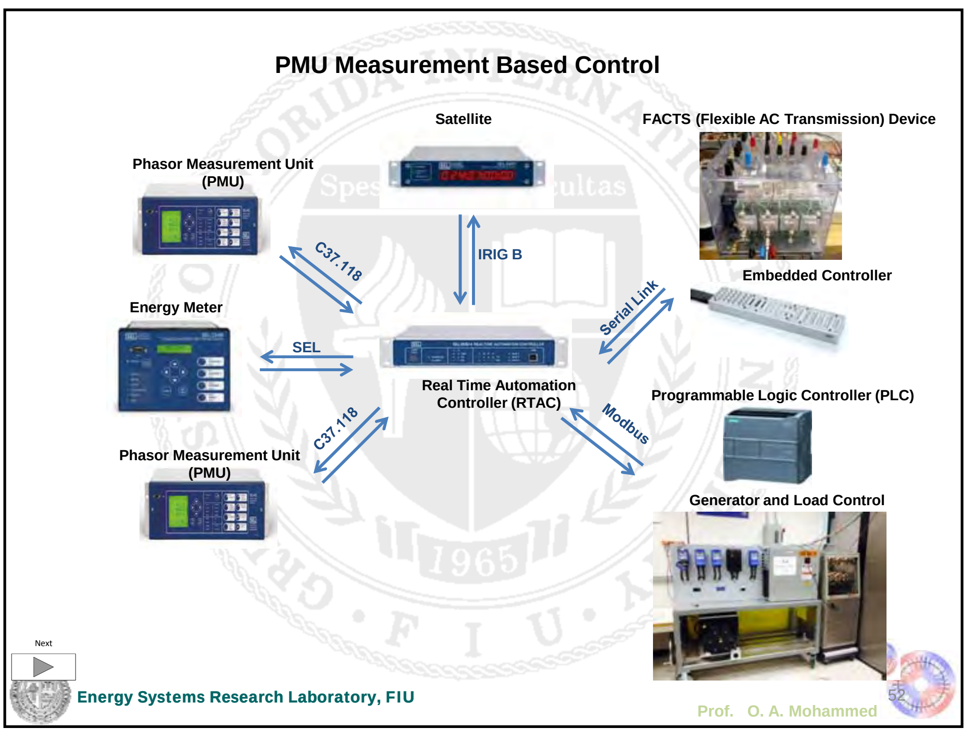
PMU Measurement Based Control
Satellite
FACTS (Flexible AC Transmission) Device
Phasor Measurement Unit (PMU)
C37.118
IRIG B
Embedded Controller
Serial Link
Energy Meter
SEL
Real Time Automation Controller (RTAC)
Programmable Logic Controller (PLC)
C37.118
Modbus
Phasor Measurement Unit (PMU)
Generator and Load Control
Next
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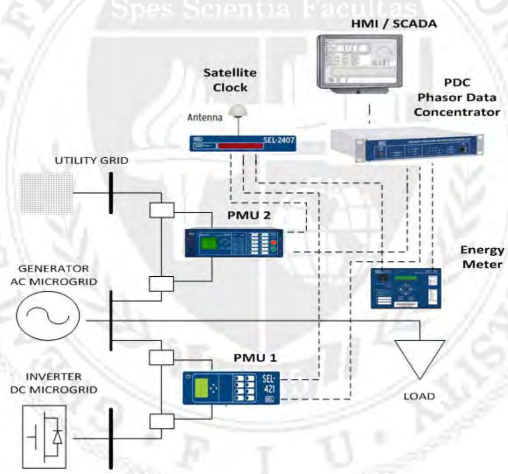
PMU Labview Interface

Analog and Discrete readings can be passed to Labview environment.

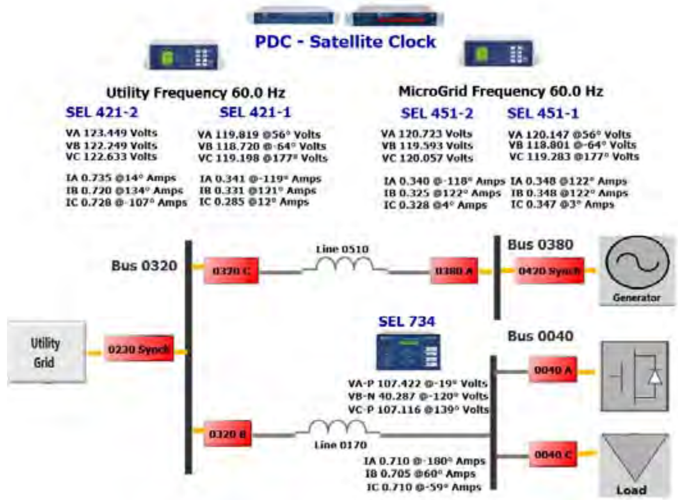
Integrating PMUs on the hybrid test bed and communication infrastructure



Applications of PMU Setup

Online monitoring of Phasor data concentration

https://131.94.117.168



Distributed control, and PMU

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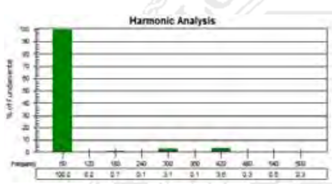
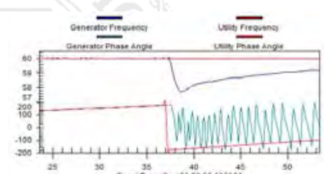
Applications of PMU Setup

1) Online Power Quality Measurement



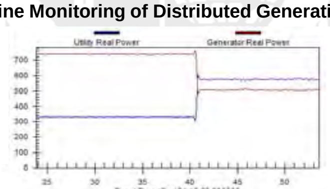
Harmonic level of microgrid

2) Islanding Detection



Rate of change of frequency monitoring
Phase angle difference monitoring

3) Online Monitoring of Distributed Generation Units



Generation control

Next

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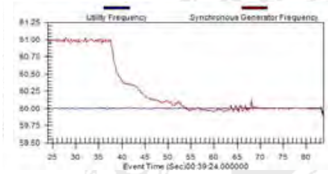
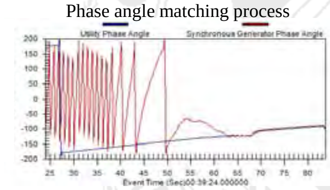
4) Synchronization of distributed generation units

