FREEDM Industry Advisory Board Minutes
December 12, 2017
8:30 am – 3:30 pm US eastern

This report summarizes the discussions of a face to face meeting of the Industry Advisory Board with research faculty from NC State, Florida State and Missouri S&T. The main goal of this meeting was to get industry representatives and faculty together to discuss overall mission and vision of the Center and to share research ideas. There were no official votes by the IAB at this meeting.

Attendees

Name	Organization	Email
Arnie de Castro	SAS	Arnie.deCastro@sas.com
Bob Yanniello	Eaton	RobertYanniello@eaton.com
Bruce McMillin	Missouri S&T	ff@mst.edu
Bruce Rogers	EPRI	brogers@epri.com
Darel Reed	Toshiba	Darel.Reed@toshiba.com
David Lubkeman	NC State	dllubkem@ncsu.edu
Douglas Hopkins	NC State	DCHopkins@ncsu.edu
Hongrae Kim	Eaton	HongraeKim@eaton.com
Iulian Nistor	ABB	iulian.nistor@us.abb.com
James McBryde	Eaton	JamesMcBryde@eaton.com
Jared Gregory	Sensus	jared.gregory@xyleminc.com
Joe Grappe	Duke Energy	joseph.grappe@duke-energy.com
John Shea	Schneider Electric	john.shea@schneider-electric.com
Ken Dulaney	NC State	kadulane@ncsu.edu
Kevin Chen	Duke Energy	Ke.Chen@duke-energy.com
Maziar Mobarrez	NC State	mmobarr@ncsu.edu
Mesut Baran	NC State	baran@ncsu.edu
Mischa Steurer	FSU	steurer@caps.fsu.edu
Mo-Yuen Chow	NC State	chow@ncsu.edu
Ning Lu	NC State	nlu2@ncsu.edu
Pam Carpenter	NC State	ppcarpen@ncsu.edu
Rebecca McLennan	NC State	rhmclenn@ncsu.edu
Roy Charles	NC State	racharl2@ncsu.edu
Sandeep Bala	ABB	sandeep.bala@us.abb.com
Scott Peele	Duke Energy	scott.peele@duke-energy.com
Srdan Srdic	NC State	ssrdic@ncsu.edu
Terri Kallal	NC State	tlkallal@ncsu.edu
Wensong Yu	NC State	wyu2@ncsu.edu
Wente Zeng	Total	wente.zeng@total.com
Wenyaun Tang	NC State	wtang8@ncsu.edu

Center Update
Attendees briefly introduced themselves and Ken presented an update on recent Industry Program activities. His slides are in Appendix A. He highlighted activities with several members to demonstrate the breadth of interactions. He also indicated which companies had recently dropped membership and provided some background information on each. Company recruiting efforts continue as well as general marketing efforts. He concluded by listing recent inventions that were not funded through NSF but highlighted the broad range of developments among Center researchers.

A key question raised during Ken's presentation was regarding financials and budgets. Members have asked several times in the past for a center level budget and explanation of how the Center plans to meet expenses after NSF funding. Ken provided some background on financial statements. The member response was that this information is critical to their continued participation and support of the Center.

Industry Presentations
Several industry members had agreed to briefly present updates on their business or general updates on their particular industry.

Scott Peele, Duke Energy, is a field engineer and discussed power quality issues for Duke customers. He noted that they have installed 3,000 MW of new PV but have not decreased peak system demand. For example, the winter peak so far was set the morning of this meeting at 6 am when there is no solar production. Ramp rates to backstop intermittent PV output require natural gas units. Only solution seems to be storage on a massive scale for intermittency and new rate structures to change customer behavior and shift peak to match solar production. He also noted that day ahead load forecasting is critical to economical dispatch, but now a summer storm that normally drops temperature and reduces system load can actually cause an increase in load due to PV shading. This can create emergency situations for utilities.

Bruce Rogers, EPRI, manages a research portfolio for US and international customers. He wondered about the new normal for distribution planning. Utilities cannot forecast load without models and models begin customer behavior. However, customers are adopting new technologies that change load patterns. Adoption is not uniform and depends on wealth and neighborhood demographics. Distribution load models are now much more location dependent. This is forcing utilities to include scenario planning for both transmission and distribution. He feels that utility transitions to something like FREEDM will be piecemeal rather than wholesale. Other industry members agreed and noted problems incorporating legacy equipment with new system designs. Bruce said there is a real need for low cost sensors for distribution equipment.

Jared Gregory, Sensus, is a product engineer for their electric sector. He followed Bruce comments noting that in Hawaii, only the wealthy are installing PV and forcing non-PV owners to bear more of the fixed costs of grid support. Regulators reacted by placing caps on total PV allowed to connect and also granting utility control of power factor to grid tied inverters. Jared raised another question: how long with utility commissions allow residential PV charging anywhere?

John Shea, Schneider, gave a brief slide presentation discussing their work in energy management for commercial buildings. He specifically discussed the new product that was tested in FREEDM's lab at NC State. John's slides are included in Appendix B.

Sandeep Bala, ABB, manages a power electronics research group. ABB highly values the student training and the research production from FREEDM. They value the disruptive ideas from universities but also hope that students had more chances to work on real problems to better prepare them for industry employment.

Darel Reed, Toshiba, is in business development for a line of Toshiba battery products. He presented some information on a new lithium niobium chemistry that drastically improves energy density for existing Toshiba products. Expect this to be available in two years. He also noted that Toshiba now offers a high power DC fast charger for electric busses.

During the industry presentations, there was some discussion about standardization across utilities. We noted that each state operates under a utilities commission that sets the rules for that state. These rules vary from state to state and affect utility decisions differently. There are some efforts at technology standardization like through IEEE or IEC, but there are no efforts towards a standard microgrid controller or standard storage interface for example. There are also issues communicating between protocols of old and new equipment. We briefly discussed OpenFMB as a way to address this problem.

Solar PV management was another general topic. At some point, Duke Energy was granted VAR control for some of their grid tied inverters. However, this resulted in excessive cycling of other equipment like cap banks and tap changers. So they adjusted all the inverters to unity power factor and kept them there. FSU developed algorithms to address dynamic PV coordination issues and Mischa agreed to share the paper. That report was shared separately with attendees.

Center Vision

Education and Diversity are valued programs and are integral to continued Center operations. Dr. Pam Carpenter briefly discussed the impact of K12 outreach and workforce development programs. Dr. Roy Charles then presented on the value of diverse perspectives in research. Dr. Carpenter's slides are included as Appendix C.

Ken then described the process for the Vision discussion. Attendees agreed that keeping the group together was a better way to discuss the issues than dividing into smaller breakouts. He started by reminding us that our Mission answers “Why are we here?” and the Vision answers “Where are we going?”

Responses to “Why are we here?” included:

- Talent: Graduates make excellent new hires.
- Thought Leadership: More than research papers, this concept includes pushing the FREEDM concept through presentations, general purpose articles and conference speeches.
- Innovation: New ideas in our areas of expertise.
- Lab and Facilities: Members valued the physical assets available through their membership.
- Foster collaborative research: Working with multiple universities in collaboration.

Vision statements can include BHAG’s (Big, Hairy, Audacious Goals). Samples for these included “Energy for Everyone” and “A Global Power Electronic Grid.” We also discussed the potential of Transactive Energy and how FREEDM is really a framework capable of accepting new grid technologies as they are developed.

The current FREEDM vision statement is:

> The FREEDM System vision is to create the Energy Internet that allows renewable energy, storage, and usage to be added and controlled seamlessly at the distribution level of the power system.

We had some debate over the term Energy Internet. Attendees liked the analogy. The internet is now being used for applications that were not conceived 20 years ago. Likewise, the Energy Internet allows for future technologies to “plug in” and is highly adaptable. Devices connect seamlessly to the internet and renewable sources and loads will be able to seamlessly connect to the Energy Internet through the SST paradigm. We also noted how the Energy Internet moves communications to the edge of the grid much like today’s internet has pushed computing to the edge through distributed devices.

Later in the meeting, we debated other research topics that should be incorporated into our vision. Some members encouraged us to include economic aspects of the Energy Internet. If that is included, then we must also address markets and regulatory aspects. The Center currently includes enabling technologies but some felt that we should purposely extend further down the value chain to include device development at the semiconductor level and packaging. Others urged us to include more undergraduates.

We then shifted the discussion to vision for Center operations. Attendees agreed we should continue our Education programs since graduates are a key reason for many members' involvement. FREEDM should be the model for collaboration between industry and academia in the energy sector. This led to a discussion of how FREEDM is different from other university programs focused on the electric grid. Comparable centers include:

- CAPER: Center for Advanced Power Engineering Research. A collaboration led by Duke Energy that includes NC State, UNC Charlotte and Clemson. Focus on power systems research for the Southeastern US and undergraduate education.
- CPES: Center for Power Electronics Systems at Virginia Tech. Expertise in power electronics components, modeling and control, EMI and power quality.
- CURENT: Center for Ultra-Wide-Area Resilient Electric Energy Transmission Networks. Vision to develop a nation-wide transmission grid that is fully monitored and dynamically controlled in real-time.
- CDE: Center for Distributed Energy at Georgia Tech founded for research and development that can transform electricity delivery and utilization.
- GRAPES: Grid Connected Advanced Power Electronic Systems is led by the University of Arkansas. Mission is to accelerate the adoption and insertion of power electronics into the electric grid in order to improve system stability, flexibility, robustness, and economy.
- EPIC: Energy Production and Infrastructure Center at UNC Charlotte. Research clusters include energy analytics, environment, large power component design, power infrastructure, grid modernization, renewables and energy efficiency, and transportation.
- PowerAmerica: Headquarters at NC State with a focus on reducing manufacturing costs for silicon carbide and gallium nitride devices.
- Bits and Watts: Stanford University initiative that organizes its research into three thematic areas: grid core, grid edge and grid data science.

