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Application of RTDS Simulator for Real-Time Large-Scale Power System Hybrid Electromagnetic-Transient and Phasor-Domain Simulation

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- Powertech Labs Inc.

About RTDS User - Powertech Labs

- A subsidiary of BC Hydro in great Vancouver area, BC, Canada
- Business in high power/voltage/current testing, engineering consulting, hydrogen, EV, and power system software development, etc.
- Use RTDS simulator for power systems study, HIL testing, and hybrid simulation tool TSAT-RTDS Interface (TRI)

Powertech Labs Campus

Outline

- **Hybrid Simulation**
- Boundary Definition
- Co-Simulation Setup
- Simulation Results

Hybrid Simulation

- Power system dynamics are conventionally categorized into low- and high-frequency transients

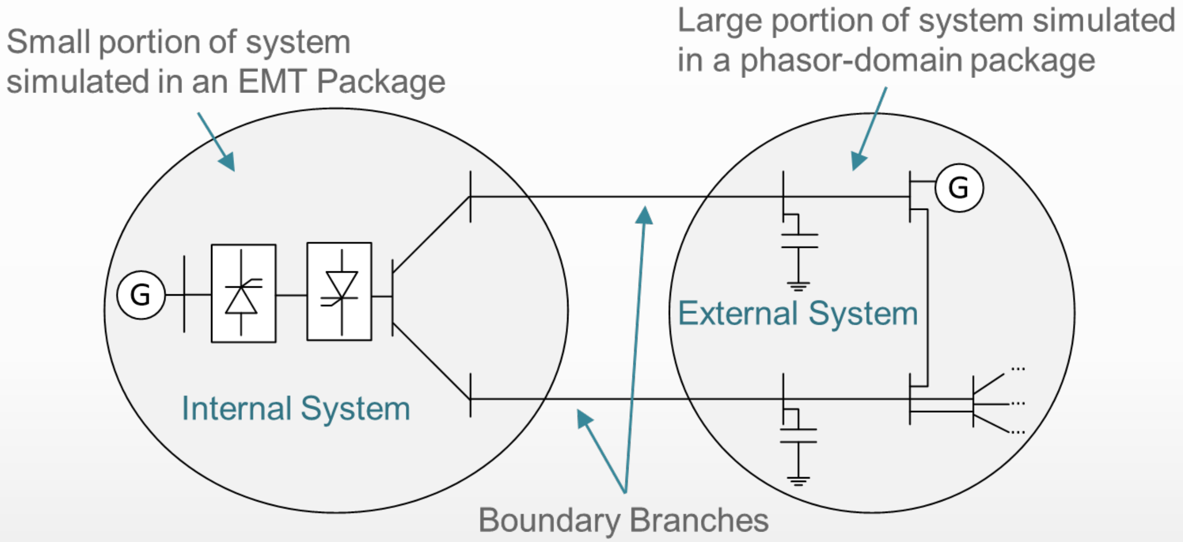
Feature	Electromagnetic Transients (EMT)	Phasor-Domain (TSA)
Sample Programs	RTDS, PSCAD	TSAT, PSS/E, PSLF
Level of details	✓ Three-phase instantaneous values ✓ Detailed models	✓ Phasor-domain positive sequence ✓ Simplified dynamic models ✓ Network dynamics ignored
Size of modeled system	✓ Varies between 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

Hybrid Simulation

- Power System Modeling and Simulation 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
    - Fault analysis in HVDC systems
    - Sub-synchronous resonance studies
  - A detailed model might be available only in an EMT package
    - HVDC, IBR, FACTS, etc.
  - To built a full system model for EMT simulation is challenging
    - While this is a common practice in TSA studies

Hybrid Simulation

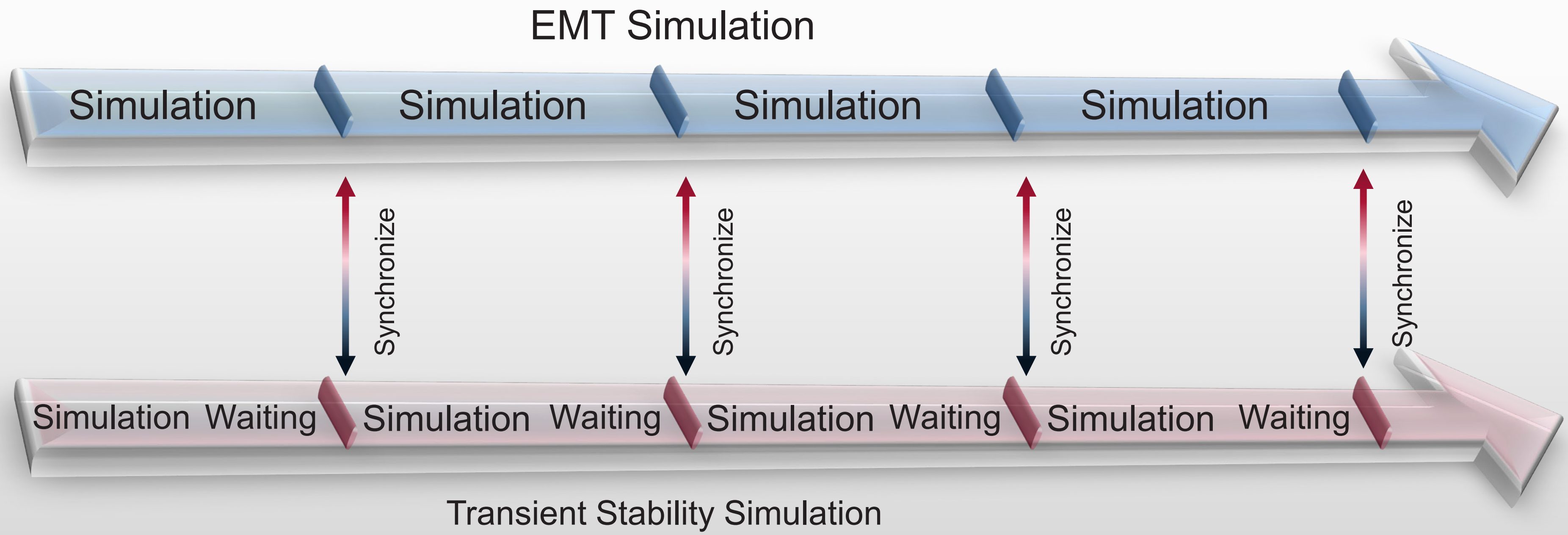
- Hybrid simulation approach addresses these challenges by using both EMT- and phasor-domain simulation methods



- Advantages
  - Effective in analyzing impact of low-frequency oscillations on specific components and vice-versa
  - A more cost-effective 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

Hybrid Simulation

- Implementation
  - Platform for synchronized simulation using EMT and TSA packages
  - System partitioned into two or multiple regions
  - EMT and TSA simulate each region independently (e.g., 50us vs 4ms)
  - Injections are exchanged at the end of each TSA time-step



