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MIT Lincoln Laboratory



Power Systems Hardware-in-the-Loop Laboratory Testbed and Open Platform (HILLTOP)



MIT Lincoln Laboratory

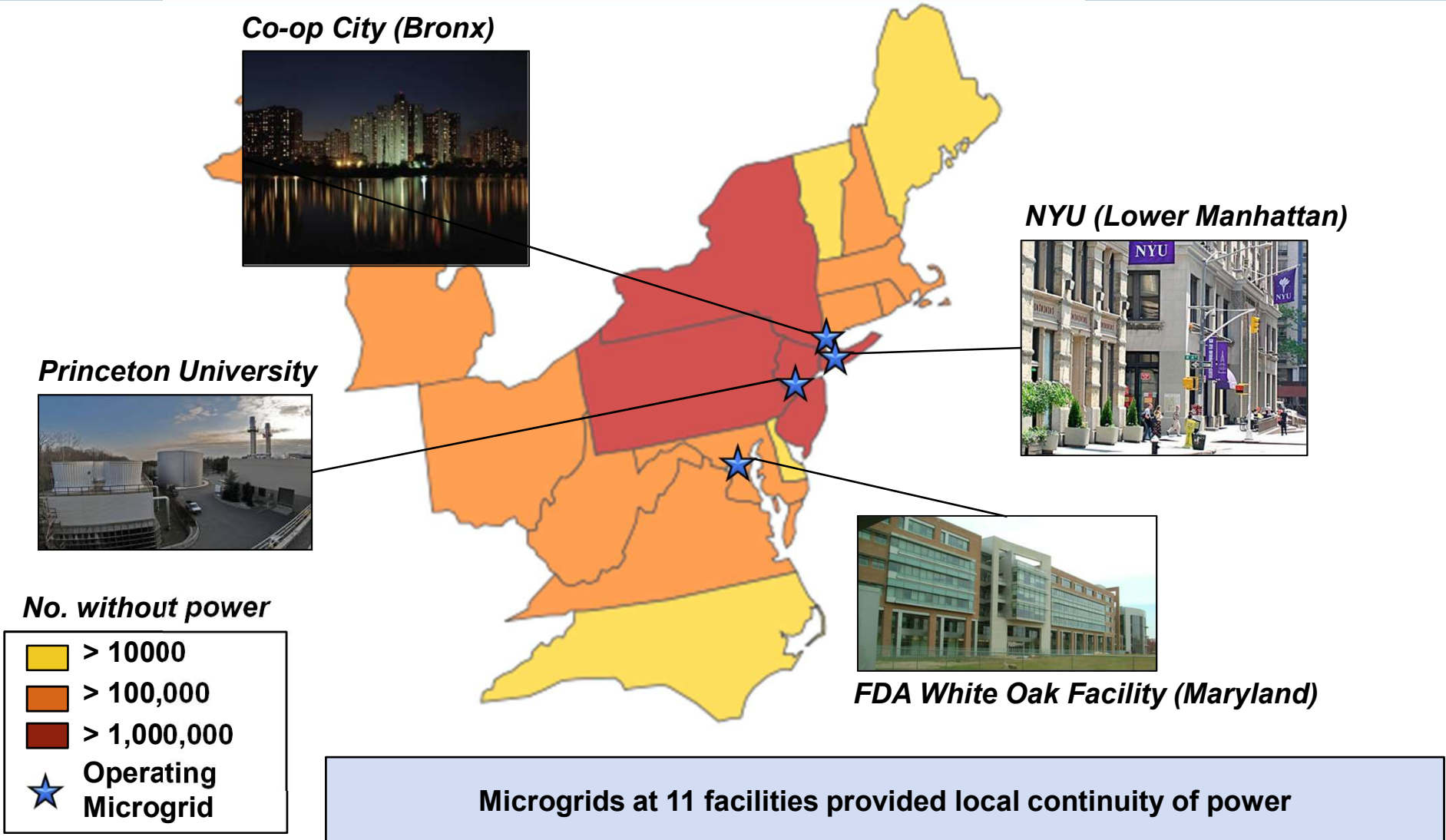


U.S. DEPARTMENT OF
ENERGY

Electricity Delivery
& Energy Reliability

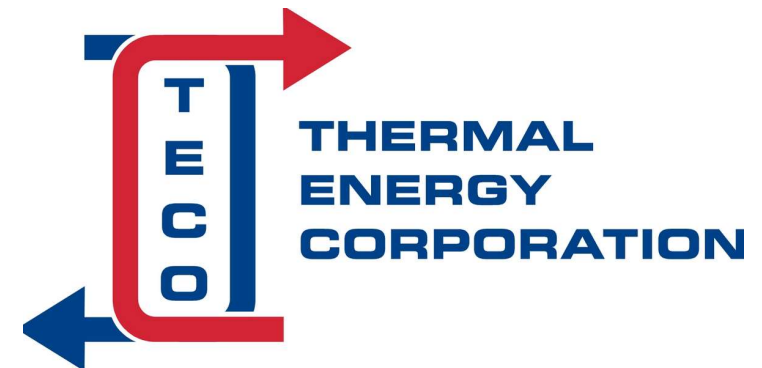


Distribution System Resilience: Microgrids During Hurricane Sandy





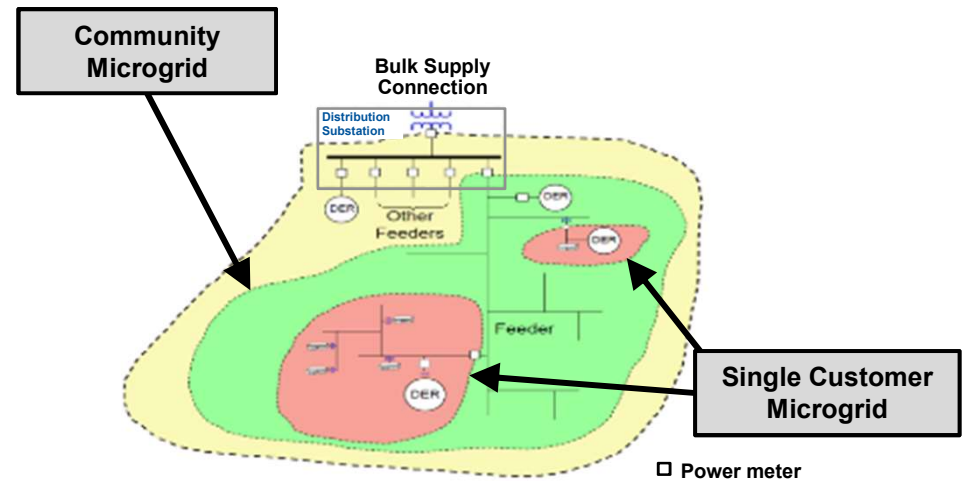
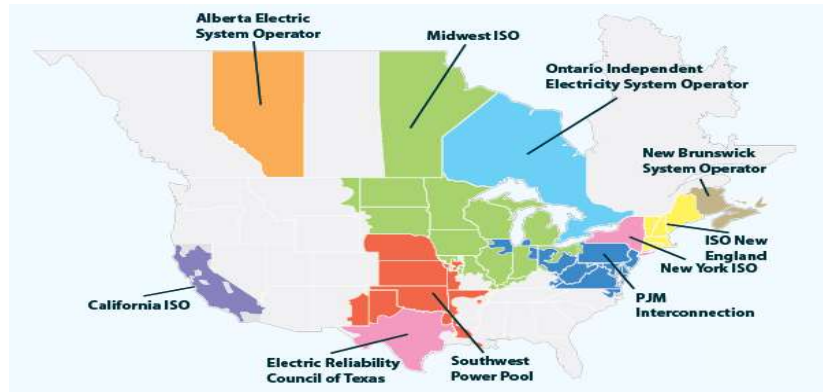
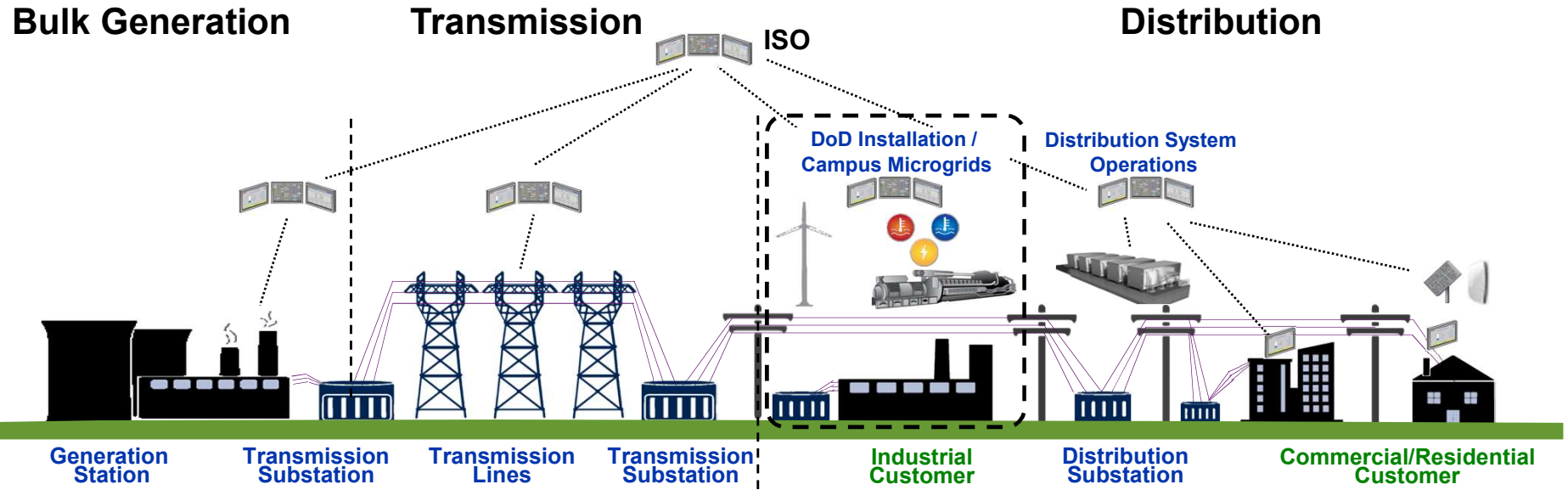
Distribution System Resilience: Microgrids During Hurricane Harvey