Though these centers are similar, FREEDM is unique with an emphasis on the distribution system and wide bandgap semiconductors. We have capabilities in both power systems and power electronics. However, our systems level emphasis has not been clear to industry members.

Research Presentations

After lunch, individual researchers made brief presentations to highlight aspects of their projects and answer questions from industry. All slides are in Appendix D.

Bruce McMillin, MS&T, presented work on Distributed Grid Intelligence and Reliable and Secure Communications (DGI/RSC).

Mischa Steurer, FSU, summarized his latest progress with the HIL testbed. He also discussed an IEEE working group and best practices document for HIL.

Wenyuan Tang, NC State, discussed his interest in applying game theory to power system economics. Wenyuan was recently hired as part of the new NC State Energy Cluster.

Srdan Srdic, NC State, is a visiting research scholar who has worked closely with Srdjan Lukic to develop a modular medium voltage, electric vehicle fast charger. This project was funded by PowerAmerica.

Doug Hopkins, NC State, presented several projects from the PREES Lab (Packaging Research in Electric Energy Systems) including work with 6.5kV devices and very high frequency converters.

Maziar Mobarrez, NC State, is a PhD student working under Subhashish Bhattacharya. He presented on their work to develop a controller for a DC microgrid.

Ning Lu, NC State, highlighted her work applying machine learning to distribution system data.

At the conclusion of the research presentations, Kevin from Duke Energy announced that he is now managing Duke's budget for R&D funding under the NC Renewable Energy and Efficiency Portfolio Standard. Researchers should talk to him regarding applications for funding.

Future Research

After a break, we adjusted the published agenda and focused our last hour on future research ideas. Researchers expressed a desire to be relevant to industry needs but acknowledged the inherent conflicts between short term needs and long term projects, simulation versus practical solutions, and broad value chain for the FREEDM vision. This was a wide ranging discussion but covered the following areas:

Systems Research

Bruce wondered about industry interest in systems level research. He asked about the major challenges beyond DERMS. Members acknowledged that integrating new equipment into legacy systems is a huge challenge and a major barrier to adopting new technology. This seemed like more of a practical application and less "researchy" but members argued this was the kind of experience they wanted graduates to have. Modeling is good but students need practical experience in the field. We later agreed that utilities are fundamentally changing the way distribution systems are managed. Instead of thinking about specific, static feeders, utilities are facing amorphous changes that need to be addressed in real time.

Reliability

Industry also emphasized the need to address reliability issues for components and systems. A good example is the Solid State Transformer. SST's will require extra protection and the component count alone for an SST compared to a traditional transformer indicates lower reliability. Industry needs to understand FREEDM system reliability and fail safe designs. Researchers countered that initial research is focused on functionality and then moves to reliability.

This concern for reliability extended to software and firmware. Duke Energy has real security challenges updating software for substation devices. Gateways also need to be evaluated for firmware updates. Basically, it is no longer reasonable to assume that everything in the domain is trustworthy. Future NERC CIP requirements will extend inside the facility boundary.

Standards

The general consensus was that University researchers should be aware of standards and make sure that what is developed complies with applicable standards. In general, industry needs are shorter term (e.g., 3 years out) and standards development may be longer (e.g., 10 years). There is also a mismatch between technology development (which is very rapid) versus standards and regulatory development. One story focused on autonomous vehicle standards. The tech was moving so fast they adopted guidelines rather than standards.

Power Quality

Much of the discussion came back to power quality and specifically power quality inside industrial facilities. There was some sense that FREEDM's initial emphasis on residential was misplaced. Motor ride through is a huge issue that could be addressed by an SST operating inside the plant. It could use the DC bus as a buffer to drives and other sensitive equipment like robotics. This might be a great demonstration deployment and then open a new market for SST's. This could also interest large industrial users in Center membership.

We also debated why industrial customers would be interested in this technology and what incentives they might need. Power quality issues can cause product losses due to quality concerns. Production is the only incentive industrial users need. Harmonics are less of a concern than ride through. It is possible that large industrial power users could work with FREEDM on solutions specific to their needs. We all agreed that an industrial pilot project would be an excellent demonstration for the SST.

Microgrids

Some research ideas in this area included developing an open source controller design that increased overall system efficiency. There is also a need for protection coordination in microgrids and how to handle both high and low fault currents. Other suggestions included stability analysis for multiple microgrid systems and microgrid controllers designed for resilience.

Blockchain
This is certainly a popular topic currently. The technology can be used for energy trading. Most attendees felt this was mainly applicable to retail commerce and distribution system operators. Its use would be a seismic shift in the utility world. Some agreed that transmission energy trading models might filter down to distribution but they did not foresee displacement by Blockchain any time soon. The recommendation was for FREEDM to consider evaluating tools like blockchain as compared to current technologies.

Education Programs
Although not a research area, we did conclude the research discussion around general education needs. New hires is a major reason for FREEDM engagement for several companies and helps justify their membership dues. We noted that FREEDM has limited interaction with undergraduates. This is primarily because faculty pursue research funding which requires graduate students. Members were encouraged to submit Senior Design Project ideas and EPSE Capstone ideas. Researchers noted that time spent with undergrads leaves less time for research and submitting funding proposals. But it also recruits some of those students to attend graduate school. The emphasis depends on the researcher's preference.

One researcher strongly encouraged industry to allow new hires to pursue graduate degrees. Just one more year of education can significantly increase technical competency. NC State and MS&T allow students to pursue a PhD with no course requirements beyond the Masters level. This means some students can get their PhD in situ at the company's location.

Adjourn
The meeting concluded at 3:30 local time.

Appendix A
Center Update

FREEDM SYSTEMS CENTER

December 12, 2017

Agenda

8:30	Introductions
	Center Update
9:30	Industry Speaks
10:15	Break
10:30	Mission and Vision
12:00	Lunch
1:00	Researchers Speak
2:00	Research Future
3:15	Break
3:30	Vision Recap
4:00	Adjourn

Introductions

1. Name, Company and Role

Center Update

1. Member Engagement
2. Member Changes
3. Recruiting
4. Inventions

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Member Engagement

1. Total
   - Fellowship
   - Sponsored Research
2. NYPA
   - Sponsored Research
   - Fellowship
3. Eaton
   - Lab Tour
   - Joint Proposals
4. Duke
   - DC Fast Charger
5. EPRI
   - ISGT Tutorial
   - HVDC Workshop
   - Electrification Magazine Articles
6. Schneider
   - Testing. Show webpage.
   - Summer Intern

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Member Disengagement

Full

Associate

Affiliate

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Member Recruiting

1. Honeywell
2. Vestas
3. Mercedes Benz
4. Danfoss
5. Kohler
6. Landis + Gyr
7. LG
8. Power Analytics
9. PowerSecure
10. Siemens
11. Texas Instruments
12. Dominion Energy
13. AES
14. Anord
15. CREE
16. Megger
17. Microsemi
18. Rogers Corporation
19. Trilliant
20. Woodward

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Other Marketing

1. Conferences
   1. PAC World
   2. iMAPS
   3. PES General Meeting
   4. ECCE
   5. Sustainable Fleet Technology Expo
2. Twitter
3. Newsletters

8

Inventions

1. Modular Medium Voltage Fast Charger - Srdic
   - DC electric vehicle charger using SiC modules up to 100’s kW
2. Multi-layer Motor Winding for AC Machines – Kabir
   - Experimentally proven to decrease losses by 9% with zero increase in manufacturing costs.
3. Grid Connected Buck Boost Converter - Yu
   - Transformer-less system that eliminates the minimum DC voltage requirement allowing any number of PV in a string

Inventions

4. DC Circuit Breaker - White
   - Novel Isolating transformer, capacitor, switch circuit to effectively create zero crossing.
5. Transformer Materials and Testing - Beddingfield
   - Mixed material magnetic core for shielding of eddy current induced losses
   - Circuit for providing variable waveform excitation
6. Energy Recirculation Circuit and Controls - Hopkins
   - Applications include power semiconductor device characterization
7. Power Mosfets Design and Forming - Baliga
   - Superior high frequency Figure-of-Merit

Appendix B
Schneider Electric Presentation

Our technologies ensure that Life Is On
everywhere, for **everyone** and at **every moment**.