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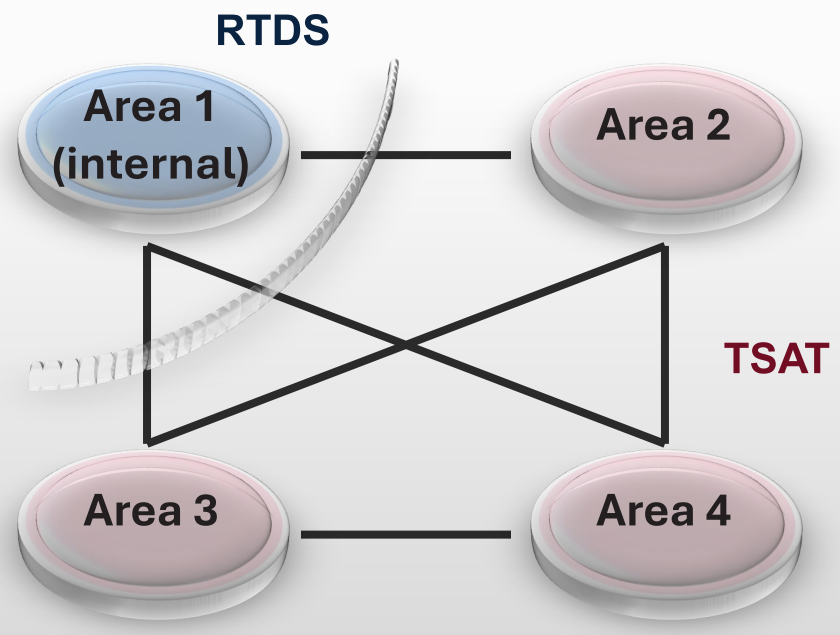
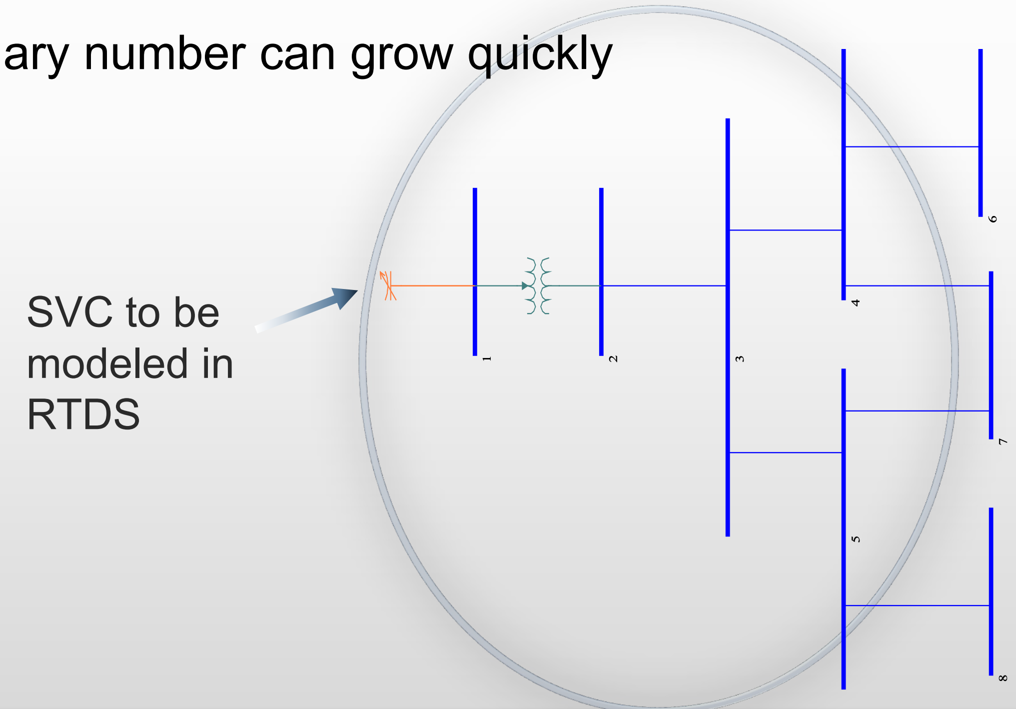
Boundary Definition

- Boundaries define internal and external systems
  - Size of internal system vs. existing computational resources
  - Device(s) of interest
    - Focusing on a device such as SVC, STATCOM, HVDC, renewables?
    - Simulating unbalanced faults?
  - Number of boundaries
    - Should be kept minimum
  - Intended fault locations
    - Cannot be too close to boundary
  - Location of harmonic sources
    - Better to be away from boundary

Boundary Definition

- Choosing Boundaries
  - Based on geographical location
    - ✓ In-depth knowledge about the system
    - ✓ Typically has well-defined interfaces
    - ✓ Easy to understand
  - Focus on a specific device
    - ✓ Can be STATCOM, HVDC, etc.
    - ✓ A buffer zone around the device is considered
      - Electrical distance between device and external system
    - ✓ Defining boundaries can be challenging
    - ✓ Boundary number can grow quickly





Boundary Definition

- Conversion of Boundary Quantities
  - Phasor-domain injection
  - Equivalent three-phase injection

$$\vec{I}_{TSA} = I\measuredangle\theta$$

Phasor-domain to three-phase quantities

$$\alpha(t) = 2\pi f_0 t + \theta$$
$$i_A(t) = \sqrt{2}.I.sin\left(\alpha(t)\right)$$
$$i_B(t) = \sqrt{2}.I.sin\left(\alpha(t) - \frac{2}{3}\pi\right)$$
$$i_C(t) = \sqrt{2}.I.sin\left(\alpha(t) + \frac{2}{3}\pi\right)$$

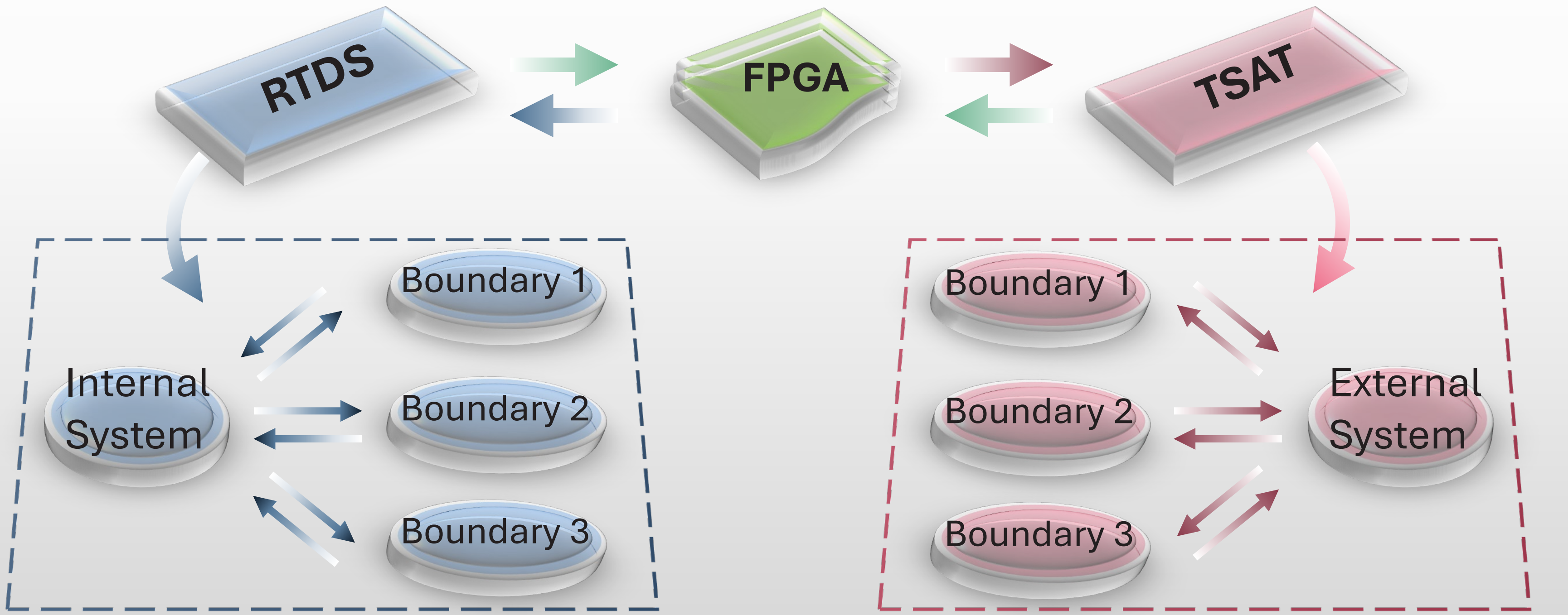
$$P_B = v_A i_A + v_B i_B + v_C i_C$$
$$Q_B = v_A i_B + v_B i_C + v_C i_A$$