Microgrids provided electricity to Texas Medical Center and grocery stores during times of need



The Electric Power System





Microgrid Controller Vendor Space

Non-comprehensive

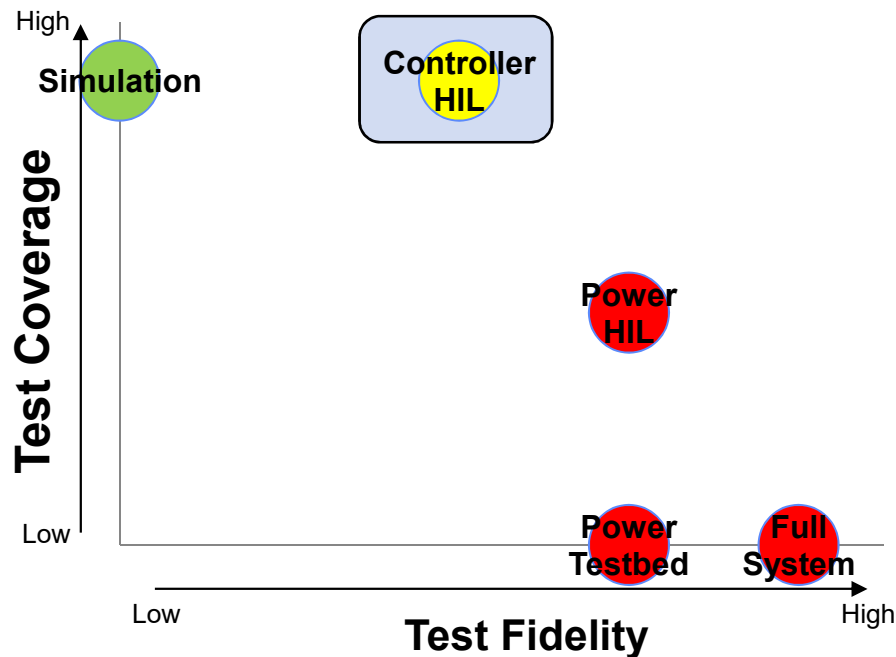
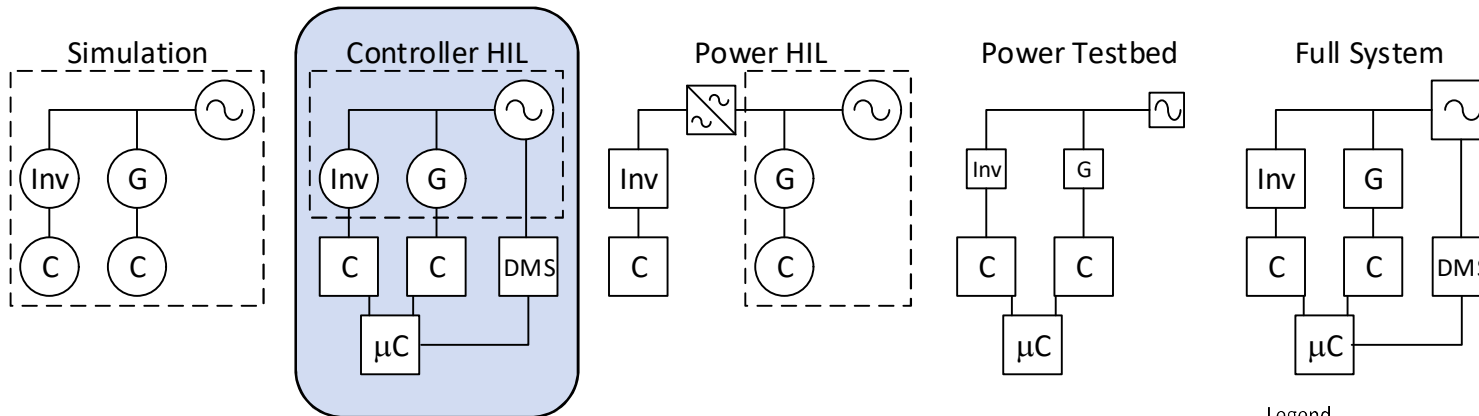


- **Schweitzer Engineering Laboratories (SEL)**
- **Eaton**
- **Schneider Electric**
- **General Electric**
- **Alstom (now with GE)**
- **Raytheon**
- **ABB**
- **Siemens**
- **Lockheed Martin**
- **Spirae**
- **Iperc**
- **Etap**
- **Smart Grid Solutions**
- **Pareto Energy**
- **Lawrence Berkeley National Laboratory (LBNL)**
- **Oak Ridge National Laboratory (ORNL)**

The Power industry needs ways to identify “vaporware” and reduce deployment risk



Power Distribution Integration Platforms and Testbeds



Legend

- G generator
- Inv battery or solar inverter
- C device controller
- μC microgrid controller
- DMS distribution management system controller
- ~ power grid
- ⚡ high-bandwidth AC-AC converter
- simulation or emulation boundary
- hardware
- virtual (simulated or emulated)
- low cost
- moderate cost
- high cost



HILLTOP Rack #1 Using OPAL-RT Simulator



- **Real-time target with Xeon Intel® Processor**
 - Using 8 of 12 cores
 - 2.7 to 3.2 GHz
- **FPGA-based I/O management with**
 - Xilinx Spartan-3



