Attributes and design of Resilient Renewable Microgrid Laboratory

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Incentives to build resilient and reliable grid in south-east Texas

- Hurricane Rita and Hurricane Ike were the largest and most damaging hurricanes to hit Beaumont, TX, causing $11.3 billion and $31.5 billion, respectively, in total damage to the U.S.

- The state of New York and New Jersey had the same experience with hurricane sandy and after the hurricane they have implemented CHP incentive programs focused on improving state energy resiliency.

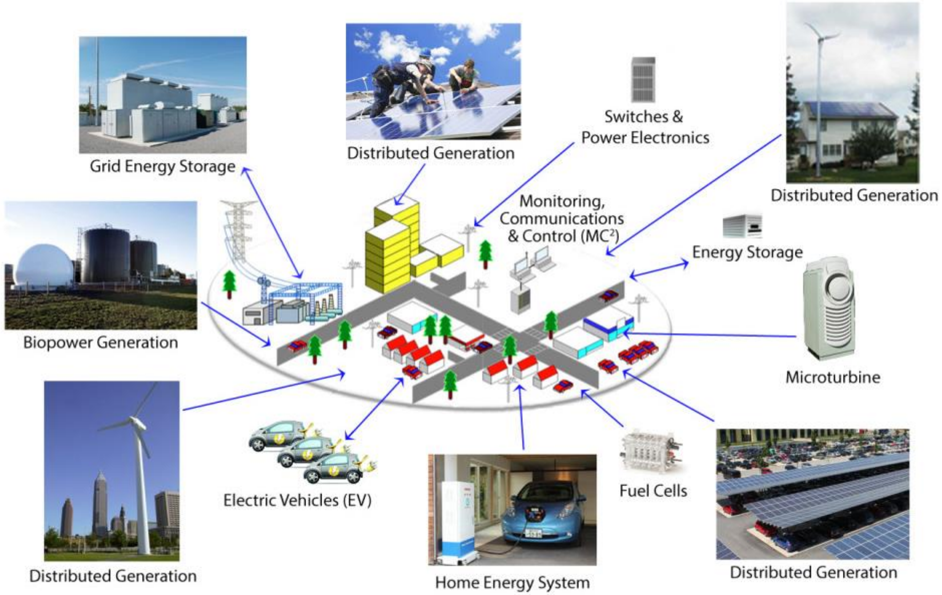
- The state of Texas and specially the south Texas has the highest capacity of CHP in U.S

- The presence of the huge resources and refineries in this area “golden triangle” which produces and consumes hydrogen for their production is the main resource of renewable cogeneration

- In the United States, the annual cost of outages in 2002 is estimated to be in the order of $79B, which equals about a third of the total electricity retail revenue of $249B. Much higher estimates have been reported by others.

Community microgrid

Community microgrids aim primarily at supplying electricity to a group of consumers in a neighborhood or several connected neighborhoods in close proximity



must have three distinct characteristics:

1) the electrical boundaries must be clearly defined,
2) there must be control systems in place to dispatch Distributed Energy Resources in a coordinated fashion and maintain voltage and frequency within acceptable limits
3) the aggregated installed capacity of DERs and controllable loads must be adequate to reliably supply the critical demand.

So what's the problem and how to fix it

Several obstacles exist in the rapid and widespread deployment of community microgrids, including:

- **The high capital cost of microgrid deployment**

efficient planning models are required to:

- ensure the economic viability of microgrid deployments
- justify investments based on cost-benefit analyses under uncertain conditions

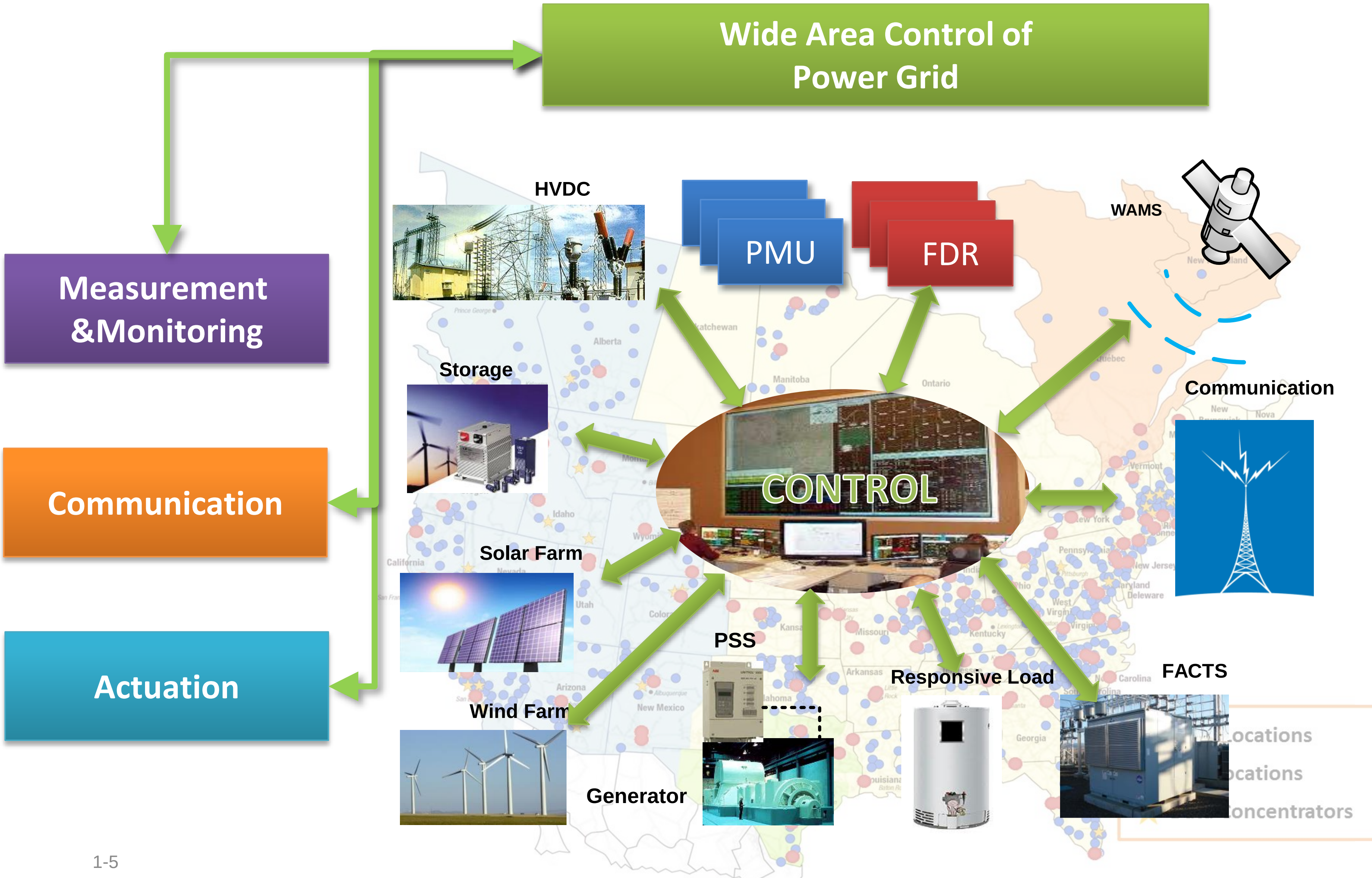
- **The lack of consumer knowledge on potential impacts of DG and load scheduling strategies**

the most powerful driver for performing load scheduling:

- The financial incentives offered to consumers, who would consider load scheduling strategies.
- Furthermore, the emergence of smart metering as well as state-of-the-art devices and building management systems have helped reduce this barrier

