FREEDM SYSTEMS CENTER

The Power System Research Group at NC State FREEDM Center

Presented by Dr. Ning Lu

ECE, North Carolina State University

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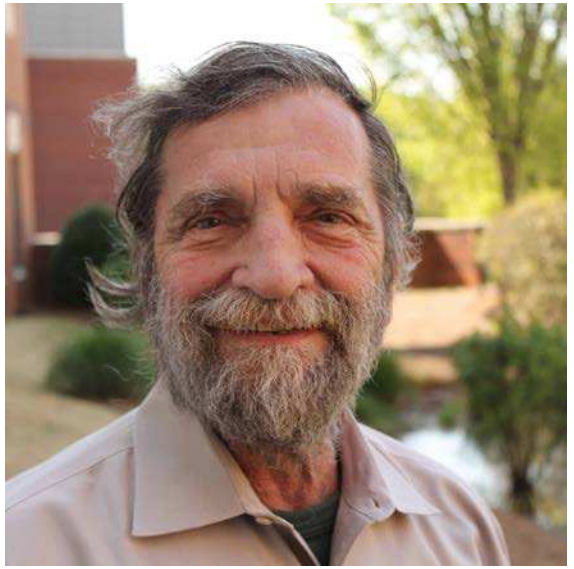
Power Systems Group at NC State






Achievements of the Power Systems Group

7 Faculty

- Offer a full range of power system engineering courses to undergraduate students
- Maintain a Master of Electric Power System Engineering (EPSE) program
- Most of the courses are online
- Short course and tutorials

4 Research Labs

- **GridWrx** (Smart Distribution and MicroGrid)
- Grid Analytics, Markets, Economics, and Systems (**GAMES**) Lab
- Advanced Diagnosis, Automation, and Control (**ADAC**) Laboratory
- **RTDS** (PMU, Wide-area Monitoring & Control)

20+ Ongoing Projects (project volume: 6+ million)

Supports 31 PhD students, **2** post-docs, and **9** undergraduate students

Fully committed to transfer technology to our sponsors

- Patents, software License, Training Modules, etc.
- Software, devices developed are being licensed, transferred, and used by sponsors

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Power Systems Research Sponsors

GridWrx Lab

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An Outline

- Overall Trends in Power Systems Research
- An Overview of the Power Systems Research at NC State
- Future Directions
- Summary of Achievements
- Labs, Facilities and Equipment
- Research Projects and Collaborations
- Future Research Directions

An Overview of Power System Research

- **Generation and Transmission**
  - Electricity Market: Non-discriminative right to provide grid services
    - Allow Storage and PV/Wind to provide services
    - Engage Aggregated Customer-side Services
  - Wide-area Energy Management, Monitoring, and Control
  - Synchrophasor Applications
  - Cyber Security, Resiliency
- **Distribution**
  - Microgrid, Distributed Energy Resources, PV integration, Demand Response
  - New Operation and Planning methods, Cost-benefit Study
  - Resiliency
- **Load Side**
  - Behind the meter distributed energy resources
  - Data Analytics for customer consumption analysis

An Overview of FREEDM Power System Research

- **Generation and Transmission**
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- **Distribution**
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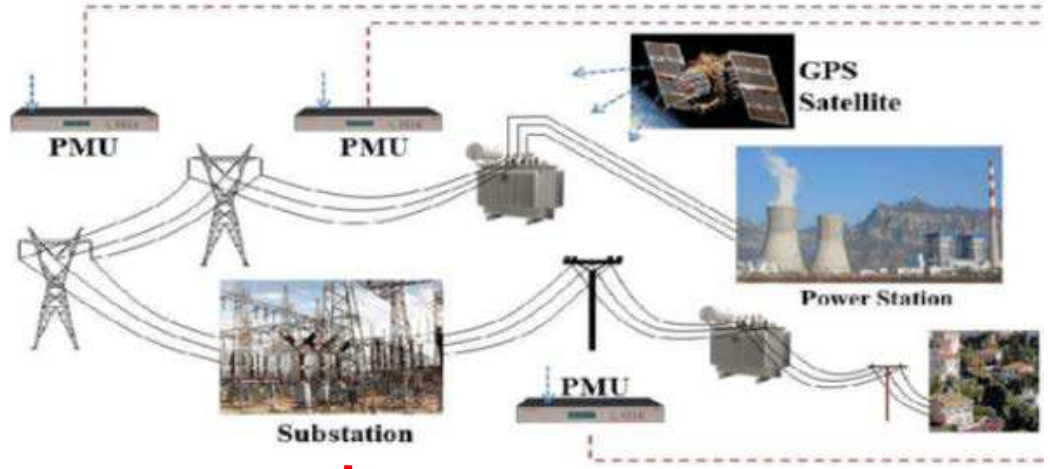
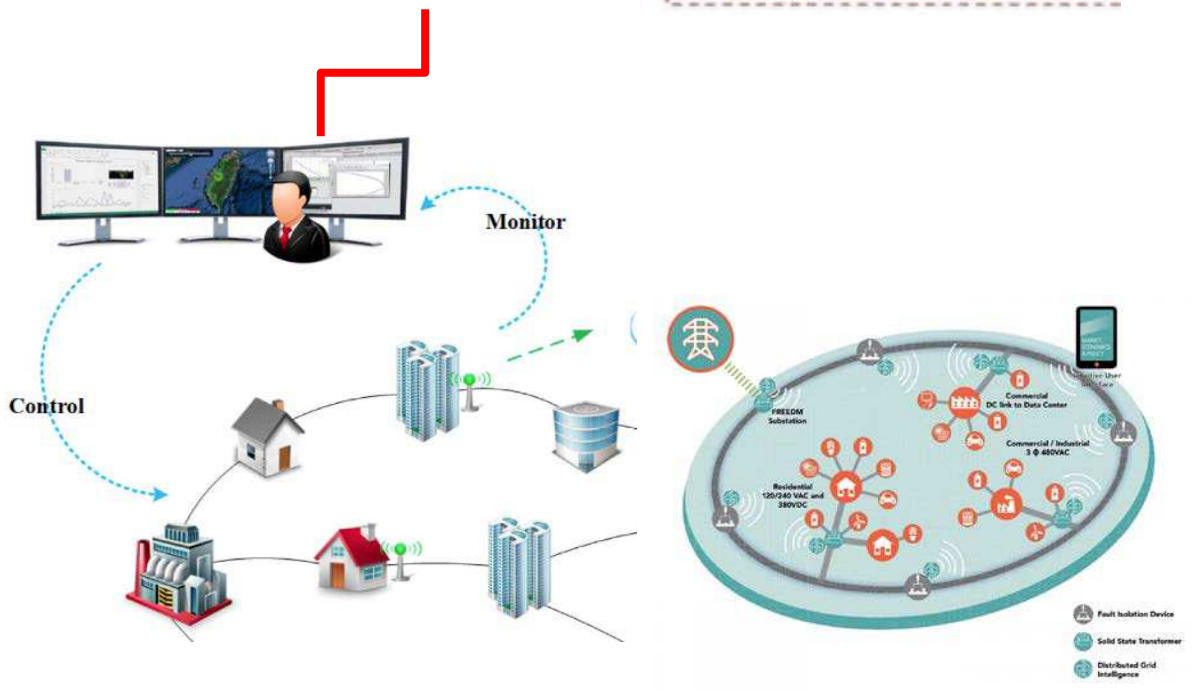
  - Cyber Security, Resiliency
- **Load Side**
  - Behind the meter distributed energy resources (storage, electric vehicles, PV, building energy management)
  - Data Analytics for customer consumption analysis (Load Disaggregation, Revenue analysis, customer grouping, etc.)

