An Overview of Collaborative Testbeds Within the Future Renewable Electric Energy Delivery and Management Center

ASU Arizona State University

Missouri S&T University of Science & Technology

NC State University

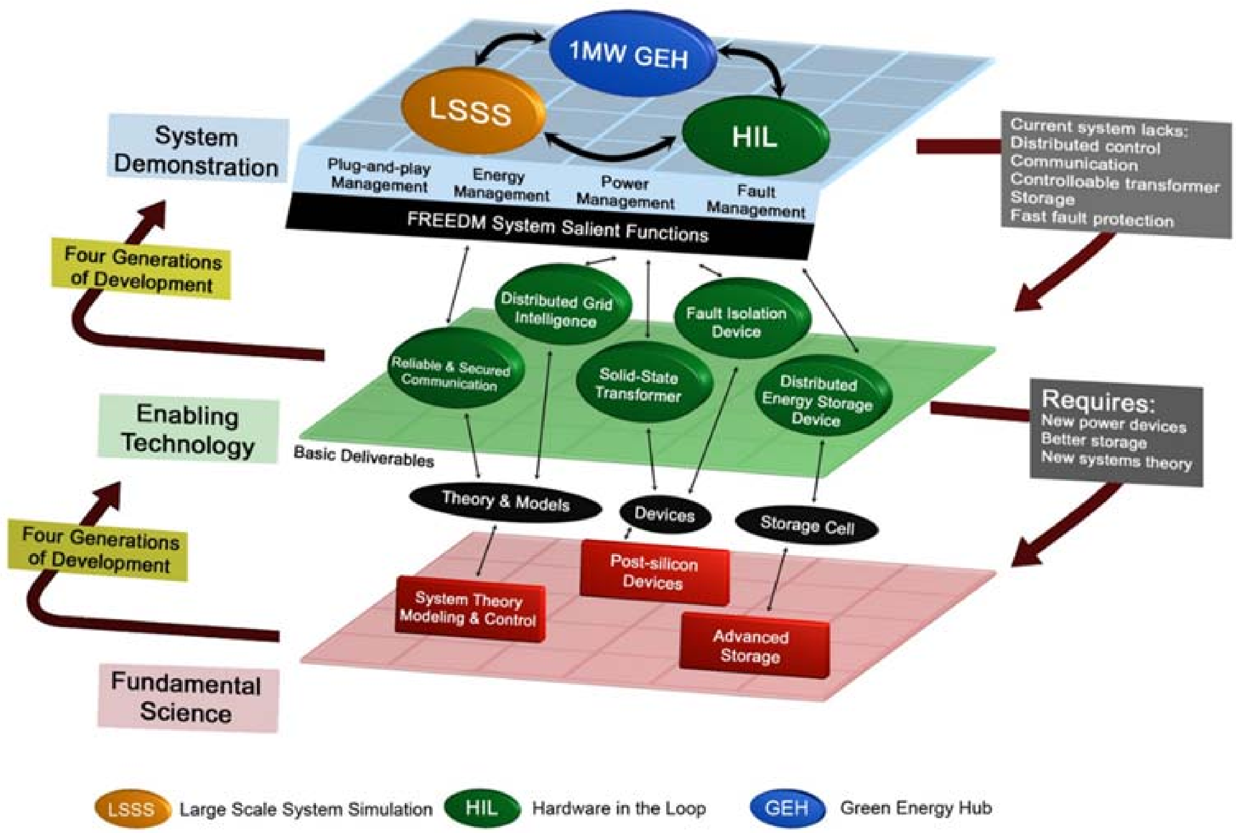
Florida State University 1851

Florida Agricultural Mechanical University

RWTH Aachen University

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

FREEDM Center



GEH

Project Objectives

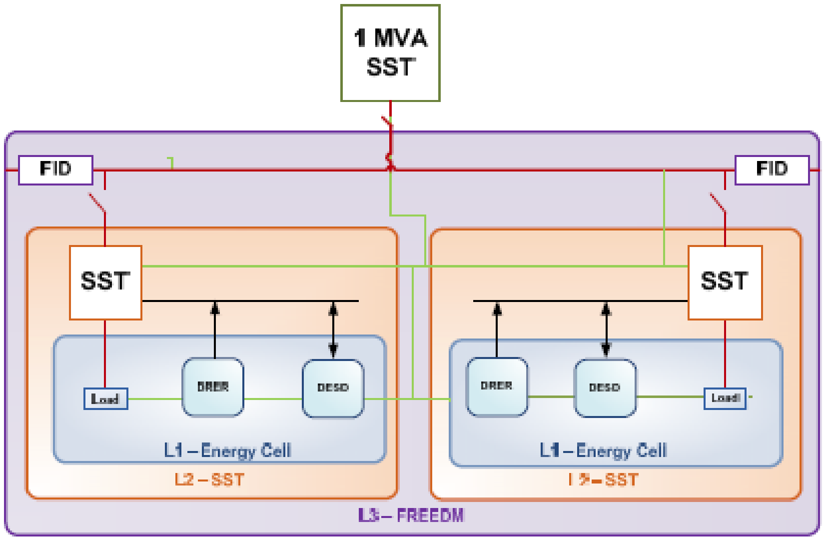
The Green Energy Hub testbed is an integrated hardware system demonstration incorporating technologies from the Enabling Technology and Fundamental Science research planes.

Technical Approach

The focus for Year 7 is to integrate SST, DESD and DRER devices with FREEDM IEM algorithms in the testbed.

System Integration

Activities are aligned with DGI/SMC integration, and development of GEH functionality for validating IPM, IEM and IFM functionality.



Project Number: Y7.GEH

PI: David Lubkeman

Co-PIs: Alex Huang, Subhashish Bhattacharya, Mesut Baran, Mo-Yuen Chow, Ning Lu, Iqbal Husain

Major Milestones

- Demonstration of SST-Based Residential Microgrid
- Two grid-connected low-voltage SSTs with DRER and DESD into GEH.
- Demonstration of distributed-logic IEM algorithms..