- **Particularly ownership and regulatory issues**

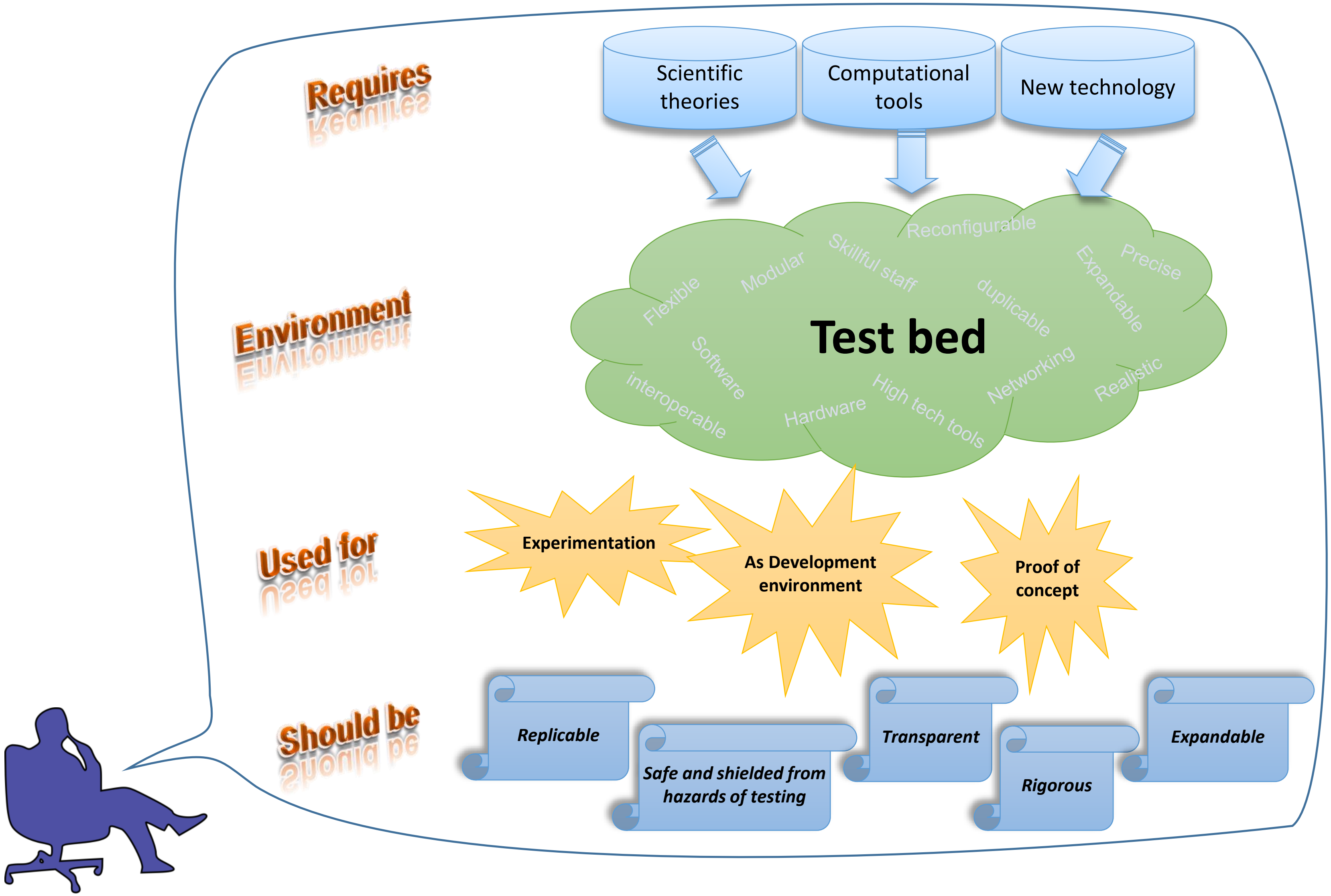
- microgrid ownership, third-party generation participation, investment recovery, and inclusion in the utility rate case are the issues that must be resolved


Wide Area Control of Power Grid
Measurement &Monitoring
Communication
Actuation
HVDC
PMU
FDR
WAMS
Storage
Communication
CONTROL
Solar Farm
PSS
Wind Farm
Responsive Load
FACTS
Generator

Benefits of community microgrids

- Security: mitigate the impacts of physical and cyber threats through islanding
- Reliability: intrinsic intelligence (control and automation systems) of community microgrids and the utilization of DERs
- Resiliency: local supply of loads even when the supply of power from the utility grid is not available
- Emission reduction: using the coordinated control of a combination of dispatchable DGs, DES, and controllable loads to “smooth down” the intermittent output of renewable energy resources
- Reduced cost of recurring system upgrades: reducing T&D congestion issues by deploying distributed energy resources and storage
- Energy efficiency: by reducing T&D losses and allowing the implementation of optimal load control and resource dispatch.
- Power quality: by enabling local control of the frequency, voltage, and load, and a rapid response from the DES
- Lowered energy cost: reducing T&D cost and also load scheduling strategies

Basis for developing a state of the art test bed



Attributes

- Our main objective here is to use composable modules for developing a resilient test bed microgrid 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 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.

Attributes

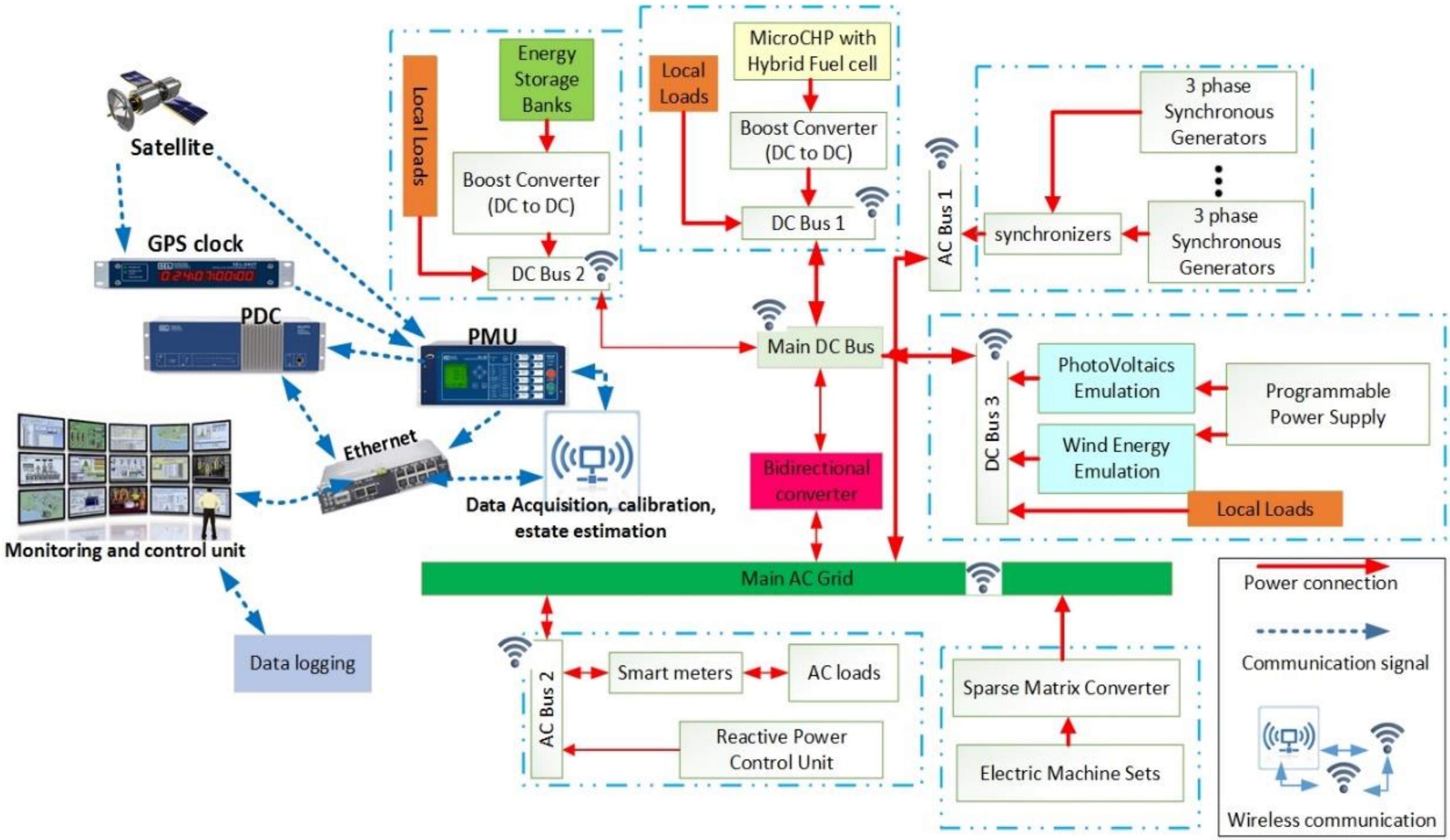
- Abilities of the Test Bed from a technical point of view:
  - Develop and implement wide area Protection System.
  - Study important issues such as real-time voltage stability
  - Develop monitoring and operation strategies using Synchorophasors
  - Conduct experiments on EMS for smart grids including alternate and sustainable sources
  - Integrating embedded architecture and distributed control through intelligent agents
  - Improving the market analysis and economic studies