FREEDM Power System Research Areas

We share the FREEDM mission to develop **Generation, Transmission, Distribution,** and **Microgrid Technologies** that can lead to major breakthroughs in:

- **Power Grid Simulation and Emulation**
  - Both steady-state & dynamic
  - Hardware-in-the-loop test bed
  - Co-simulate Tran.&Dist.&DER
  - Real-time & Faster-than-real-time
- **Power System Analysis**
  - Wide-area Monitoring and Control
  - Real power & Reactive Power
  - Voltage & Frequency
  - Automated & Optimized Control
  - Centralized & Distributed
  - Cost benefit study
- **Cyber security & Resiliency**
- **Advanced Data Analytics**





Future of FREEDM Power Systems Research

- Generation and Transmission
  - Cyber Security, Resiliency, Real-time Modeling and Control
  - Application of Machine Learning in Wide Area Measurement Systems (WAMS)
- Distribution and Load
  - Data Analytics (Data mining, Machine learning, etc.)
  - Self-generation vs supply-by-the-main-grid
    - Retail Market
    - Economics, utility functions, policy, rates, etc
  - Energy Storage and Electric Vehicles
    - Charging stations
    - New load patterns
- Microgrid

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4 Power System Research Labs

GridWrx (Smart Distribution and MicroGrid)
Grid Analytics, Markets, Economics, and Systems (GAMES) Lab
Advanced Diagnosis, Automation, and Control (ADAC) Laboratory
RTDS (PMU, Wide-area Monitoring&Control)

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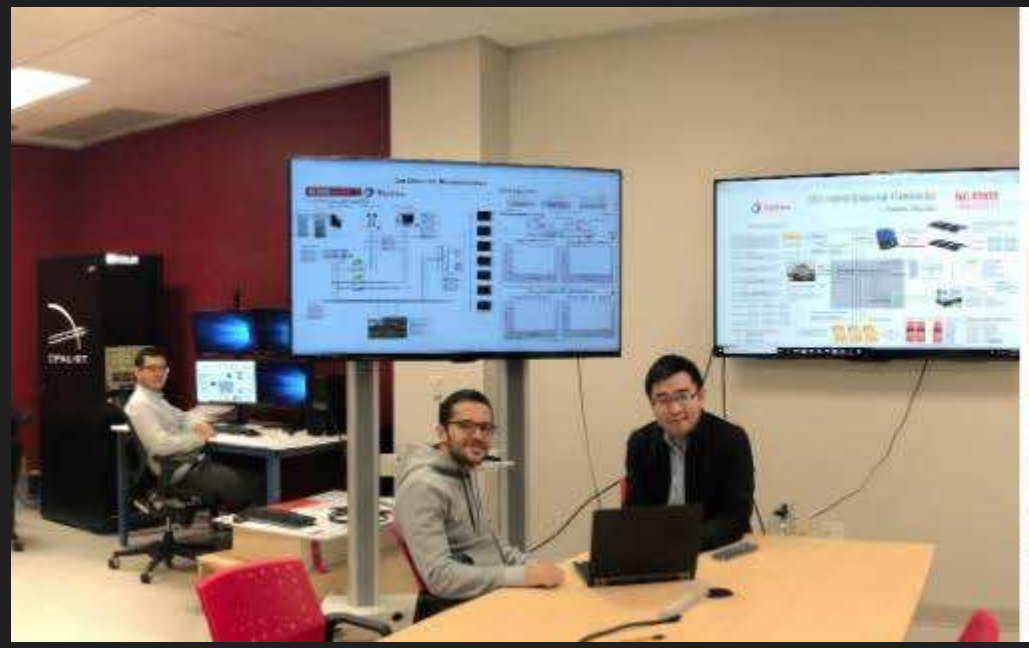
GridWrx Lab



- **15** PhD students
- **4-5** undergraduate
- Visiting scholars

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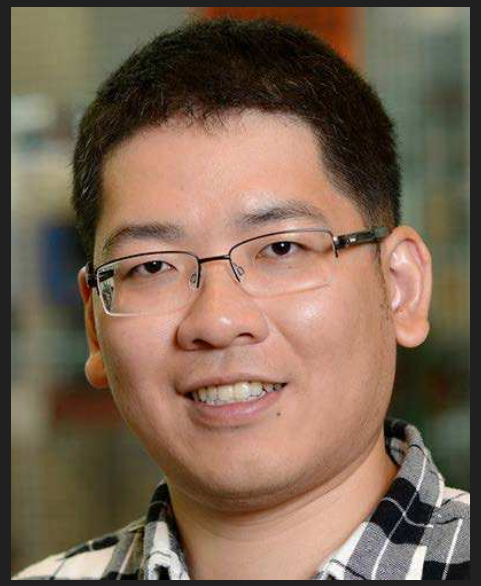
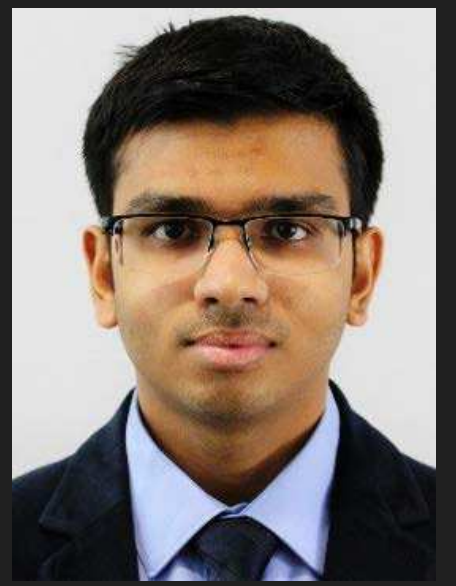
Grid Analytics, Markets, Economics, and Systems (GAMES) Lab




GridWrx Lab: Ongoing Projects and Collaborations

Mesut Baran, baran@ncsu.edu

David Lubkeman
dllubkem@ncsu.edu

Ning Lu, nlu2@ncsu.edu

Wenyuan Tang,
wtang8@ncsu.edu

	Research Project	Sponsor	Collaborator
1	Composite Load Model	CAPER	UNC Charlotte
2	Development of a Novel Passive Microgrid Islanding Events Detection and Control Mechanism	CAPER	Clemson
3	Customer-Oriented Planning Strategies for Active Distribution Systems: Core project for Center for Advanced Power Engineering Research	CAPER	Clemson
4	A cost/benefit based method to assess the economic value of DGs on a utility system	CAPER	UNC Charlotte
5	Control, Optimization, and Market Design for Residential PV-Storage Systems	CAPER	UNC Charlotte

