Hardware In The Loop
REAL TIME DIGITAL SIMULATOR:
A Critical Grid Modernization Tool

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Need for Testing System of Devices

- Today *The Modern Grid* means embedded digital communications, wide-area protection and controls, distributed and renewable energy resources in addition to a wide range of power electronic devices.
- From analytical perspective, demarcation between distribution and transmission systems has blurred.
- This has rendered protection, operation and control of the network more complex and hence made the testing these system of devices very critical.
- Design, development, commissioning, maintenance, failure analysis and operator training are just some of the areas that are looking for new analytical and testing tools.
- Laboratory testbeds need to precisely replicate real grid dynamic behavior to properly represent faster dynamic interaction between multiple, distributed controllers.
- Such testbeds are called **Hardware In the Loop (HIL) Simulators**.
- **Real Time Digital Simulator or RTDS®** in our case, is the most versatile HIL testbed.
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**State of the Art**

**Analog**
- Analog Simulator were made out of miniature analog equivalent devices.

**Digital**
- Digital Simulator uses multi-core, multi-processor computational platforms with high speed A/D, D/A and protocol based Input/Output interfaces
- Ideally suited for testing *the modern grid* with *cyber-physical interface*
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Parallel Processing Power

All-in-one chassis!
- Designed around IBM’s POWER8® RISC-based 10-core processor
- Clock speed: - 3.5 GHz!
- Fast, on-chip, core-to-core communication
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High Speed Precision I/O

Flexible and Expandable I/O

- **Analog Input (GTAI)**
  12 channel, isolated 16-bit analogue input

- **Analog Output (GTAO)**
  12 channel, isolated 16-bit analogue output

- **Digital Input (GTDI)**
  64 channel, isolated digital input

- **Digital Output (GTDO)**
  64 channel, isolated digital output

The GT family of I/O cards can be daisy chain connected to a single NovaCor fiber port allowing for easy scaling of the simulators IO capabilities.
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Real-Time I/O Protocols

- **IEC 61850:**
  - GSE: binary messaging
  - SV: sampled values

- **PLAYBACK**

- **SCADA:** DNP3 and IEC 60870-5-104
- **PMU:** IEEE C37.118
- **MODBUS:** TCP, RTU over TCP, ASCII over TCP
- **SOCKET:** TCP/UDP (bidirectional, Asynchronous)

NovaCor Processor

GTNETx2

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Controller Hardware in Loop - CHIL

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Power Hardware in Loop - PHIL

- Real-time simulation environment exchanging power with real, physical power hardware, such as renewable energy resources, electric vehicles, batteries, motors and loads
- System (utility or microgrid) is simulated in Real Time Simulator and interfaced via power amplifier to the power device(s) under test

Analog I/O or Arora Protocol
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RTDS Applications

Hardware in the Loop for Grid Modernization

- **DISTRIBUTION**
  - Microgrid Testing
  - Renewables/DERs
  - Distribution Automation
  - Inverter Testing

- **POWER ELECTRONICS**
  - HVDC & FACTS
  - Energy Conversion
  - Drives

- **SMART GRID**
  - WAMPAC Testing
  - PMU Studies
  - Cyber Security

- **PROTECTION**
  - Digital Substations
  - Traveling Wave Testing
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- BESS is becoming a prominent component of renewable energy strategy for utilities worldwide

- A real-time testbed based on RTDS simulator lets the BESS suppliers and the utilities to test the controls, DERMS interface and protection system under all types of grid conditions and BESS operating modes

- The testbed is also a great facility to develop, test and validate a standardized interface so that the utility can specify the interface requirements and verify it before commissioning. The architecture shown here is an example of one such testbed
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Model Details

• 3MWh Li-ion battery
• Average voltage model converter (480V AC)
• P and Q modes of operation
• Battery is interfaced to the grid through a 480V to 12kV Star-delta transformer
• Critical, non-critical and variable loads added at 12kV side
• Breakers Way 1, Way 2, Way 3 and Way 4 (SEL 487E)
• P and Q modes control set points and reference - Local/ DNP(DERMS)
• Currents and voltages of the breakers sent to SEL487E through Analogue IOs and Statuses through Digital IOs.
• Breaker operation from SEL487E and permission from SEL700G received through low voltage front panel interface.

Testbed Highlights:

- Developing real-time grid connected battery energy storage system (BESS) model
- BESS operation in various modes based on real power (P) and reactive power (Q) support
- Islanded mode of operation
- Controls and setpoints are provided either in Software-in-Loop (SIL) approach or remote (DNP) approach
- Real-time IO operation of breakers and other control logic with actual SEL 480E and 700G relays
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BESS in RSCAD