Consequently:

Test bed needs to have the following components in an integrated platform and will provide us several capabilities. The main Requirements are listed here:

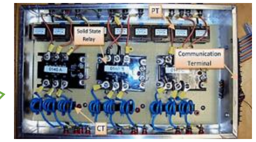
- Phasor measurements units
    - monitoring, protection, and control
- Integration of distributed and renewable energy sources
    - wind, solar, Fuel cell, etc.
- The development of new schemes
    - protective digital relaying
    - Wide Area Protection
- Intelligent protection schemes and their application for
    - Prevent cascading outages
    - Islanding situations
    - Grid blackout
- Emulation of Plug-In-Hybrid Electric Vehicles (PHEVs) and Electric Battery Vehicles (EBVs)
    - 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

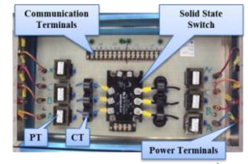
Schematic of composable modules integrated in the test bed

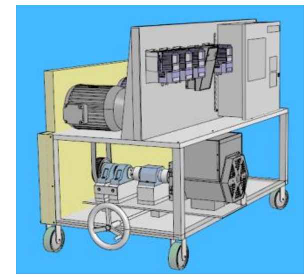


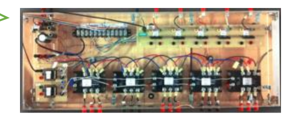
Composing a smart grid test bed at a laboratory scale

- **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

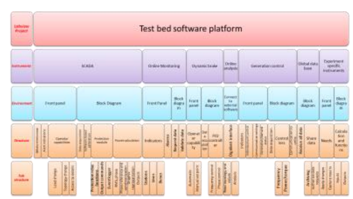


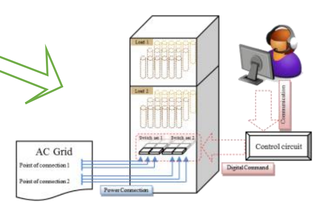






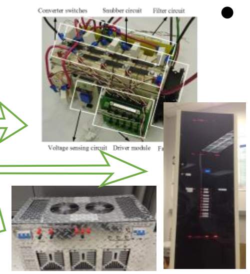
Multi port Dynamic Brake
(Good for up to 5 Gens.)

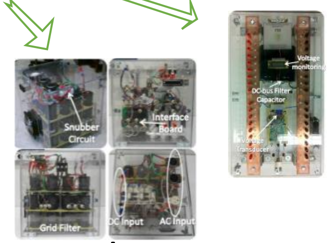


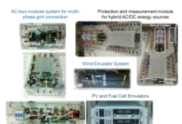


Composing a smart grid test bed at a laboratory scale

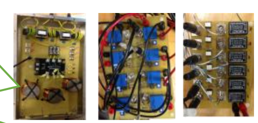
- DC Microgrids Components
  - Modular MIBBC
  - Battery Bank
  - Programmable Load emulator
  - DC bus module
  - High Freq. Inverter
  - more

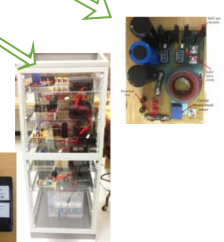


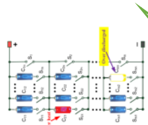




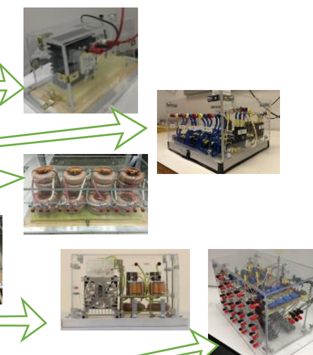
- Hybrid PEVs Charging system Components
  - RL Filter
  - Bidirectional ac/dc converter
  - Bidirectional dc/dc converter
  - Hardware Overview
  - Lithium-ion Battery
  - Management, Diagnostics Software





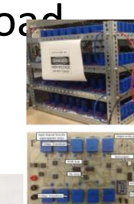


- AC/DC interconnected network components
  - Uncontrolled rectifier
  - Dynamic load emulation
  - AC Filter
  - DC Filter
  - DC/Dc Boost Converter
  - AC/DC Measurements and Protection
  - DC Power Module
  - Medium voltage DC Transmission line model



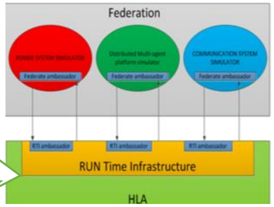
Components of Microgrids for pulse load studies

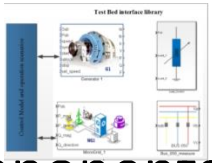
- Super capacitor bank
- Bidirectional converter
- Multi port Boost Converter
- Lead Acid Battery Bank
- Programmable DC Load



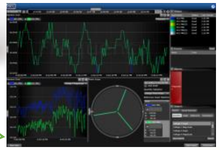
Composing a smart grid test bed at a laboratory scale

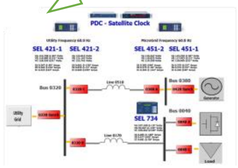
- Distributed control components
  - Embedded agent platform
  - HIL simulators
  - DDS infrastructure
  - Smart Meters
  - Developed Interface library

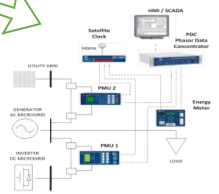




- Phasor measurement Components
  - PMUs
  - PDCs
  - RTACs
  - Interface for control and protection modules
  - Real time phasor data server

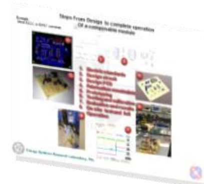


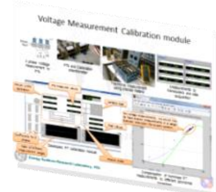


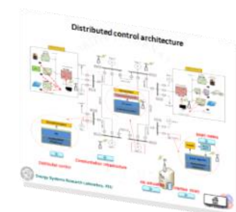


Utilization and Applications of composable modules in smart grid test bed

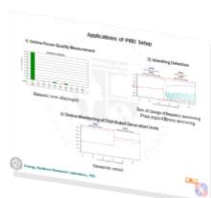
- Steps from design to operation
  - Voltage and current measurement
    - Security analysis
      - Embedded Control architecture

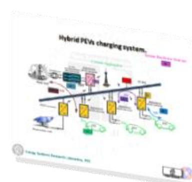






- PMUs and RTAC
  - Hybrid PEV charging station
    - Pulse load studies
      - DC System monitoring and protection

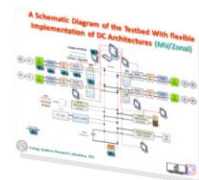




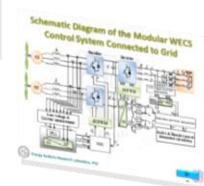
Utilization and Applications of composable modules in smart grid test bed

- Wind, PV and Energy storage integration

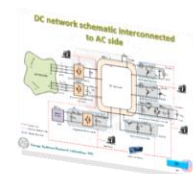
  - Implementation of DC architecture studies



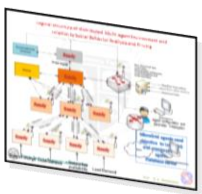
    - Modular interconnected WECS Control system



      - AC/DC Interconnection Grid Studies



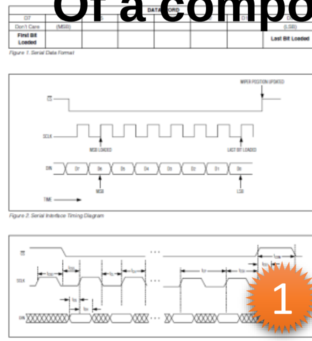
- Multi Agent Environment and Social behavior analysis and pricing

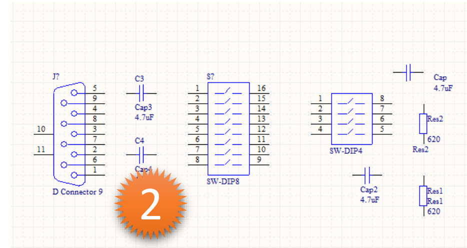


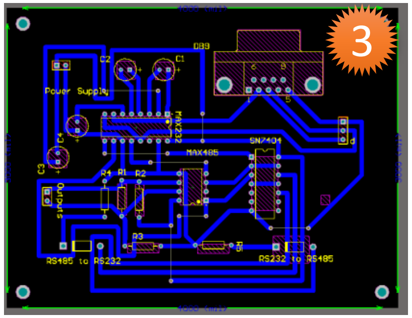
Steps From Design to complete operation
Of a composable module