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wtang8@ncsu.edu

	Research Project	Sponsor	Collaborator
6	Economical Data-fused Grid Edge Processor (EDGEPRO) for Future Distribution Grid Control Applications	DOE	ABB
7	Enabling high penetration of distributed PV through the optimization of sub-transmission voltage regulation	DOE	PNNL, Duke Energy, GE, VCC Control
8	Developing a Path Forward for the Integration of the Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT) into Energy Management Systems (EMS)	DOE	PNNL &ABB&NCSU
9	Photovoltaic Analysis and Response Support Platform for Solar Situational Awareness and Resiliency Services	DOE	PNNL, Strata, NYPA, Roanoke, OPAL-RT
10	NSF CyberSEEs Type 2: Cyber-Enabled Water and Energy Systems Sustainability Utilizing Climate Information	NSF	
11	Data Analytics Using Advanced Meeting Data	ElectriCities	Utility, Co-op
12	Hybrid Energy Management System Development	Total S.A.	Private Company

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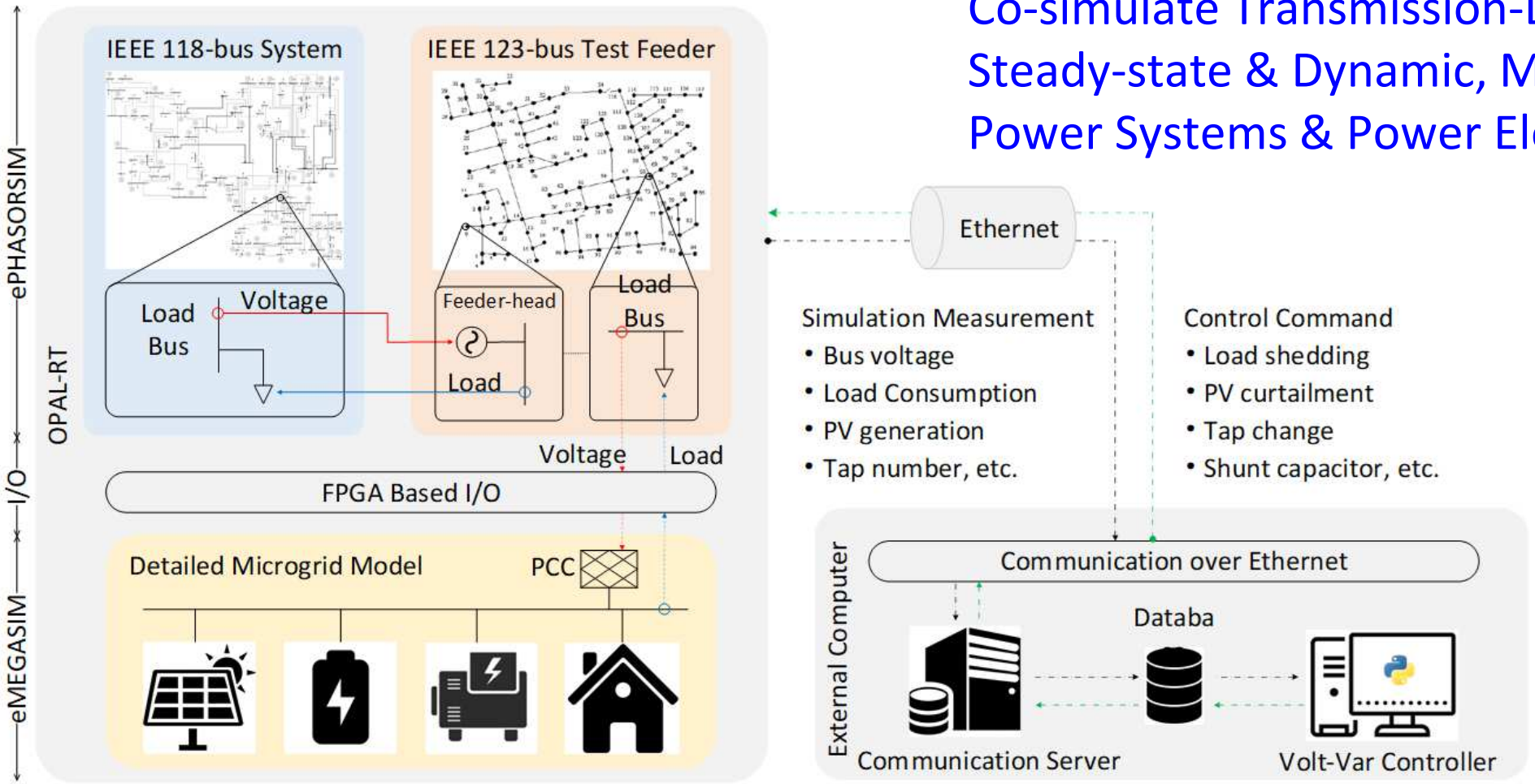
Sponsors of our Research Programs

GridWrx Lab

Development of a Co-Simulation Platform

- Develop, test, and validate smart grid technologies, resiliency, cyber Security
- Run faster-than-real-time to conduct cost benefit Studies

Co-simulate Transmission-Distribution-DER
Steady-state & Dynamic, Multi-rate
Power Systems & Power Electronics