Life Is On | Schneider Electric

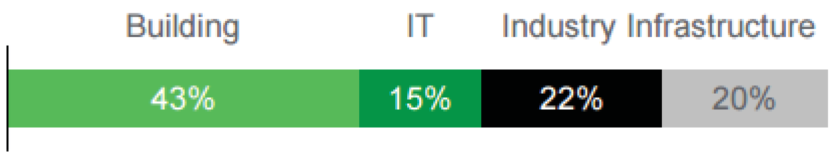
Schneider Electric, the Global Specialist in
Energy Management and Automation

€24.7 billion
FY 2016 revenues

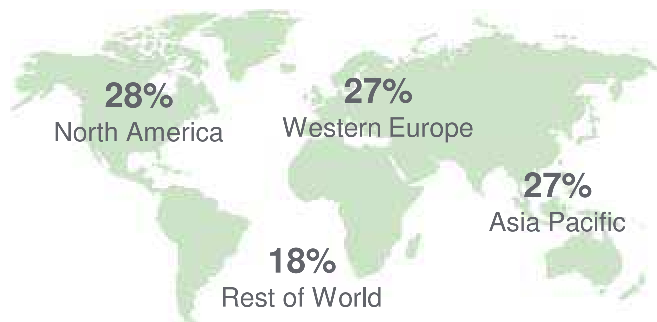
~5%
of FY revenues devoted to R&D

160,000+
people in 100+ countries

Four integrated and synergetic businesses
– FY 2016 revenues



Balanced geographies – FY 2016 revenues



Life Is On | Schneider Electric

As alternative means of producing and distributing energy becomes commercially viable…

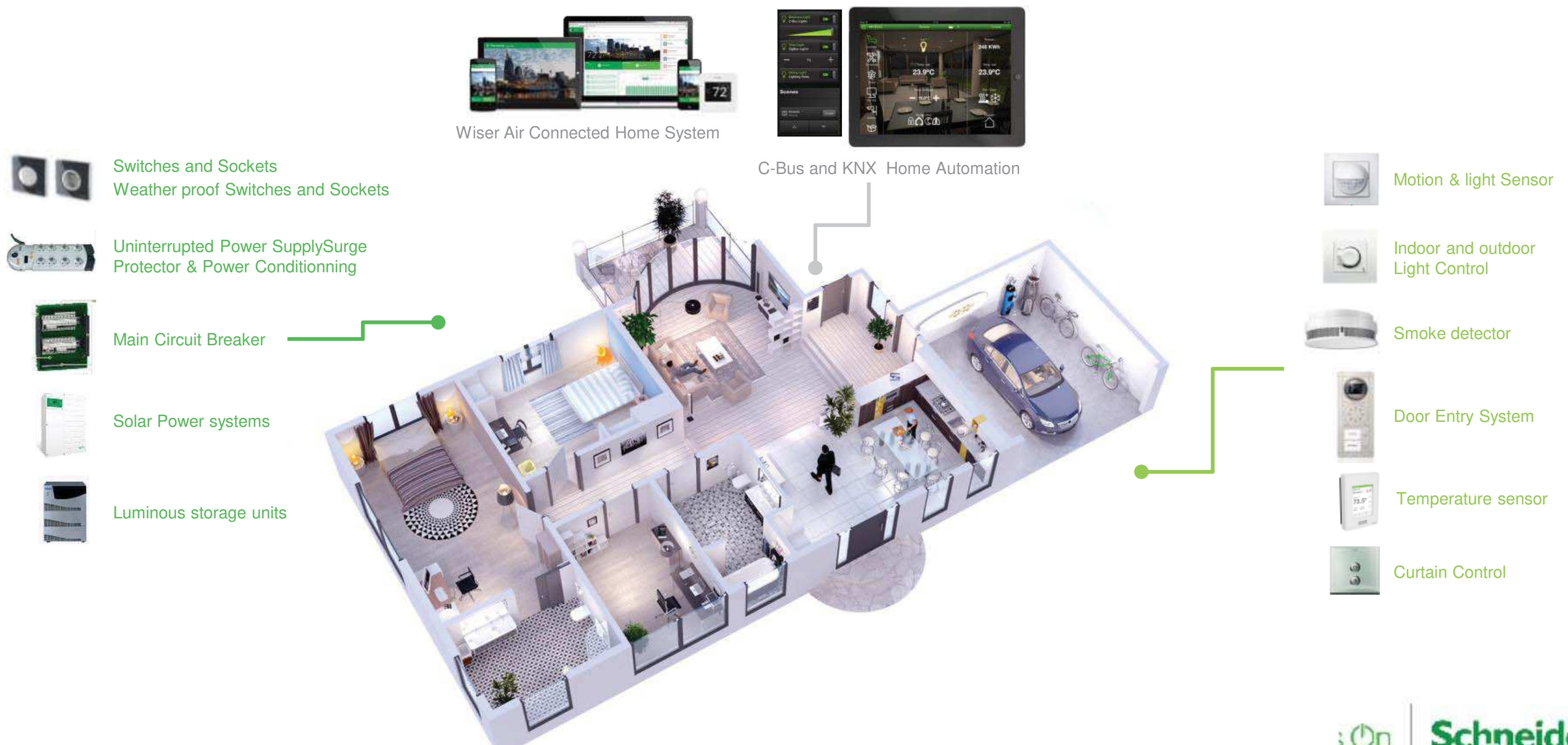
Businesses and Utilities will seize new, unique opportunities to differentiate goods and services through intelligent infrastructure. The traditional approach is no longer adequate—models will be developed to create new value for businesses and utilities to benefit from the new energy economy.

Life is On with Schneider Electric Building Solutions:

From **grid to floor space**, we ensure **safety, comfort, reliability, efficiency and sustainability**

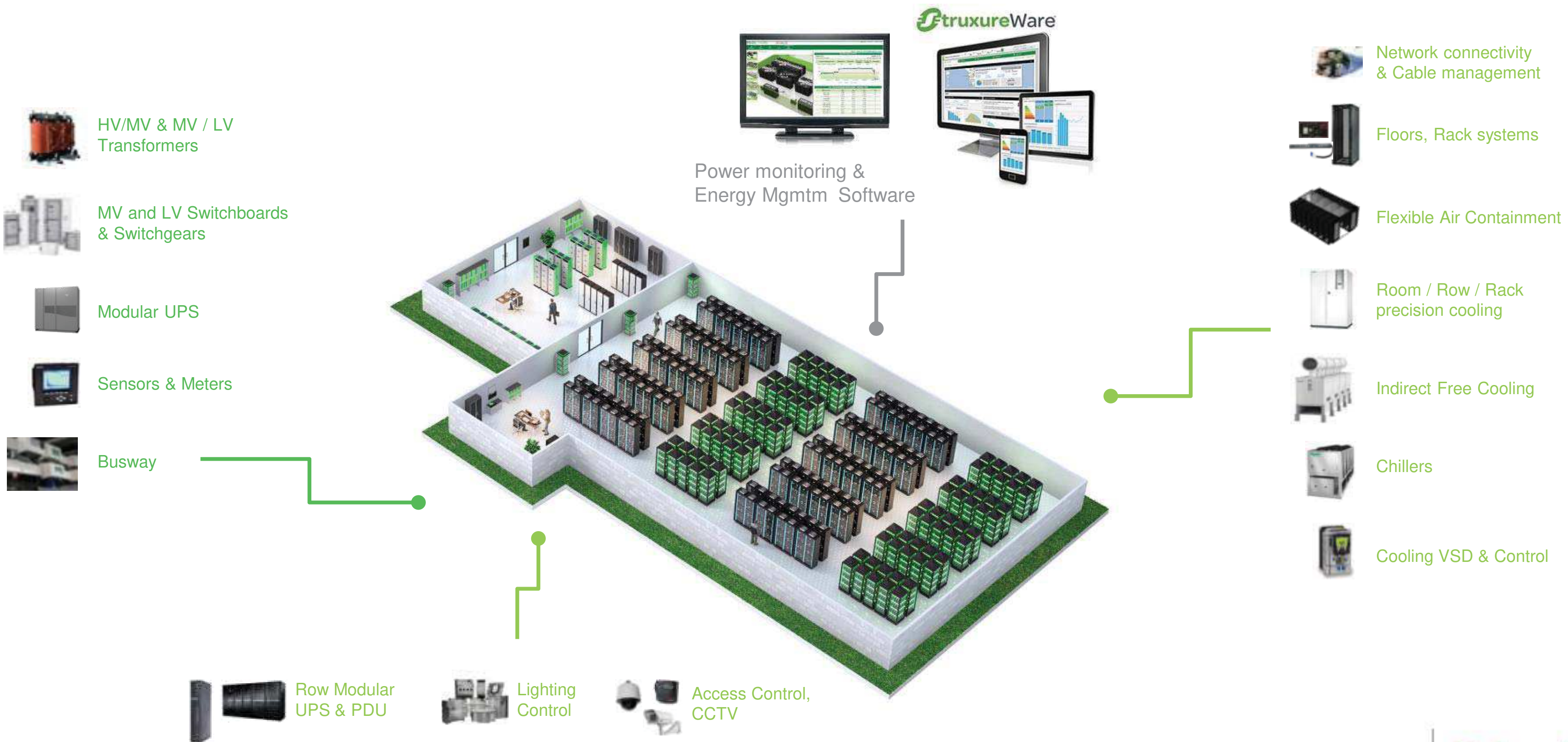
Life is On with Schneider Electric Residential Solutions:

From **grid to living space**, we ensure **peace of mind, comfort, sustainability**



Life is On with Schneider Electric Datacenter Solutions:

From **rack to cyber space**, we **optimize performance, speed and cost**



Life is On with Schneider Electric Smart City Solutions:

From **downtown** to **suburb** , we deliver **urban efficiency today**

Smart Integration

- Weather Services
- Energy and Sustainability Services
- Asset Management, GIS
- Energy Performance Contracting

Smart Energy

- Smart Grid
  - Asset Management
  - Smart Generation
  - Demand Side Management
  - Utility Services
- Micro Grid
- District Heating/Cooling Management
- District Energy Management Information System
- Gas Distribution Management
- Shore Connection
- EV Charging Infrastructure & Supervision Services