HILLTOP Testbed #2 Using Typhoon HIL Simulator



• HIL603 real-time simulator

• SEL HIL Connect

• Woodward HIL Connect

• EPC HIL Connect (PV and ESS)

- 4 HIL603 units
 - High speed serial link interconnection 8 lane - 5GHz
- 2 μ s & 4 μ s time steps
 - Multirate electrical simulation
- 23 cores used
- 20ns digital sampling
- 42 simulated relays with Modbus comms
 - 1.2 ms execution rate

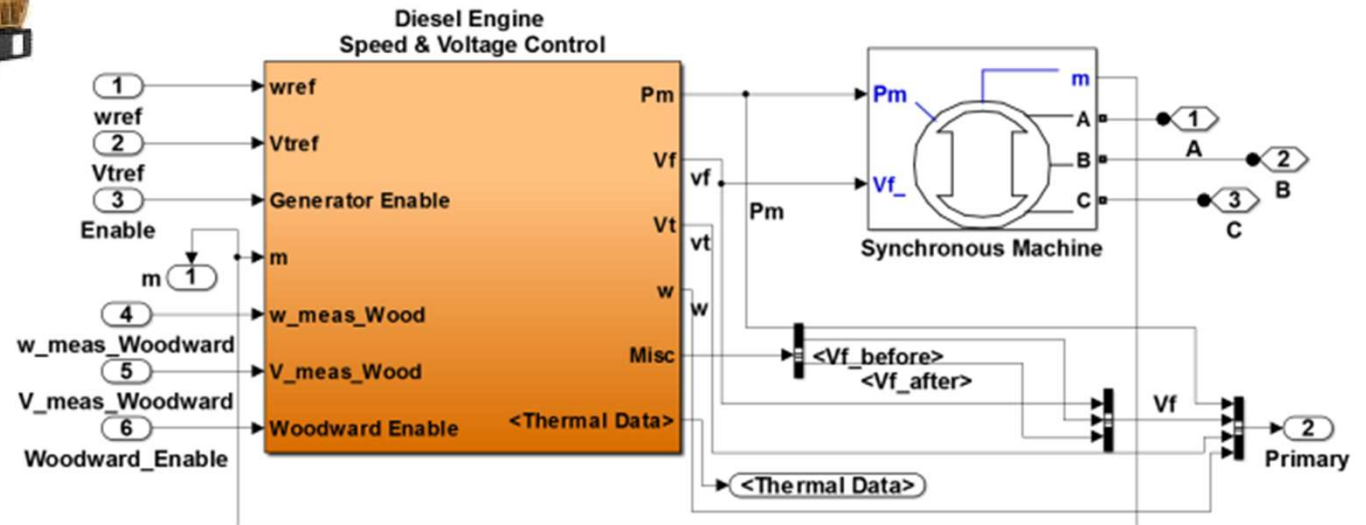


Simulated Diesel Genset Block



	1 MW Genset	4 MW Genset
Manufacturer / Model	CAT C32	CAT C175-20
Rating (kVA)	1,000	4,000
Power Factor	TBD	TBD
Voltage (V)	480	13,800
Frequency (Hz)	60	60
Speed (RPM)	1800	1800
Minimum Output Power	25kW	100kW
Startup Time	<10 sec	<15 sec

Genset ratings and characteristics



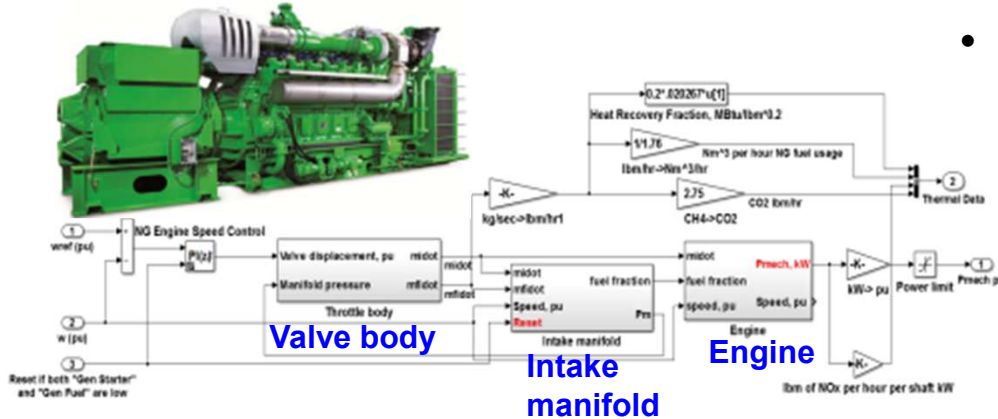
Synchronous Machine, Governor, and AVR Models



Natural Gas Combined Heat and Power



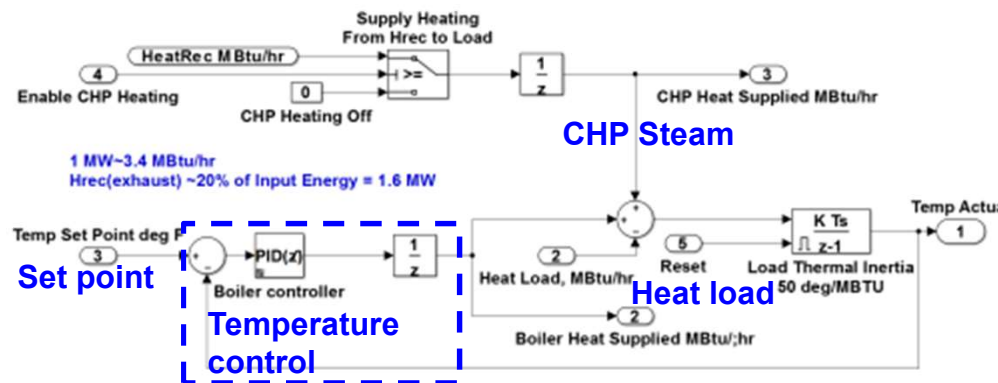
Electrical



GE/Jenbacher J620 NG Engine (1800 RPM)
3.5 MW Natural Gas Engine Model (Physics Based)

- Physics-based, scalable 3.5 MW NG genset with gas valve, intake manifold, combustion
 - Fuel usage
 - GHG emissions
 - Heat recovery
 - Woodward easYgen 3500 compatible