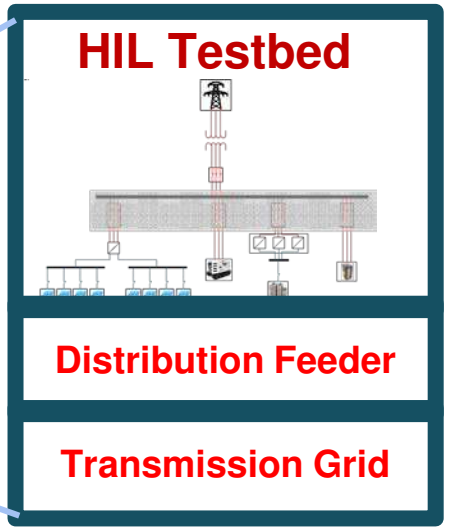
Hybrid Real-time HIL Test Bed

Communication Links

External Microgrid Controller and Energy Management Interface

OPAL-RT

Hardware-in-the-loop (HIL) Simulation of the Lyon Test System



Hardware

Loads

Controller

Energy Storage

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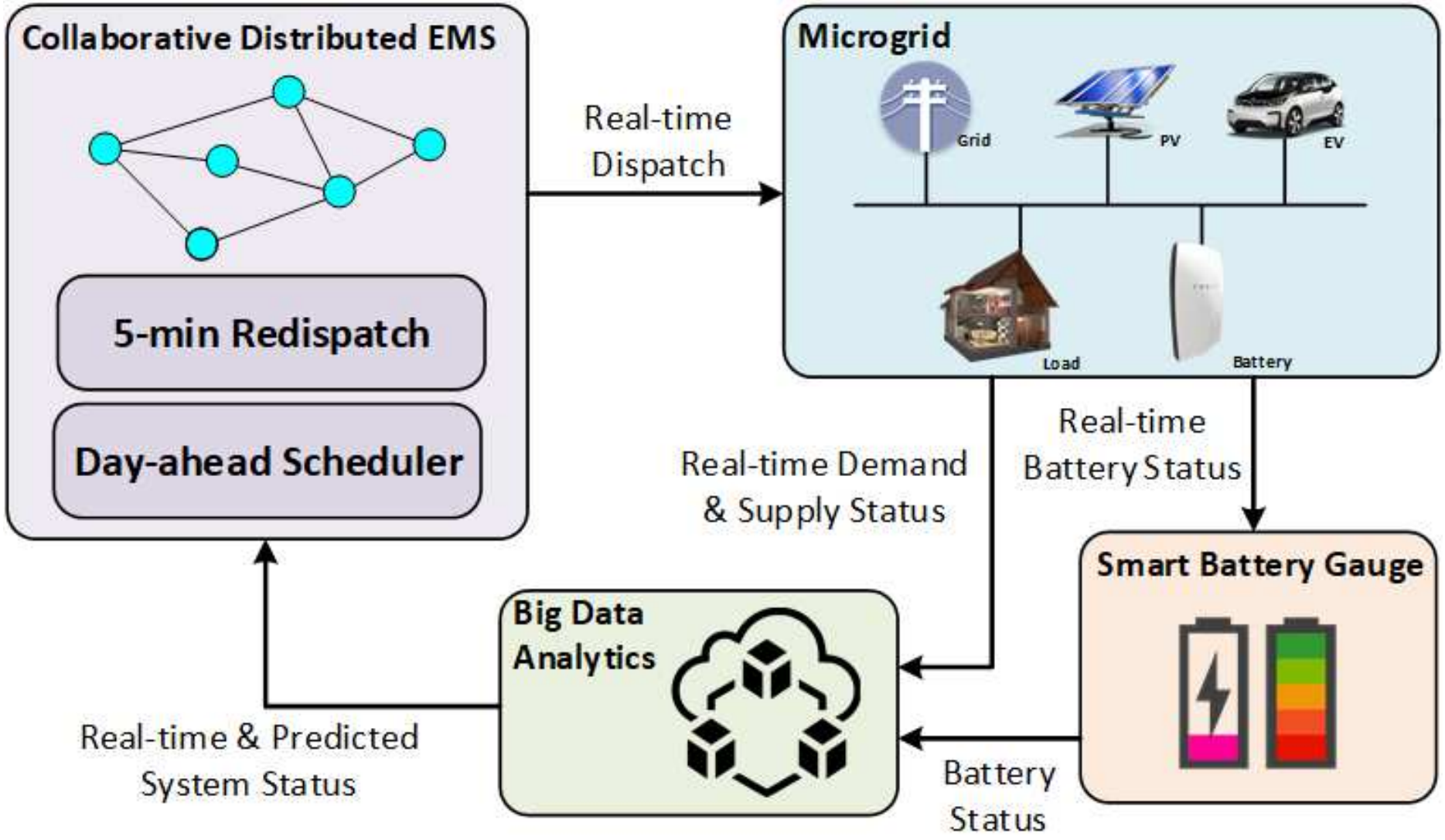
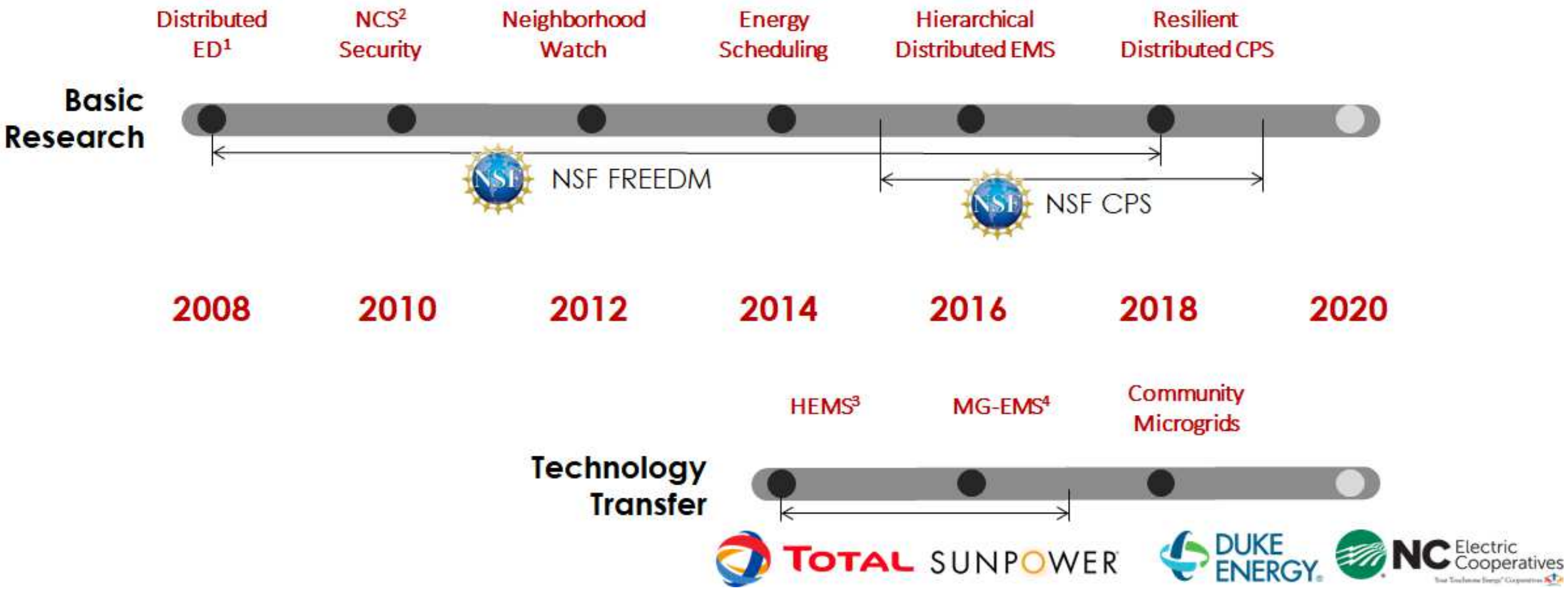
Advanced Diagnosis, Automation, and Control (ADAC) Laboratory

ADAC LAB

Big Picture


Collaborative Distributed EMS
5-min Redispatch
Day-ahead Scheduler
Real-time Dispatch
Microgrid
Grid
PV
EV
Load
Battery
Real-time Demand & Supply Status
Real-time Battery Status
Smart Battery Gauge
Big Data Analytics
Real-time & Predicted System Status
Battery Status