Final Deliverables

- Multi-SST FREEDM system with DGI operating system integrated with SST-based hardware platforms.

Significant Technical Challenges

Implementation of IEM algorithms with GEH hardware (SST, DRER, DESD).

Islanded operation of single-SST for energy applications.

Grid-connected operation of multiple SSTs for energy applications.

Accomplishments

Formulation of distributed dispatch for DESD scheduling.

Home Energy Management software platform established.

Two low-voltage SSTs assembled.

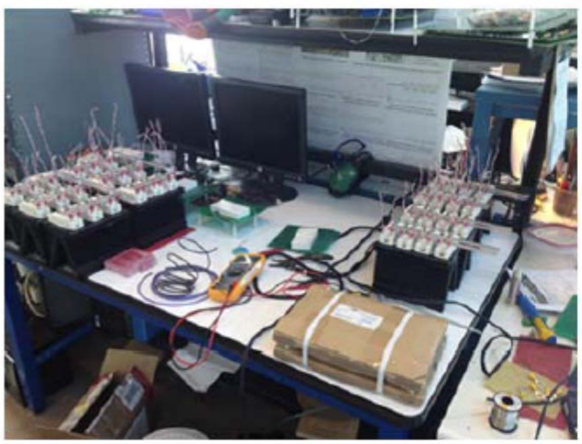
Verification of wind DRER control.

Date 1/22/2015

Green Energy Hub

- The Green Energy Hub testbed is an integrated hardware system demonstration incorporating technologies from the Enabling Technology and Fundamental Science research planes.
- Functions include testing and demonstration of
  - Solid State Transformer - SST (Gen I, Gen II)
  - Fault Isolation Device - FID (Gen I, Gen II)
  - Distributed Energy Storage Device – DESD (AC and DC)
  - Distributed Renewable Energy Resource - DRER (PV, Wind)
  - Household Load Emulator
- Previous focus on basic power (Intelligent Power Management - IPM) and fault management (Intelligent Fault Management - IFM) functions.