Thermal

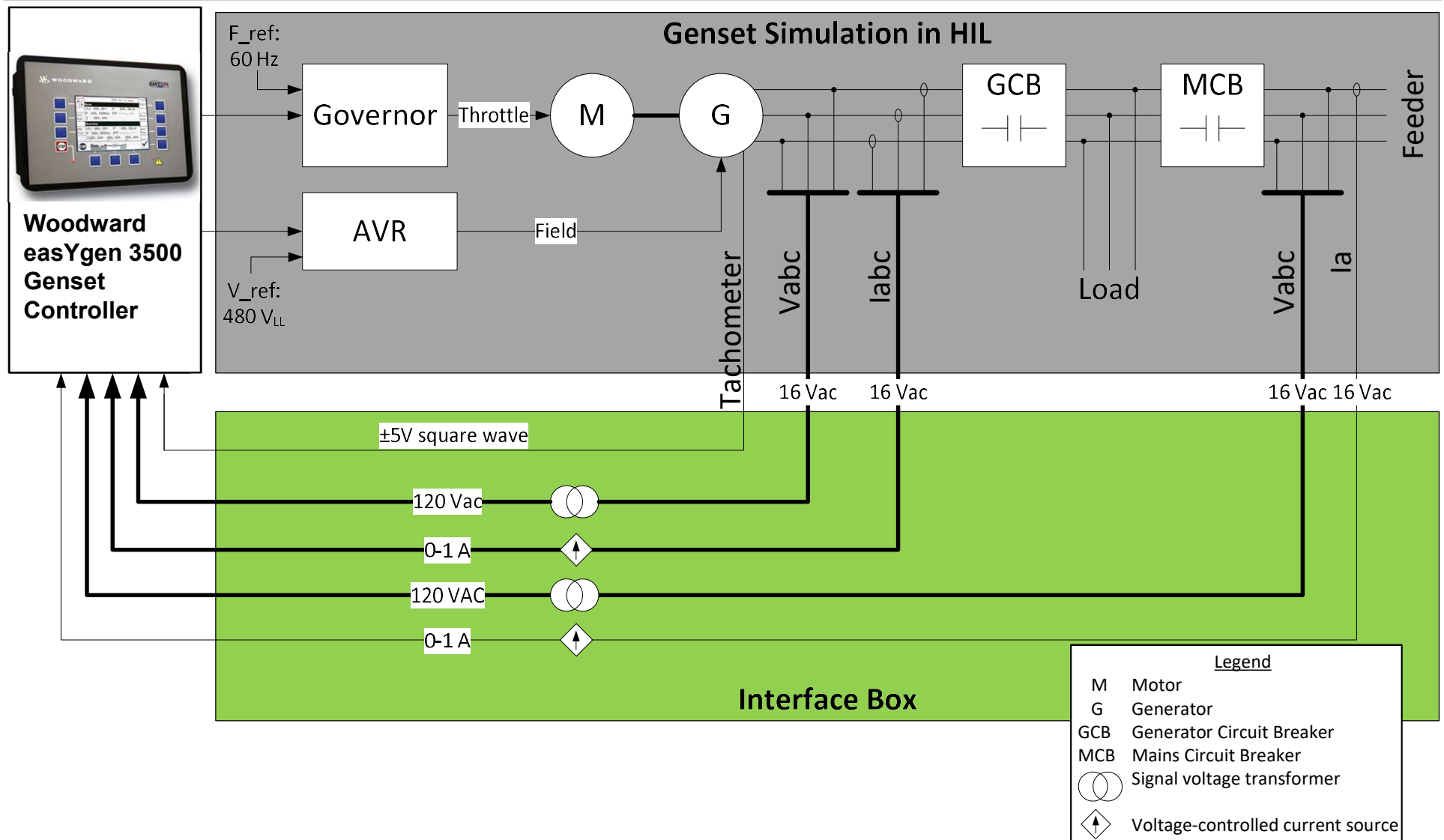


CHP Aggregate Thermal Model

- Aggregate CHP system model
 - Modbus commanded heating or cooling mode, temperature set-point
 - Independent heat load input
 - Parametrically settable losses, cooling coefficient of performance, thermal inertia

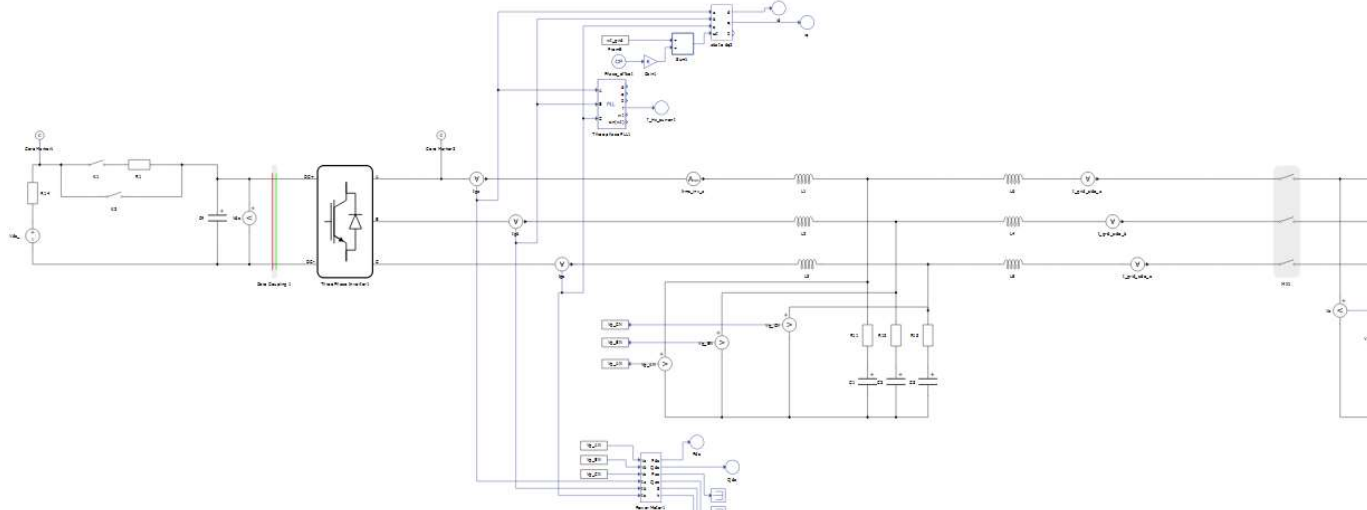


Device Controller Integration: Woodward easYgen 3500





EPC Power Electronics Models: Solar PV and Energy Storage System



- **4-quadrant control module**
- **Control capabilities for microgrid operation**
 - Real (P) and Reactive (Q) power dispatch
 - Voltage islanding mode
 - UPS parallel backup mode
- **Manufacturer validated inverter model**
- **Modbus over RS485 Communication**

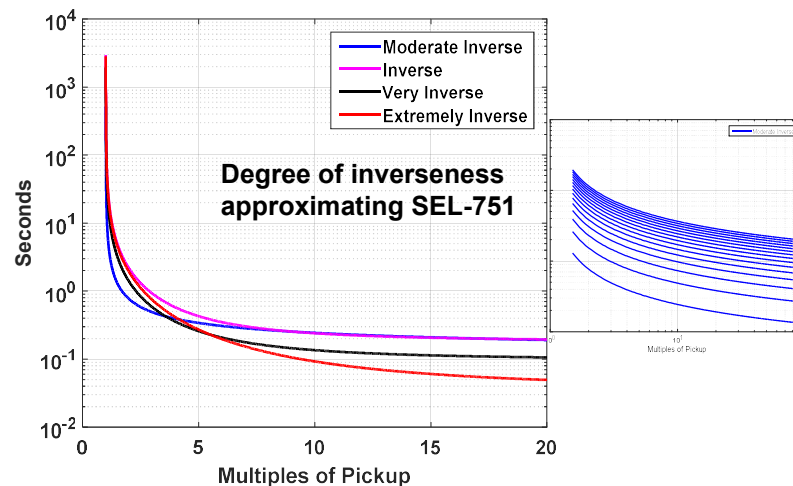
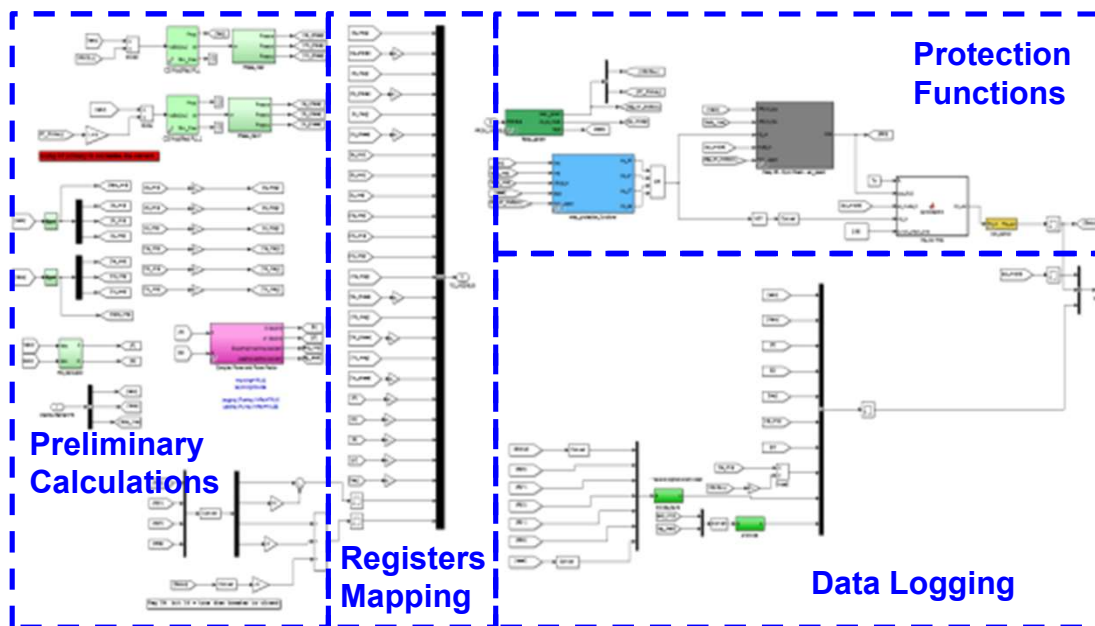