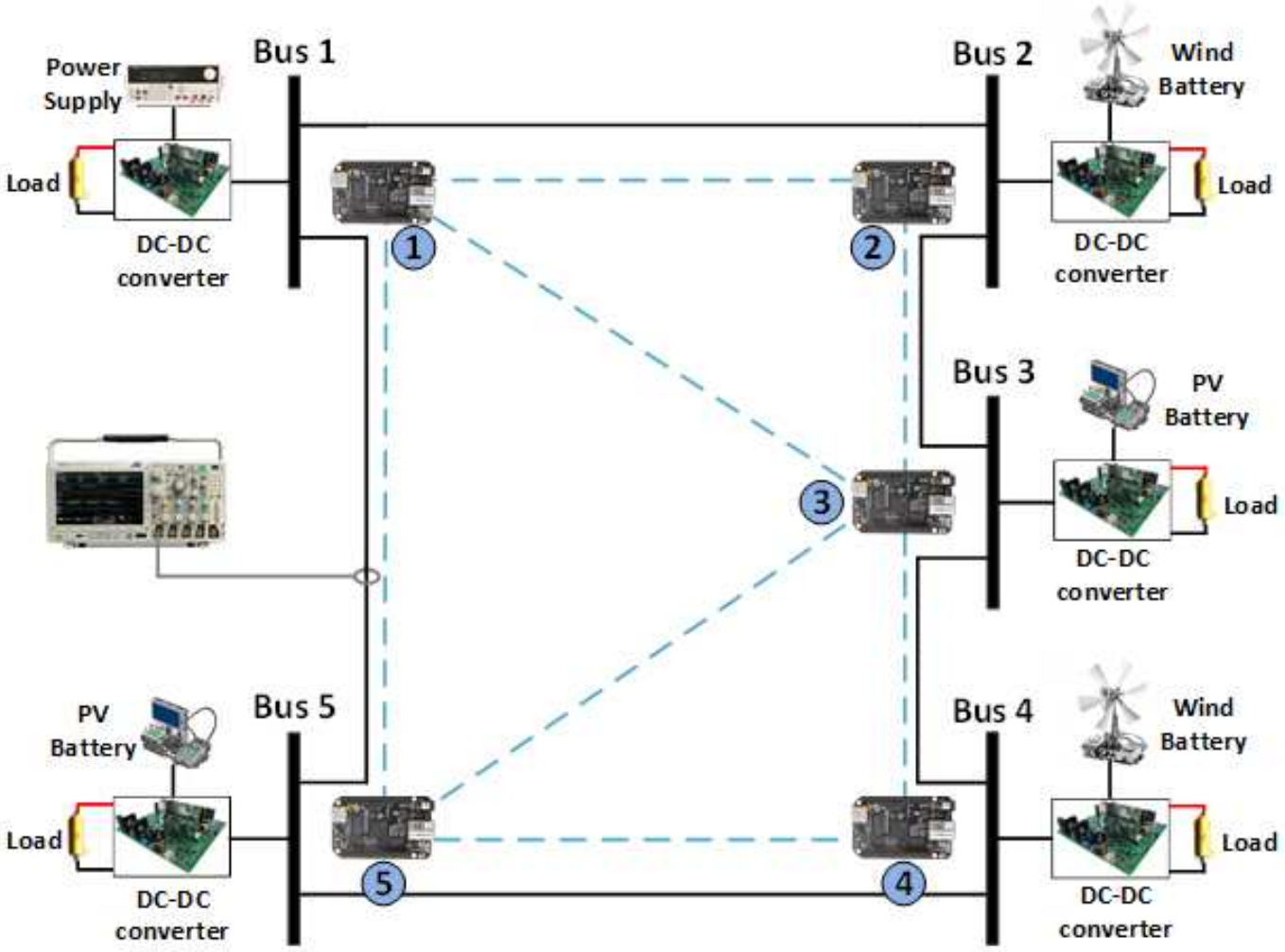
Timeline for Collaborative Distributed EMS



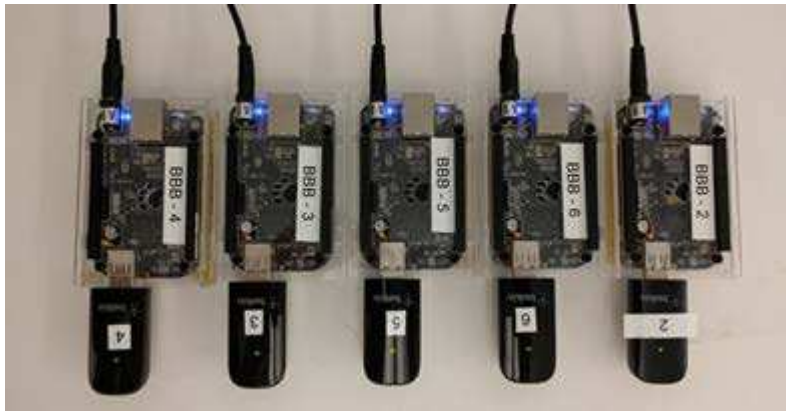
[1] Economic Dispatch; [2] Networked Control System; [3] Home Energy Management System; [4] Micro-Grid Energy Management System

Cyberphysical DC Microgrid Testbed

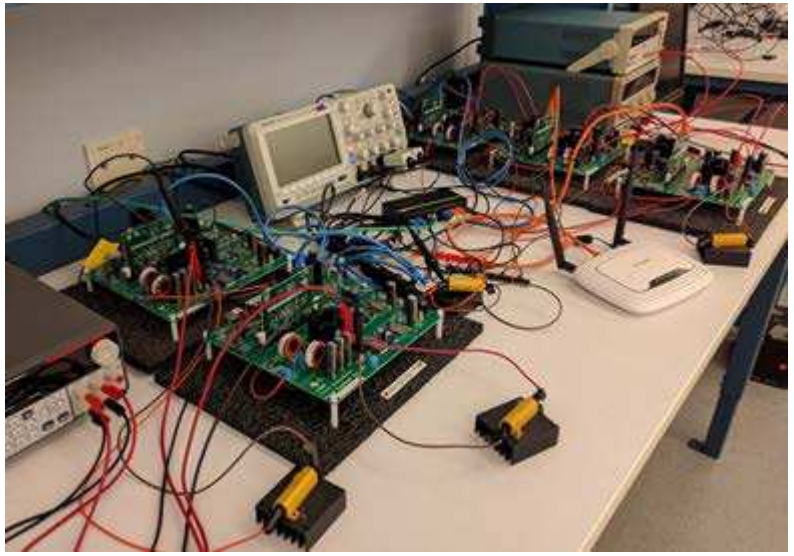
System Diagram:



Cyber layer:



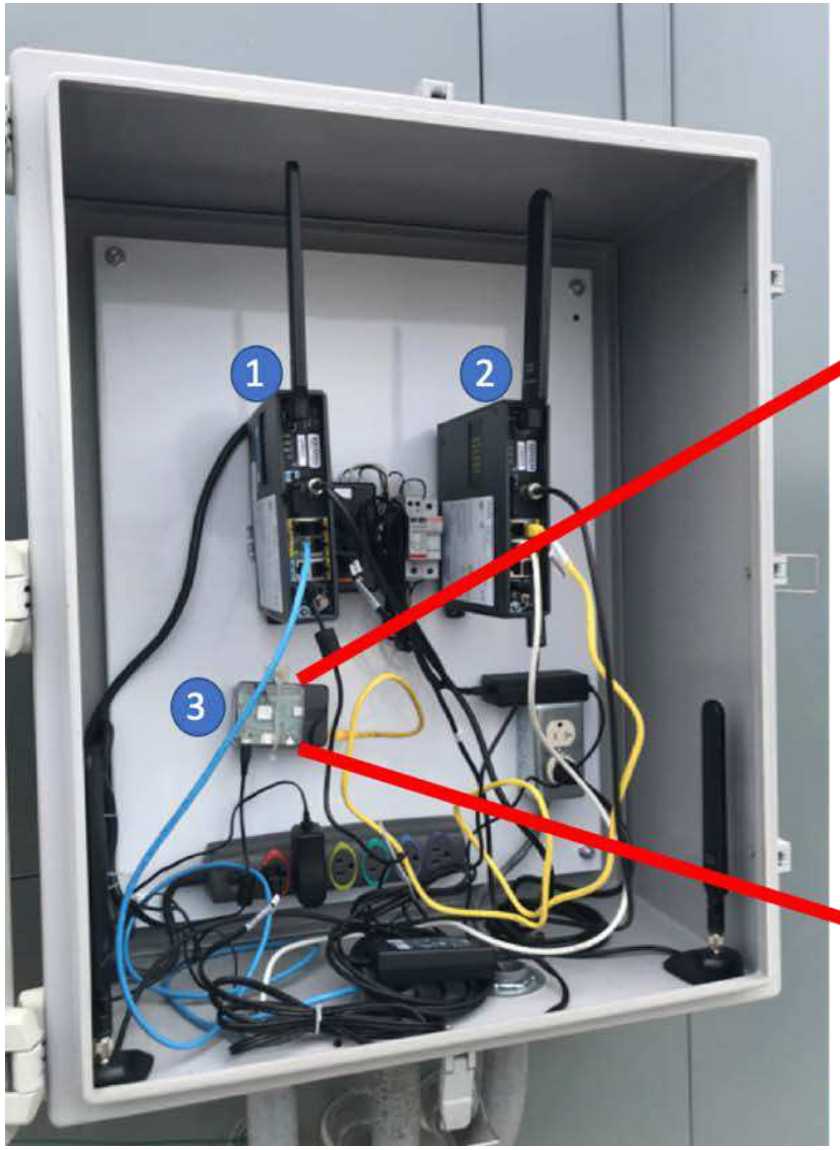
Physical layer:



Timeline for Smart Battery Gauge

SAMSUNG TOTAL HUAWEI DUKE ENERGY NC Electric Cooperatives

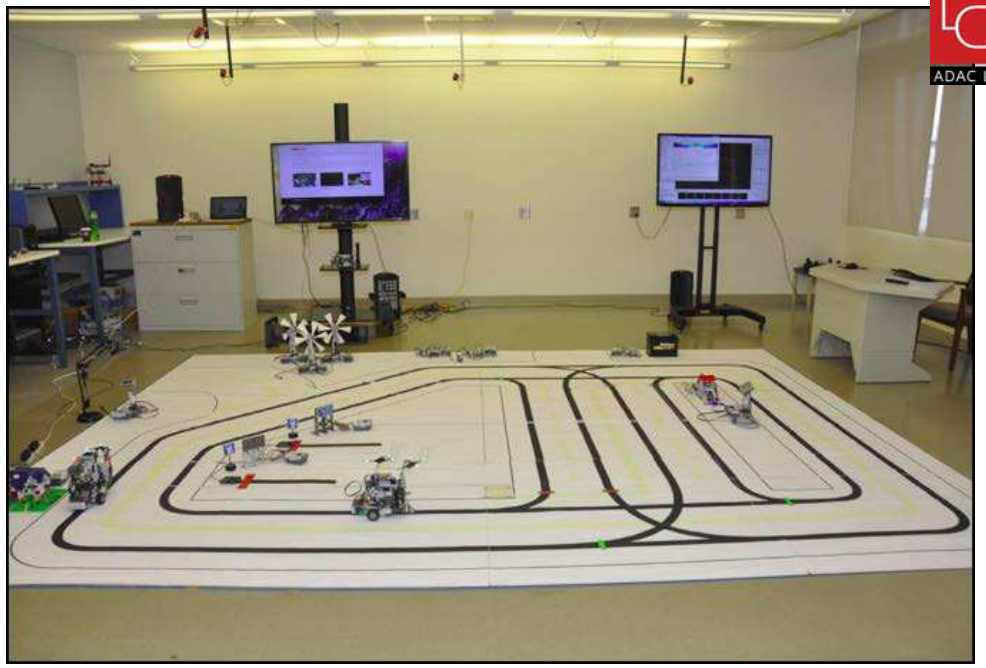
Smart Battery Gauge (SBG) Implementation

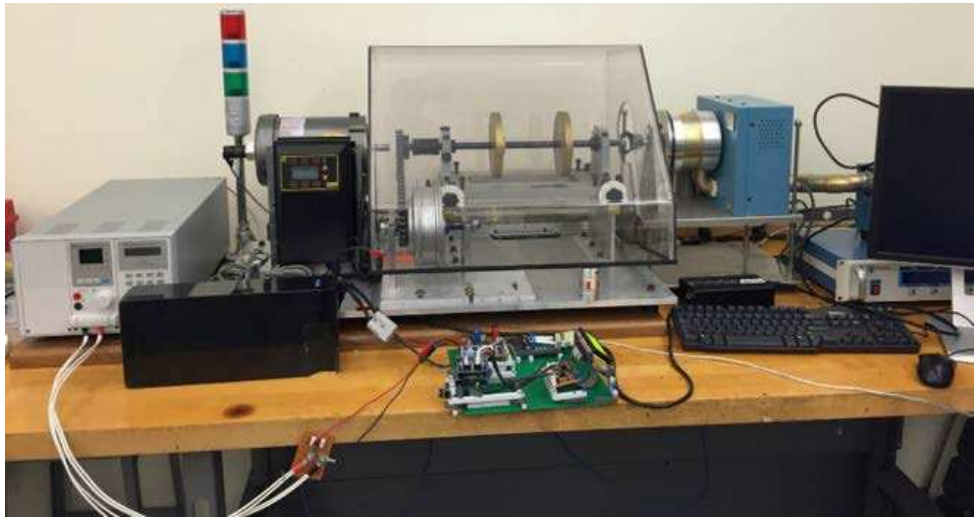


1. Router for remote monitoring of Microgrid System
2. Router to interface SBG with Microgrid System for Data Acquisition
3. Router to interface SBG with Microgrid System

