TSAT-RTDS Interface
- The Development of a Hybrid Simulation Tool

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## Power System Simulation Methods

- Power system dynamics are conventionally categorized into low- and high-frequency transients
- Two groups of industrial-grade tools have been developed based on this categorization

<table>
<thead>
<tr>
<th>Feature</th>
<th>Electro-Magnetic Transients (EMT)</th>
<th>Phasor Domain (TSA)</th>
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</thead>
<tbody>
<tr>
<td>Sample Programs</td>
<td>PSCAD, RTDS</td>
<td>TSAT, PSS/E, PSLF</td>
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</table>
| Level of details      | ✓ Three-phase instantaneous values  
                         ✓ Detailed models                                                                           | ✓ Phasor-domain positive sequence  
                         ✓ Simplified dynamic models  
                         ✓ Network dynamics ignored                                                          |
| Size of modeled system| ✓ Varies between a few to several hundreds of buses                                              | ✓ Often used for simulating systems with tens of thousands of buses                |
| Common Application    | ✓ Any types of studies that need detailed modeling  
                         ✓ Hardware in Loop (HIL) simulation                                                           | ✓ Bulk power system planning and operation  
                         ✓ On-line Dynamic Security Assessment                                                          |
Conventional Simulation Methods - Challenges

- Can focus on either detailed models in small system or simplified models in large system
  - Increasing level of details without reducing system size can be costly
- Study interactions between system-wide events and detailed devices can be challenging, e.g.
  - Fault analysis in HVDC systems
  - Sub-synchronous resonance studies
- A detailed model might be available only in an EMT package, e.g.
  - HVDC systems, renewable generators, FACTS devices, etc.
- To built a full system model for EMT simulation is challenging
  - While this is a common practice in TSA studies
Hybrid Simulation

- Hybrid simulation approach addresses these challenges by using both EMT and phasor-domain simulation methods.

- Advantages
  - Effective in analyzing impact of low-frequency oscillations on specific components and vice-versa
  - A cheaper solution for studying large systems compared to full-EMT simulation
  - Takes advantage of rich modeling library available in EMT and phasor-domain simulation packages
  - Perform Hardware-In-Loop simulation with a large system model
TSAT-RTDS Interface (TRI)

- A tool for performing hybrid simulation studies
  - Using both TSAT from Powertech Labs and RTDS from RTDS Technologies
- TRI is developed with special focus on practical aspects
  - User-friendly, minimizing case setup efforts, simplifying results analysis steps etc.
- How does TRI work
  - TSAT simulates external system at normal time-step (e.g. 4ms)
  - RTDS simulates internal system at normal time-step (e.g. 50us)
  - Boundary injections are exchanged at the end of every TSAT time-step
TRI Structure

Xilinx VC707 FPGA Board
(mounted on PCI Express slot of PC which runs TSAT)

RTDS

FPGA Board

TSAT

RTDS Case

Internal System

Boundary 1

Boundary 2

Boundary 3

TSAT Case

External System

Boundary 1

Boundary 2

Boundary 3
Representation of External System in EMT

• Approach 1 – simple Norton (or Thevenin) Equivalent
  – External system is modeled as a Norton equivalent
  – Easy-to-use since TSAT automatically
    • calculates Thevenin impedance
    • updates Norton source current
  – High frequency transients of the external system are ignored
    • may fail when fault is applied at boundary
  – A buffer zone between internal and external systems is recommended
Approach 2 – Frequency Dependent Network Equivalent (FDNE)

- External system is modeled as a frequency-dependent mathematical model plus Norton current source(s)
- More accurate than Norton (Thevenin) equivalent
- May not need buffer zone
- Difficult to build the FDNE
  - Numerical stability
  - Computation burden on the EMT
  - Especially difficult for multi-port (2+)
- Handling network changes in external system is challenging
TRI Features

- Supports single-port and multi-port boundaries

One-port system

Two-port system
TRI Features (cont’d)

• Supports both (simple) Norton Equivalent and FDNE

• Potential TSAT-RTDS Configurations
Simulation Case Setup – RTDS Side

- RTDS case is being setup as normal
- With addition of GTFPGA and TSA-Interface

Handling data exchange with FPGA board

Custom model representing one TSAT boundary
Simulation Case Setup – TSAT Side

- TSAT case is being setup as normal
  - Commonly used planning data
  - With addition of the Hybrid Simulation data

Provided in a typical TSA study

Provided in hybrid simulation study
Defining boundaries between internal and external systems

RTDS quantities may be monitored on TSAT side (optional)
System Setup – Hardware

FPGA Board mounted on PCI Express slot

RTDS PB5 card connected to FPGA Board through an optical fiber
Starting Hybrid Simulation

TSAT waits during RTDS start-up

User notifies TSAT once RTDS starts-up (may automate this step in future)

Boundary mismatch during RTDS start-up can be monitored
Running Hybrid Simulation

TSAT and RTDS run simultaneously

A disturbance applied in one tool affects the other
Case Study #1

- IEEE 39-bus test system
- Fault applied in internal system (bus 28)
- Generator at bus 38 is monitored

Internal system modeled in RTDS
Case Study #1 – Generator Rotor Speed
Case Study #1 – Generator Terminal Voltage
Case Study #2

- IEEE 39-bus test system with 4 ports

External System
Internal System
Case Study #2 – Generator Rotor Speed

Graph showing the comparison of generator speed with RTDS Only, Hybrid Simulation, and TSAT Only.
Case Study #1 – Generator Terminal Voltage
Case Study #3

- A practical case with 2189 buses and 459 generators
  - Two generators modeled in RTDS
  - Rest of system is modeled in TSAT (2 ports)
- Contingency description
  - Fault is applied on TSAT-side (2 buses away from one of boundaries)
  - Cleared after 0.1 seconds
- A generator close to fault is monitored
- Long time simulation test
  - The fault is applied and cleared every ~200 seconds
  - Simulation ran for 3 hours
  - TSAT simulation keeps synchronization with RTDS
    - Hard real time
    - Using a Intel Core i7 7700K 4.2 GHz CPU (one core is used) and 32 GB RAM
    - 4ms time-step on TSAT side (50us on RTDS side)
Case Study #3 – Generator Rotor Speed

![Graph showing generator rotor speed over time]

- **Hybrid Simulation**
- **TSAT Only**
Case Study #3 – Generator Terminal Voltage
Summaries

• Why using hybrid simulation?
  – Takes advantage of both EMT and phasor-domain simulation packages
  – Facilitates analyzing interactions between low- and high-frequency transients

• TSAT-RTDS Interface
  – Performs hybrid simulation studies using TSAT and RTDS
  – Practical aspects have been one of the main objectives
  – Preliminary testing demonstrated that the tool is promising
  – Allows monitoring interactions that may be missed in pure EMT or pure phasor-domain simulations