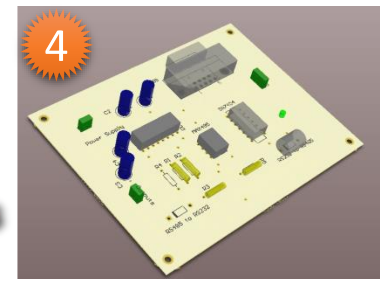
Example:

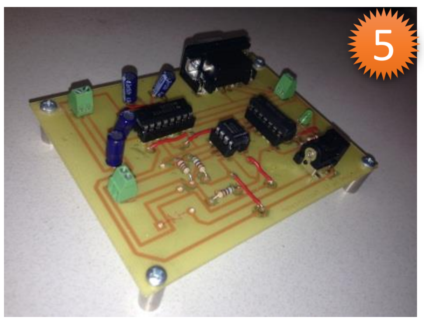
Serial RS232 to RS485 converter



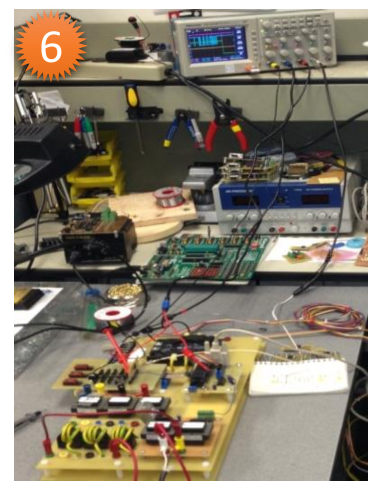


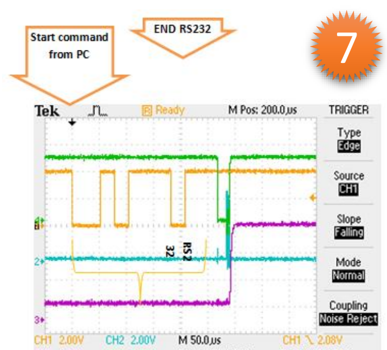






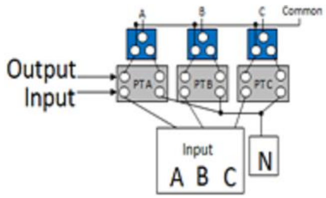
1. Electric standards
2. Design circuit
3. Design PCB
4. Fabrication constraints
5. Prototyping
6. Testing and calibration
7. Evaluation and results
8. On site test and full Operation