Generic Software Relay

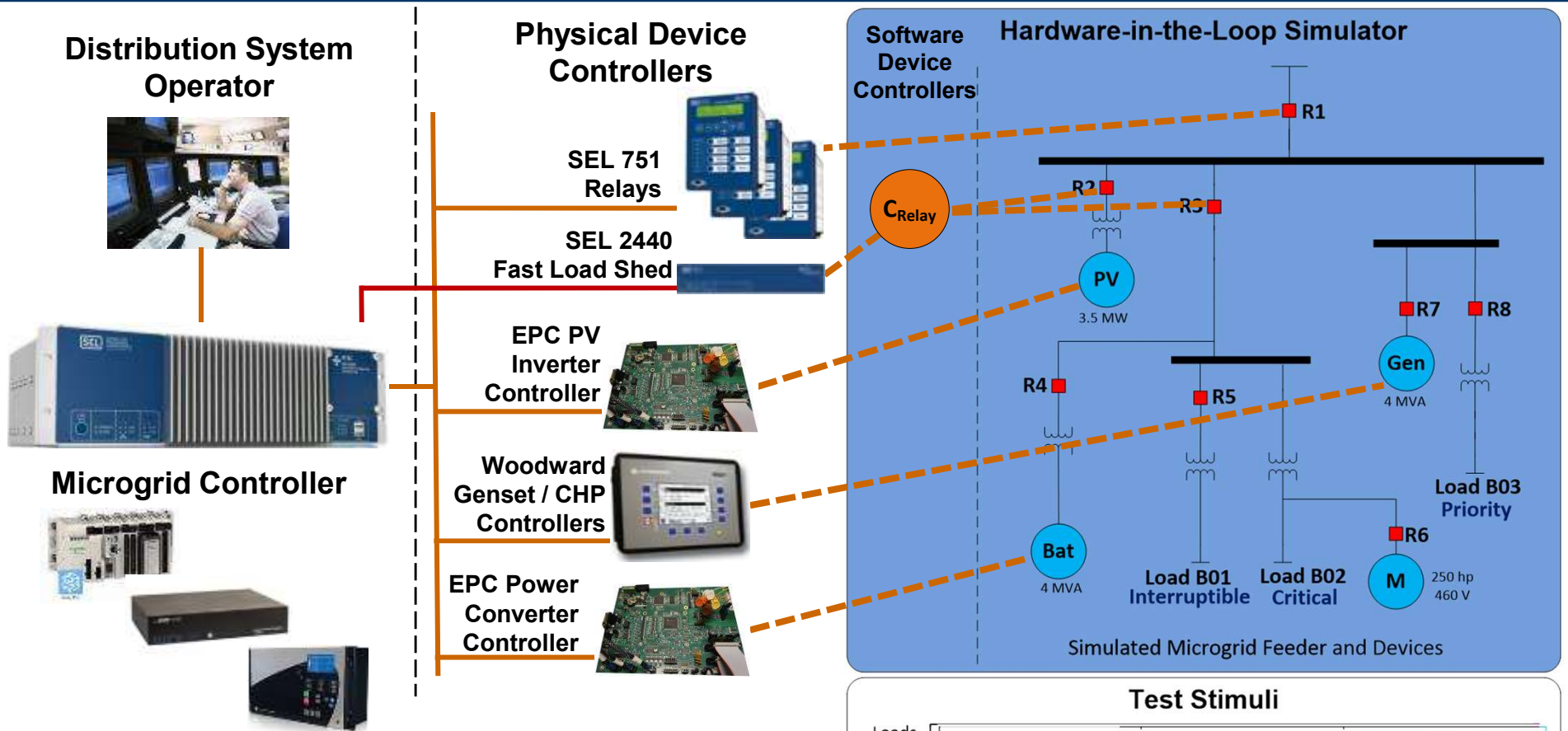


- Used for telemetry
- Various time current characteristic curves (TCC)
- Active protection features:
 - Overcurrent (50, 51)
 - Over/under voltage (27, 59)
 - Synchronism check (25)
 - Reclosing (79)
- Modbus TCP interface
- Multiple protection group settings accessible by the microgrid controller
 - Grid-tied protection
 - Islanded protection