Smart Built Environment

- High Performance Buildings
- Workplace Efficiency
- District and Campus-wide building management
- Data Centers
  - Efficient
  - Prefabricated
  - Management Services
- Video surveilance
- Tunnels
- Prosumer Buildings
- Efficienct Homes

Smart Water

- Plant & Network Energy Performance
- Water Distribution Optimization & Loss Mgt
- Stormwater management and Urban Flooding
- Irrigation Management

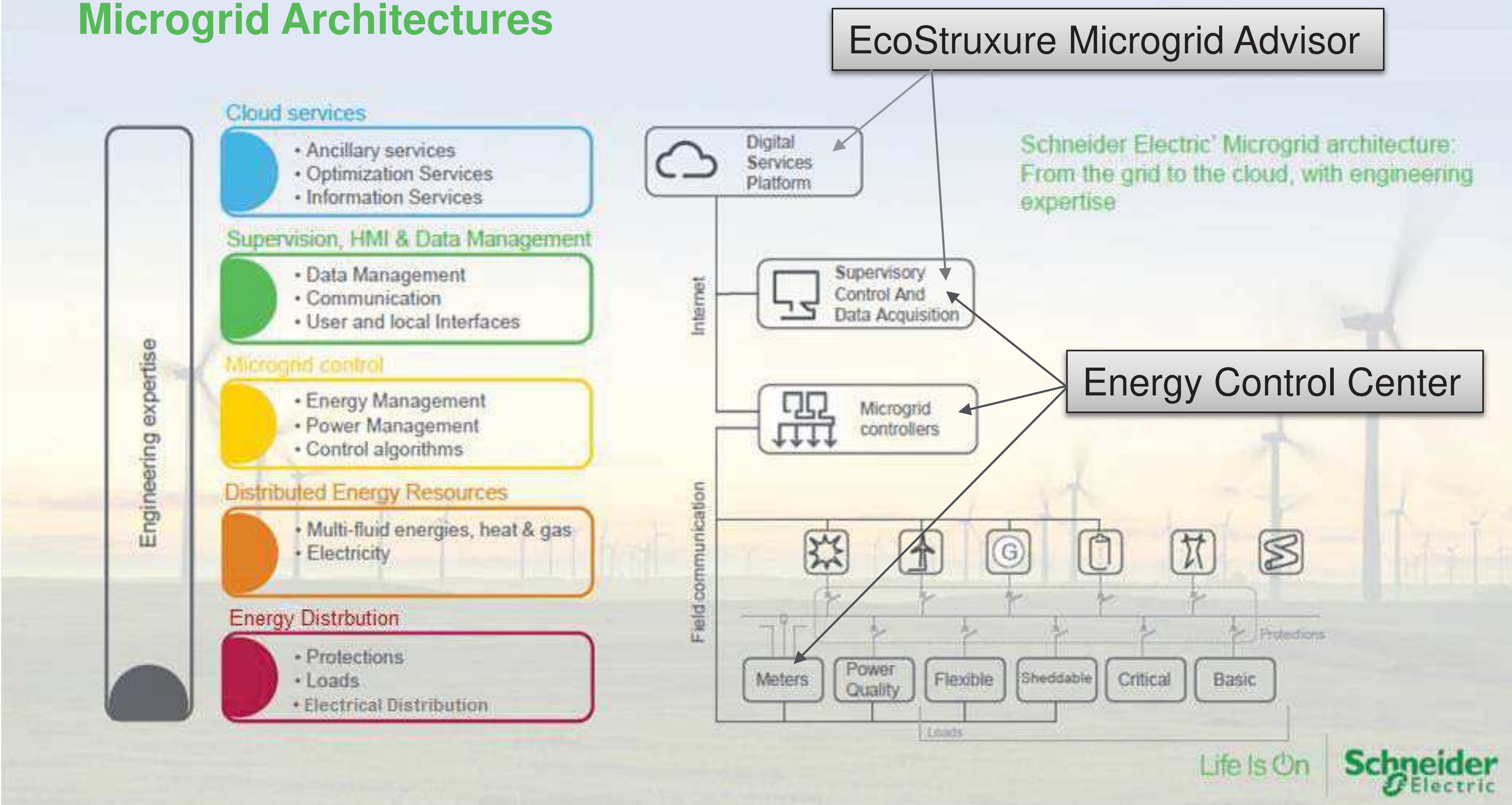
Life Is On | Schneider Electric

Microgrid Solutions

North American Competency Center

Life Is On | Schneider Electric

Microgrid Architectures



Expertise & Offer Summary for Microgrids

Planning

- **Financial, Regulatory and Power Systems Feasibility**
- **Full Power Systems design for Microgrid and Interconnection**
  - Licensed in all 50 states
- **Full Power Systems design for Substation/Feeder Area** of Distribution network to incorporate 1 or many microgrid and DERs
- **Incorporation of the MG/DERs into the Control Center Operating procedures**

Equipment for MG and Distribution System

- **SE Square D Metalclad MV Breakers or Selected Vendor Switchgear** (S&C partner)
- **Square D Low Voltage Switching, Controls, Motor Operators**
- **Nulec Reclosers or Selected Vendor Reclosers**
- **ION Power Monitoring/Quality/Revenue Metering**
- **Automation Servers, RTUs, PLCs, Protective Relays, IEDs**
- **Building Management Systems** (BMS)
- **ArcFlash Mitigation Solutions** for all apparatus
- **Smart Inverters** (Conext)
- **Ecoblade Battery Energy Storage Systems** or Selected BESS

IT/OT Integrated Software Platforms

- **Demand Side Operations** (DSO) for 1-n Sites
- **PowerScadaExpert** (MG SCADA) for 1-n Sites
- **Advanced DMS** (ADMS) and DSCADA Platform for Utility Control Center
- **DCS** for larger Generation Facilities
- **Asset Monitoring** (PRiSM)
- **Time Series Historian** (eDNA)
- **Weather Information Services** (Weather Sentry) for Utility Control Center and Sites
- **Demand Response Platform**

Service

- **Installation, integration, testing, commissioning and/or EPC**
- **Program Management, IT/OT Integration with Control Center**
- **Maintenance and extended services in the field**

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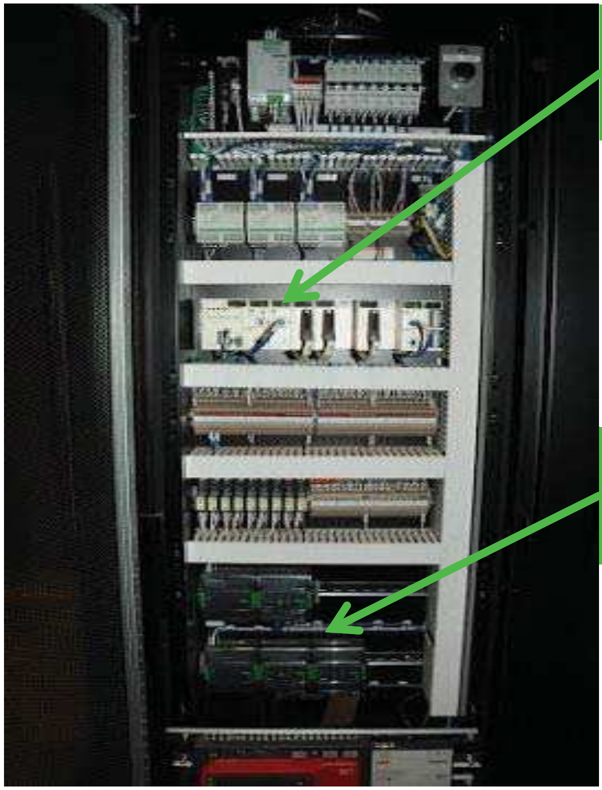
Schneider Electric Multi-Level Complementary Microgrid Control System Components



Microgrid Controller

- ✓ Reactive management of DER (ms, s, minute)
- ✓ Dispatches orders and collects DER data
- ✓ Data storage for improving reliability
- ✓ Management of Islanding Disconnection/Reconnection to the Grid
- ✓ Black start capability
- ✓ On demand use case development

Demand Side Operation Hardware

- ✓ Predictive management of DER (minute, hour, day forecast)
- ✓ Weather and Load Forecast information
- ✓ Interaction with third party actors (utilities, commercial aggregators etc)

EcoStruxure Microgrid Advisor

Forecast and optimize when to consume, produce, store, or sell energy

Remote Monitoring of DER

- Peace of mind for monitoring and visualization

Tariff Management

- Consume or produce energy at the most advantageous time based on variable utility rates