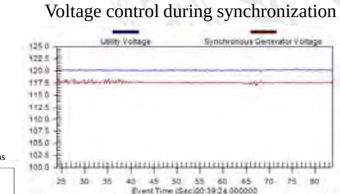
Frequency matching process



Phase angle matching process



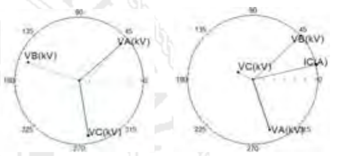
Voltage control during synchronization



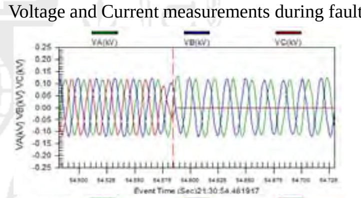
5) Post-Fault Analysis

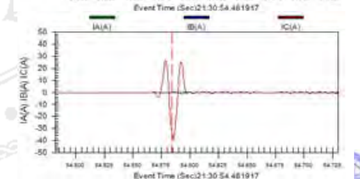
Single phase fault event example

Voltage phasors a) Prior fault b) During fault



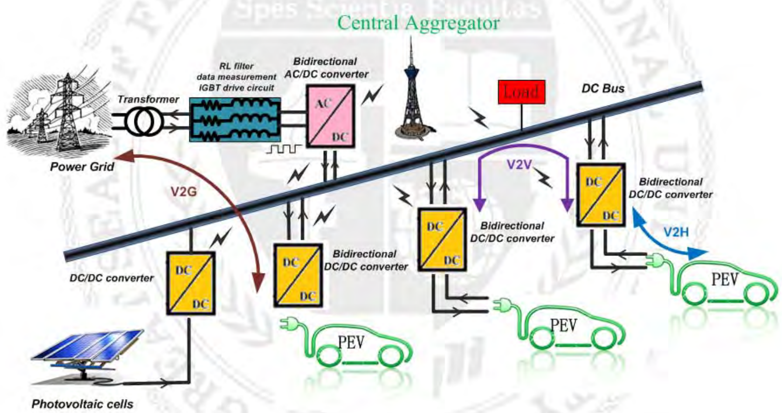
Voltage and Current measurements during fault





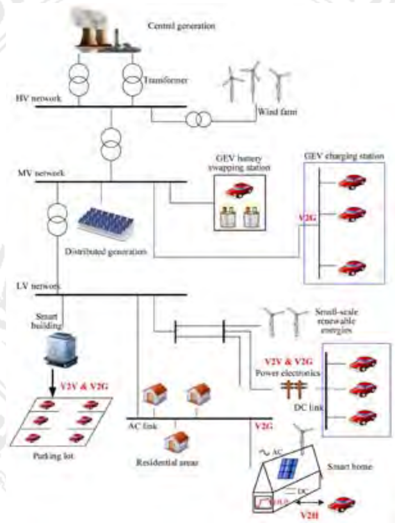
Applications

Hybrid PEVs charging system.



Next

Framework for V2G



Next

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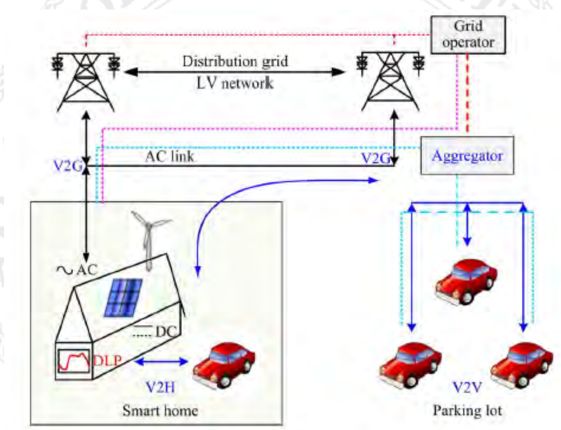
Framework for V2H



Next

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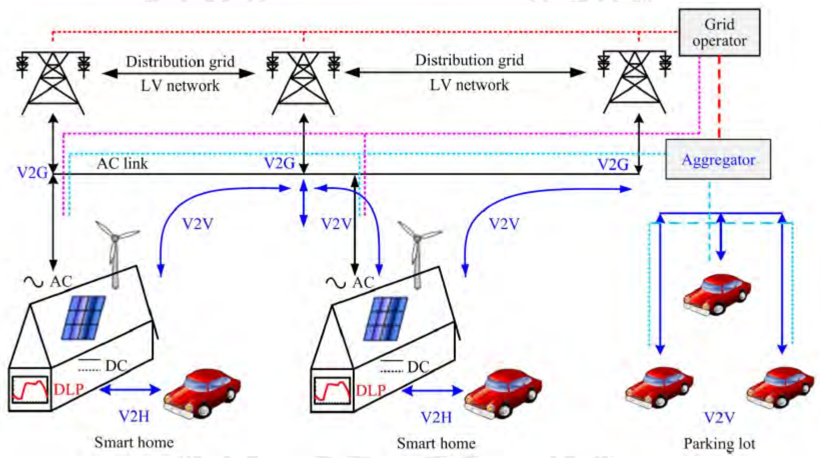
Framework for V2V

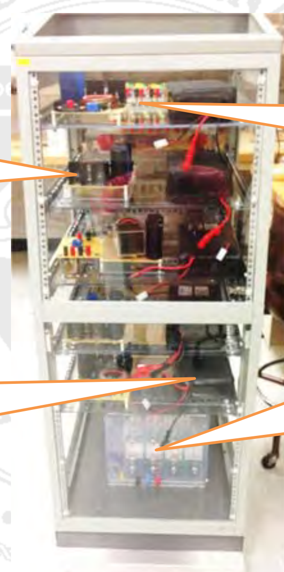


Applications

Grid Connected battery energy storage bank system

Bidirectional DC-DC converter
- *High switching frequency*
- *Low consumption*
- *Fast response, symmetrical*
- *High efficiency*

Battery monitor system
- *SOCs monitor for SOC balancing*
- *Temperatures monitor for thermal balancing*



Lithium-ion battery
- *Five lithium-ion batteries stands for five individual PEVs.*
- *High energy capacity: 21 Ah.*
- *High energy density.*
- *High terminal voltage.*

Bidirectional AC-DC converter
- *High switching frequency*
- *Low consumption*
- *Fast response, symmetrical*
- *High efficiency*

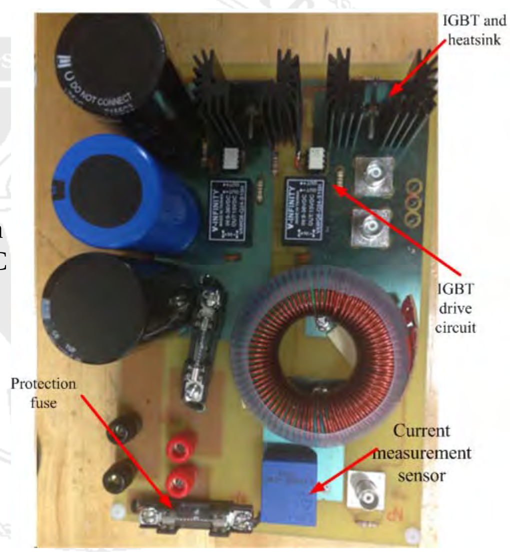
DC microgrids Components

Lithium-ion battery (PEV emulator)

- Lithium-ion battery bank with 21 Ah capacity, 51.8V terminal voltage, and 40A maximum charging/discharging current is used to emulate a single PEV.
- Five lithium-ion battery banks are used to emulate five PEVs in a parking garage.