SST Development



- Software
  - Redesign of Dual Active Bridge Code for Interleaved Operation – HIL Tested
  - Inverter Implementation – HIL Tested
  - Original LV-SST Started by Sumit – Full Hardware Tested
- Hardware
  - 2x21 Semiconductor and Busbar Mounting – Complete
  - 14 Gate Drivers - Complete
  - Interface Board – Borrowing MMC Boards
  - Transducers – Borrowing MMC Boards
  - 3/12 HF Transformers – Complete
  - Inverter, Rectifier – Sumit Version Working
- Other Results
  - DRER Tested in HIL
  - DESD Tested in HIL

Hardware in the Loop Testbed

Project Objectives

Gen-II SST PHIL experimental test setup

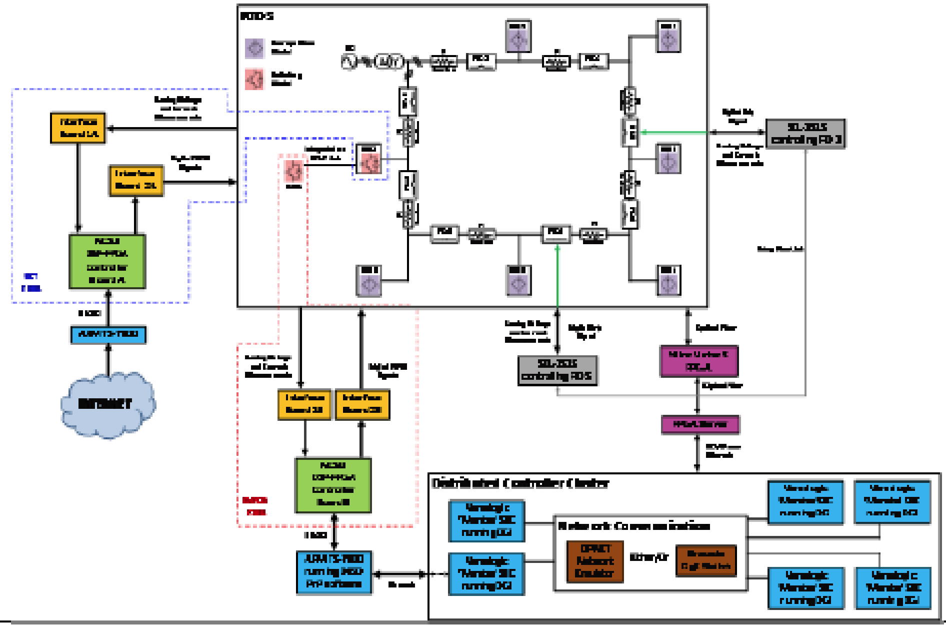
Demonstrated invariant for Multi-Domain Cyber-Physical Systems

Technical Approach

The HIL testbed sub-thrust aims at integrating enabling technology (ET), and testing fundamental science (FS) methods in a real-time simulation environment via hardware-in-the-loop (HIL) experiments of larger systems before migrating them to the GEH.

System Integration

The HIL testbed fills the gap between the other two testbeds by providing a flexible platform to study physical and simulated components together.



Project Number: Y7.HIL

PI: Mischa Steurer (FSU)

Co-PIs: Raja Ayyanar (ASU), Alex Huang (NCSU), Jonathan Kimball (MS&T), Bruce McMillin (MS&T), Ming Yu (FSU)

Major Milestones

- Gen-II SST PHIL testing at FSU Q2 2015
- Demonstrated invariants for Multi-Domain Cyber-Physical Systems Q2 2015

Final Deliverables

- PHIL setup ready for demo; updated FREEDM model library; completed validation of SST model

Significant Technical Challenges

- Gen-II SST PHIL test setup at CAPS still in-progress; detailed test plan still to be drafted
- OPNET support for ECN to facilitate network congestion notifications to DGI

Accomplishments

- ASU SST CHIL updated; new low-loss bridge used in RTDS SST model, higher efficiency
- MS&T demonstrated reverse power flow invariant on HIL-TB

Date 1/28/2015

HIL

- HIL experiments with 10 kW Gen-II SST at FSU-CAPS
  - Setup will also incorporate DESD interface developed under DESD sub-thrust (Dr. Li)
- Implement and test invariants for Multi-Domain Cyber-Physical Systems control in the HIL-TB real-time environment
- Implement and test DGI algorithms with Cyber-Physical Security
  - Develop and test new security association (SA) mechanisms, and demonstrate the Ipsecbased security platform using OPNET network emulator on the HIL-TB
- RTDS SST Model Validation
  - Will validate switching and average models of SSTs used in HIL-TB through correlation with test results from Gen-II SST hardware
- Advanced Controller Validation
  - Implement robust control laws partly developed in Y6 (impedance uncertainty) and new robust control laws to be developed in Y7 as part of SMC project (communication uncertainty) in the DSP/FPGA controller board used for SST CHIL on HIL-TB
- Model Maintenance
  - Develop, maintain, and version control SST simulation model library; ensure compatibility with the analytical models delivered to SMC
  - Engage with the FREEDM Architecture Working Group (FAWG)