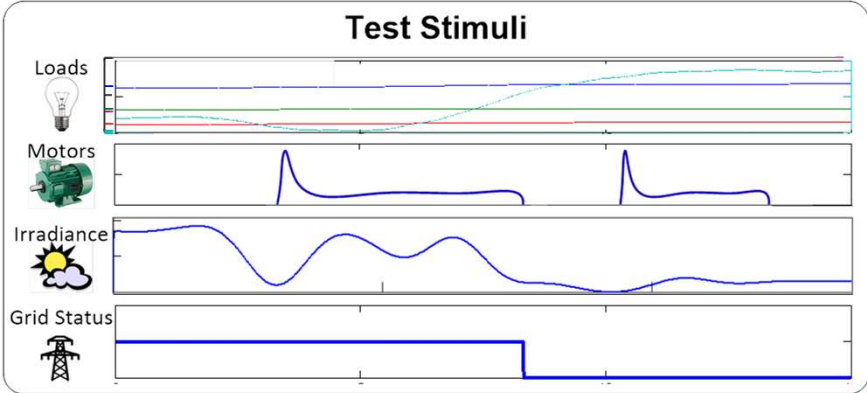




Controller HIL with Three Layers of Control

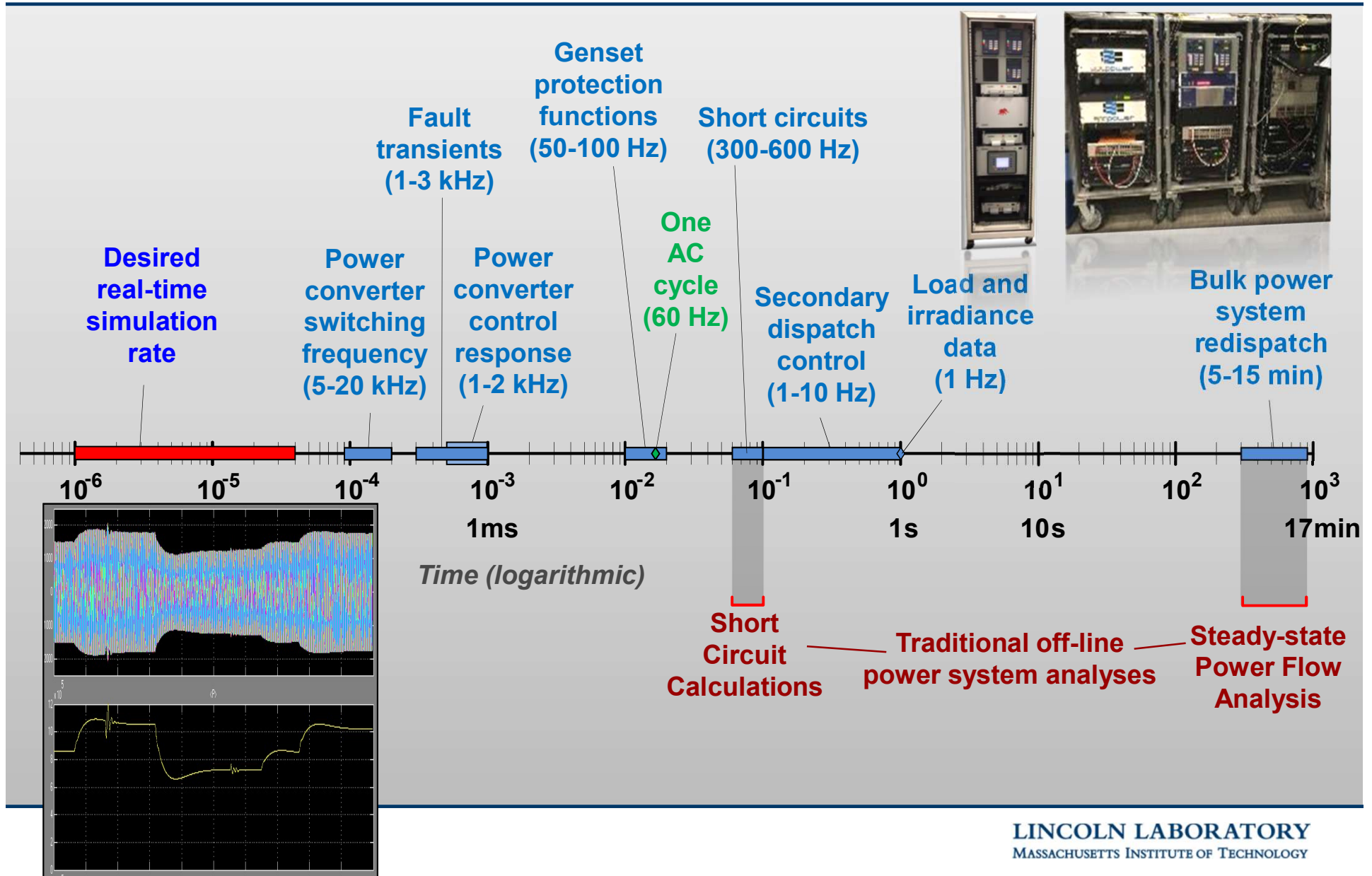


Command	Range of Values
DSO Export/Import	+10 MW (import) to -5 MW (export); 0 = any import/export permitted
DSO PF	-0.75 - +0.75
Volt/VAR support	-5 MVar - +5 MVar
Demand Response	0 - 5 MW





HILLTOP for Temporal Fidelity

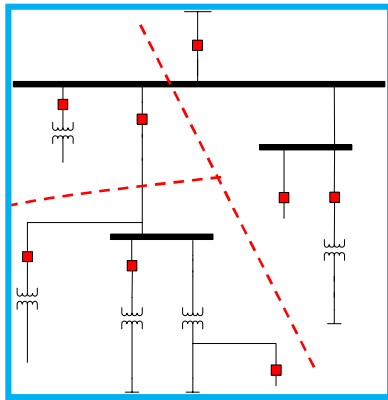




Construction of Detailed Microgrid Test Feeder Model



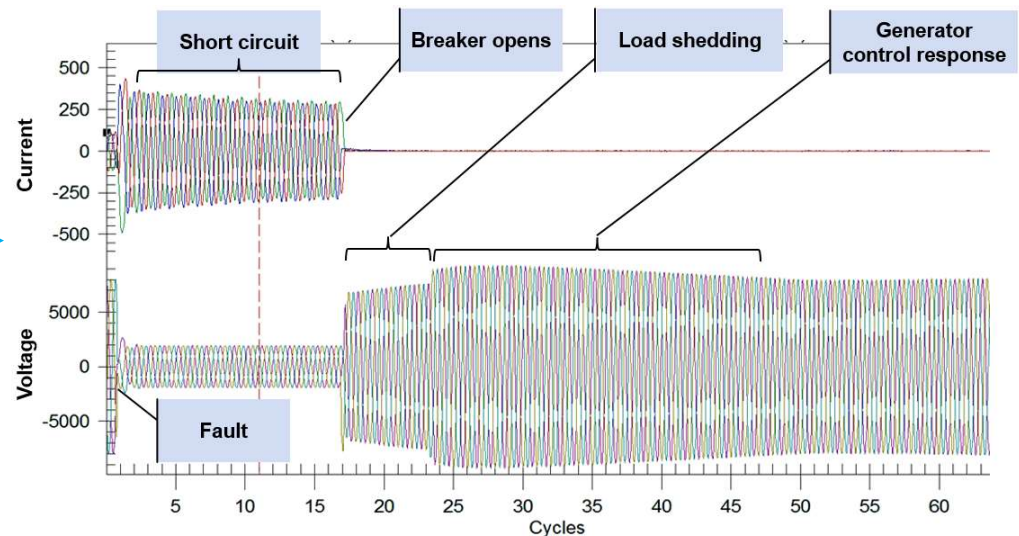
One-Line Diagram



RT Simulator



Detailed Studies



Data capture: Scott Manson, SEL

High fidelity evaluation of the power system and DER controller response



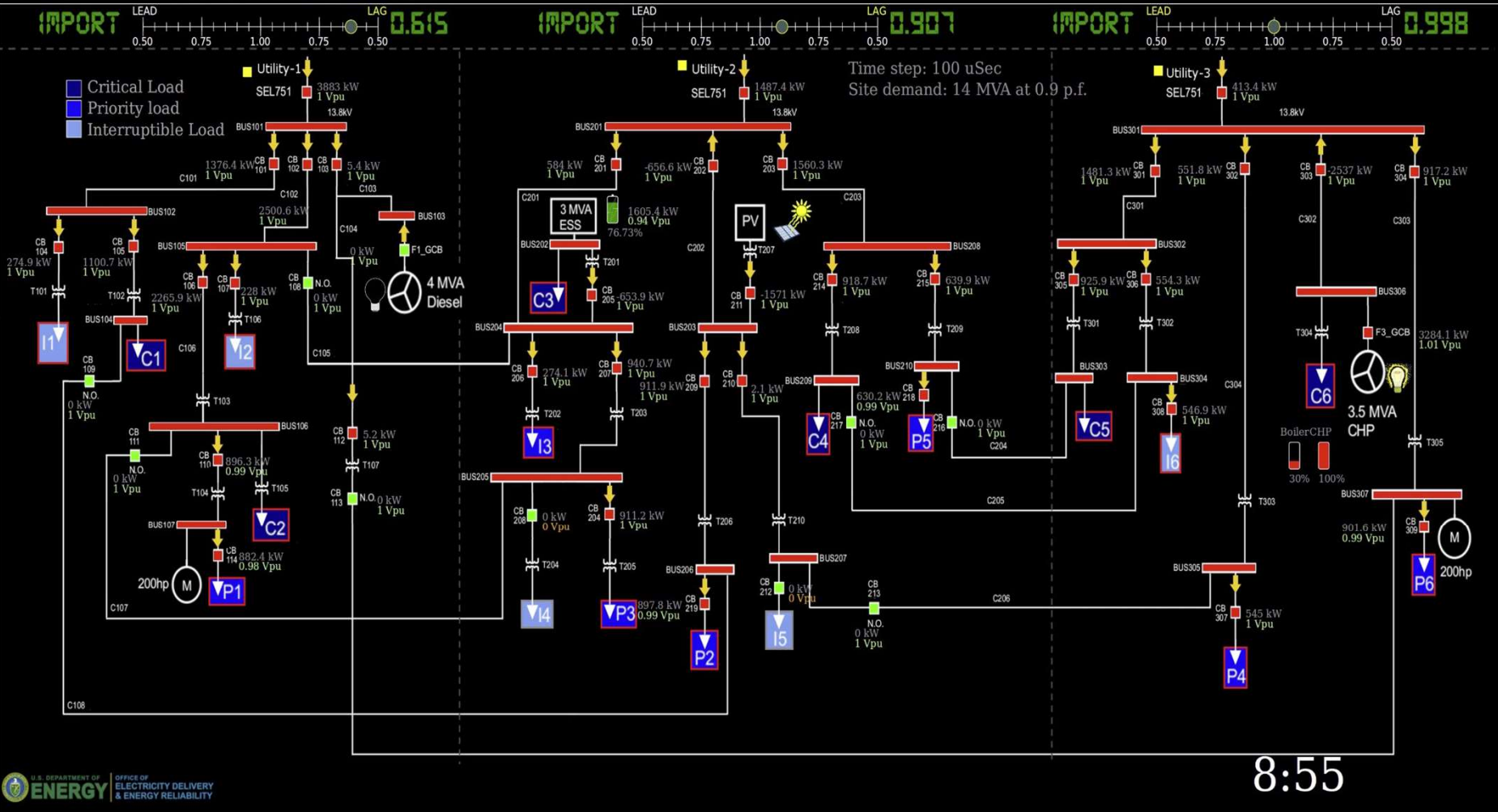
Real Life Distribution Network as Controller Integration Benchmark