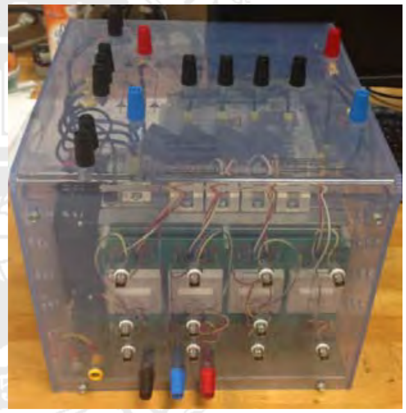
High Efficiency Bidirectional DC-DC Converter Design

- A 50V to 350V current control bidirectional DC-DC converter with 20K switching frequency is built on PCB board.
- Each PEV can be connected to the common DC bus through a DC-DC converter, also the charging/discharging of the battery can be controlled by the current flow the converter.



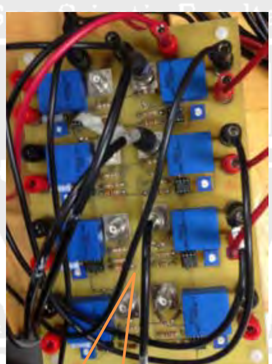
Bidirectional AC-DC inverter design and control

- This bidirectional AC-DC inverter links this DC PEVs car park system to the utility grid. Both active and reactive power flow from both directions can be controlled.
- Therefore, the energy system can be used to do some services such as frequency regulation and voltage regulation by control the active and reactive power flow.

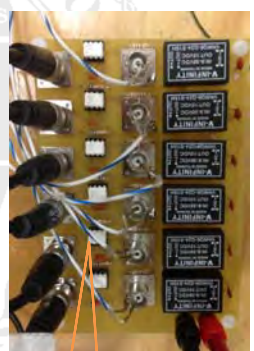


RL filter, AC voltage and current measuring circuit, IGBT drive circuit

RL filter fuse & relay protections

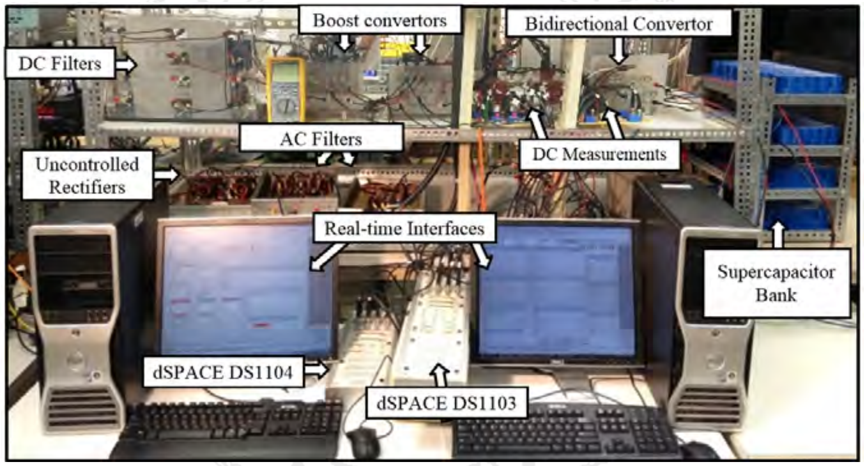


AC voltage and current measuring circuit



IGBT drive circuit

Modular Hybrid DC Microgrid For Pulse study

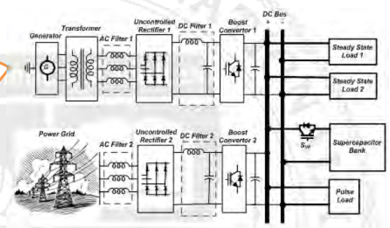


Next

Examples of Possible Hybrid DC Microgrid Configuration with composable modules

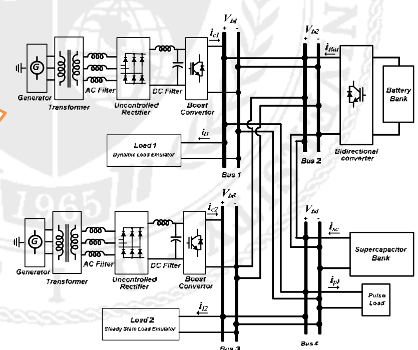
One bus hybrid DC microgrid:

- *The grid is supplied by internal generator and AC grid.*
- *All the loads are connected to a common coupling bus.*



Four buses Hybrid DC Microgrid for Pulse study:

- *This system can be a shipboard power system or a DC microgrid connected to a utility grid.*



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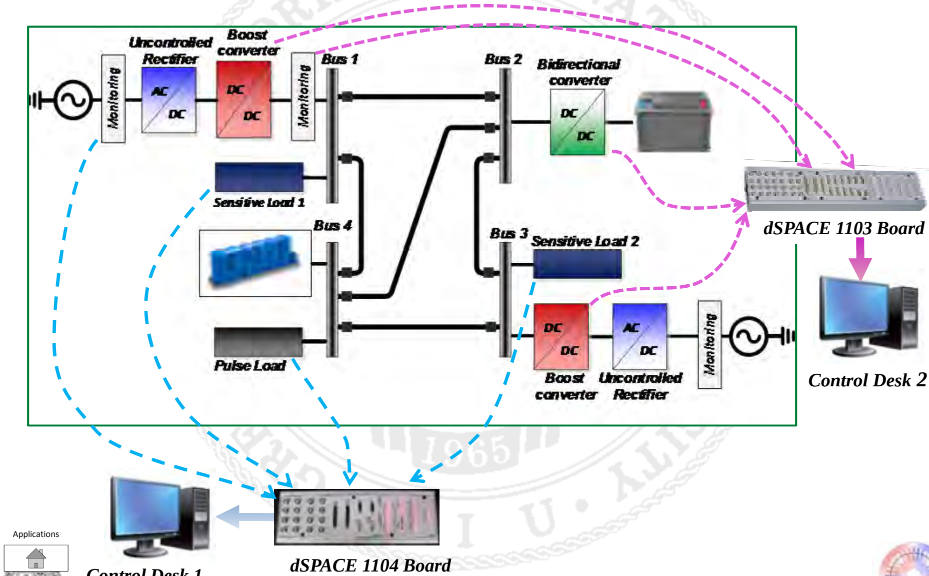
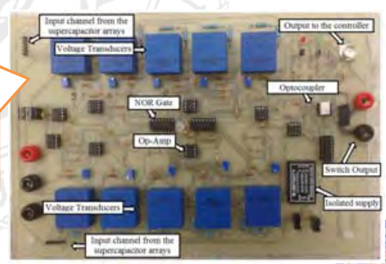
Composable modules in a Hybrid DC Microgrid for Pulse study



Supercapacitor Bank

Composed of 58 F, 16 V supercapacitor Module:
- *19 A maximum continues current*
- *Very high efficiency*
- *Wide range of operation temperature*
- *Long cyclic life time*

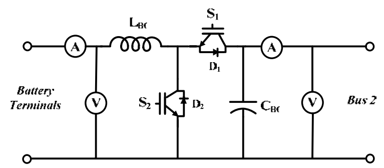
Analog Voltage Protection of the Supercapacitor Bank:
- *Each four 16-V module is protected*
- *In the case of overvoltage the charging path will be open and the supercapacitor bank can only be discharged.*