Facilities at ADAC Lab

- Battery Testing Bench
- Humidity and Temperature Chamber
- PHEV Emulator
- Intelligent Space (iSpace)





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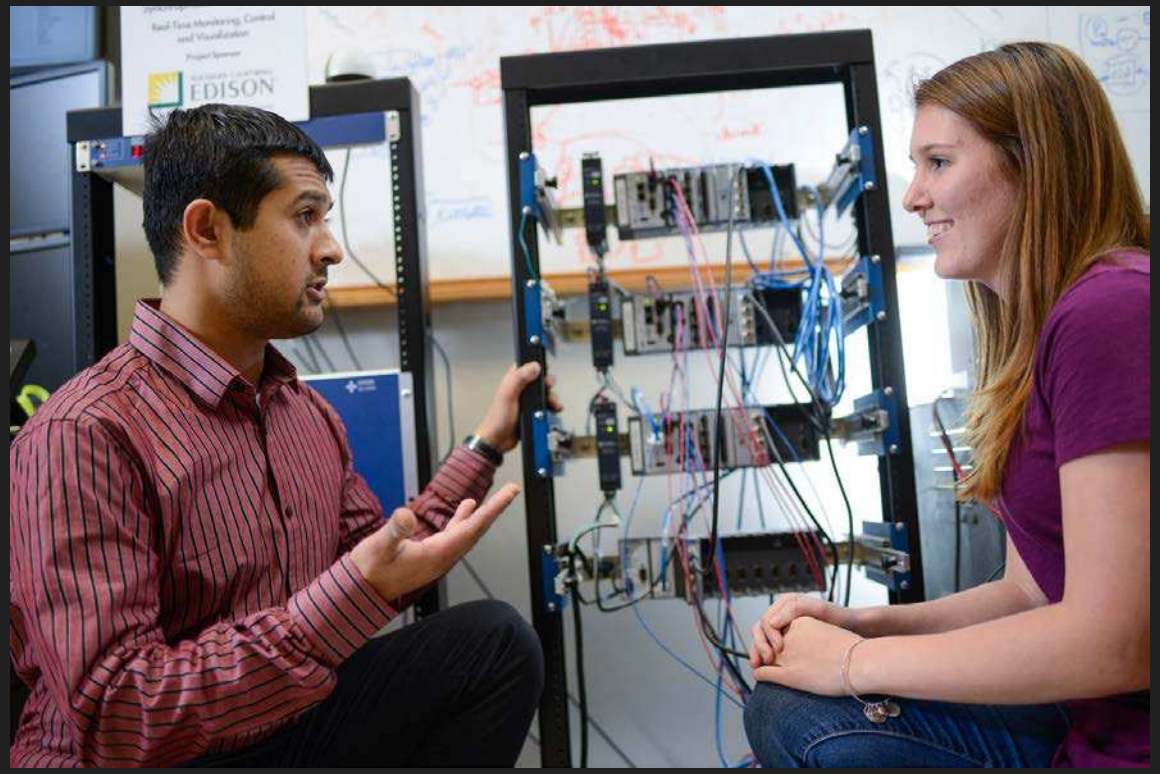
RTDS Lab



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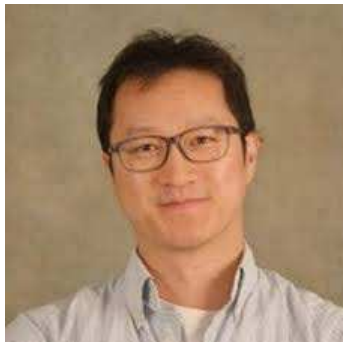
RTDS Lab