BANSHEE SYSTEM PROFILE

04-28-2017-22-03-35

00:06:56 416

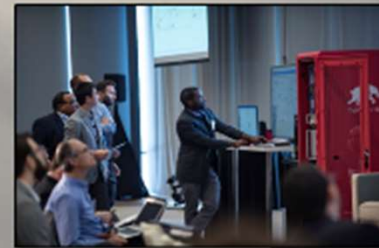
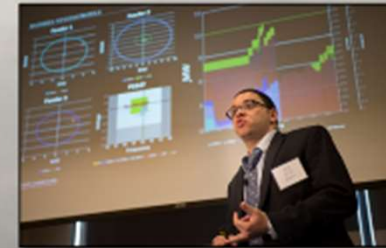




Showcasing Microgrid and DER Technology

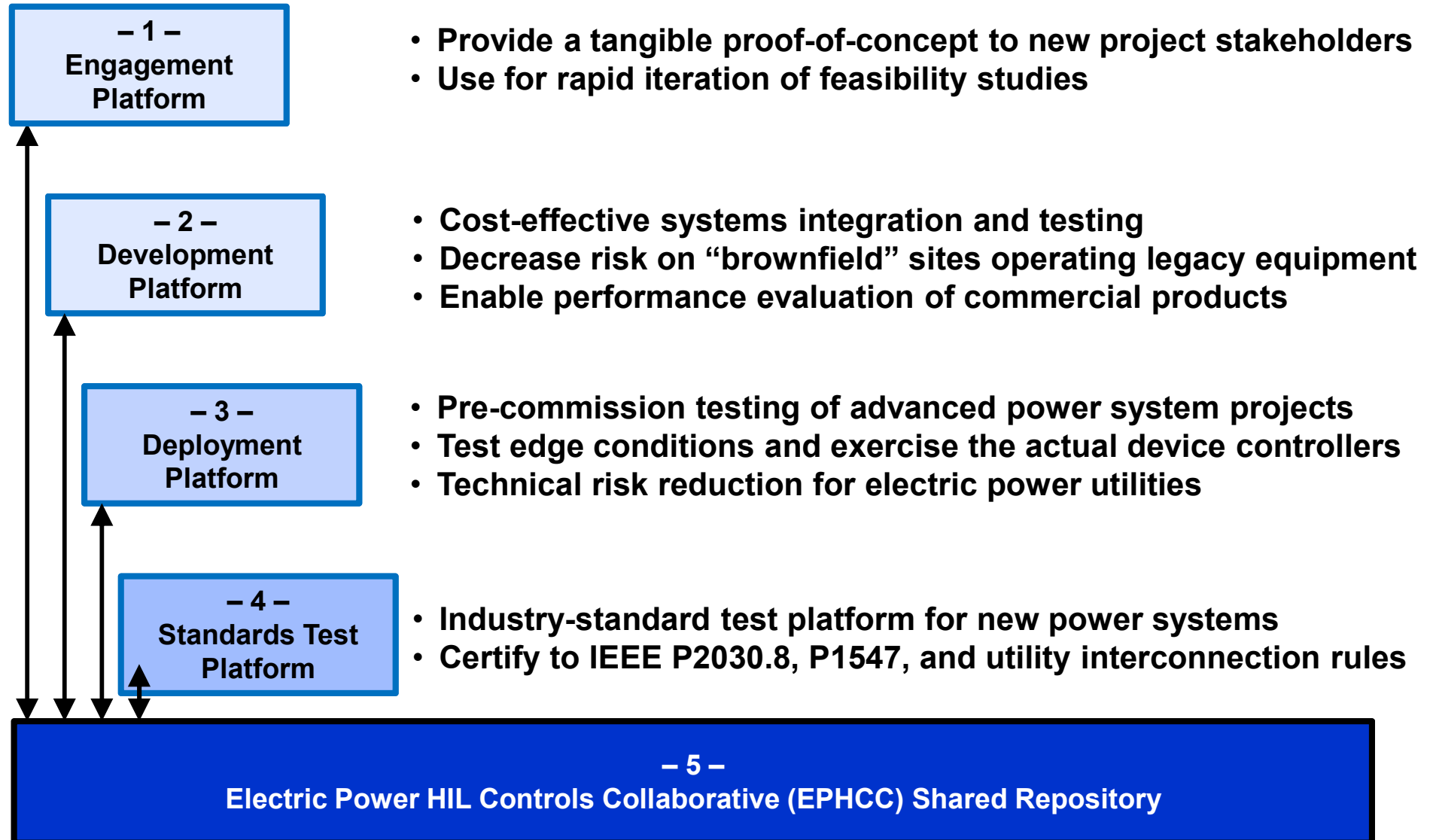


Second Microgrid and DER Controller Symposium
February 2017, MIT Samberg Center, ~300 attendees





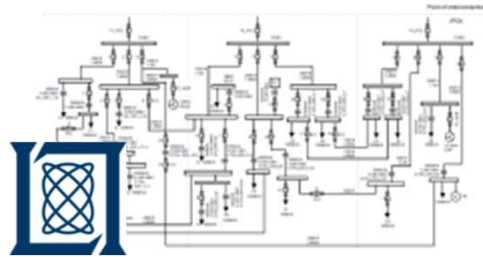
Vision for Power Systems HILLTOP





EPHCC Shared Repository

github.com/PowerSystemsHIL



MIT-LL Test Feeders and Models



NREL Microgrid Testbed



SEL RTDS Testbed
Factory Acceptance Test



MIT Smart Grid in a Room
Simulator for ARPA-E



Eaton Protection
Coordination Study



Typhoon HIL
HILLTOP testbed



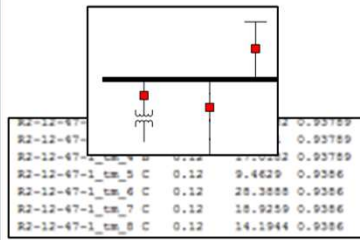
Elements of the EPHCC Shared Repository

github.com/PowerSystemsHIL



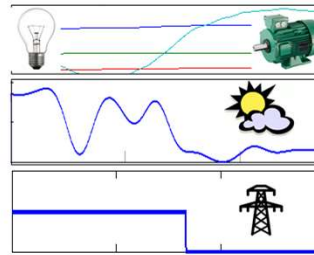
Microgrid Test Repository

Microgrid Test Feeders



Netlists

Standard Test Stimuli



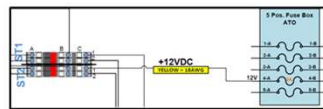
Load profiles, irradiance profiles, grid outages, faults