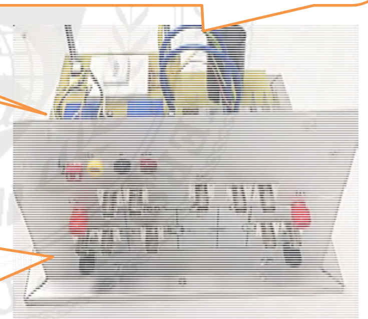


Bidirectional Converter

IGBT and Switching:
- *Isolated switching*
- *Switching capability up to 20kHz*
  - *Continues current operation up to 30A*
    - *Operating voltage up to 600 V*
- *High short circuit capability*

Configuration of the Converter:





Monitoring Capabilities:
- *Voltage and current measurement of the input and output*
  - *Isolated measurement*
- *Very low noise with application of analog low pass filter*

DC microgrids Components

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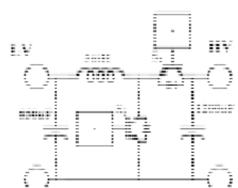
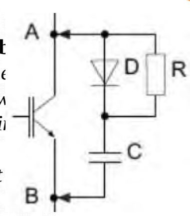
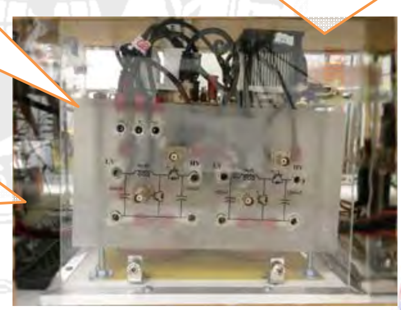
Multiport-Boost Converter

Configuration of the Converter:
- *Two Boost-converters are compacted in one unit.*
- *The units can be connected in parallel or in series.*



RCD Snub
- *Reduces the switching pow*
- *Peak voltage li the switches during transient*





IGBT and Switching:
- *Isolated switching*
- *Switching capability up to 20kHz*
  - *Continues current operation up to 30A*
    - *Operating voltage up to 600 V*
- *High short circuit capability*

DC microgrids Components

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Lead-Acid Battery Bank

12-V 110 A
- *Low cost*
- *Reliable*
- *Wide range of sizes*
- *Modular series parallel connection capability*
- *Wide applicability*

Possible Configuration in our Test Setup:
- *From 24-V up to 120-V in series connection*
- *From 12-V up to 60-V in parallel connection*

DC microgrids Components

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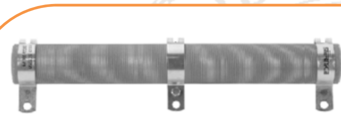
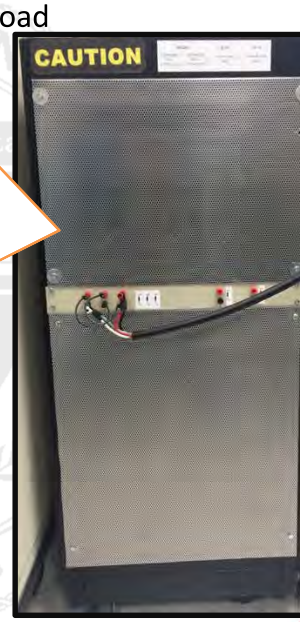
Programmable DC Load





320-V 6-kW Programmable Load :
- *High frequency switching DC load*
- *Very fast response using IGBT switches*
- *Completely programmable*
- *Long Time Operation.*

Example of load emulation:
- *Step change load emulator*
- *High inrush current load emulator*
- *Pulse load emulator*

DC microgrids Components

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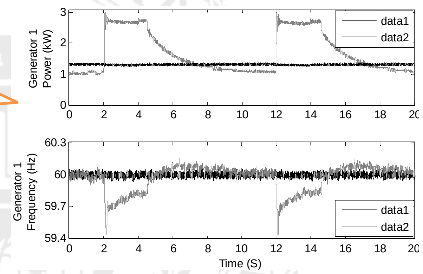
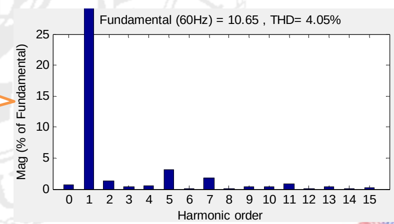
AC System Monitoring for Pulse study

The following parameters can be measured and further analyzed for pulse study:
- *Current and voltage variation*
- *Power fluctuation*
- *Frequency variation*



Harmonic analysis:
- *The harmonic content under different operation condition*
- *The effect of grid isolation on the harmonic contents*
- *Design of active or passive filter for harmonic suppuration*



DC microgrids Components

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DC System Monitoring

DC System Monitoring for the Control of the Hybrid DC Microgrid

DC System Monitoring for the Protection of the Hybrid DC Microgrid

Next

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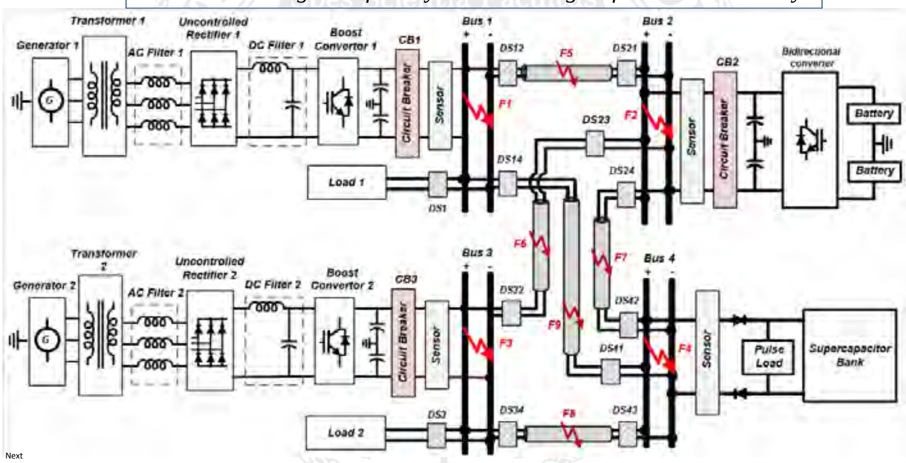
DC System Monitoring for Protection Purpose

A schematic diagram of the hybrid dc microgrid for Protection study



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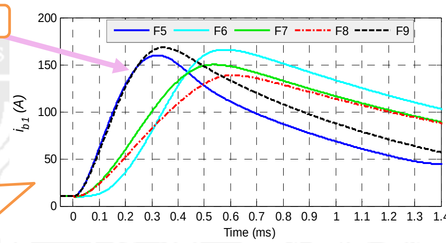
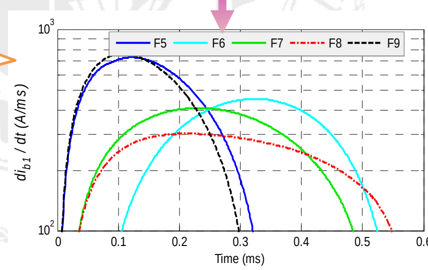
DC System Monitoring for Protection Purpose

Different types of fault

- *The Output current of the Capacitor at the DC link are measured.*
- *RC low pass filter are implemented to reduce EMI effect on the measurements.*