Demand Control

- Reduce utility peak demand charges

Self Consumption

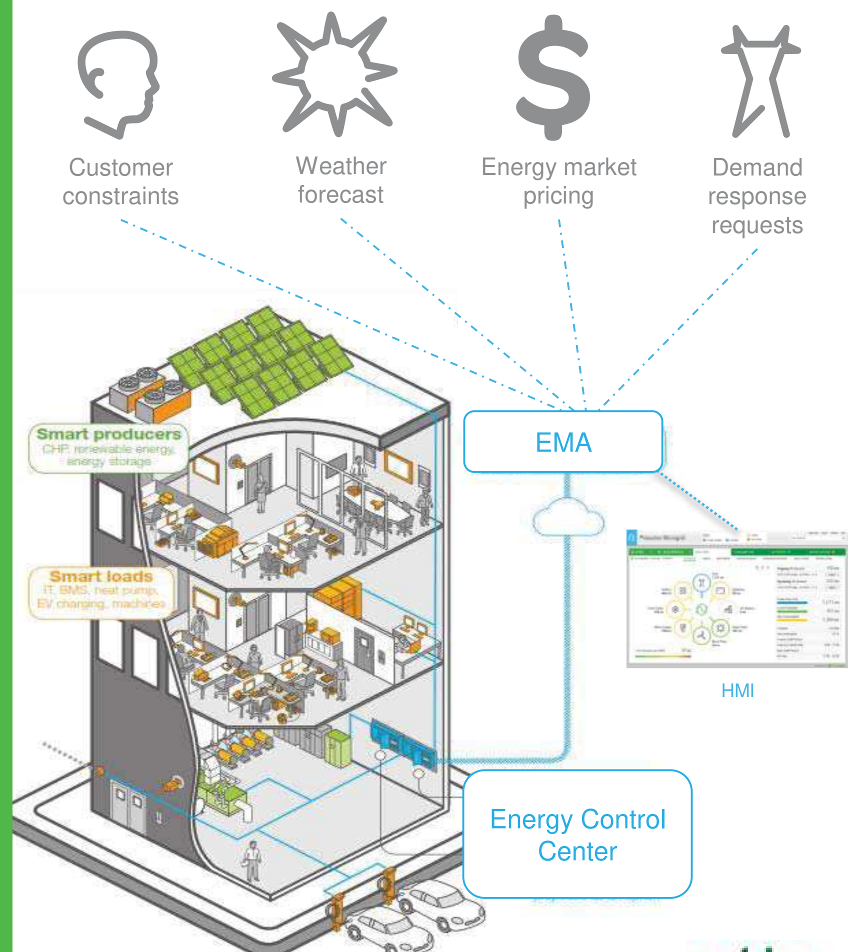
- Leverage your on site production capability

Demand Response

- Participate into the grid balancing mechanisms

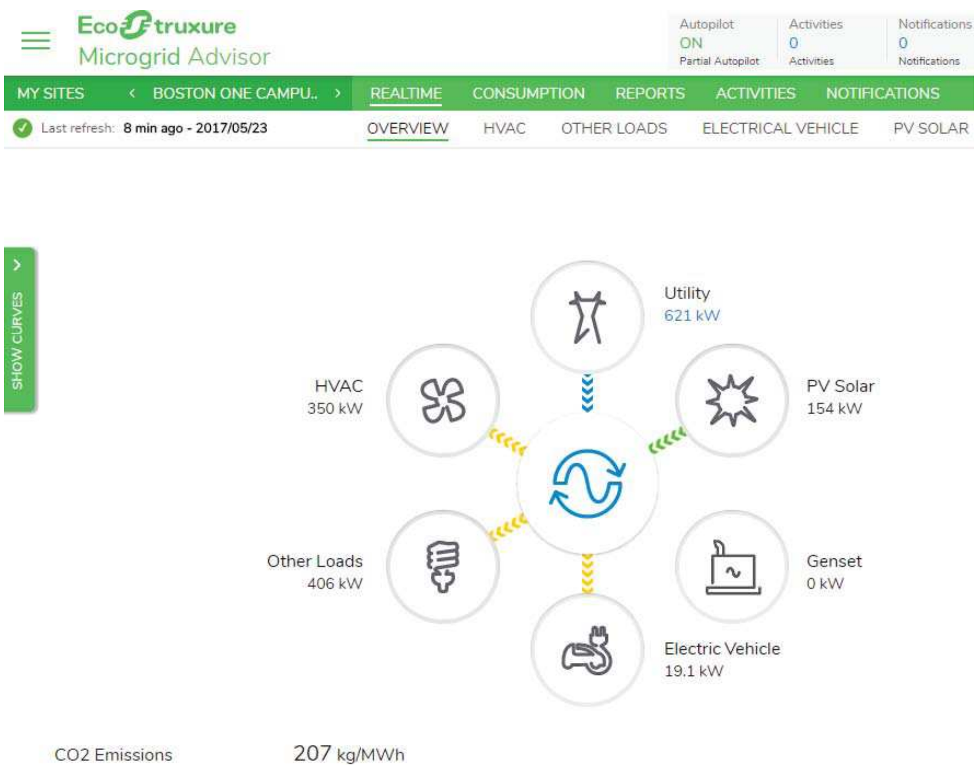
Island Mode

- Leverage weather forecasts to anticipate black-outs

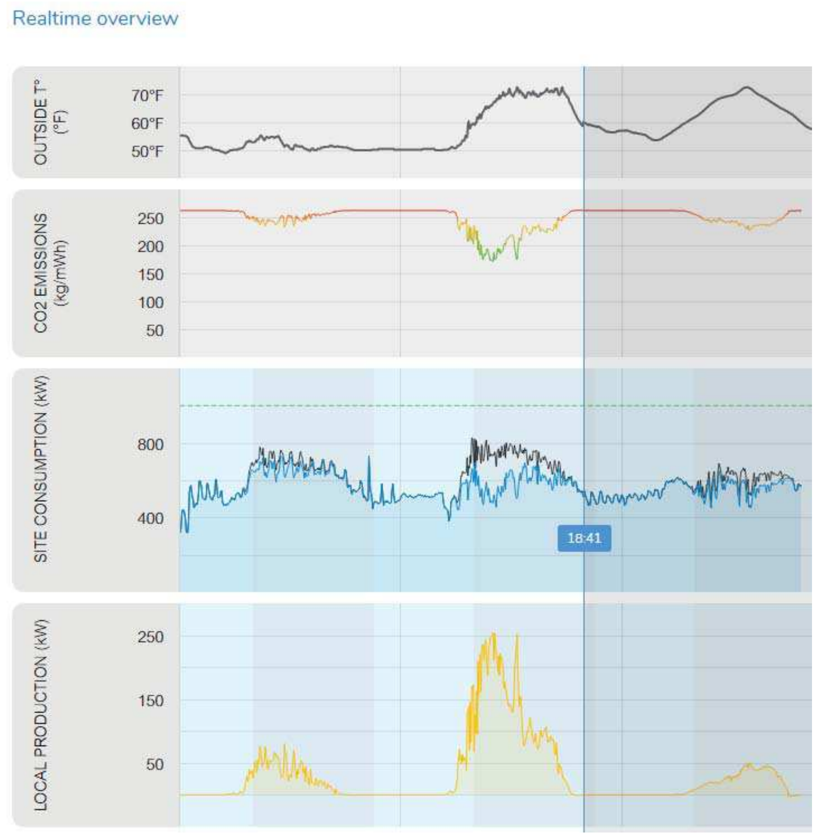


EcoStruxure Microgrid Advisor

Cloud-based Monitoring and Control to Optimize ROI and Sustainability



Power Flow at a Glance



Historical and Forecasted Values

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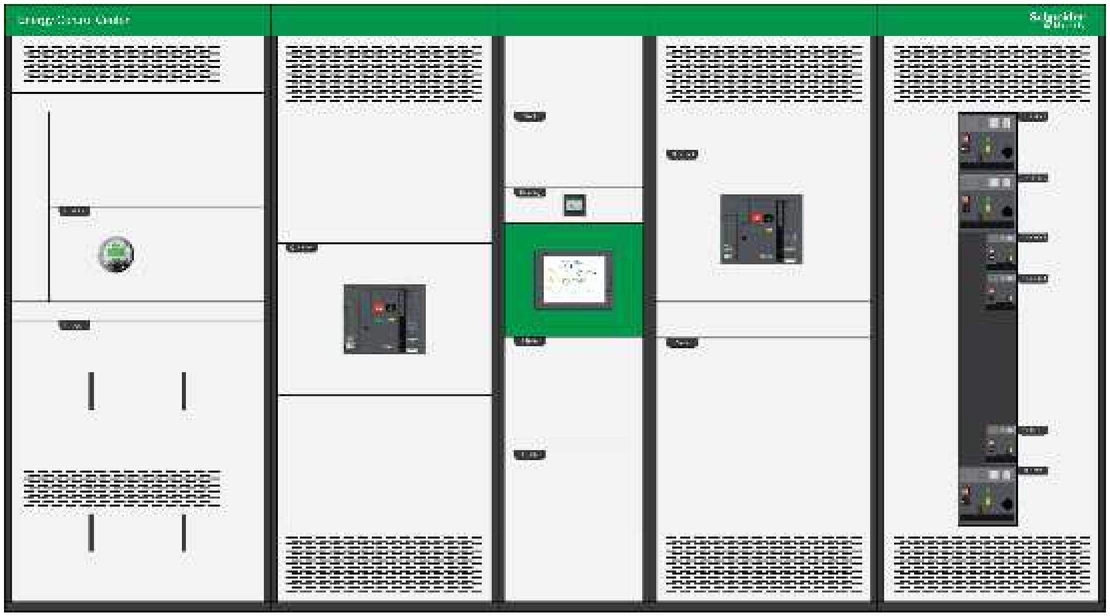
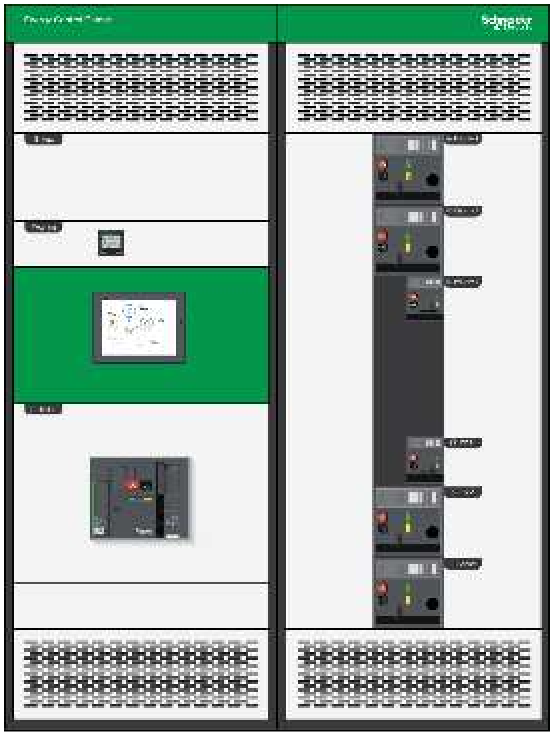


Energy Control Center

Energy Control Center

This modular control center is designed to be repeatable, scalable and future ready – providing optimized power and energy management to make it simpler to achieve one's savings, sustainability and resiliency goals.