$$\vec{I}_B = \left(\frac{\tilde{P}_B + j\tilde{Q}_B}{\vec{V}_B}\right)^*$$

Three-phase quantities to phasor-domain - Energy-based technique

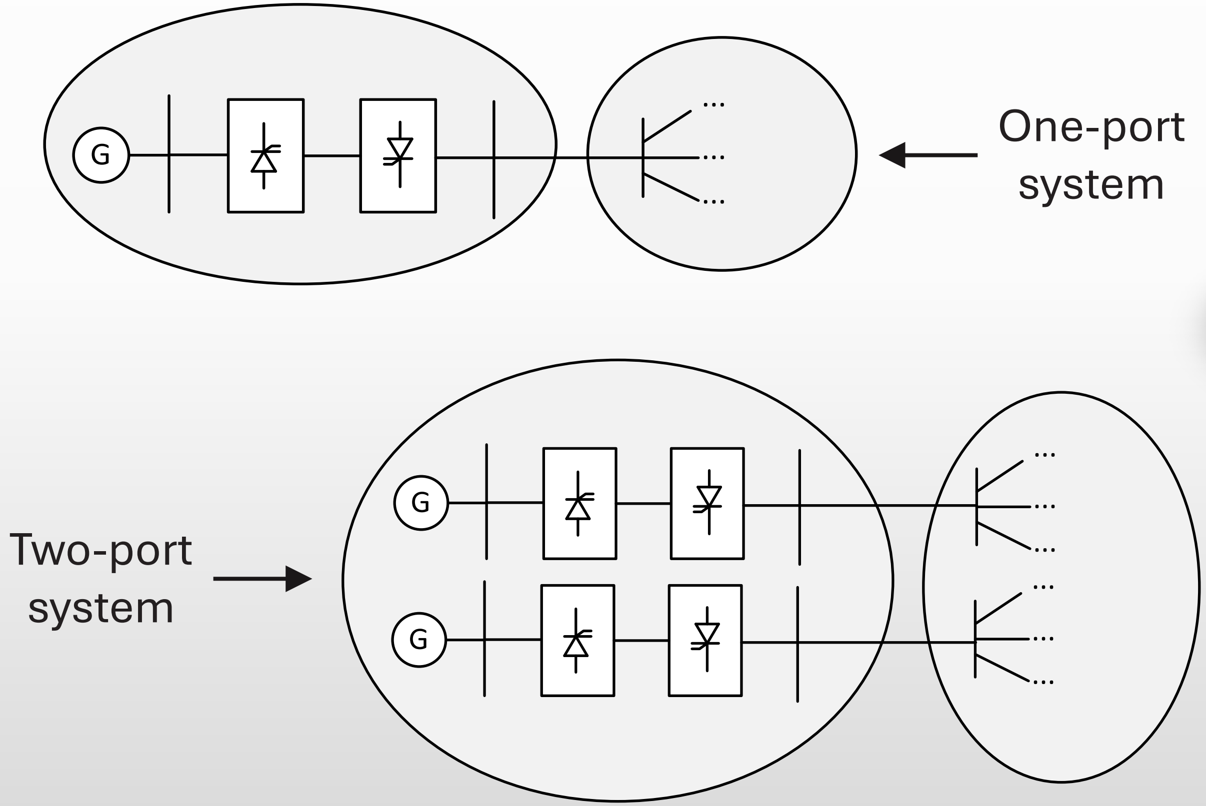
Boundary Definition

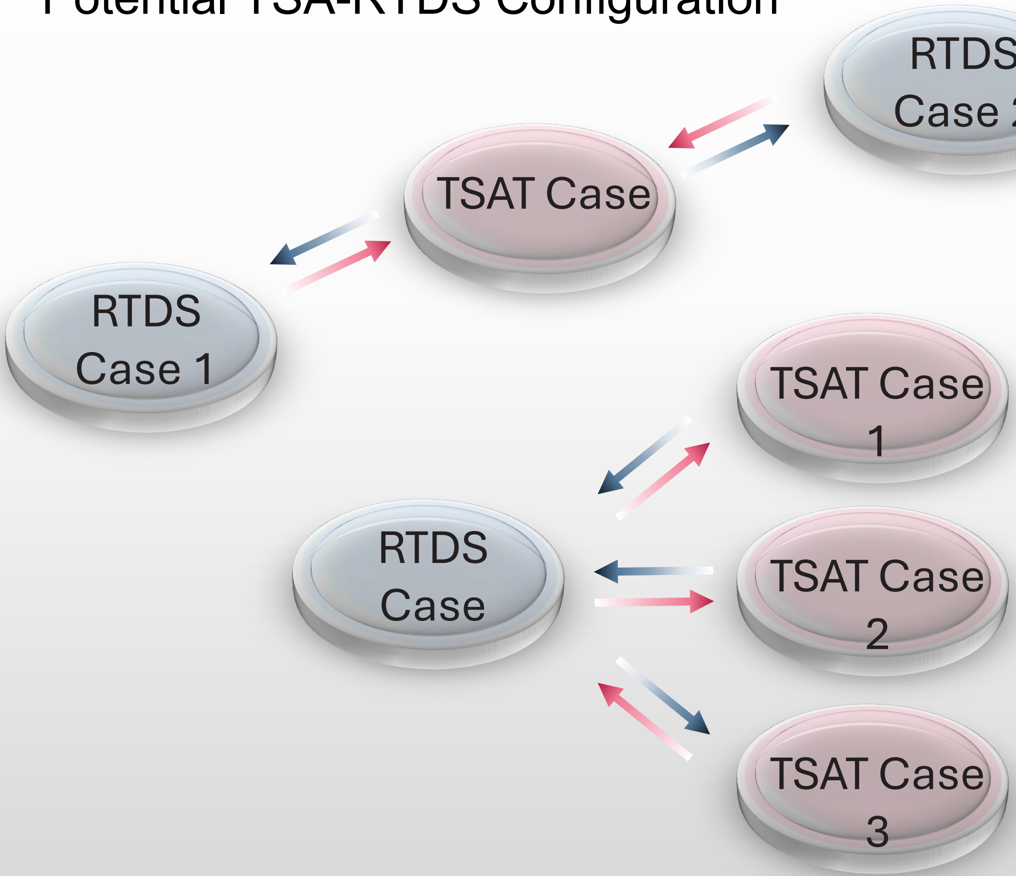
- Communication between boundaries on RTDS- and TSAT-side
  - Use GTFPGA block and the FPGA board
  - GTFPGA block supports up to 64 channels to send/receive integer/float numbers
  - Each boundary needs two channels - Specified by a unique port number assigned to them



Boundary Definition

- Boundaries in TSAT-RTDS
  - Supports single-port and multi-port boundaries
  - Supports both (simple) Norton Equivalent and FDNE
  - Potential TSA-RTDS Configuration