Derivative



Advantages of derivative fault identification method:

- *It is very fast to identify a fault.*
- *It is accurate for fault classification*

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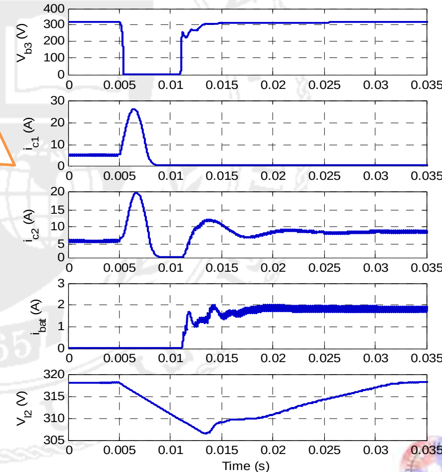
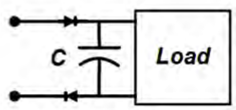
DC System Monitoring for Protection Purpose

The Protection scheme of the hybrid dc microgrid is able to;

- **Accurately identify the type of fault,**
- **Isolate the faulted area very fast**
- **Restore the system quickly**
- **Maintain the load voltage during the system transient using clamp capacitor.**

Performance of the Hybrid Dc microgrid during bus fault F1





Applications

Energy Systems Research Laboratory, FIU

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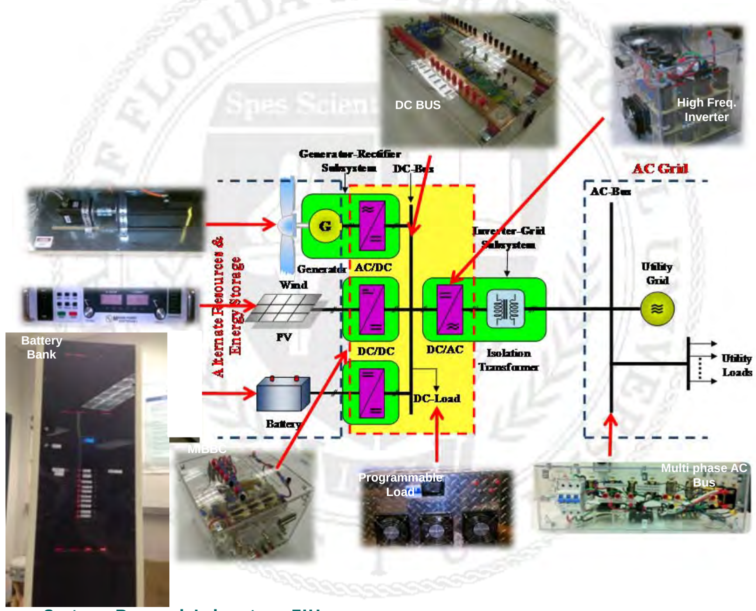
Practical Implementation of wind, PV, energy storages in Microgrids with Modular Components



Applications

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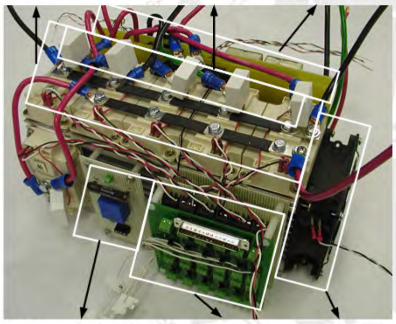
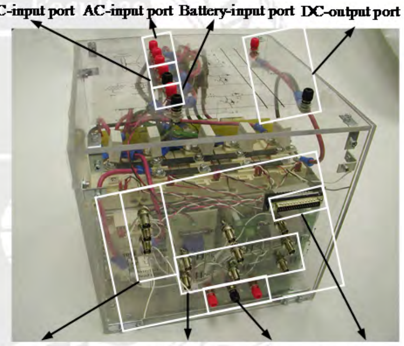
Modular MIBBC

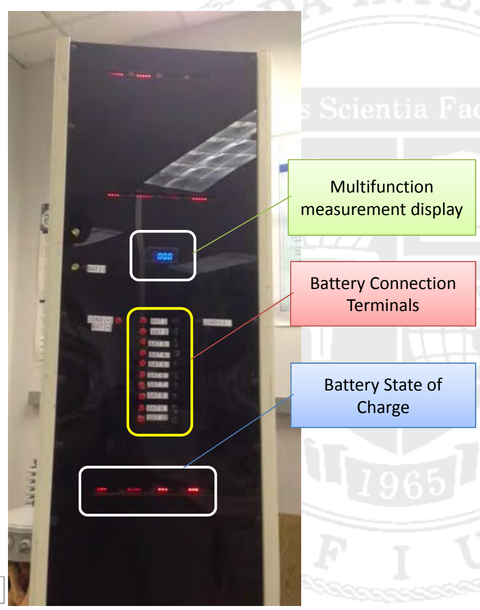




Open frame prototype

Modularized frame

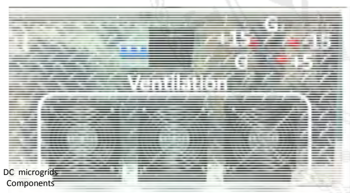
Battery Bank

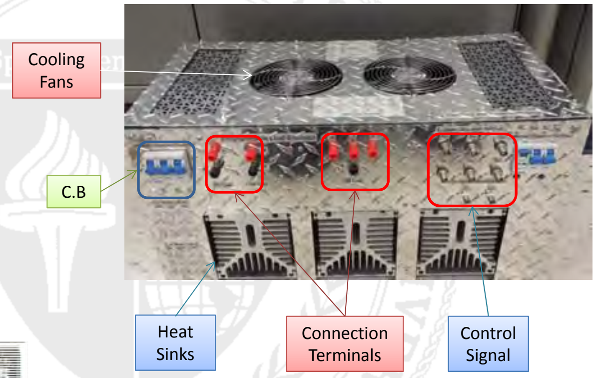


12-V 110 Ah Module:

- *Low cost*
- *Reliable*
- *Wide range of sizes*
- *Modular series parallel connection capability*
- *Wide applicability*

Programmable Load Emulator



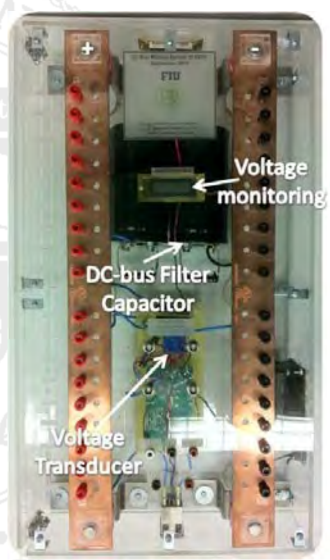


DC microgrids Components

DC-Bus Module System (0-1000V)

This DC bus is integrating various types of energy sources and loads.