Overall BESS Model

Battery Model

Grid Model
## Operating Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>P Mode</th>
<th>Q Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Idle</strong>: SOC maintained at same point when initialized</td>
<td>Idle: 0 Q support</td>
</tr>
<tr>
<td>2</td>
<td><strong>Base P</strong>: Constant real power support</td>
<td><strong>Base Q</strong>: Constant reactive power support</td>
</tr>
<tr>
<td>3</td>
<td><strong>Frequency regulation</strong>: Supports requested Frequency at PCC</td>
<td>Power factor correction: Maintain Specified Power Factor at Inverter output</td>
</tr>
<tr>
<td>4</td>
<td><strong>Real power load shift</strong>: Peak Shaving</td>
<td>Voltage regulation: Maintain specified voltage at PCC</td>
</tr>
<tr>
<td>5</td>
<td><strong>Real Power load smoothing</strong>: Restricts the sudden ramp in generation or grid supply</td>
<td>Reactive power load shift: Peak Shaving</td>
</tr>
<tr>
<td>6</td>
<td><strong>Target SOC</strong>: Maintains the specified SOC level in battery</td>
<td>Reactive power load smoothing: Restricts the sudden ramp in generation or grid supply</td>
</tr>
</tbody>
</table>
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DERMS Interface

- DERMS is interface to the RSCAD model through GTNETx2 card.
- RTDS acts as slave: DNP signals out from DERMS are CONTROL signals and DNP signals in to DERMS are STATUS signals.
- All control and status points of DNP point list are provided as a “.txt” file.

- **Analogue control (output) points:**
  - Set values, reference values (from PCC), SOC limits, dead band values, upper and lower limits and mode selecting settings
  - RTDS can receive 100 Analogue control signals in one GTNET card

```
AO: DNP address variable name default value [serializer name]
```

- **Analogue Status (Input) points:**
  - Voltages, currents, P and Q power values, upper/lower limits, feedback signals (acknowledged control set points)
  - RTDS can send up to 500 status points in one GTNET card

```
AI: DNP address variable name deadband% [serializer name]
```

- **Binary Status (Input) points:**
  - breaker signals, binary setting, alarms
  - RTDS can send up to 1024 status bits in one GTNET card

```
BI: DNP address user label bitmap name bitmap bit num
```
Portective Relay Interface

- SEL487E monitors and controls the WAY1, WAY 2, WAY3 and WAY4 breakers
- The statuses of the breakers are sent through GTDO by converting the bits to 16-bit word. All the analogue voltage and currents are sent through GTAO
- SEL 700G provides the permissions to operate the battery units
- SEL 487E provides the trip and close signals to all the breakers
- LV GTFPI has 16 I/O channels and provides the input or output as a word
Simulation Results: RSCAD Runtime

- LOC/REM allows to choose the setpoints either from DNP or Local setting.
- When the switch is set to REM, “MODE selection and set point” box is disabled.
- Similarly the Relay permission can be provided locally or from SEL 700G.
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Simulation Results: P Modes of operation

- **Base P**
  - Pgrid
  - PLoad
  - Pbat

- **Freq Reg.**
  - Pgrid
  - PLoad
  - Pbat

- **P Load Shift**
  - Pgrid
  - PLoad
  - Pbat

- **Target SOC/Idle**
  - SOC
  - Target SOC

- **Target SOC/Idle**
  - SOC
  - Target SOC
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Simulation Results: Q Modes of operation

- QLoad
- Qgrid
- Qbat ref
- Qbat
- V at 12kV
- V reg.
- PF correction
- Q Load Shift
- Smooth
- Q Load Smooth

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Simulation Results: Islanded operation

- For islanding SEL 700G and DNP provides the permissions to operate the battery in island
- “Interchange allow” permission is required to allow the grid to be at zero energy flow state
- Way 3 breaker is tripped to islanded the system

WAY 3 trip (Island)

WAY 3 Close (re-grid)
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Distribution Automation Testing

TECHNOLOGIES:
- OPENFMB
- MODBUS, DNP, GOOSE, R-GOOSE
- Grid edge connectivity
- Exhaustive set of use cases

DEVICES:
- Three cap bank controllers
- Two switched loads
- Two DERs
- Two substation relays
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DA: Communication Architecture
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DA: Real Time HIL Model

RSCAD
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Technologies and Features:
- OPENFMB
- MODBUS, DNP, GOOSE, R-GOOSE
- EDGE CONNECTIVITY
- EXHAUSTIVE SET OF USE CASES

Courtesy: GE Grid Solutions from live demo at DistribuTECH 2018
DA: Open FMB Use Cases

- Use Case 1a: OpenFMB Connection to Vendor B Devices and Virtual DER / Cap Bank
- Use Case 2a: Var Control
- Use Case 2b: Man-in-the-Middle Augmented Voltage/Var Control
- Use Case 2c: Peer-to-Peer Voltage/Var Control
- Use Case 2d: Voltage Override
- Use Case 4a: DER Active Power Control
- Use Case 6a: Enhanced Automatic Feeder re-deployment
- Use Case 7a: Automatic Feeder Re-Close
- Use Case 8b: Synchrophasors via R-GOOSE
- ......
- 13a OpenFMB using DDS

REFERENCE: EPRIC 2, Project 3, SDG&E Final Report

Protection: IEC 61850 Interface

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Generator Controls Testing
Testing of Generator Controllers
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Cyber-Physical Security Hardware-in-the-Loop Testbed
Florida State University – Center for Advanced Power Systems

- Capability to study cyber-physical system operation and security of physical power and controls hardware in a system relevant environment.
- Substantial real-time power network and communication network simulation capacity provides large-scale rest of the system.
- Physical devices such as embedded controllers and protective relays along with physical power hardware such as power electronic converters can be studied interacting with realistic simulated devices.

Heterogeneous Large-Scale Distributed Control Platforms
Thank you!