Flexible

- Scales from small and simple to large and complex
- Allows for future facility expansion and integration of additional DER [1]

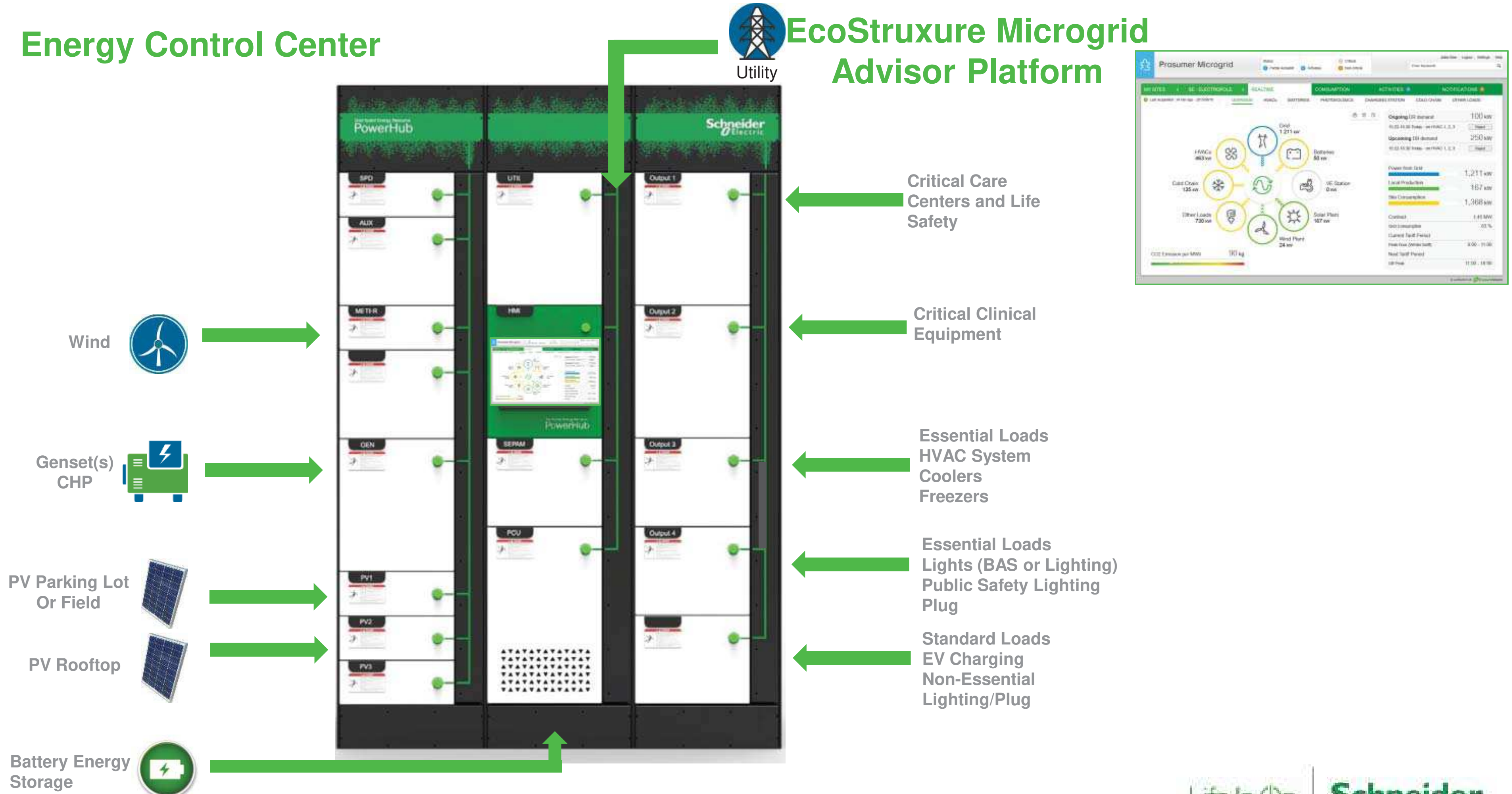
Fast

- 'Configured to Order' approach simplifies ordering process, reducing design and order time
- Factory wired, programmed and tested to streamline commissioning, which minimizes risk and disruption to the site

Smart

- EcoStruxure Microgrid Advisor maximizes ROI [2] from DER
- Edge control enables resiliency during outages
- Intelligent metering provides insight into power quality, usage, and DER production

[1] DER = Distributed Energy Resource, i.e. solar PV, battery storage, etc.
[2] ROI = Return On Investment



AC or DC or Hybrid AC/DC with Load Management

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Appendix C
Education Program Presentation

FREEDM SYSTEMS CENTER

PowerAmerica

Education and Workforce Program

Dr. Pam Page Carpenter
Education Director

Megan Patberg Morin, Ph.D. student
Graduate Assistant-FREEDM and PowerAmerica

ASU

MISSOURI S&T University of Science & Technology

NC STATE UNIVERSITY

NSF

1

FREEDM SYSTEMS CENTER

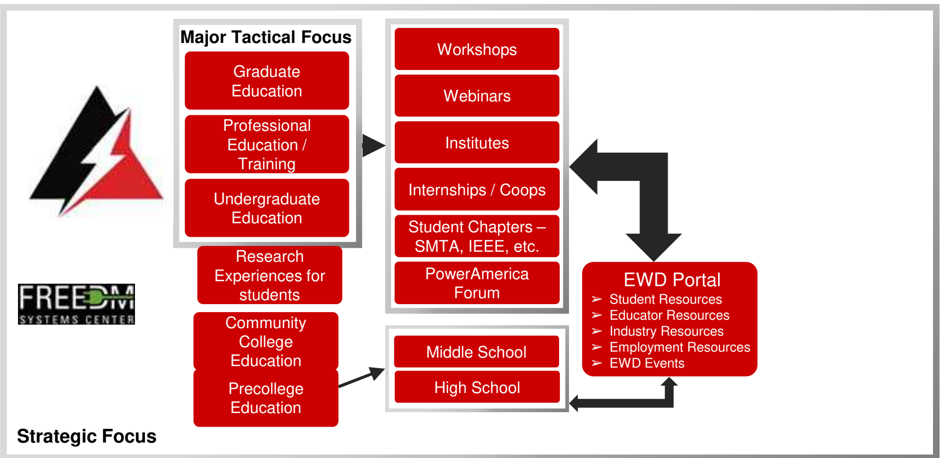
NSF

First, a quick reminder of EWD's mission …

- *Our mission is to assist educators, trainers, and industry in building an education ecosystem of **"Career pathways"** for individuals to work in the next generation power systems and power electronics.*

FREEDM SYSTEMS CENTER

Education & Workforce Development (EWD) Focus



FREEDM SYSTEMS CENTER

Education Working Group

ABB Power and productivity for a better world™

DUKE ENERGY

EPRI ELECTRIC POWER RESEARCH INSTITUTE

SAS

EATON

4

FREEDM SYSTEMS CENTER

NSF

WBG Lab Training Summer 2017 for Teachers and Undergraduates

5

FREEDM SYSTEMS CENTER

STEP SUSTAINABLE TRANSPORTATION EDUCATION PROGRAM

NSF

DUKE ENERGY®

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FREEDM SYSTEMS CENTER

Questions and Contact

- ppcarpen@ncsu.edu

Appendix D
Research Presentations

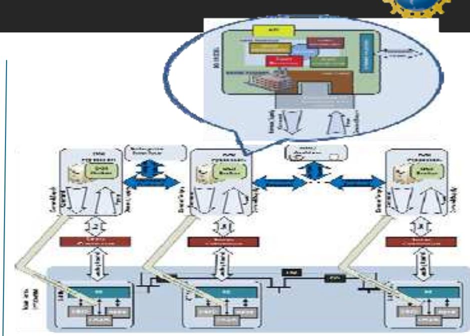
FREEDM SYSTEMS CENTER

Research Presentations

FREEDM SYSTEMS CENTER

DGI/RSC

Project Objectives
Develop Secure, Distributed DGI Applications
Develop Invariants for System Correctness and Security
Design Resilient Sensing and Attestation
Integrate DGI into GEH and HIL
Technical Approach
Algorithm development against DGI platform
Invariants built against power system infrastructure
Federated real-time DGI
Cyber-Physical attestation and sensing
System Integration
DGI/RSC Provides FREEDM's Operating System services and algorithm support.