LSSS

Project Objectives

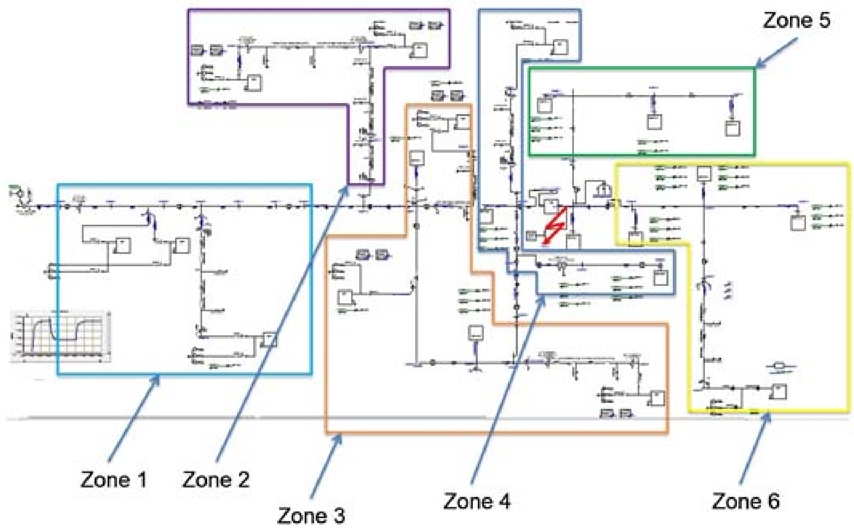
To demonstrate FREEDM capabilities and functionalities in a large scale, multi-bus, distribution system

Technical Approach

Develop a consistent distribution system on several software platforms to provide

System Integration

Describe the ways that this project interacts with other projects and it's role in the overall FREEDM system



Project Number: Y7.LSSS

PI: Crow

Co-PIs: Baran, Bhattacharya, Karady, Ferdowsi

Major Milestones

- PSCAD model of FREEDM system – stable operation
- OpenDSS model of FREEDM system
- SST and FID coordinate with pilot protection to isolate and clear fault – radial system
- Centralized volt-var control

Final Deliverables

- Looped/meshed pilot protection for fault management
- Decentralized volt-var control

Significant Technical Challenges

- Computational burden of fully-modeled system
- SST model validation

Accomplishments

- Extension of system to mesh-looped system with performance validation (stable small signal operation)