Outline

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- **Co-Simulation Setup**
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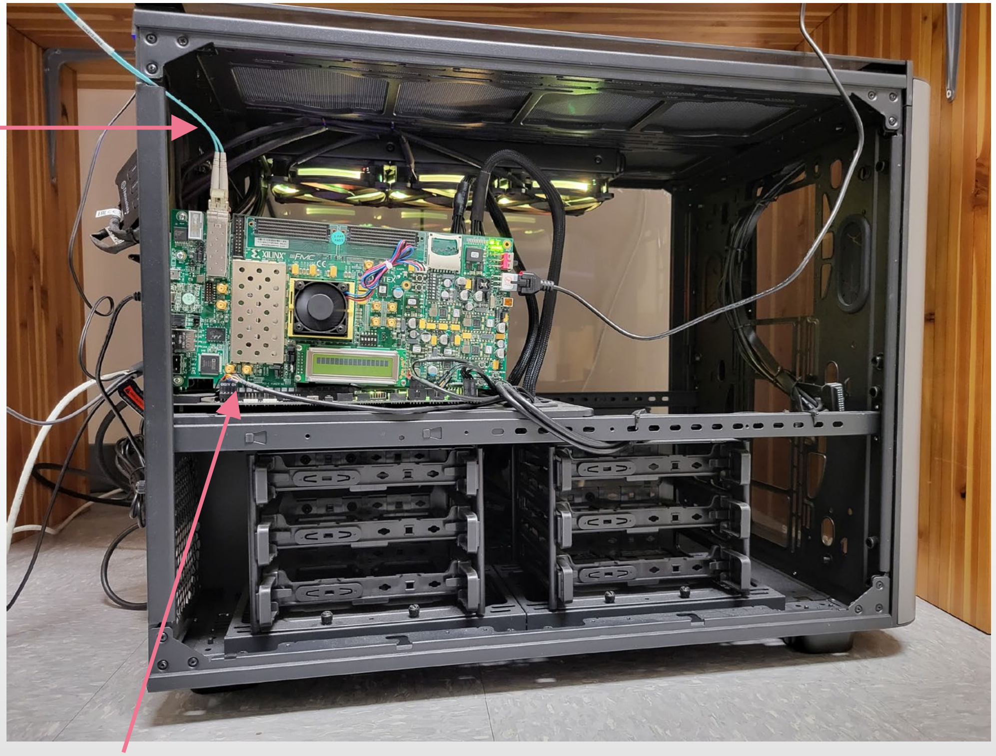
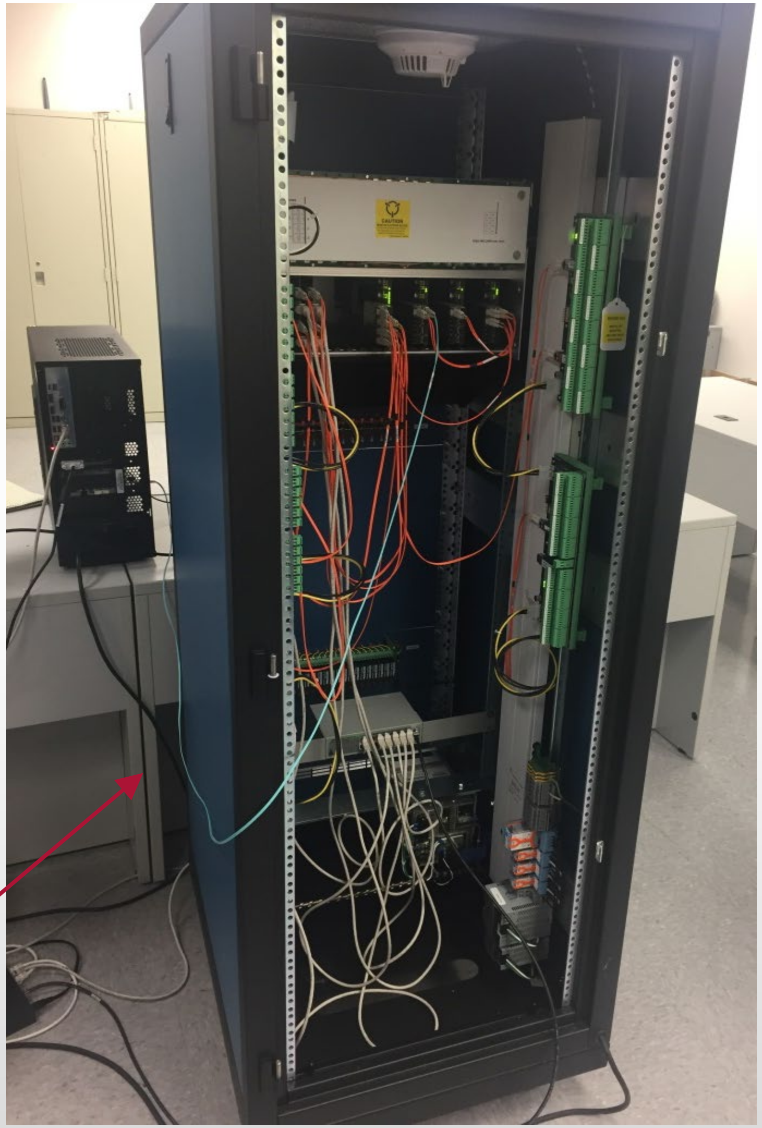
Co-simulation Setup

- TSAT-RTDS Co-simulation Setup – Hardware

To RTDS





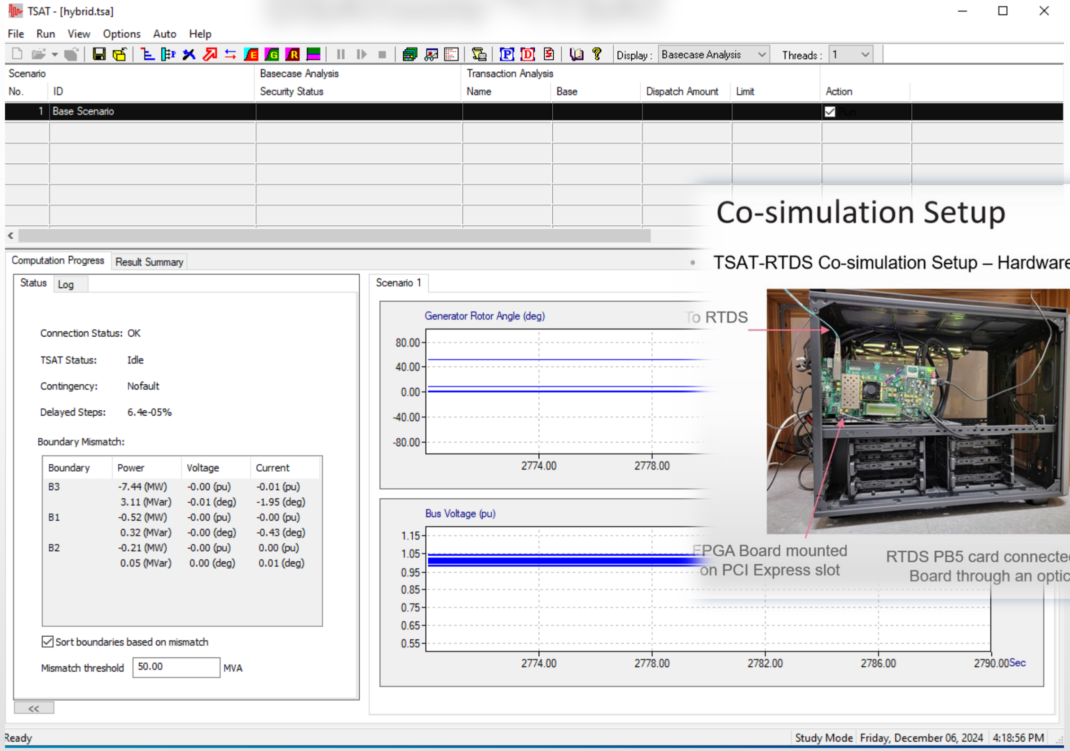
FPGA Board mounted on PCI Express slot

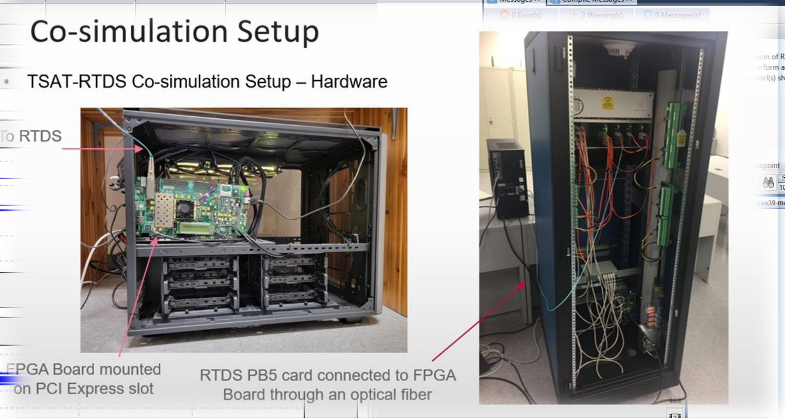
RTDS PB5 card connected to FPGA Board through an optical fiber