PI: Bruce McMillin
Co-PIs: Mesut Baran, Mo-Yuen Chow, Jonathan Kimball
Major Milestones
- Suite of Energy Management Algorithms
- System Management

Final Deliverables
- DGI 3.0 – Integrated with HIL and GEH

Industrial Applications
- DGI as a prototype system
  - Missouri S&T's nanogrid solar village
  - Fog Architecture
  - Secure DGI Applications
- DERMS vs. openFMB vs. Fog
  - Security, Privacy, Resilience
- openFMB
  - DGI – distributed application suite
  - Cooperating Edge Device interaction

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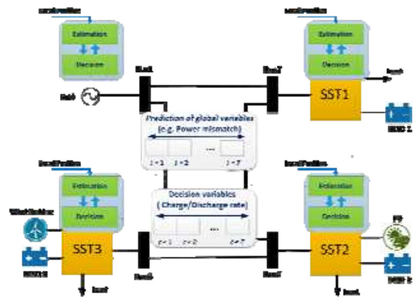
DGI/RSC - CODES

Project Objectives
Community Energy Storage
Neighborhood Watch

Technical Approach
Day ahead dispatch
Prediction error correction
Reputation-Based system

System Integration
CODES runs as an application under DGI



PI: Bruce McMillin
Co-PIs: Mesut Baran, **Mo-Yuen Chow**, Jonathan Kimball
Major Milestones
- Fully distributed dispatch application
- Resilient dispatch algorithms

Final Deliverables
- CODES – Integrated with HIL and GEH

Industrial Applications
- CODES as an energy management application
  - Islanded systems under disaster recovery
  - Internet of Things(IoT) in grid
  - Localized control in rural distribution system
  - Local energy market

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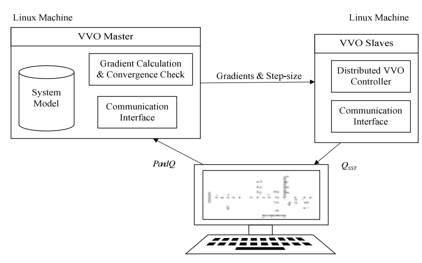
DGI/RSC – Volt-VAR

Project Objectives
Decentralized Master/Slave Volt/VAR control

Technical Approach
VVC aims at minimizing power loss while keeping voltages within limits on a FREEDM System

System Integration
Volt-VAR runs as an application under DGI



PI: Bruce McMillin
Co-PIs: Mesut Baran, Mo-Yuen Chow, Jonathan Kimball
Major Milestones
- A master-slave based decentralized VVC scheme has been developed based on gradient.

Final Deliverables
- VVC – Integrated with HIL and GEH

Industrial Applications

VVC is ready for adoption as part of advanced Distribution System Monitoring and Control at a Distribution Control Center

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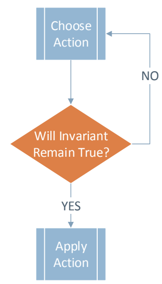
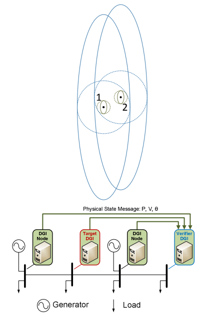
DGI/RSC – Invariants for Resilience

Project Objectives
Implement safeguards against malicious cyber actions

Technical Approach
Develop physical invariants that encode stability and correctness using
- Lyapunov functions
- Physical properties

System Integration
Invariants are embedded in DGI as monitors and attestation





PI: Bruce McMillin
Co-PIs: Mesut Baran, Mo-Yuen Chow, **Jonathan Kimball**
Major Milestones
- Secure invariants to detect instabilities
- Secure invariants to locate intruders

Final Deliverables
- Invariants integrated with HIL and GEH

Industrial Applications

Provide resilient distributed grid intelligence in the presence of security intrusions

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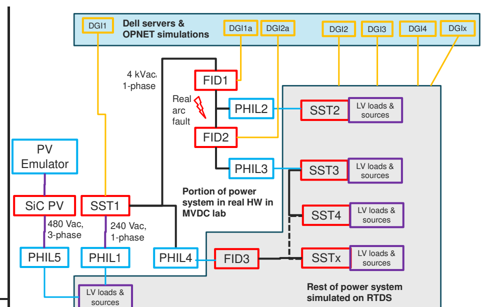
Hardware in the Loop Test Bed

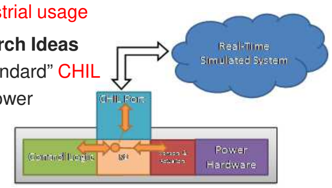
Project Objectives
Test & demonstrate emerging electric power and energy system technology up to TRL6; Develop a recommended practice via IEEE WG P2004
Technical Approach
Expand hardware-in-the-loop test bed (HIL-TB) to 30 DGI nodes; establish multiple PHIL interfaces (LV to ca. 4 kV; up to 13.8 kV possible)
System Integration
Testing DGI with Volt/Var, CoDES, SST, and FID

PI: Mischa Steurer; **Co-PIs:** Mesut Baran, Mo-Yuen Chow, Helen Li, Bruce McMillin, Ming Yu, Alex Huang (now at UTA)
Major Milestones
Refurbish & test Gen1 FID; Verify 4 kV PHIL test site using MMCs in inverter mode; Install Gen3 SST at FSU; Test & document 30-SST cases (RTDS & OpenDSS); Execute PHIL demo
Deliverables
Joint journal level publications with all the results of the PHIL demonstrations



Industrial Applications
Mature version-controlled system level HIL testbed ready for industrial usage

Future Research Ideas
Develop a "standard" CHIL interface for power electronic converter controllers at the average value model level



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IEEE WG P2004

Recommended Practice for Hardware-in-the-Loop (HIL) Simulation Based Testing of Electric Power Apparatus and Controls

This recommended practice will provide **established practices** for the use of the method of **Hardware-in-the-Loop** (HIL) **Simulation** based **Testing** of Electric **Power Apparatus** and **Controls**. It is intended to be **generically applicable** in synergy (in conjunction) with any specific testing standard (if applicable).

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IEEE WG P2004 Basics

- Chair: **Michael "Mischa" Steurer,** steurer@caps.fsu.edu
  Florida State University, Tallahassee, FL, USA
- Co-Chair: **Georg Lauss**, georg.lauss@ait.ac.at
  Austrian Institute of Technology, Vienna, Austria
- Secretary: **Blake Lundstrom**, blake.lundstrom@nrel.gov
  National Renewable Energy Laboratory, Golden, CO, USA
- Sponsor: **PELS**
- Co-sponsor: **IAS, IES**
- Collaborator: **PES-PSRC** Task Force CTF-33
- PAR ends **12/31/2021**
- **Monthly web meetings**
- Next **Face-Face Meetings** (always with live web-link)**:**
  - **Jan 9. 2018, 9:30am-10:45am, PES-PSRC Task Force CTF-33, Jacksonville, FL, USA**
  - **Feb. 1, 2018, Hamilton, New Zealand (IESES)**

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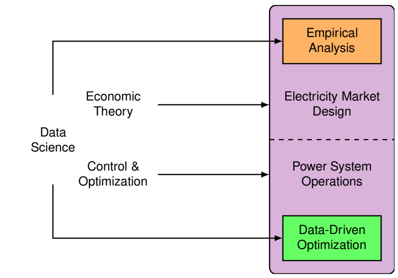
FREEDM SYSTEMS CENTER — Power System Economics

Research Goal
Understand the interactions between power systems and electricity markets
Improve the system efficiency through innovative market design

Technical Approach
Control and optimization
Economic theory
Data science



PI: Wenyuan Tang
Research Topics
1. Economic modeling and data analytics of electricity markets
2. Game-theoretic analysis and design of market mechanisms
3. Control and optimization for the smart grid
4. Learning, forecasting, and financial trading
5. Energy systems and policy

Industrial Applications
1. Design of demand response programs
2. Cost-benefit analysis of energy storage systems
3. Electricity-gas integration

Future Research Ideas
Toward a smarter grid which leverages state-of-the-art grid technologies and data analytics methods for the deeper integration of markets, data, and resources

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FREEDM SYSTEMS CENTER — Medium-voltage DC Ultra-fast EV Charger

Project Objectives
350 kW Medium-voltage DC Ultra-fast EV Charger

Technical Approach
Compact, Efficient and Modular EV Charger that connects directly to the MV distribution line.