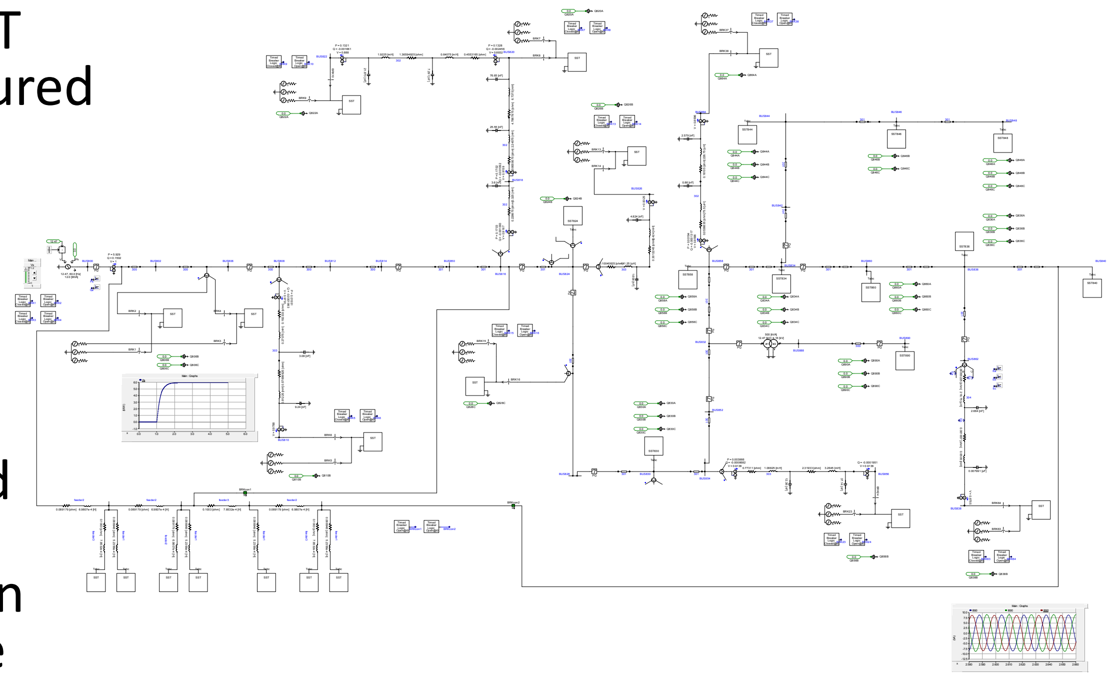
Date 1/28/2015

Background/Motivation

The ultimate customer of the FREEDM system are utilities. Utilities will not adopt the SST and FID until they can be assured that

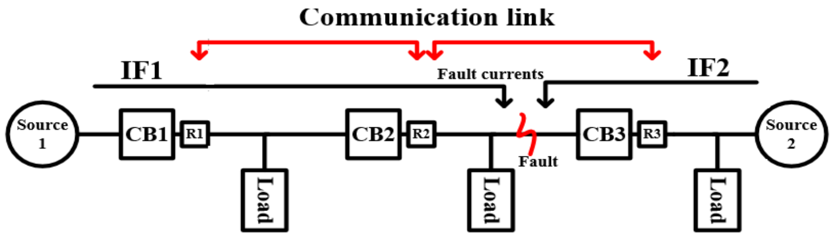
- The SSTs and FIDs will not interact poorly
- System stability will be maintained
- System reliability and resiliency will be improved (benefit > cost)

The LSSS is **the** demonstration platform that will provide the evidence of SST and FID operation in a distribution system



Example Project 1

Pilot directional protection



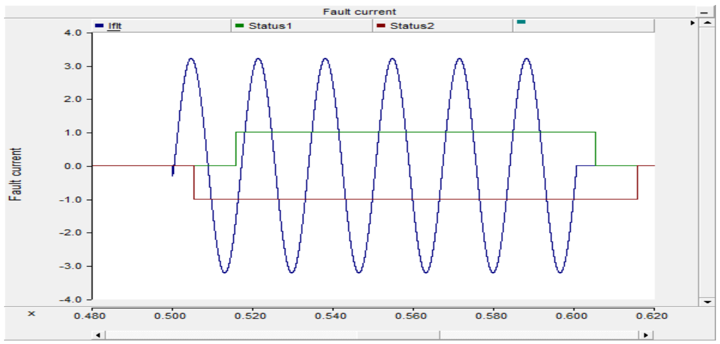
Unsymmetrical faults

- For a fault at the given location, R1, R2 and R3 calculate the direction of fault currents. The directionality of fault current is communicated between the relays R1, R2 and R2, R3.

- Since R1 and R2 have the same direction of fault current, fault is not located in between them. R2 and R3 have different fault current directions. Hence fault location is in between them.