Applications

Voltage Measurement Calibration module

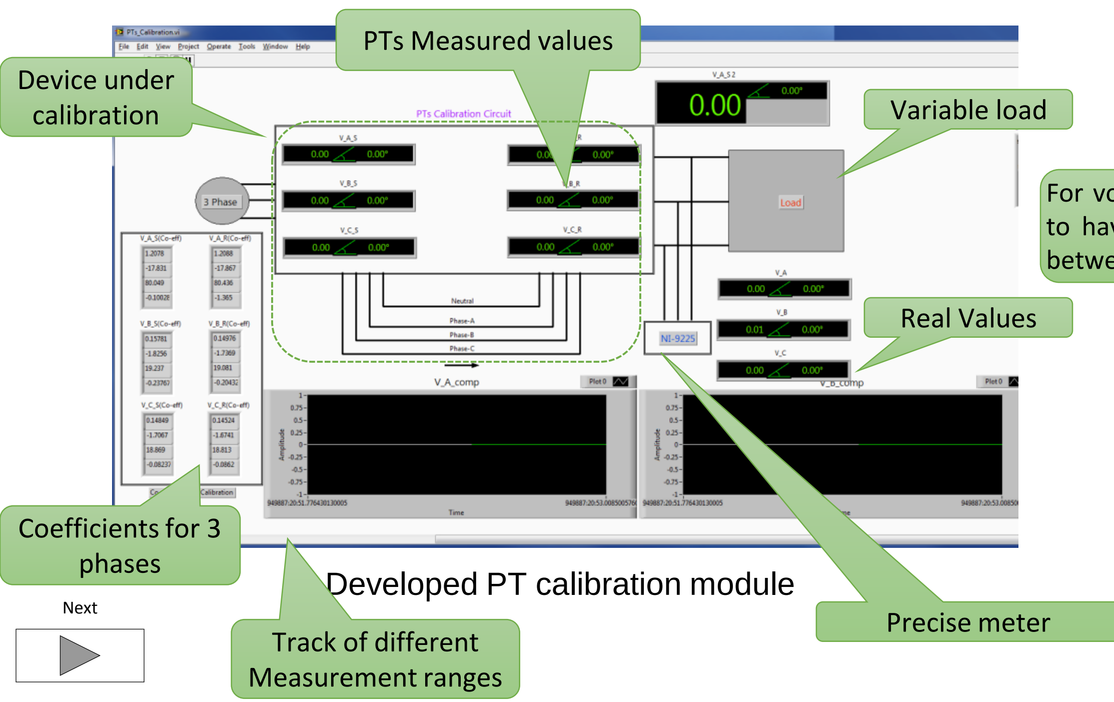


3 phase Voltage measurement by PTs

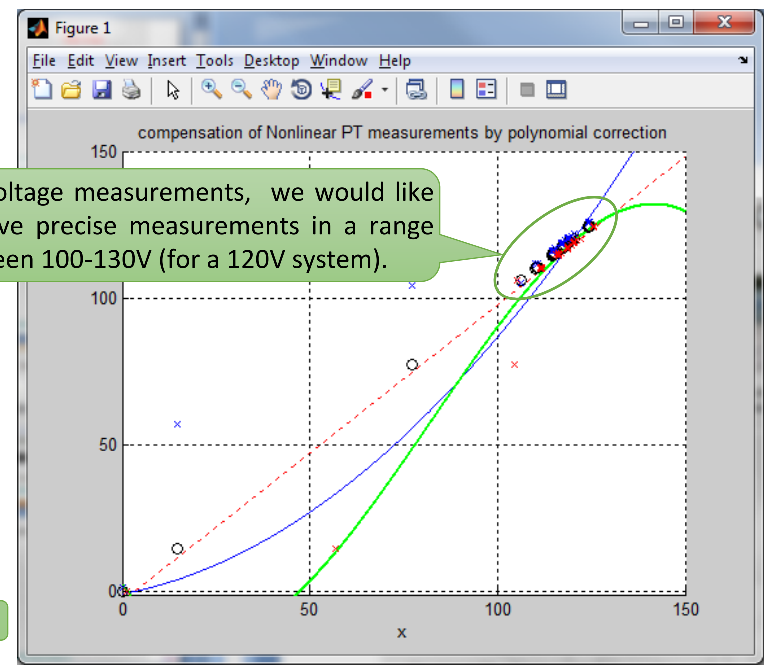
PTs and Calibration potentiometer

Traditional Measurement using precise meters

Measurements by transducers and data acquisition



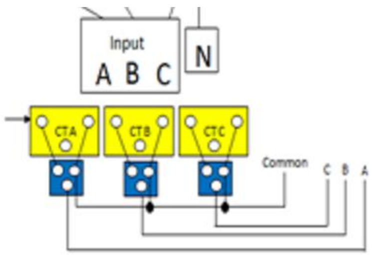
Developed PT calibration module



Compensation of Nonlinear PT measurements by different polynomial correction

Next

Current Measurement Calibration module

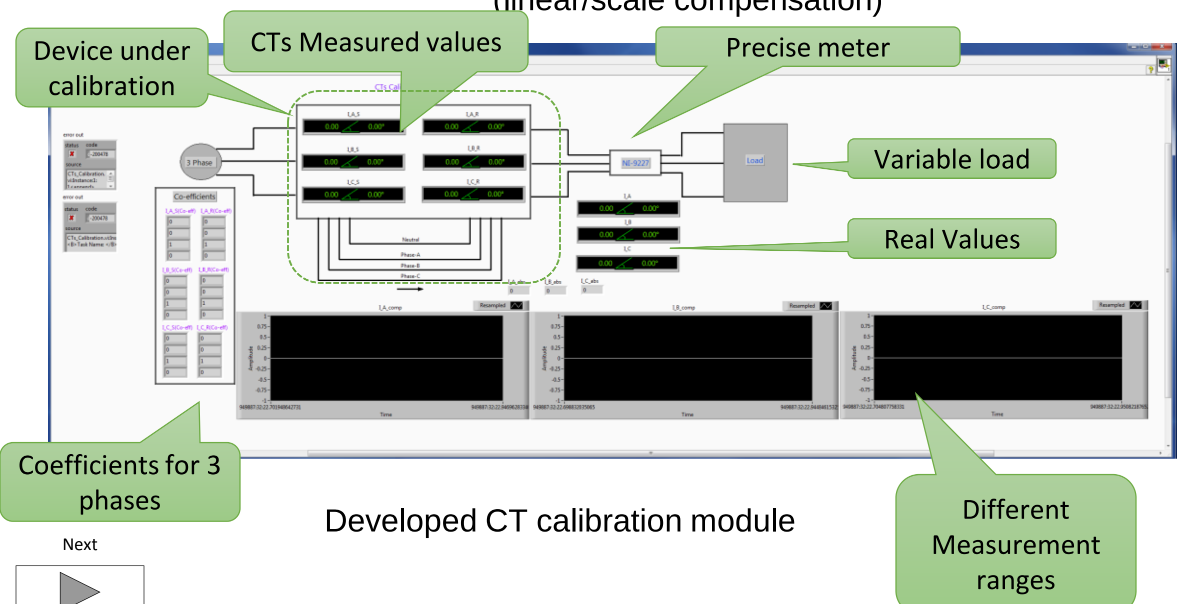


3 phase Voltage measurement by PTs

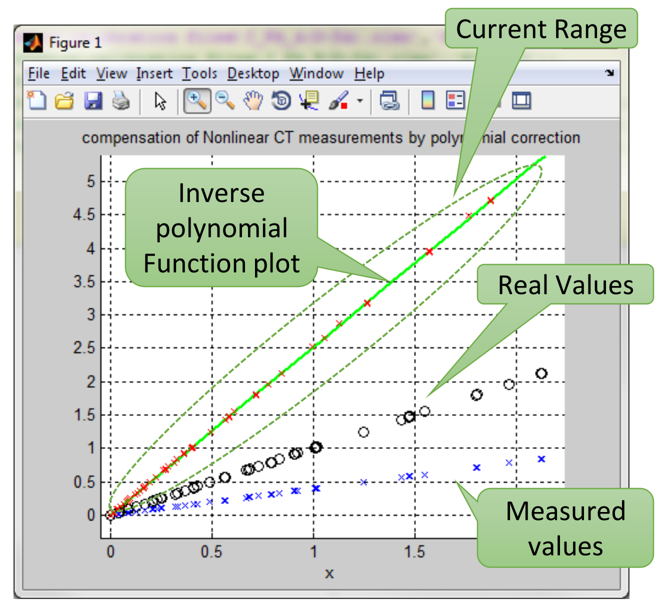
PTs and Calibration potentiometer (linear/scale compensation)

Traditional Measurement using precise meters

Measurements by transducers and data acquisition



Developed CT calibration module

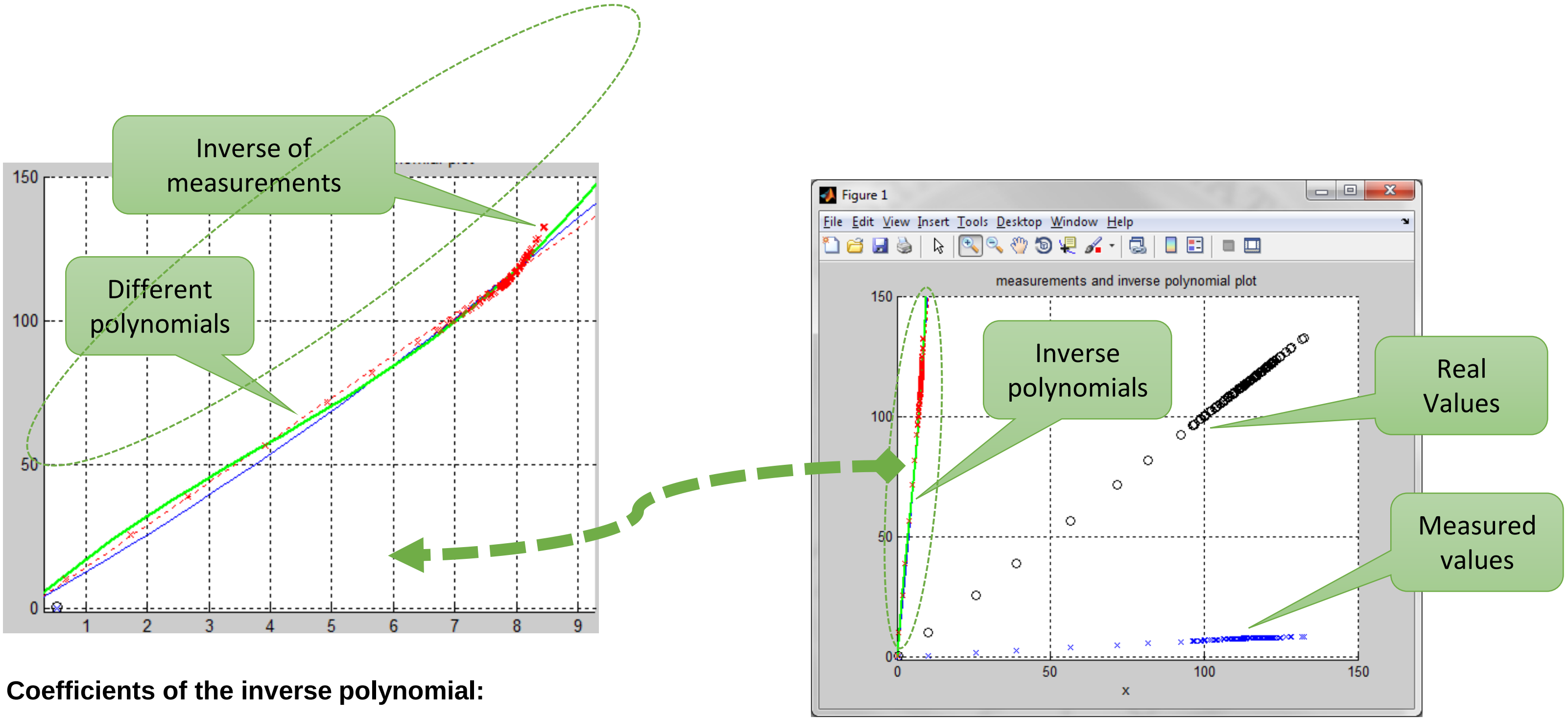


Compensation of Nonlinear CT measurements by different polynomial correction

Next

Post design requirement checks:

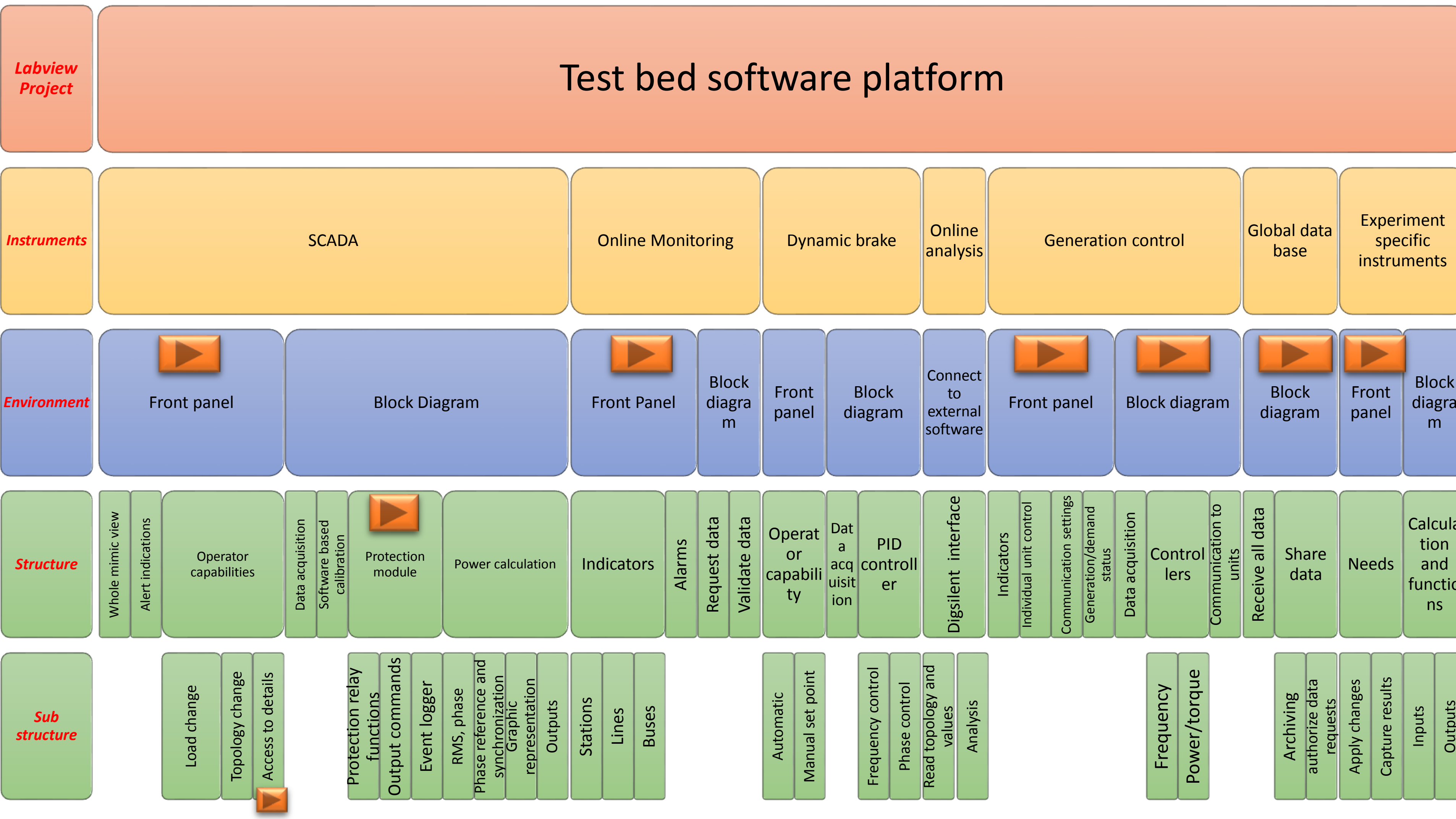
Measurement Calibration
&
Measurement linearization



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***

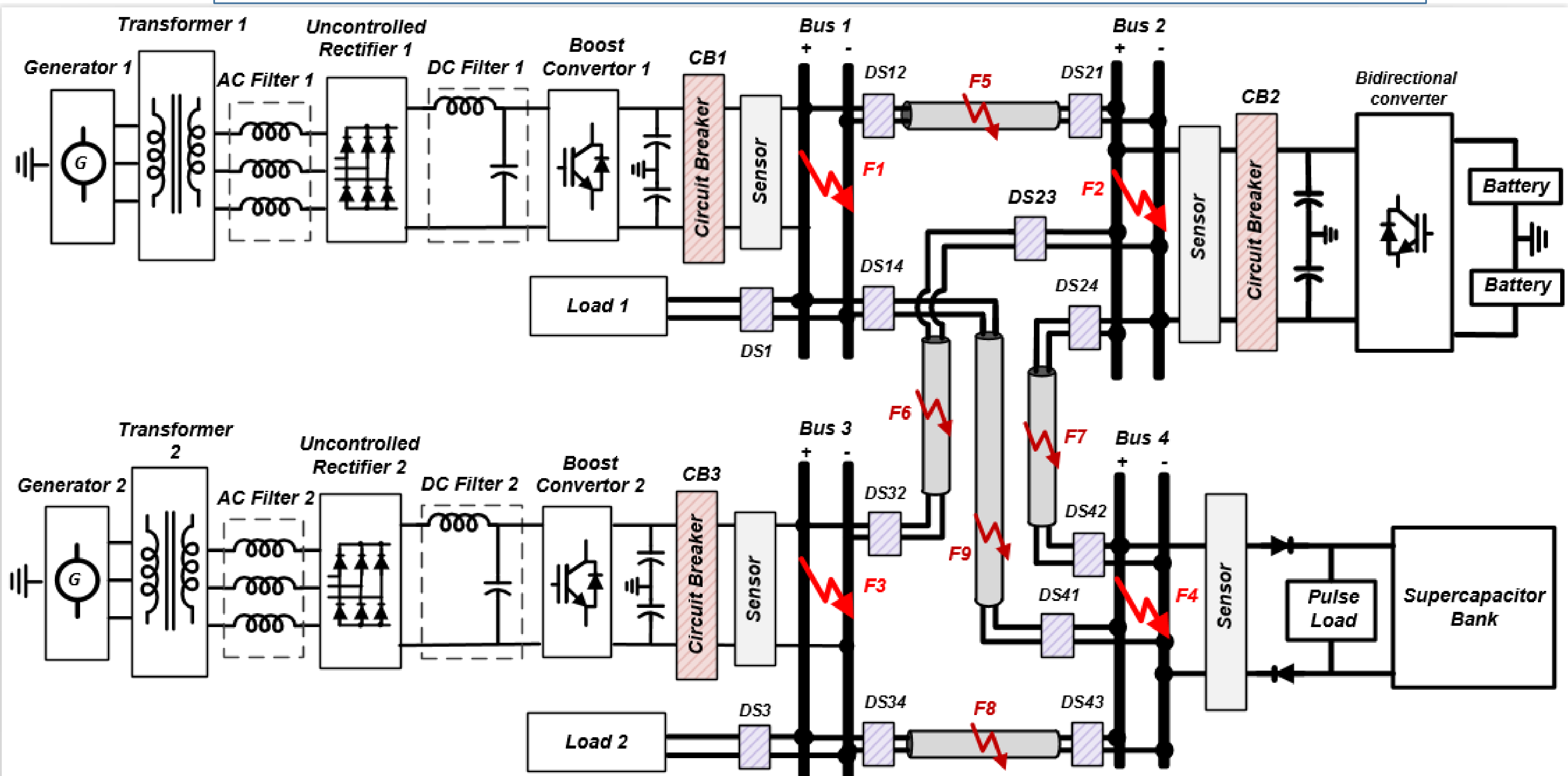
Applications



Return to AC Grid Components

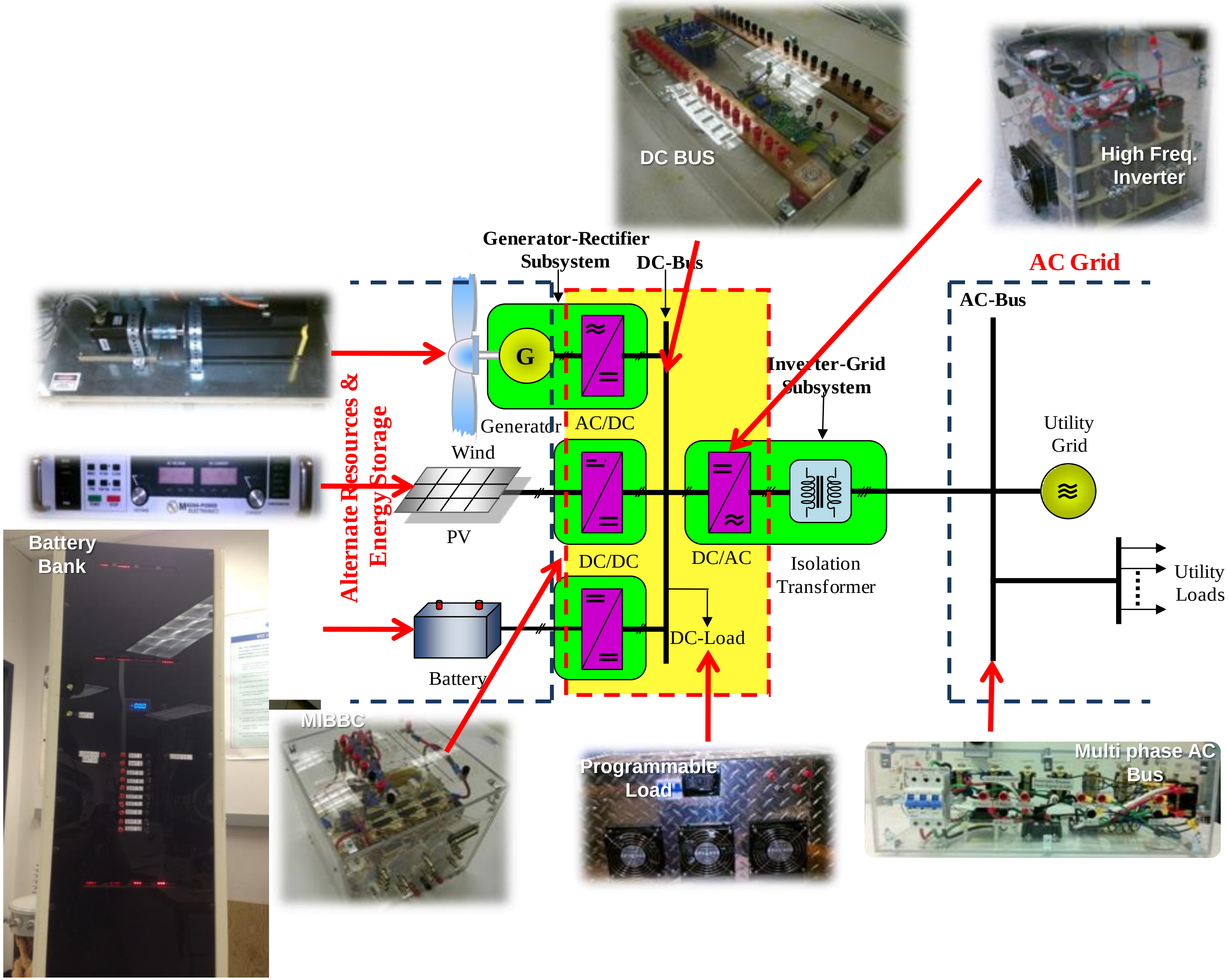
DC System Monitoring for Protection Purpose