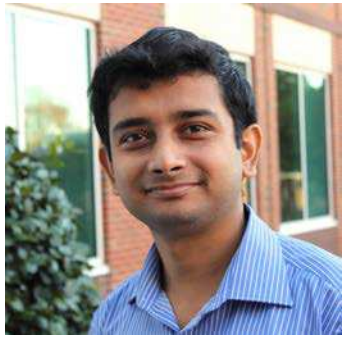
Directed by Dr. Aranya Chakrabortty

Associate Professor
FREEDM System Center

8 PhD students, 2 postdocs:

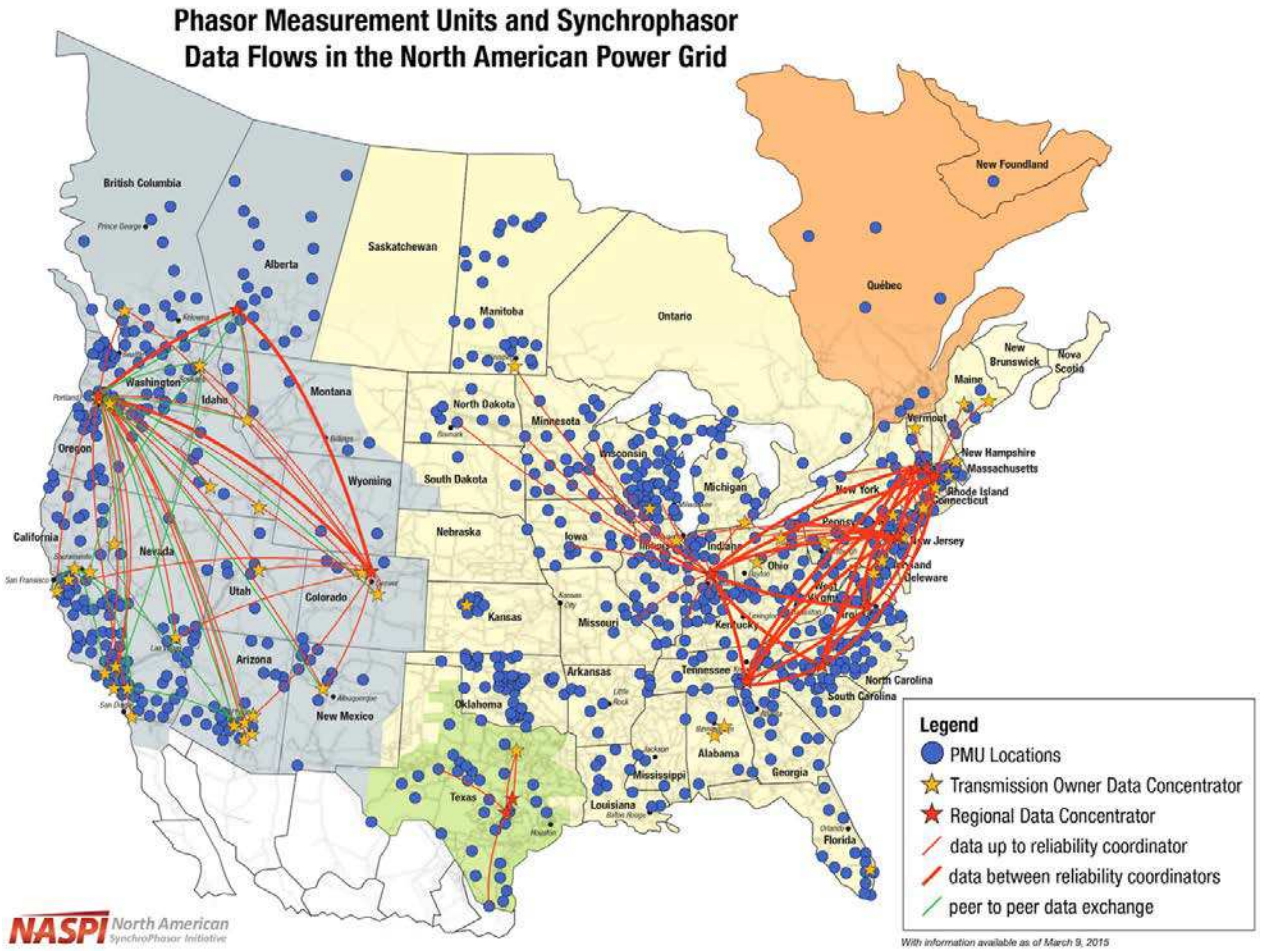






RTDS Lab - Ongoing Research

- Wide-area monitoring and control using Synchrophasors
- System identification using PMU data
- Co-design of communication and control for WAMS
- Cyber-security of Synchrophasor applications
- Distributed optimization
- Application of machine learning and control in transmission and distribution grids, micro-grid controls



RTDS-PMU based WAMS Testbed

Hardware & Software Facilities:

- Two racks of RTDS
- RSCAD – software to develop models in RTDS
- GTAO – hardware interface of Gigabit Transceiver Analog Output to generate voltage and current waveforms to the PMUs
- GTNETx2 – Gigabit Transceiver Network interface card to communicate with remote station. Multiple protocols (TCP socket, DNP) IEEE 754 floating-point and integer type.

PMU – 10 units: 3 SEL-421, 2 SEL-487, 3 National Instruments, 2 ABB

GPS – SEL-2407 Satellite-Synchronized Clock

RTDS set-up with multi-vendor PMU racks

ExoGENI-WAMS Cyber-Physical Testbed

DOE NETL Project:

The RTDS-WAMS testbed has been recently integrated with a local cloud computing network called ExoGENI

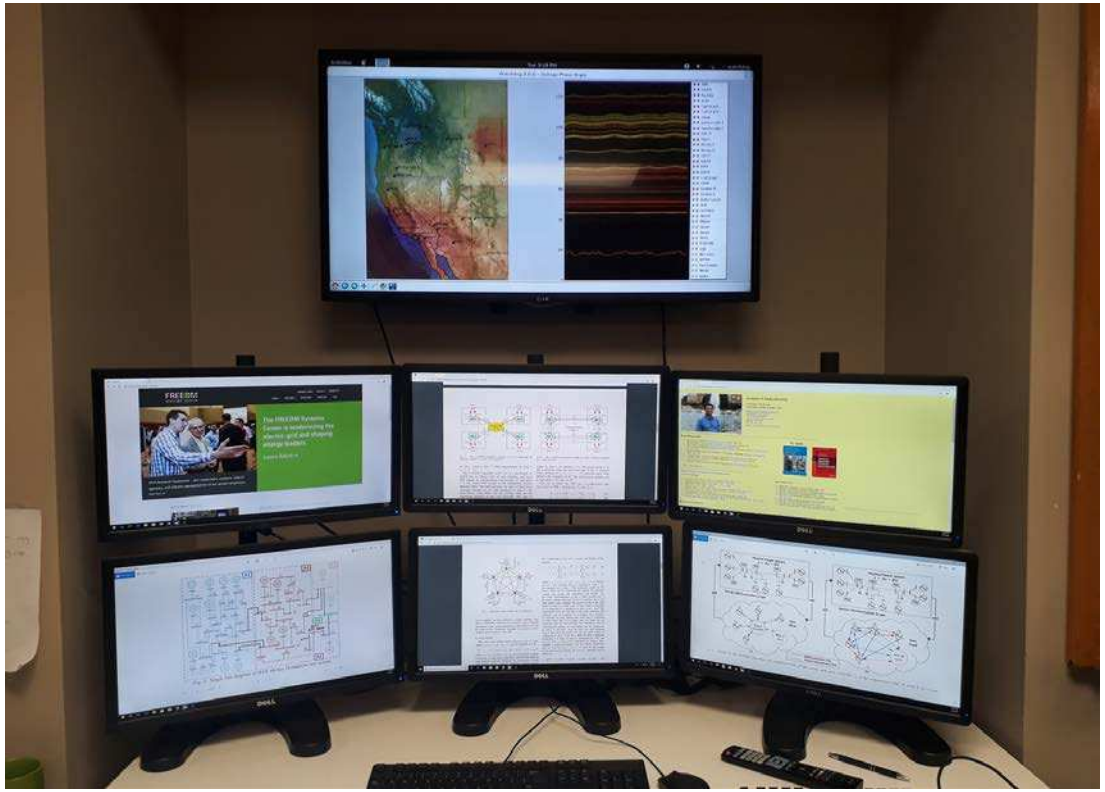
Bring Concepts of Cloud Computing and Software Defined Networking into Research of Wide-Area Monitoring and Control with PMU data

Benefits from the physical subsystem

1. Accessing of real PMU measurements due to privacy and non-disclosure issues
2. Not sufficient for studying dynamics of the entire system due to limited coverage

Requirements of the cyber subsystem

1. high-speed virtual networking
2. high performance networked cloud computing
3. virtualization and data management



WAMS visualization console

ExoGENI-WAMS Testbed

- Physical subsystem – Hardware-In-Loop Framework (RTDS + PMU-based WAMS)
- Cyber subsystem – Networked Cloud Computing Platform (ExoGENI)

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Ongoing Projects and Applications

1. Data analytics on PMU data for wide-area oscillation monitoring, voltage stability, and state estimation (recent project with Duke Energy & SAS)
2. Distributed WAMS control using cloud-computing and software-defined networking (NSF, DOE)
3. Hierarchical control of frequency and voltage using inverter-based resources (EPRI)
4. Cyber-security of wide-area control (CAPER, NSF)
5. Machine learning based hierarchical control (Army Research Lab)

NSF · DEPARTMENT OF ENERGY · EPRI ELECTRIC POWER RESEARCH INSTITUTE · CAPER Center for Advanced Power Engineering Research · DUKE ENERGY · ARL · NEW YORK STATE OF OPPORTUNITY. NY Power Authority

Please Visit Student Poster Sessions

The poster session has included 51 peer-reviewed posters introducing our research results in the following research areas:

- Electric Transportation (13)
- Modern Power Systems (10)
- Renewable Energy Systems (19)
- WBG Power Electronics (9)