Co-simulation Setup

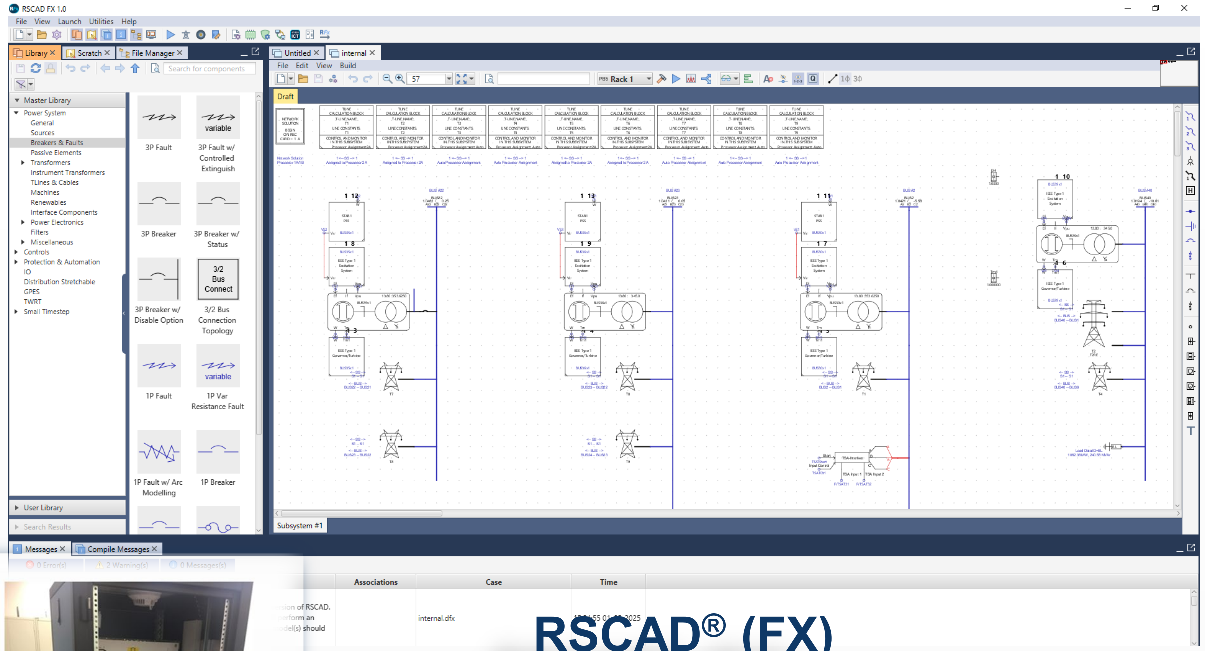
- TSAT-RTDS Co-simulation Setup – Software

DSATools™/TSAT

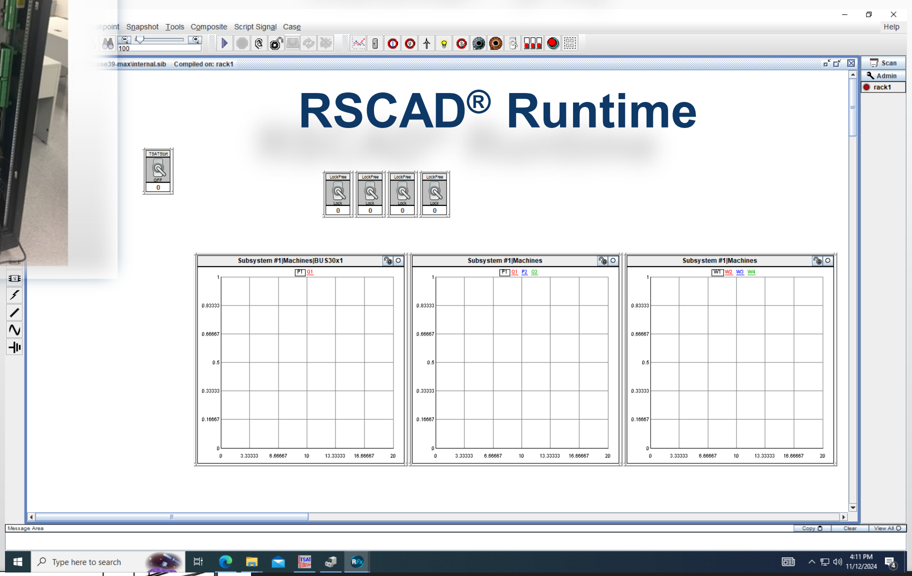




RSCAD® (FX)