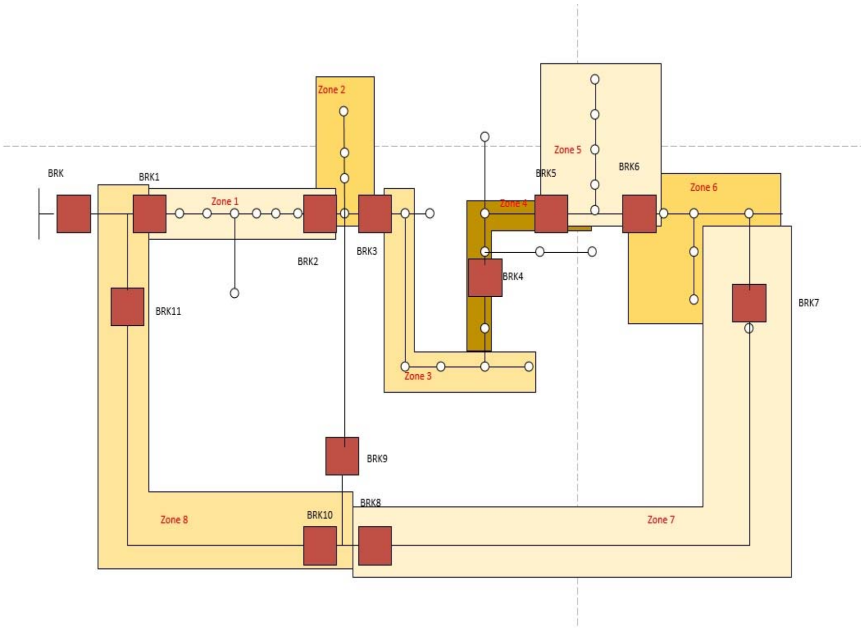
Relay	Fault direction		Relay	Fault direction
R1	Forward		**R2**	Forward
R2	Forward		**R3**	Reverse
Trip signal	No trip		**Trip signal**	Trip generated

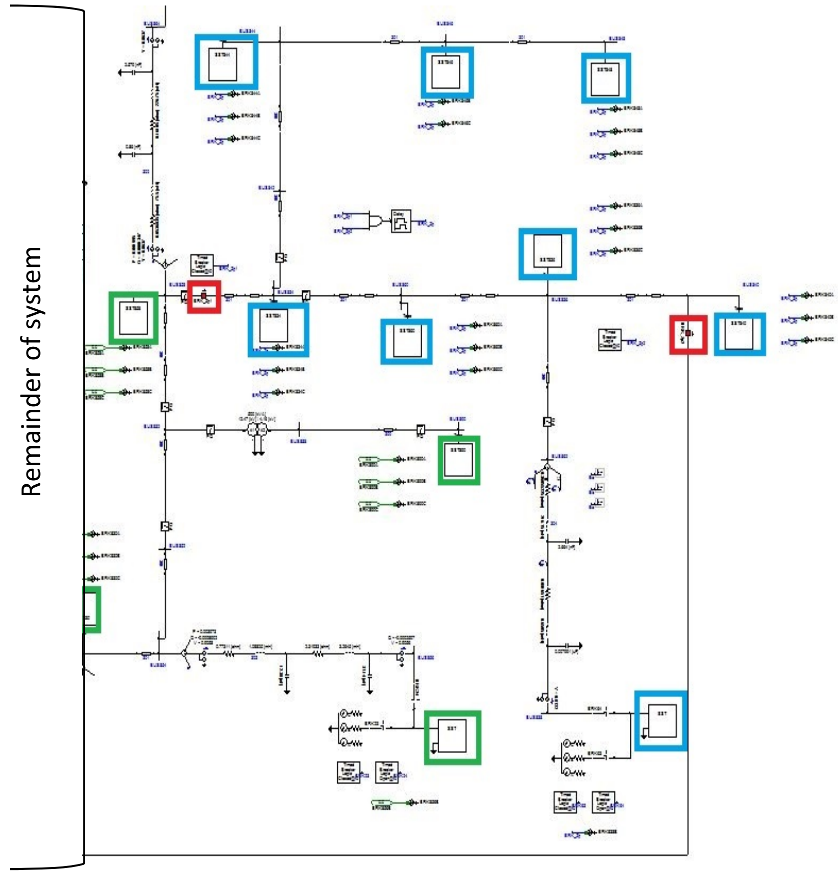
Fault is between relay 1 and relay 2

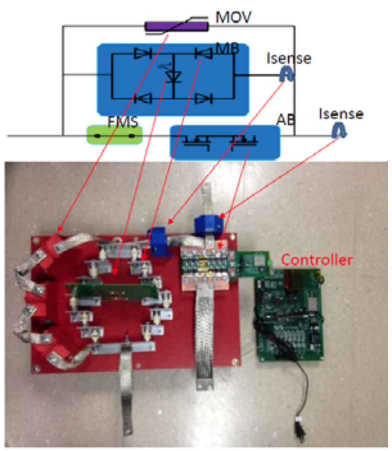


Green signal is +1 → Forward fault for relay 1
Red signal is -1→ Reverse fault for relay 2