Post-processing Scripts for Test Results



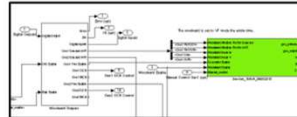
Controller-in-the-Loop Repository

Interface Circuitry for Device Controllers



Circuit schematics, bills of material

Interface Code for Device Controllers

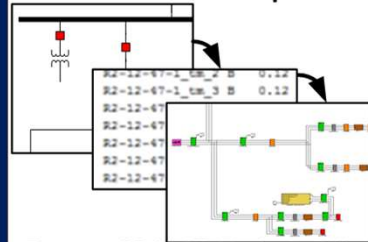


Communications Interface Translation Code



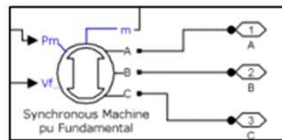
HIL Platform Repository

HIL Target Platform Conversion Scripts



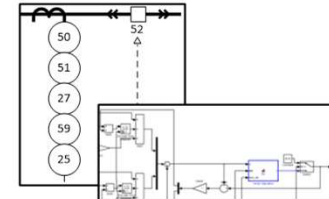
Targets: OPAL-RT, Typhoon HIL, RTDS, NI, and others

Validated Device Models



Motor-generators, power converters / inverters, and relays

Validated Device Controller Software



Genset controllers, power converter controllers, relay protection functions



Reynaldo Salcedo
Technical Staff
Energy Systems, Group 73



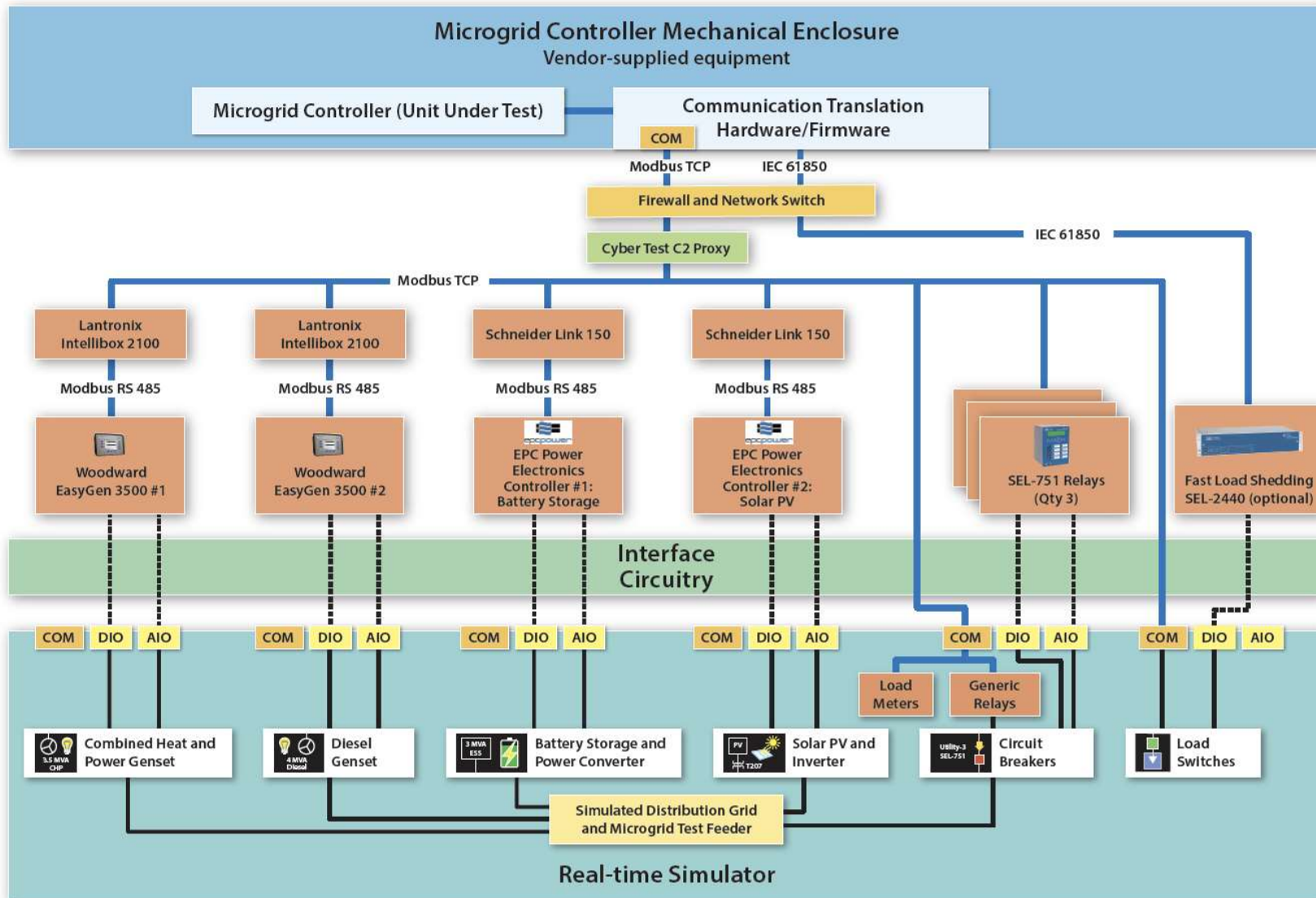
781-981-0610 (lab)
rsalcedo@ll.mit.edu



BACKUP



HILLTOP Block Diagram





Organized for Collaborative Design

github.com/PowerSystemsHIL



- ▶ CaseStudies
- ▶ Components
 - ▶ CAMPS
 - ▶ RTDS
 - ▶ SimulinkOpal
 - ▶ SimulinkSpeedgoat
 - ▶ Typhoon
 - ▶ DataProcessing
 - ▶ DistributionSystems
 - ▶ SimulinkOpal
 - ▶ Banshee
 - ▶ Canary
 - ▶ Siren
 - ▶ HighLevelDocs
 - ▶ SimulationTools
 - ▶ Templates
- ▶ SimulinkOpal
 - ▶ ActiveLoad
 - ▶ Cable
 - ▶ CHPandThermal
 - ▶ CircuitBreaker
 - ▶ DMSandTestSeq
 - ▶ EPC_BESS_PV
 - ▶ ESS
 - ▶ Fault
 - ▶ Genset
 - ▶ HWController_Diesel_Genset_4MVA
 - ▶ HWController_NGCHP_Genset_3p5MVA
 - ▶ HWCtrl_IO_InterfaceBlocks
 - ▶ MeasurementBlocks
 - ▶ Motor
 - ▶ PassiveLoad
 - ▶ PV
 - ▶ Relay
 - ▶ relay_settings
 - ▶ relays_configuration_files
 - ▶ relay_box_wiring_schematic20161104
 - ▶ relay_ANSI_50P_script
 - ▶ relay_ANSI_51P_script
 - ▶ relay_ANSI_59P_script
 - ▶ relay_ANSI_F25_lib
 - ▶ relay_ANSI_functions_li
 - ▶ relay_mgc_cmd_lib
 - ▶ relay_modbus_lib
 - ▶ relay_PLL_lib
 - ▶ relay_PQSPF_lib
 - ▶ RelayLogicDiagram
 - ▶ SEL751_Test_F1
 - ▶ SEL751_Test_F2
 - ▶ SEL751_Test_F3
 - ▶ SEL751Settings.rdb
 - ▶ SEL751Settings
 - ▶ SWRelay_CommTest
 - ▶ UnitTest_relay_tripOutMng
 - ▶ VC707_2-EX-0001-2_2_6_61-32AIO16DIO16DIOSel-01-01.bin
 - ▶ VC707_2-EX-0001-2_2_6_61-32AIO16DIO16DIOSel-01-01.conf
 - ▶ SEL751_InterfaceBlocks
 - ▶ Transformer
 - ▶ UDP
 - ▶ WoodwardEasyGen3500_InterfaceBlocks