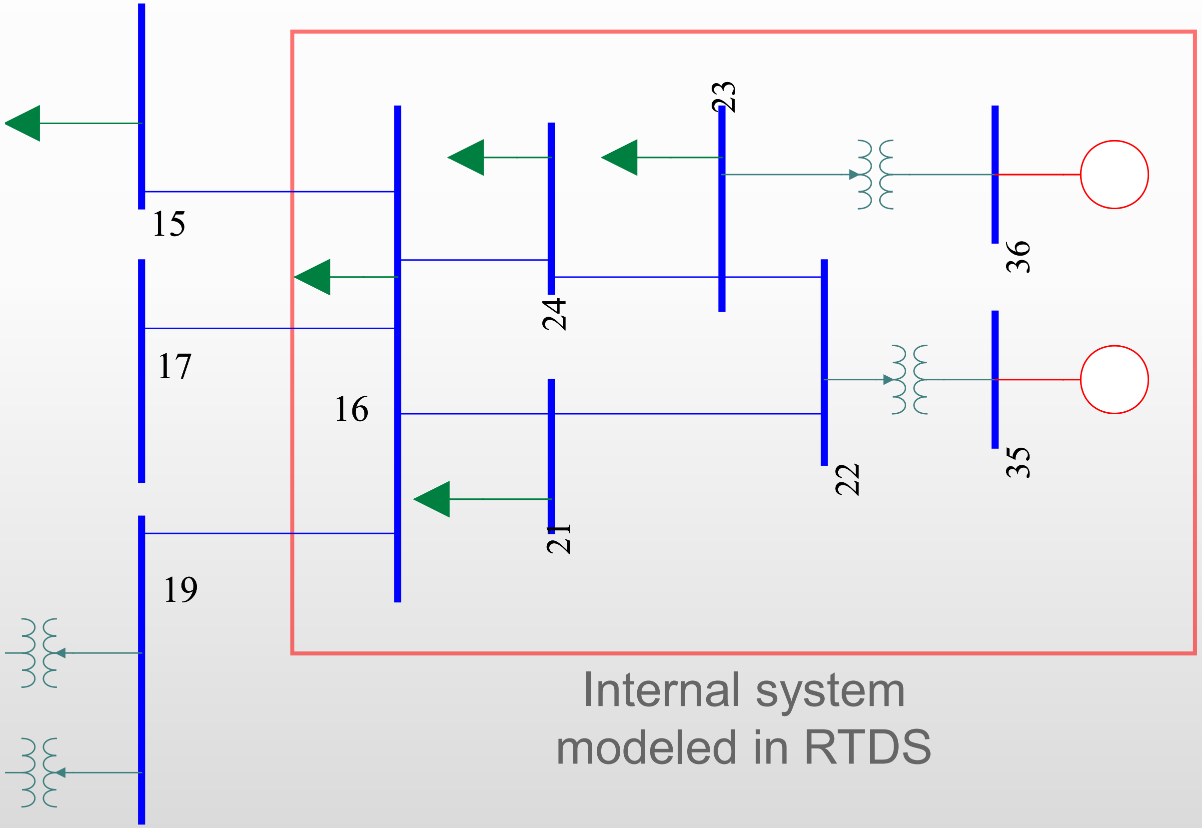


RSCAD® Runtime



Co-simulation Setup

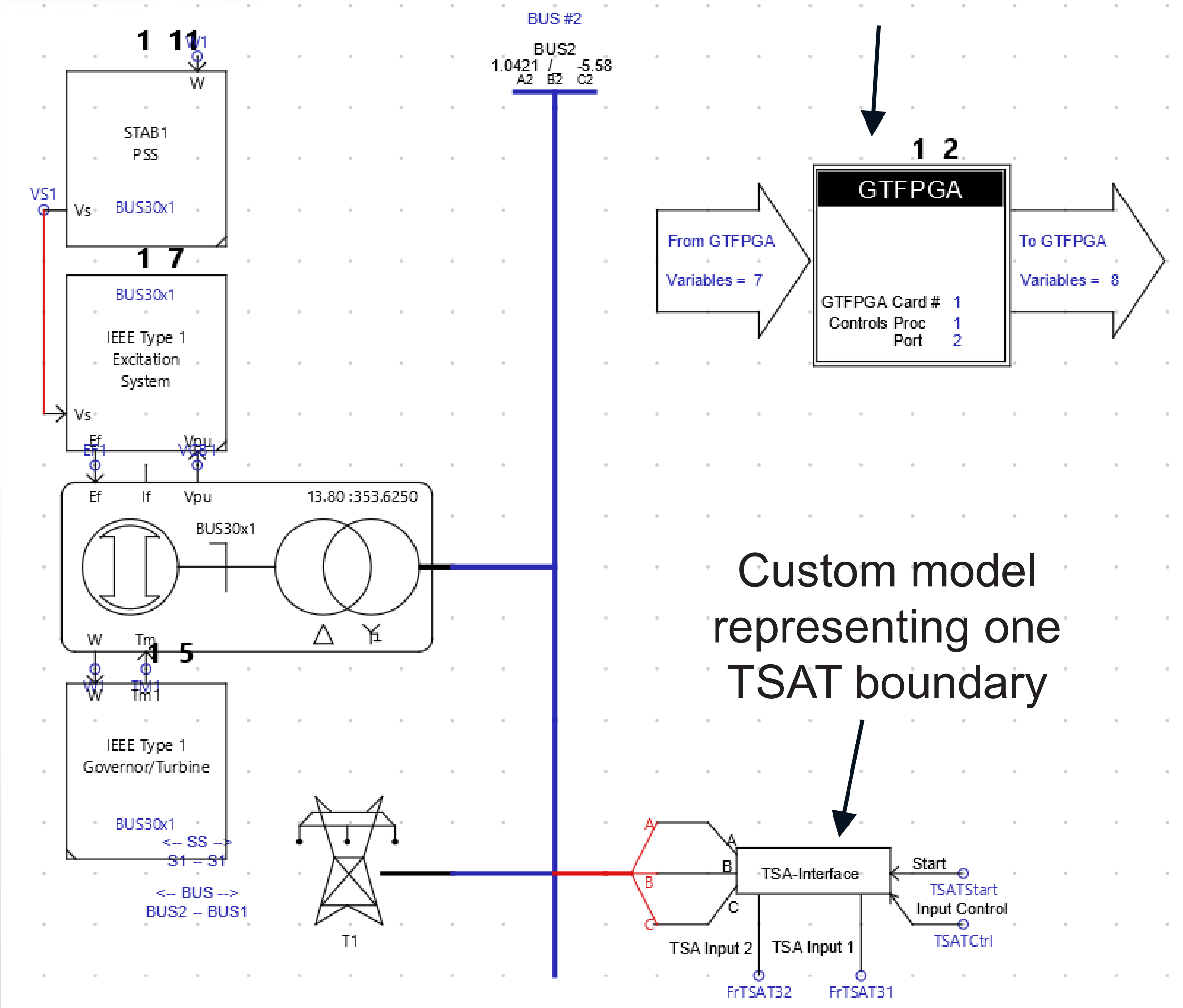
- Study Case 1: IEEE 39-Bus System
- One boundary