System Integration
The „missing link“ of the future DC Service provided by Power Utilities

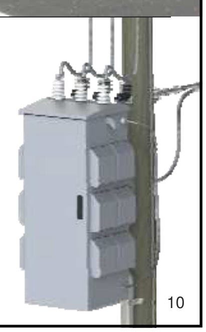
PI: Srdjan Lukic
Co-PI: Srdjan Srdic

Major Milestones
1. Single-phase system tested at reduced power **(Mo.4)**
2. Three-phase system tested at 100 kW **(Mo.8)**
3. Three-phase system tested at rated power (350 kW), with all protections integrated **(Mo.14)**
4. System Deployed in the field **(Mo.18)**

Deliverables
1. 350 kW EV Charger

Industrial Applications
EV fast charging
DC as a service
Power supply for datacenters
Naval shipboard applications

Future Research Ideas
Compact bidirectional high-power WBG-based rectification system



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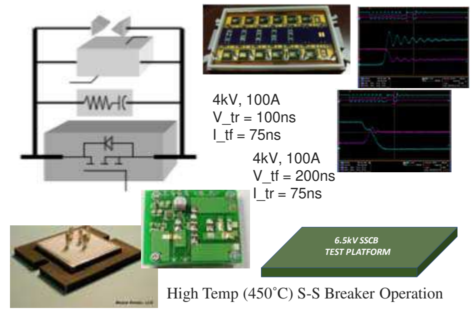
FREEDM SYSTEMS CENTER — 6.5kV Solid State Circuit Breaker

Project Objectives
A natural application of the PREES S-Series 6.5kV/200A SCPM as SSCB, taking advantage of the high temperature characteristics of JFETs

Technical Approach
Develop high thermal transient modules with fast switching detection, gate drives and layered energy absorption. (Leverages Phase-II SBIR- 2009)

System Integration
Supports medium voltage systems for protection



High Temp (450˚C) S-S Breaker Operation

PI: Douglas C Hopkins
Co-PIs: Subhashish Bhattacharya

Major Milestones
1. Simulation of electrical performance
2. Multiphysics simulation of physical modules
3. Demonstration of 6.5kV pulsed power test platform

Deliverables
1. 6.5kV/100A SSCB
2. In-situ full power test results

Industrial Applications
Applications include scalable voltage breakers from 1.7kV to 6.5kV, grid Wind and PV.

Future Research Ideas
The 6.5kV/100A is a provide power module. This project develops the power stage to extend this to 65kV with demonstration of serial modules through a Power-over-fiber gate drive system

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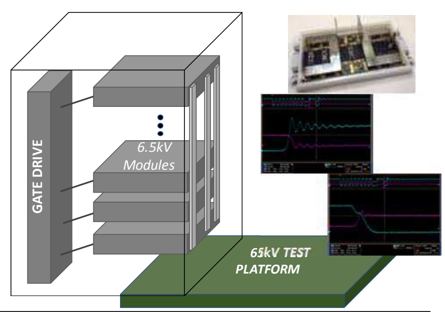
FREEDM SYSTEMS CENTER — MV 6.5kV/65kV Power Conversion

Project Objectives
Apply 6.5kV/100A/200A stacked modules for 65kV power conversion for grid applications

Technical Approach
Develop cascading of PREES S-Series 6.5kV/200A super-cascode modules to achieve >65kV power switching

System Integration
Supports medium voltage grid and drives applications.



PI: Douglas C Hopkins
Co-PIs: Subhashish Bhattacharya

Major Milestones
1. Simulation of electrical performance
2. Multiphysics simulation of physical modules
3. Demonstration of 65kV test platform

Deliverables
1. 65kV/100A/200A stacked power modules
2. In-situ full power test results

Industrial Applications
Applications include, in particular, grid related power electronic systems, such as the SSTs and medium voltage power conversion for Wind and PV.

Future Research Ideas
The 6.5kV/100A is a provide power module. This project develops the power stage to extend this to 65kV with demonstration of serial modules through a Power-over-fiber gate drive system

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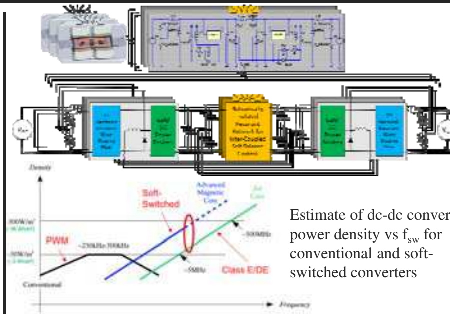
1.5kW -10kW Ultra Dense VHF Converter

Project Objectives
1. Demonstrate fastest operation for 1.2kV-Class WBG converters (VHF conversion)
2. Demonstrate new thru-package coupled parametric control

Technical Approach
Self-oscillation gating and operation operates new WBG devices at the fastest possible. Low voltage VHF techniques are extended to 1.2kV. Integral is packaging for air core magnetics & parametric ctrl.

System Integration
Circuits are naturally stackable to 10kW for PV applications.



Estimate of dc-dc converter power density vs f_{sw} for conventional and soft-switched converters

PI: Douglas C Hopkins
Co-PIs: Subhashish Bhattacharya

Major Milestones
1. Simulation of electrical performance
2. Demonstration of 30MHz SO Converter
3. Demonstration of three stacked converters with coupled parametric control

Deliverables
1. 1.5kW, 800V/2A, >20MHz converter
2. 4.5kW demonstration for sacaleability

Three grand challenges (w/ energy storage)
Proposed converter is transformational and comprised of: new bidirectional self-oscillating power circuit, scalable using parallel modules, and a new concept of inter-module compensation using coupled packaging parasitics for wire-less self-balancing power flow. WBG devices switch in VHF range of 30MHz to 300MHz enabling power densities beyond 500W/in^3, and no external gate drive circuits for increased efficiency, for PV applicaitons

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A Makers Lab for Power Electronic Systems

PCB – IMS – DBC Ceramic – Hybrid Thick-Film – Polymer Thick-Film – Chip & Wire
Board Assembly – Power Module Assembly – Box-Level Assembly
EQUIPMENT
Al & Cu & Ribbon Bonder – Sikama 5-Zone Reflow – IR 3-Zone Sintering Furnace–EFD 4-Axis Dispensing–Pick'n'Place (0602)
Full Analytics – Tek Electrical Test (40kV, 2kA) – Flir Thermal Probing & IR Imaging

PREES supports the Power Pack Club, and is operated by Undergraduates

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Full Power Packaging Laboratory

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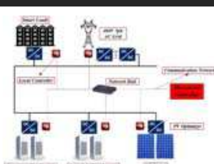
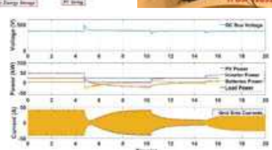
C-HIL Demonstration of DC Microgrid

Project Objectives
Developing/demonstrating a grid-interactive DC microgrid employing a hierarchical distributed control algorithm in a HIL platform.

Technical Approach
Achieve stability by paralleling multiple voltage sources. The concept is similar to the 'slack generators' in power system.

System Integration
This control strategy is applicable to any DC systems with multiple sources/loads.





PI: Dr. Subhashish Bhattacharya
Co-PIs: Dr. Mesut Baran

Major Milestones
- Design and documentation of the control strategy.
- Complete platform specifications document.
- Design for a real-world use case.

Deliverables
1. Complete design and documentation of control strategy and platform spec.
2. Demonstration of system features for a real-world use case using C-HIL simulations.

Industrial Applications
This platform is designed to accelerate deployment of DC microgrids by simplifying project-specific design, installation, and commissioning. (Data centers, rural networks, military bases)

Future Research Ideas
Additional control layer can be designed for the grid-tied converter to provide grid services such as frequency and voltage regulations.

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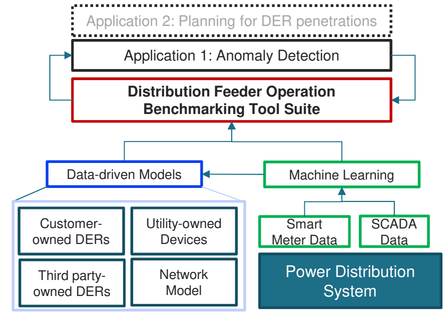
Smart Distribution Data Platform

Project Objectives
In this project, we aim at develop a smart distribution data platform including a feeder operation model database, a feeder operation benchmarking tool, and an anomaly detection tool.

Technical Approach
We plan to apply a combination of machine learning and physical-based modeling approach to derive model parameters and benchmark distribution feeders operation. Smart meter, SCADA data, and other relevant operational data will be used to for offline training and online identification.

System Integration
The development of the proposed platform is essential for developing and integration of FREEDM technologies by providing a realistic platform to benchmark the performance of the FREEDM technology.



PI: Ning Lu
Co-PIs: David Lubkeman and Mesut Baran

Major Milestones
1. Obtain data for building the feeder operation model database
2. Use data mining and machine learning approach to extract key operational parameters for benchmarking the feeder operation
3. Apply the data platform for anomaly detection on typical utility feeders

Deliverables
1. Feeder Operation Model Database
2. Feeder Operation Benchmark Tool
3. Feeder Anomaly Detection Tool

Industrial Applications and Future Research Ideas
In our first stage, the development of the data platform will be focused on data analytics. Operational data such as the **smart meter and SCADA data are used to** extract system operation baselines and model parameters. Then we will develop a real-time tool for detecting grid anomalies based on normal grid operation data and synthesized training sets. Future industrial applications include: new approaches for distribution operation (e.g. situation awareness) and planning (e.g. how we run power flows for future load growth and for penetration analysis. Through this effort, we will develop a suite of tools to extract values from data to enhance grid operation and planning in the areas of situation awareness, active planning, and proactive asset management.

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Aranya Chakrabortty
Associate Professor, Electrical & Computer Engineering
FREEDM center, NC State University

Email: achakra2@ncsu.edu

Webpage: http://people.engr.ncsu.edu/achakra2

Research Interests:

1. Wide-area oscillation monitoring using PMU data
2. Wide-Area control
3. Machine learning methods for "online learning and adaptation" of wide-area grid models under high levels of model uncertainty and renewable uncertainties (upcoming project with NYPA)
4. Integration of power system control with advanced communication technologies (cloud computing, software defined networking (SDN), time-sensitive networking (TSN))
5. Cyber-security of power system operations
6. Coordinated control of networked microgrids, storage devices, solar panels, power electronic converters