REAL TIME SIMULATION:
Tools and methods for testing the future grid of the UK and beyond
Introducing NovaCor™ – the new world standard for real time digital power system simulation

Issues facing the UK (and beyond)

• Rapidly increasing penetration of intermittent renewable generation
• Rapidly increasing interconnection via HVDC (including multi-terminal)
• Need for coordination between transmission and distribution systems (between System Operator and DNOs)
• Need to understand complex control interactions

Need for INNOVATION
to reduce risk & increase flexibility
Real time simulation

IN THE BEGINNING

- Goal of replacing analogue simulators as de facto tool for HVDC/FACTS control testing
- Continued development and refinement to produce a commercial product
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A multi-purpose innovation tool

One hardware/software package is applicable to many different projects/areas:

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

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

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

- **PROTECTION**
  - Digital Substations
  - Traveling Wave Testing
## Types of digital simulation

<table>
<thead>
<tr>
<th>Type of Simulation</th>
<th>Load Flow</th>
<th>Transient Stability Analysis (TSA)</th>
<th>Electromagnetic Transient (EMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical timestep</td>
<td>Single solution</td>
<td>~ 8 ms</td>
<td>~ 2 - 50 µs</td>
</tr>
<tr>
<td>Output</td>
<td>Magnitude and angle</td>
<td>Magnitude and angle</td>
<td>Instantaneous values</td>
</tr>
<tr>
<td>Frequency range</td>
<td>Nominal frequency</td>
<td>Nominal and off-nominal frequency</td>
<td>0 – 3 kHz (&gt;15 kHz)</td>
</tr>
</tbody>
</table>
What is real time?

- Calculations completed in real world time less than timestep
- Every timestep has same duration
- The I/O is updated at a constant period equal to timestep
- Allows the connection of real external hardware in the loop with the simulated network
Real time simulation hardware

- Custom parallel processing computer
- Modular design
- Interface through user-friendly software
- Ample I/O to connect physical devices
  - Analogue and digital input and output
  - Network protocol input and output
- Additional FPGA-based hardware for computationally intensive models
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Traveling wave protection

- In May 2018, Public Service Co. of New Mexico energized the first-ever traveling wave protection scheme applied to a high-voltage transmission line
- SEL applied the T400L relay and used the RTDS Simulator for testing
- RTDS hardware runs frequency-dependent transmission line model at a very small timestep
- TWRT testing revealed an unprecedented operation time of 600 microseconds (midline, single phase fault) and location reporting within 0.02 miles (on 33.1 mile line)
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Remedial action schemes

Southern California Edison
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Closed-loop controller testing

HVDC (High Voltage Direct Current)
- Thyristor based schemes using improved firing algorithm
- 2- and 3-level VSC plus MMC based schemes using small timestep subnetworks

STATCOM
- 2- and 3-level VSC plus MMC based schemes using small timestep subnetworks

TCSC (Thyristor Controlled Series Compensation)

SVC (Static Var Compensator)

Generator (Exciter, Governor, PSS)
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HVDC/FACTS

• The RTDS Simulator was originally developed to model HVDC schemes

• Used by all manufacturers of HVDC for Factory Acceptance Testing (FAT) of LCC and VSC/MMC based schemes
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Replica simulators

- Assist during commissioning
- Investigate proposed network and control changes
- Test scheme upgrades and refurbishment
- Train personnel on scheme theory and operation

ONS (Brazil)  DEWA (UAE)
CSG (China)   NamPower (Namibia)
ESKOM (South Africa)  RTE (France)
SEC (Saudi Arabia)  BPA (USA)
Power Grid (India)  Manitoba Hydro (Canada)
Powerlink (Australia)  Transpower (New Zealand)
REE (Spain)  SSE (UK)
Work in the UK: National HVDC Centre

- Part of Scottish and Southern Electricity Networks – funded through the Electricity Network Innovation Competition as the Multi-Terminal Test Environment (MTTE) Project
- Collaborative facility supporting HVDC solutions in Great Britain
- Opened in April 2017
- Vendor-supplied HVDC replica controls
- First ever NovaCor installation
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Smart grid, microgrids, and DERs

- Renewable energy / DER models
- Power converter models
- High-level communication protocols
  - IEC 61850
  - DNP3, IEC 60870-5-104
  - IEEE C37.118
  - MODBUS
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Banshee Microgrid Model
MIT Lincoln Labs

SEL 3530 RTAC
Load shedding Functionality

Real Time Microgrid Simulation

Communication Interface

Industrial Microgrid Control

DNP & IEC 61850 GOOSE
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- DERMS and Active Network Management testing
- Distribution-level protection, automation, and control simulation and testing
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Power hardware in the loop

- Simulated environment exchanges power with renewable energy hardware, motors, batteries, loads, etc.

![Diagram of power hardware in the loop]
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Work in the UK: the PNDC

Power Supplies
- On Grid: 11kV 2 x 1MVA connections
- 11/11kV 1MVA Isolation Transformer
- TriPhase Convertor: 500kVA ±0-1300V DC
- Off Grid: 1MVA Gen Set

HV Network (11kV)
- 11kV/400V transformers from 1.2 MVA to 25kVA
- 1 x overhead feeder for a total equivalent length of 60km
- 3 x underground feeders for a total equivalent length of 6km
- Pole mounted auto reclosers
- Series voltage regulator

Power Hardware In the Loop
- Hardware in the Loop Simulation with 6 x racks of RTDS hardware
- Optical interface provides 2 way interaction with both Gen Set and TriPhase Convertors.
- 3-50μs simulation time-step ... up to 360 x 3 phase busses
- Accurate frequency response up 3kHz

LV Network
- LV Fed from HV Network
- Mock impedances ~ 0.6 km
- Load banks total ~ 600 kVA
- Indoor and outdoor test connection points

Fault Throwing
- High Voltage Fault Throwing
- Phase to Phase, Phase to Ground, Multiple Injection Points
- Low Voltage Fault Throwing
- Unit, Flexible Connection

Industry Standard DMS / SCADA / Historian
- PowerOn Fusion monitoring control and switching management
- OSIsoft PI Historian connected to SCADA and Fast Data Acquisition System
Inverter testing

- Studying inverter response to transmission level faults
- Will ultimately feed into UK distribution code recommendations, standard inverter test procedures
PHIL at the PNDC

Inverter testing

Figure 30. 20kW inverter F output power during a solid A-B-G fault applied to the 132kV circuit. Figure 32. 10kW inverter G output power during a solid A-B-G fault applied to the 132kV circuit.
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NARI / SGEPRI

- World’s largest real time simulator
- Can simulate >3600 three-phase buses and 20 HVDC links
- System Protection Key Lab – validate wide area protection and control schemes, AC and multiple HVDC coordination, system stability control
Thank you!