Internal system modeled in RTDS

RSCAD® FX

Handling data exchange with FPGA board

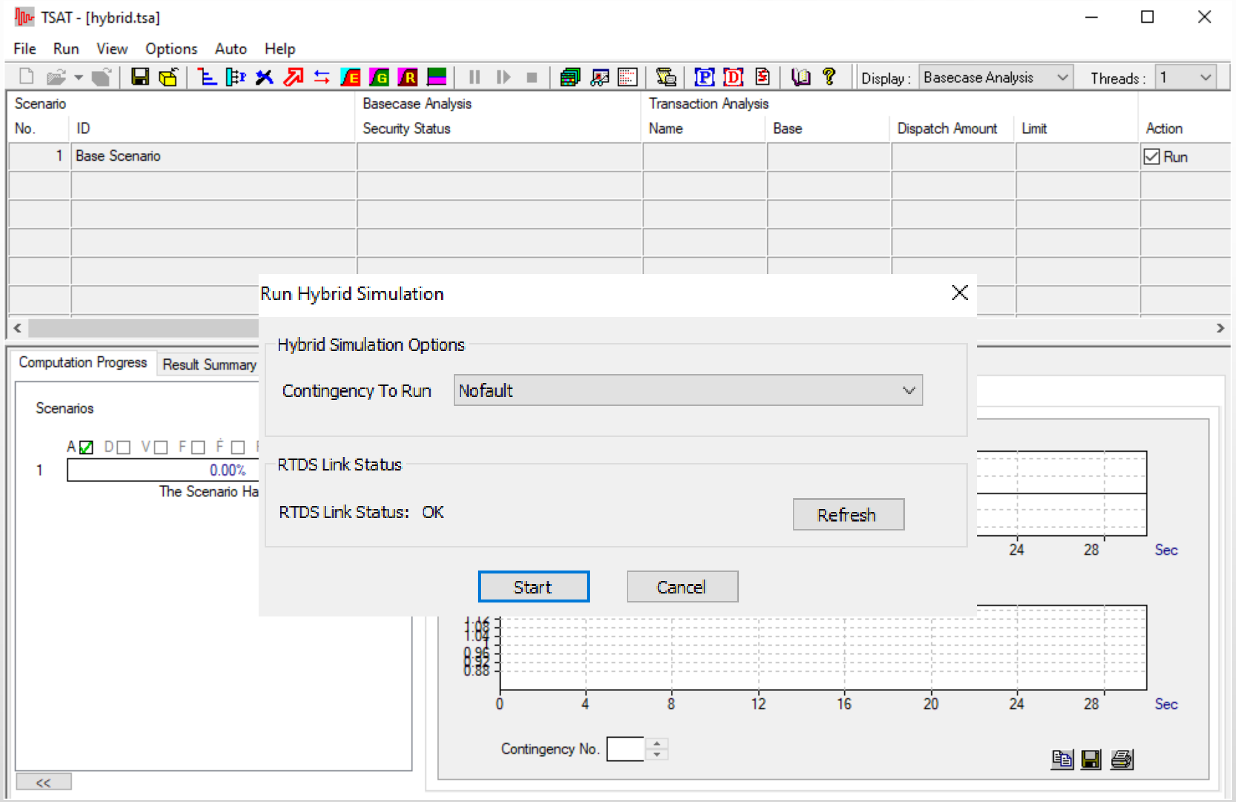


Custom model representing one TSAT boundary

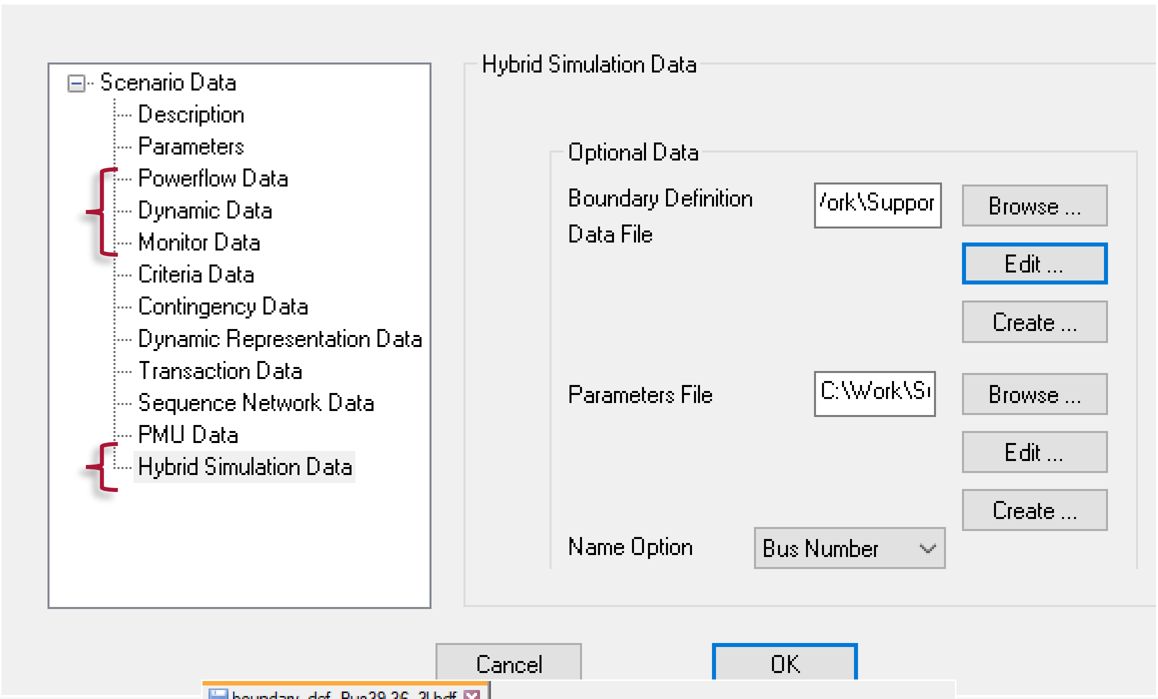
Co-simulation Setup

- Study Case 1: IEEE 39-Bus System
- One boundary

DSATools™/TSAT



TSAT Scenario Edit Window - Hybrid Simulation Data - Base Scenario [case39.pfb]



boundary_def_Bus39-36_3l.bdf

```
[TSAT 17.x Hybrid Simulation Boundary]

{Communication Data}
First Port Number = 1
{End Communication Data}

{Boundary Definition}
Name = B1
Port Number = 2
Include Branch = 15, -16, '1'
Include Branch = 17, -16, '1'
Include Branch = 19, -16, '1'
{End Boundary Definition}

[End]
```

Outline

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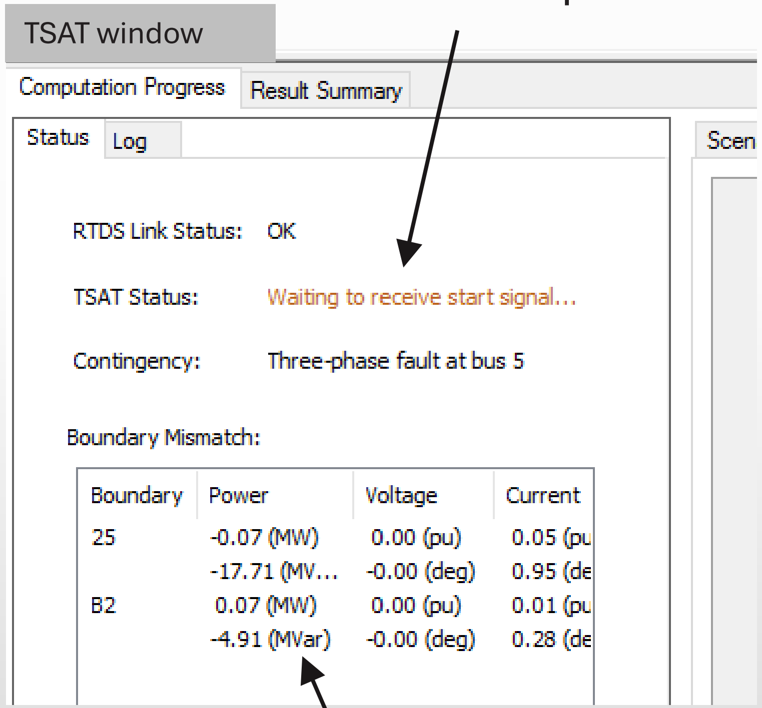
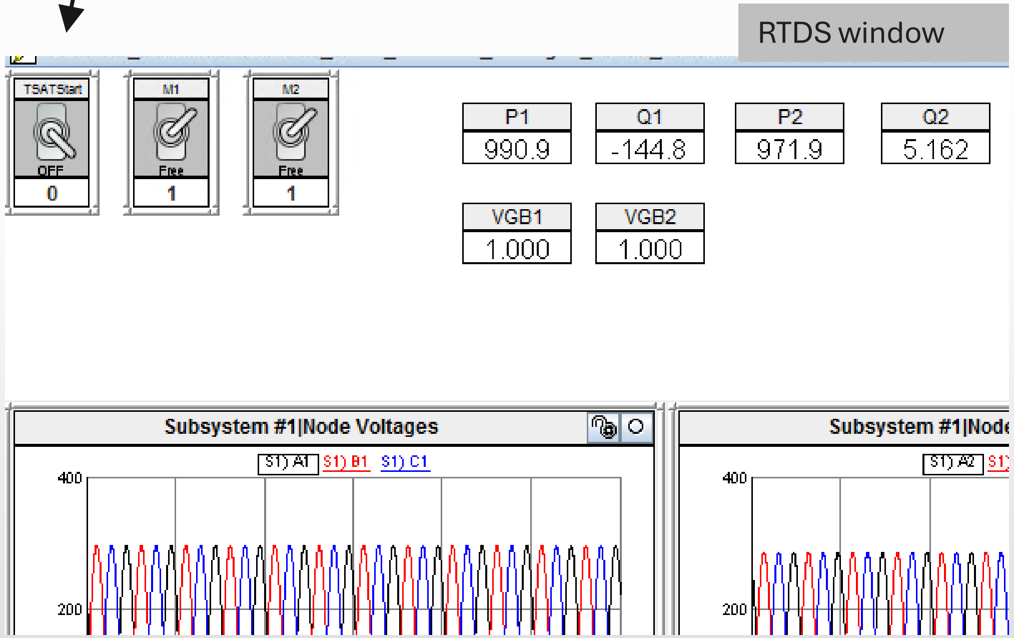
Simulation Results