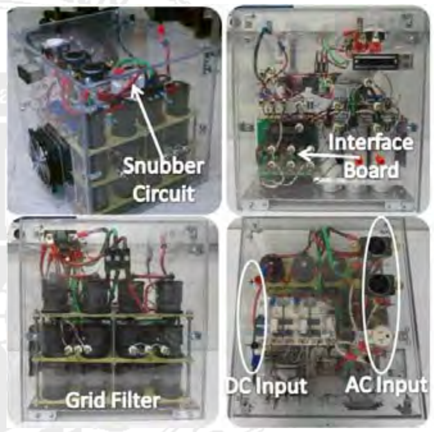
- Photovoltaic Generation Systems
- Wind Energy Conversion Systems
- Fuel cells
- DC-Loads (Static & Dynamic)
- Battery Banks
- DC-DC Converters



DC microgrids Components

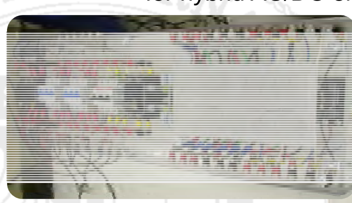
High Frequency Inverter

- Higher efficiency (average above 94%)
- Larger power density (power/weight ratio)
- Better protection against system operation faults
- Better power quality
- Multi-phase output load connectivity (single phase, two phases, and three phases)



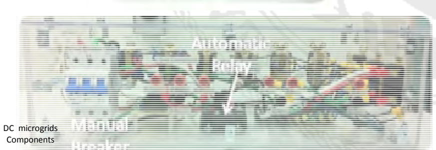
AC-bus modular system for multi-phase grid connection

Protection and measurement module for hybrid AC/DC energy sources

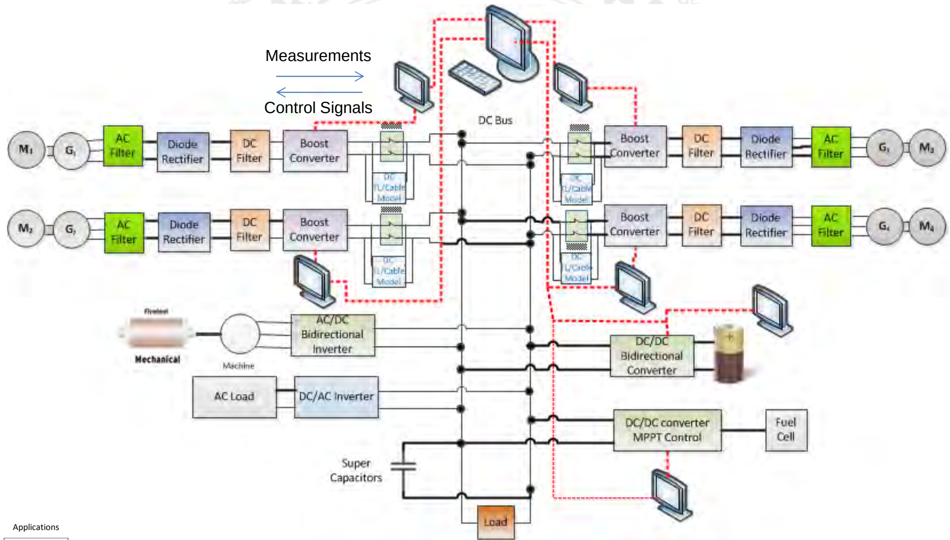


Wind Emulator System

PV and Fuel Cell Emulators

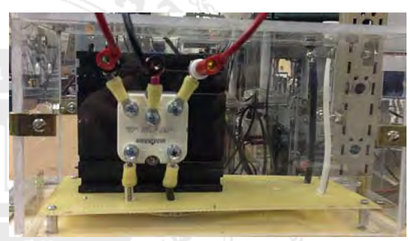


A Schematic Diagram of the Testbed With flexible Implementation of DC Architectures (MV/Zonal)

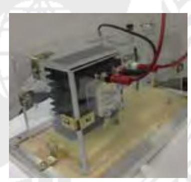


Applications

Uncontrolled Rectifier



The used module: Semikron BRIDGE RECTIFIER, 3PH, 150 A, 1.6 kV



4 rectifiers were developed

DC microgrids Components

Dynamic Load Emulation

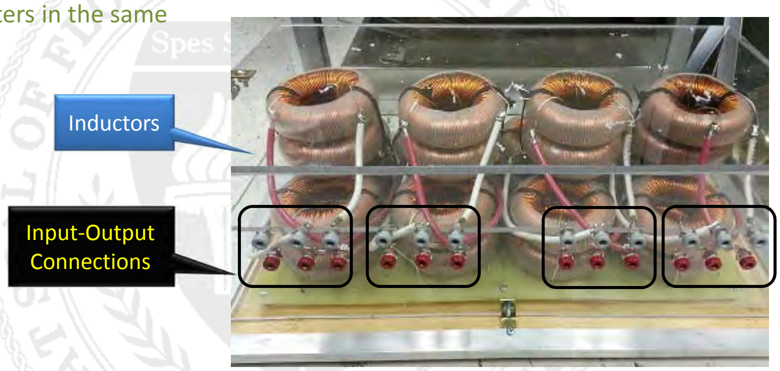
380-V 6-kW Programmable Load :
- *High frequency switching DC load*
- *Very fast response using IGBT switches*
- *Completely programmable*
- *Long Time Operation.*

Example of load emulation:
- *Step change load emulator*
- *High inrush current load emulator*
- *Pulse load emulator*

Connection between Generators and DC.

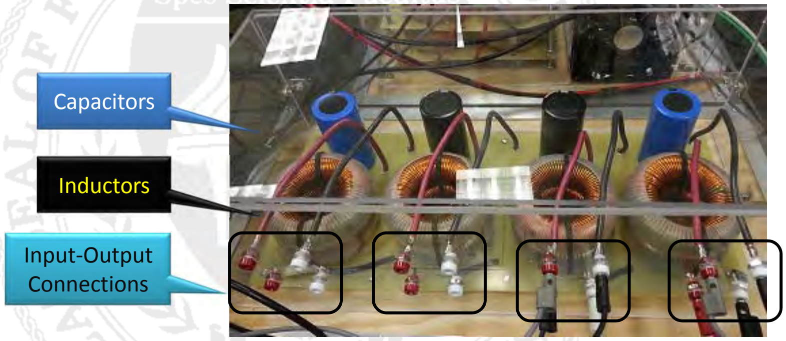
AC Filter

- Four DC filters in the same modules



DC Filter

- Four AC filters in the same modules



Controlled DC-DC Boost Converter

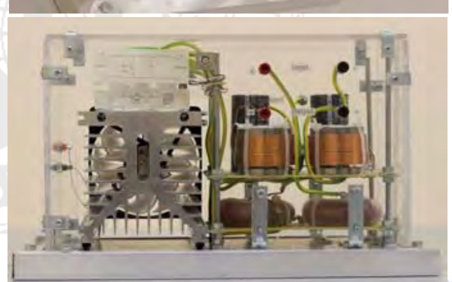
Boost Converter Parameters

- L_b=6 mH
- Cb=1200 μF
- Controller parameters: K_p=0.002, K_i=0.2

Packaging

- Each package contains two DC-DC boost converters
- Two units were developed to obtain 4 boost converters

The building block: Power Electronic Switch: IBGT, Chopper, 1200V, 176A



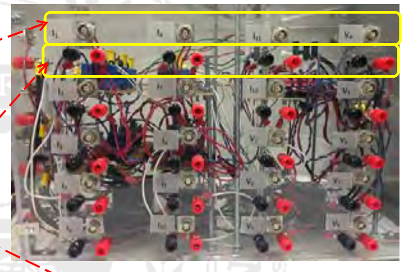
AC & DC Measurements and Protection Modules

Two modules are developed, each module is capable of:
- Measuring 12 current signals.
- Measuring 8 voltage signals.
- Controlling 8 solid state relays.