Example Project 1



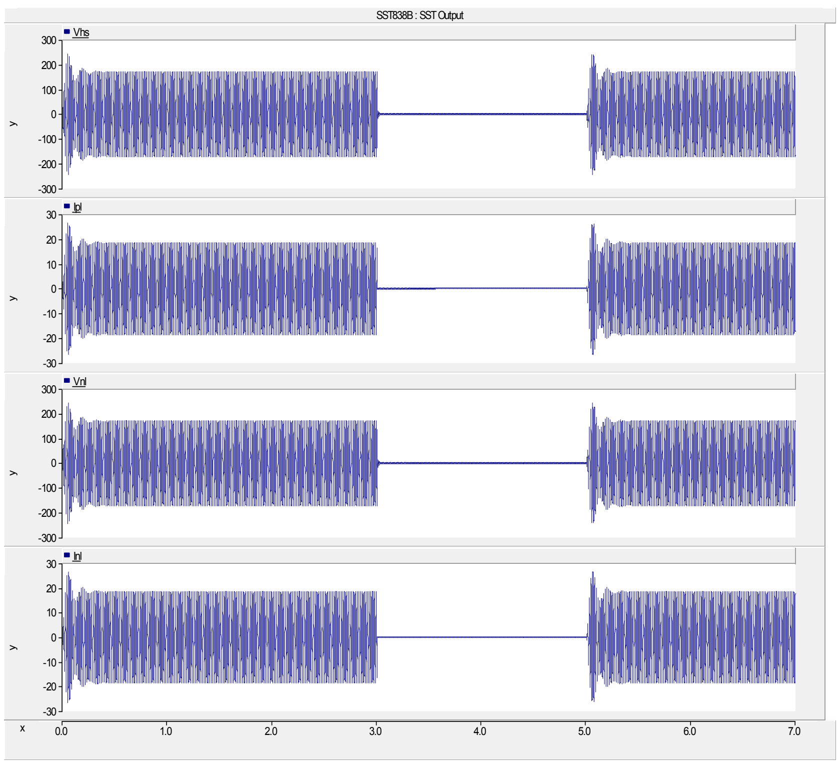




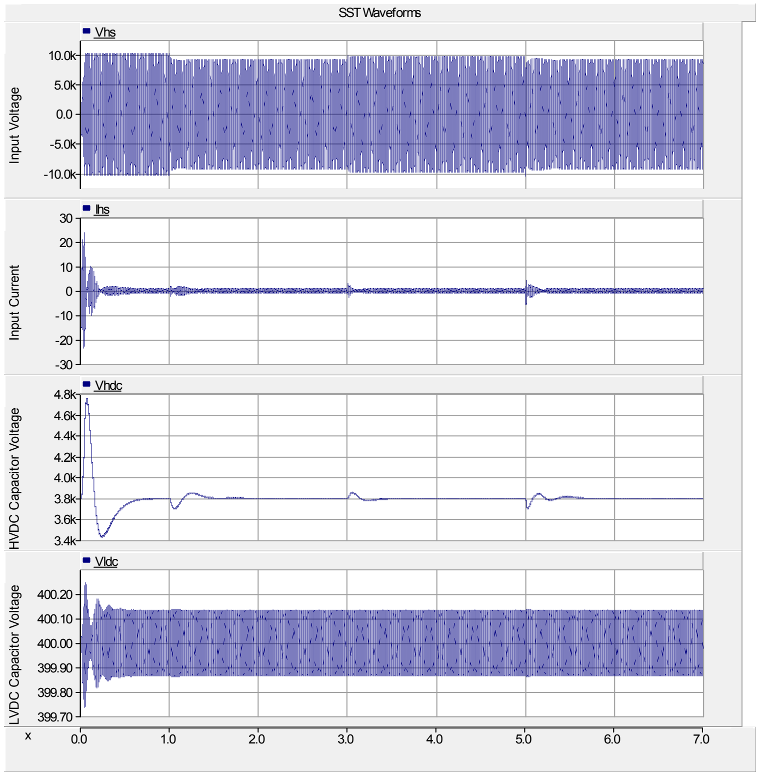
Fault Interruption Device (FID)