A schematic diagram of the hybrid dc microgrid for Protection study



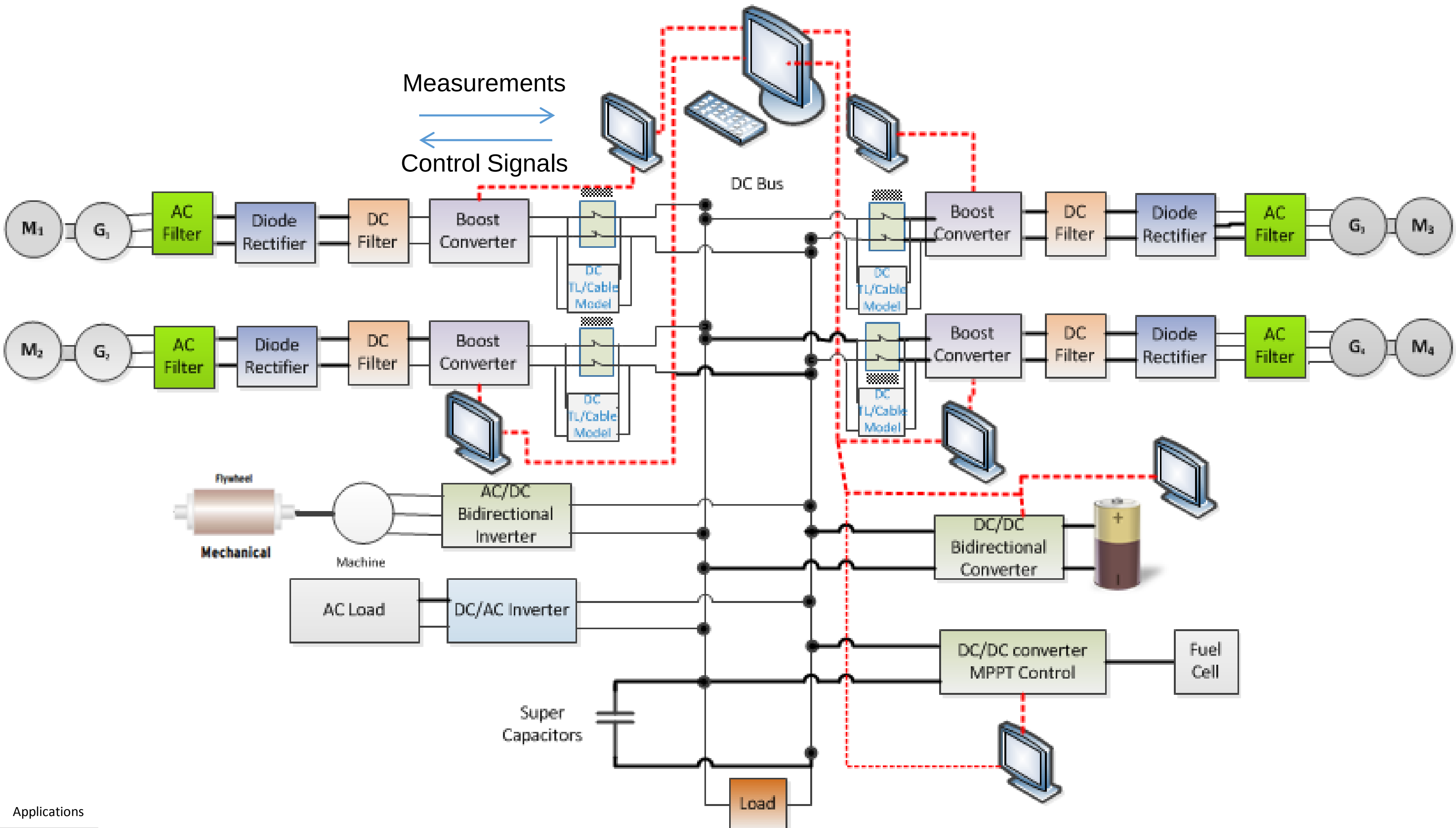
Next

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



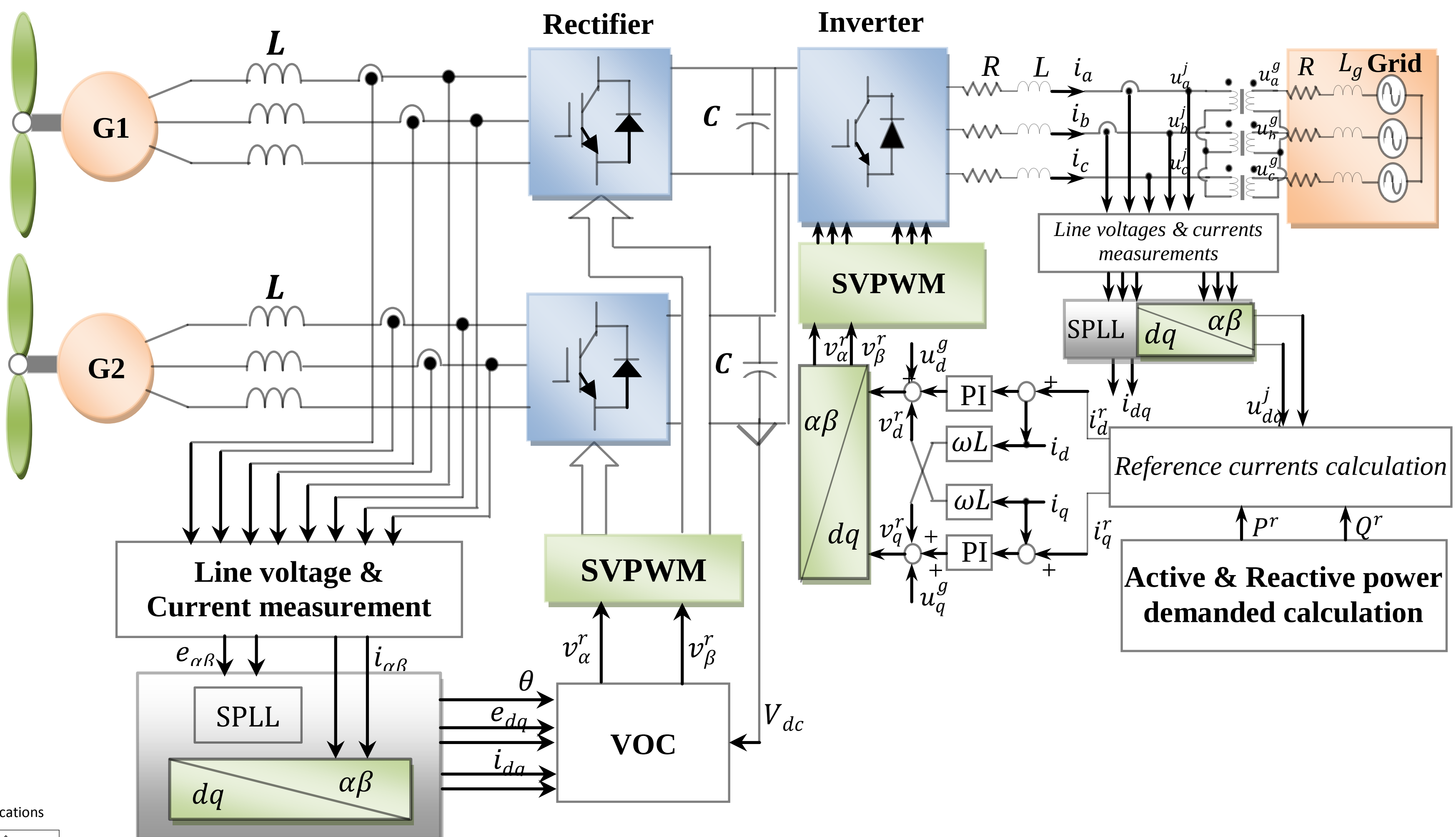
Applications

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



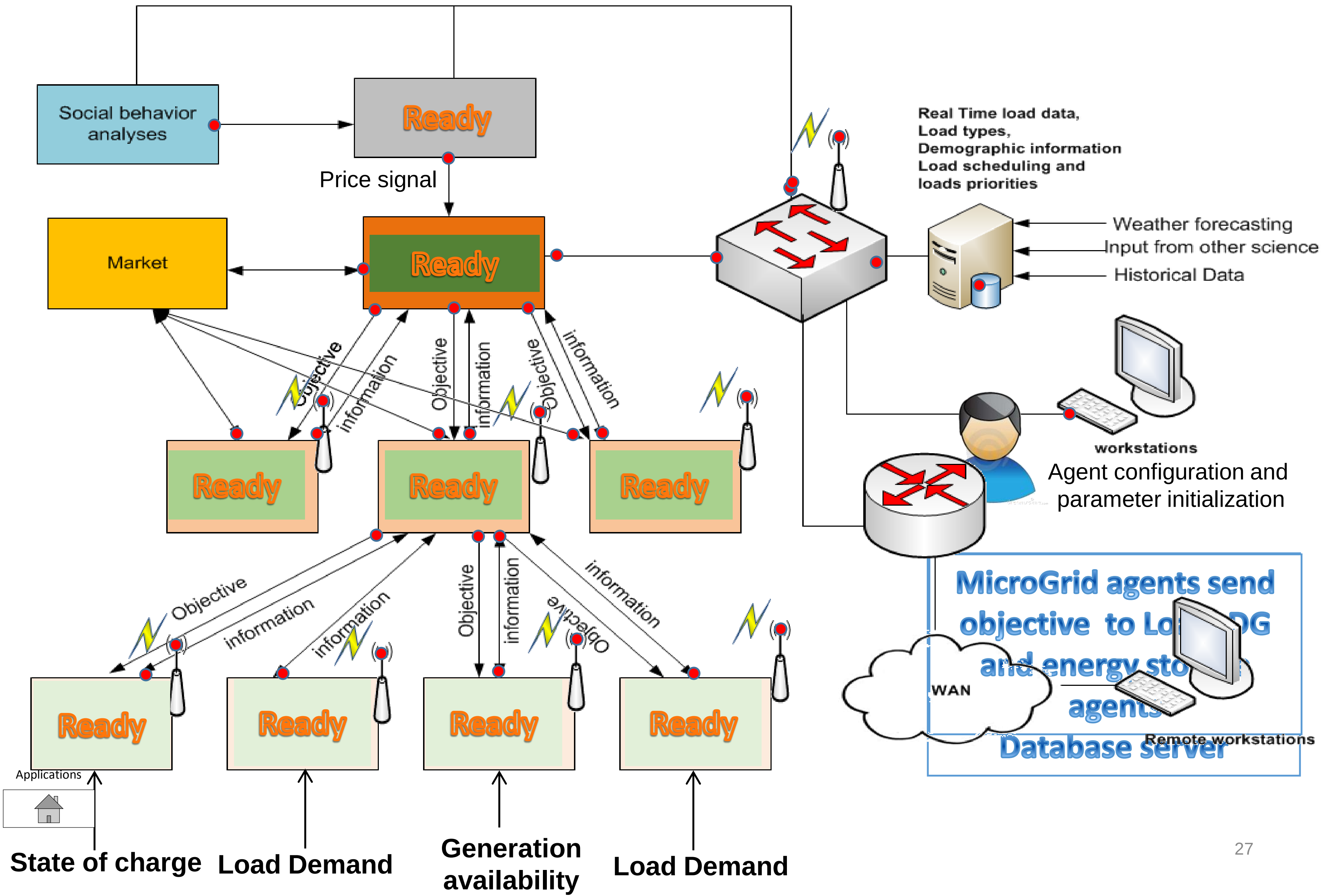
Applications

Schematic Diagram of the Modular WECS Control System Connected to Grid

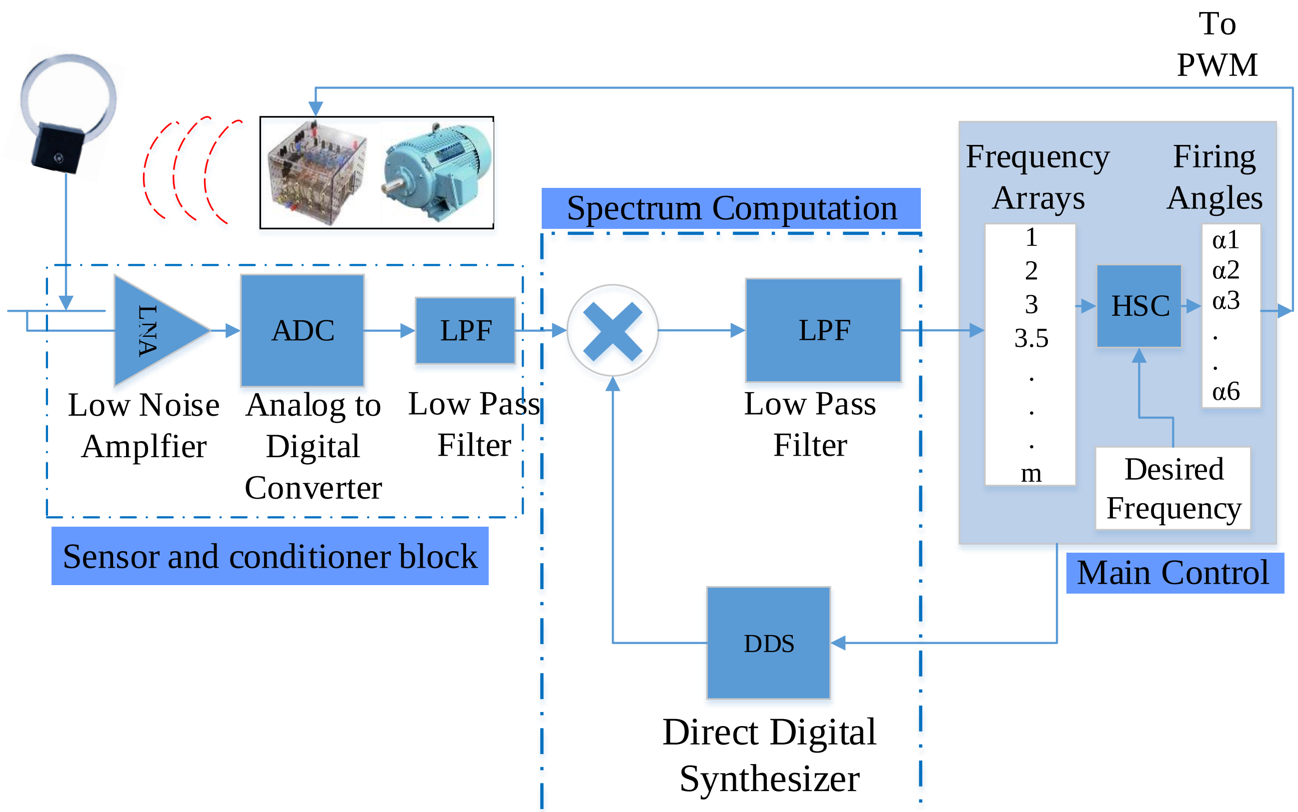


Applications

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



Real-time nondestructive Harmonic and inter-harmonic reduction of electric machine drives



The structure of the controller is composed of 3 blocks; 1) Sensor and Conditioner, 2) Spectrum Computation and 3) Main Control

Conclusion

- Having modular components in an microgrid test bed is a necessary requirement. It will help to extend the system, replace the defective component, and enhance the interconnectivity of components.
- Modules require extended specifications with lowest limitations for their application.
- It will provide environment for developing, integrating, testing and evaluating ideas, components, and recent advancements
- It need standards, to be used, tested or even improved
- Finally it should be designed in a way to achieve full potential of smart grid