Measured signal

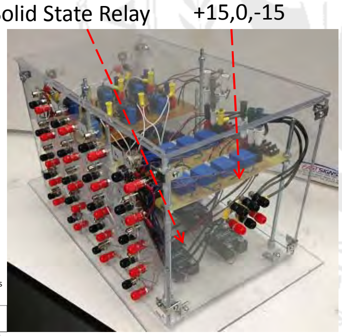
+/- Connection

Voltage Transducer

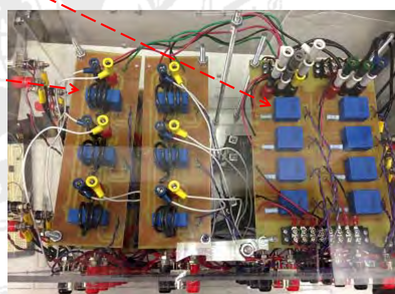


Solid State Relay

Supply Input +15,0,-15



CT



DC microgrids Components

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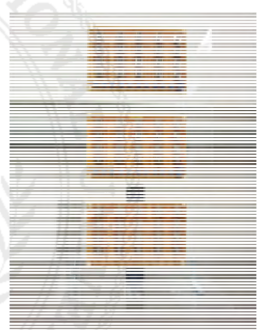
DC Power Module

Measurements Interface Panel



Output connections

DC microgrids Components

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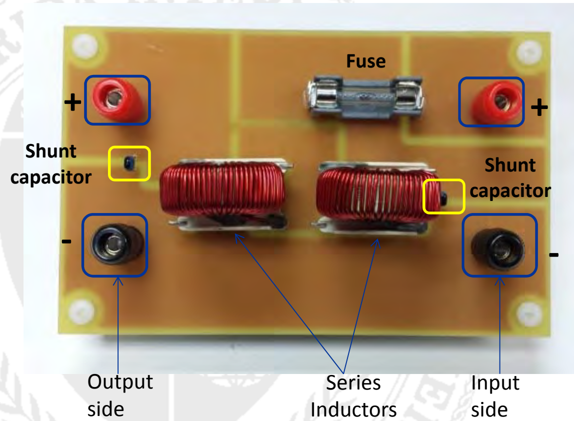
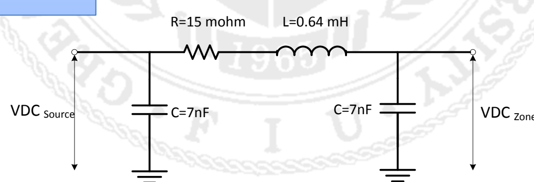
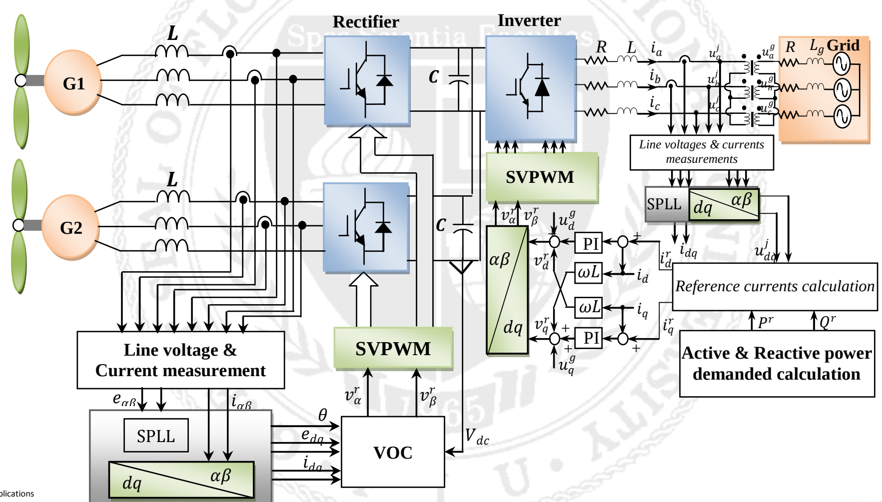
Medium Voltage DC Transmission Line Model

- The MVDC transmission line model is built as a *pi* model.
- The given parameters are for transmission line with 1 km length.
- Four DC TL models are built with different lengths.