Example Project 1

SST response inside of Fault Region

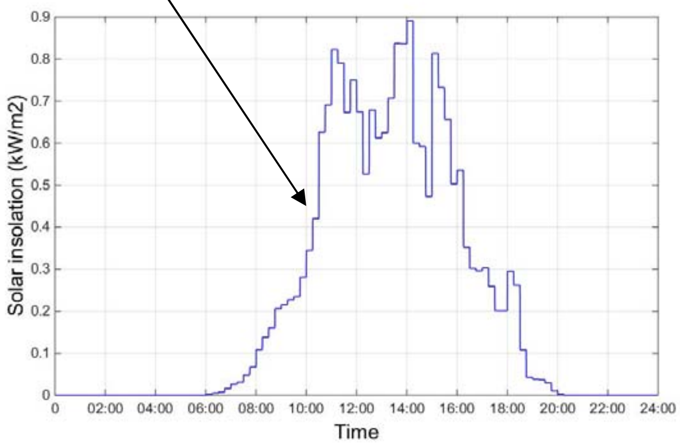


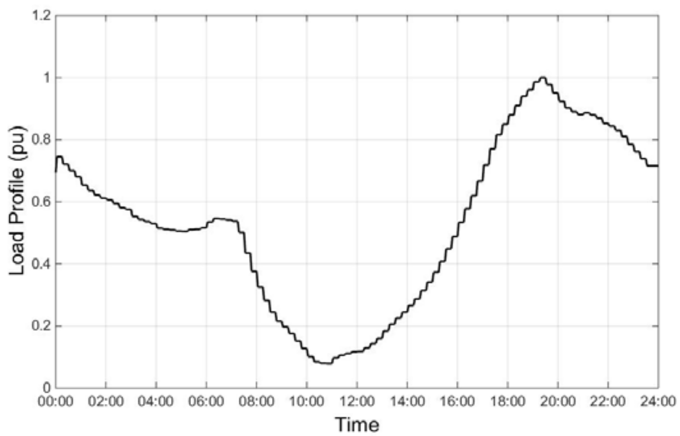
SST response outside of Fault Region



Example Project 2

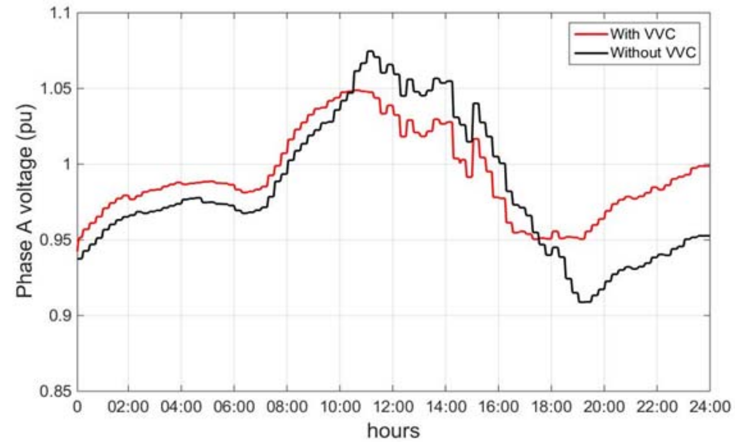
Actual solar insolation

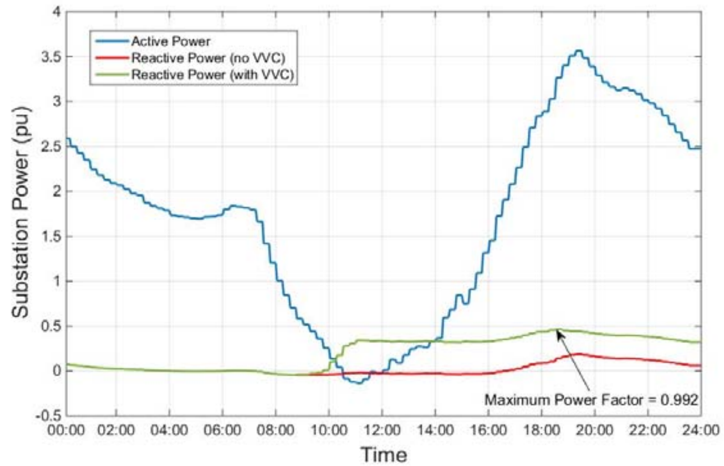




Non-VVC SSTs hold unity pf

Distributed Volt-Var Control





Example Project 2