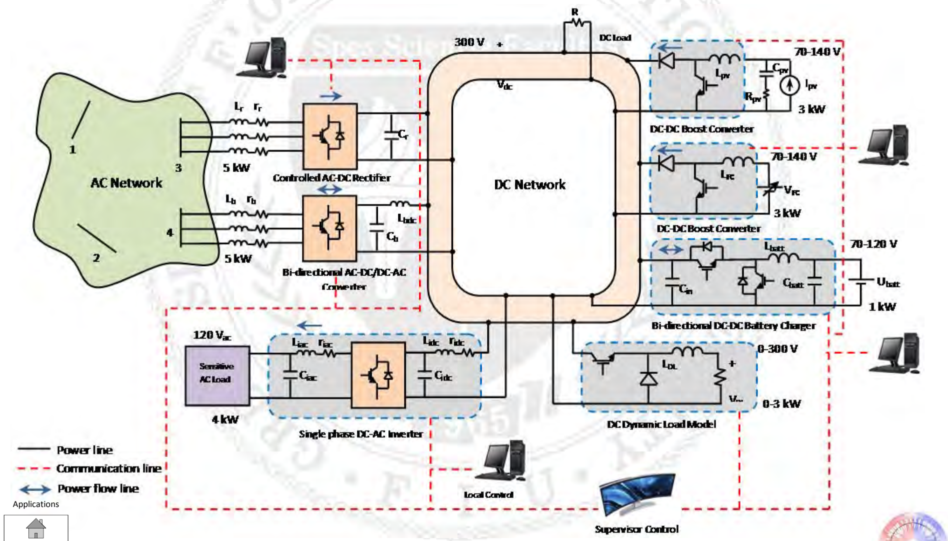




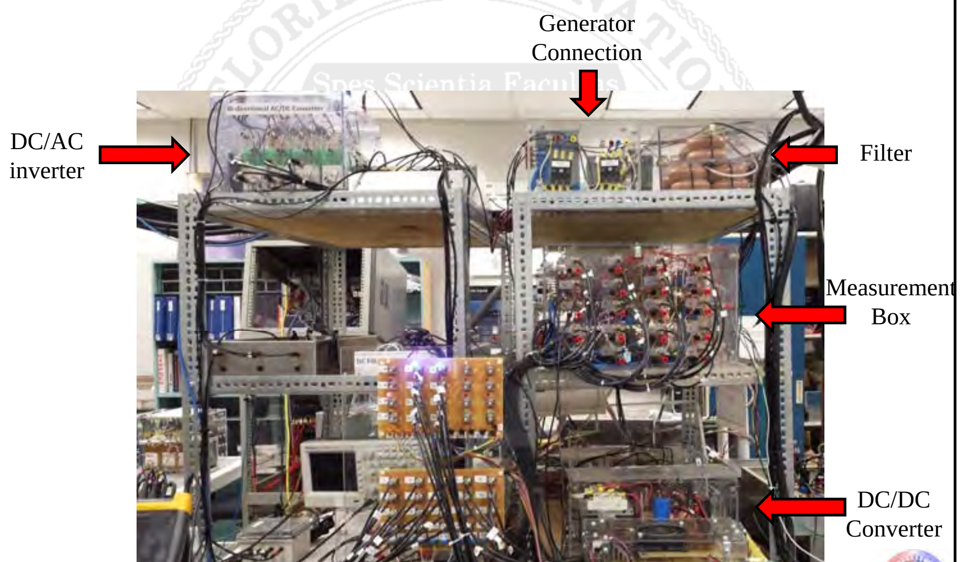
Schematic Diagram of the Modular WECS Control System Connected to Grid



DC network schematic interconnected to AC side

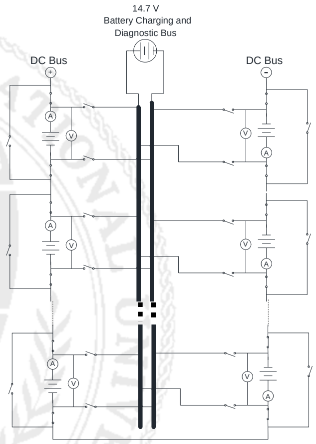


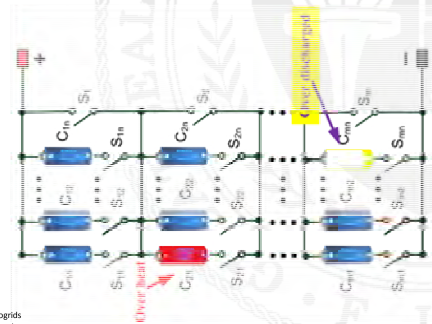
Hardware and System Implementation



Utility Battery Management, Sensing and Diagnostics Software

- Allows battery decoupling & Charge Balancing
- Multipath voltage and current flow & measurements





- Helps characterizing overall performance and efficiency
- Overdischarge or thermal stress cause system imbalance.

DC microgrids Components

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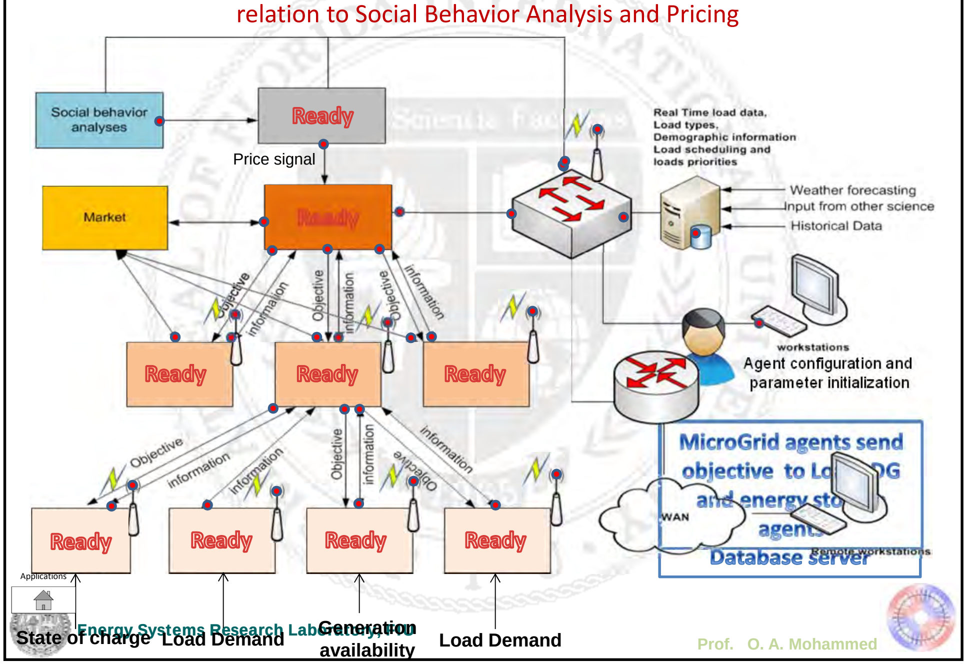
Logical structure of distributed Multi-agent Environment and relation to Social Behavior Analysis and Pricing



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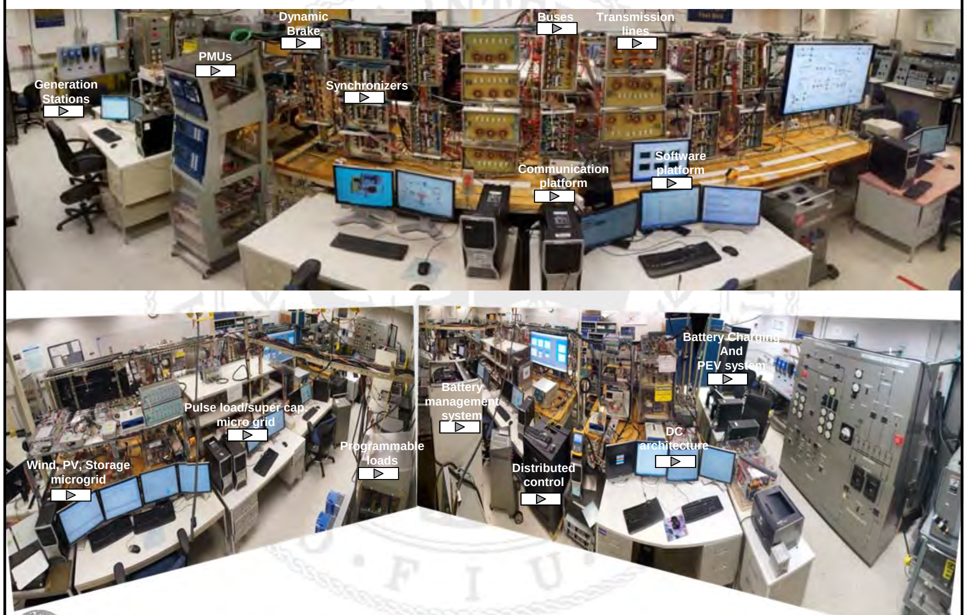

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Conclusion

- Modular components in the test bed is necessary as it enable extending the system, replace defective component, and enhance the interconnectivity and operability of components.
- Modules require extended specifications with lowest limitations for their application.
- Combining modules will provide an environment for developing, integrating, testing and evaluating ideas, components, and recent research advances
- Standards need used, tested or even improved through various studies.
- Finally the test bed should be designed in a way to achieve full potential of smart grid by enabling solution and testing of practical solutions.

Energy Systems Research Laboratory, FIU

Prof. O. A. Mohammed

Our Research Group

Energy Systems Research Laboratory, FIU

Prof. O. A. Mohammed