- Study Case 1: IEEE 39-Bus System

TSAT waits during RTDS start-up

User notifies TSAT once RTDS starts-up



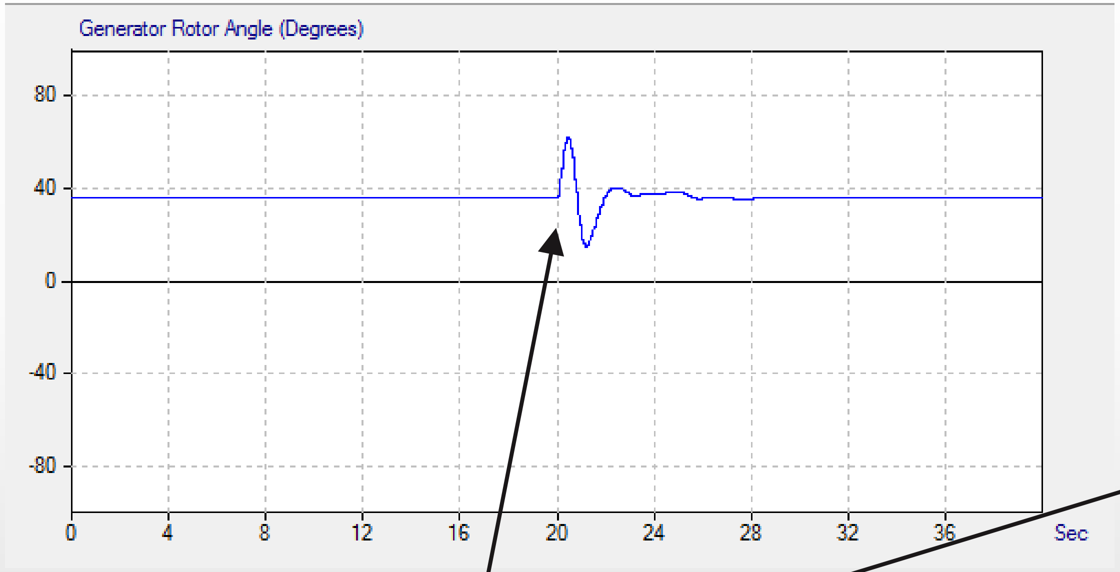


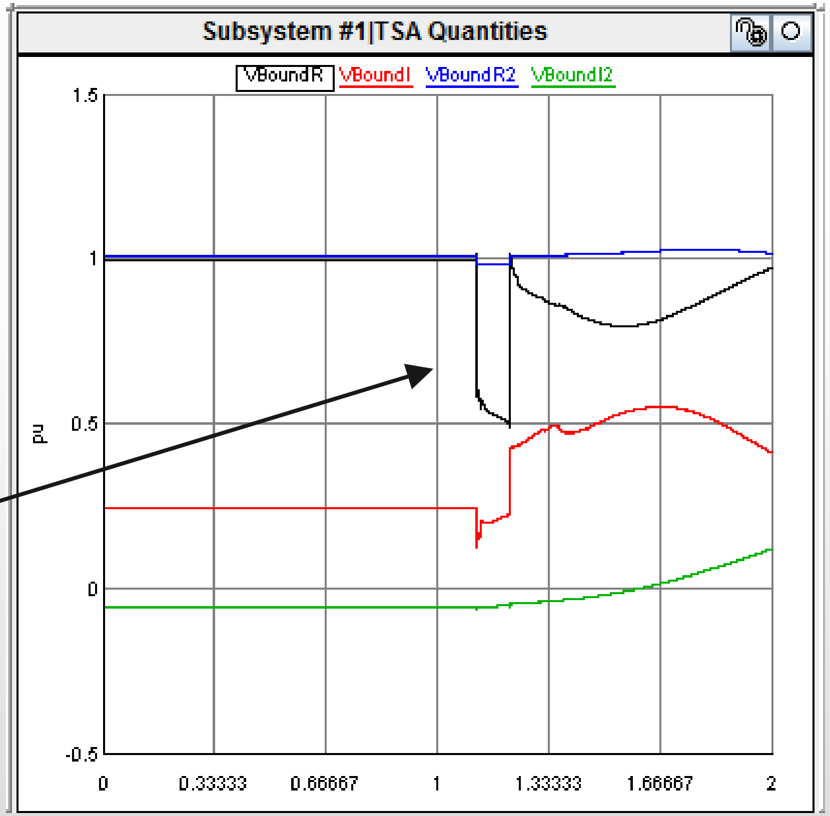
Boundary mismatch during RTDS start-up can be monitored

Simulation Results

- Study Case 1: IEEE 39-Bus System

TSAT and RTDS run simultaneously

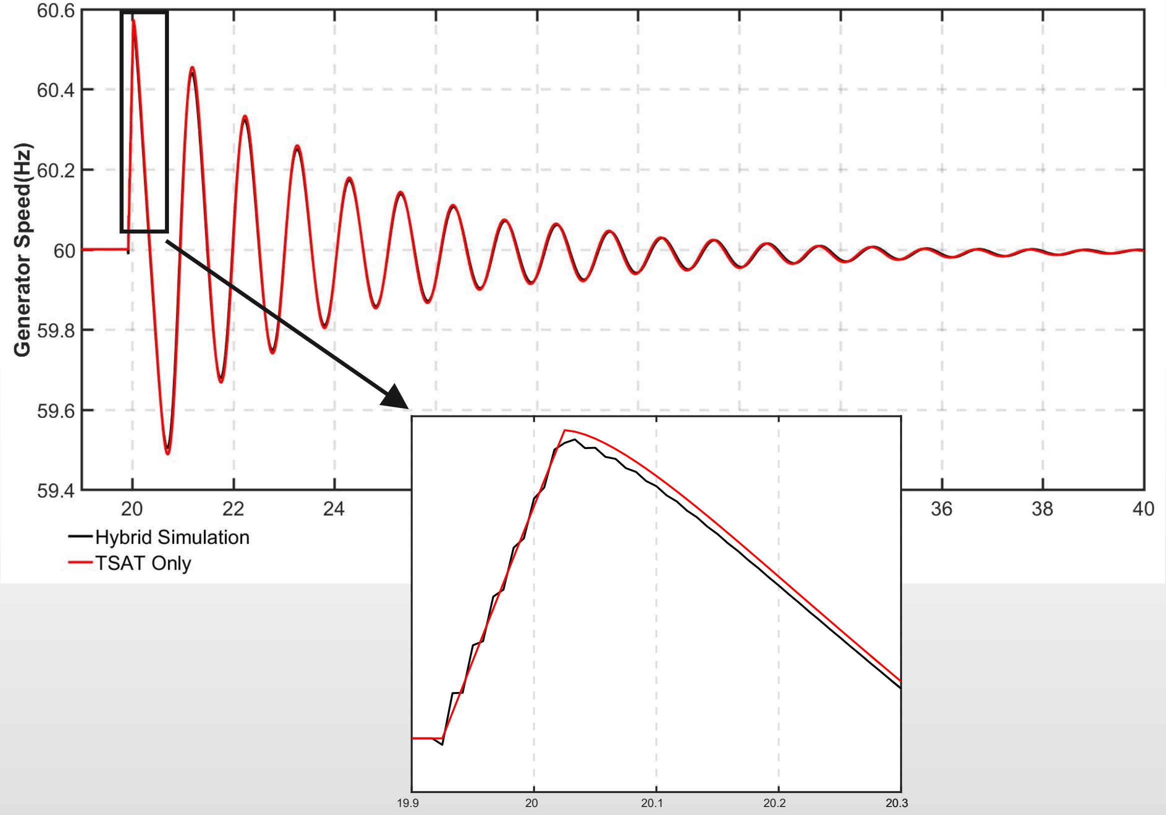


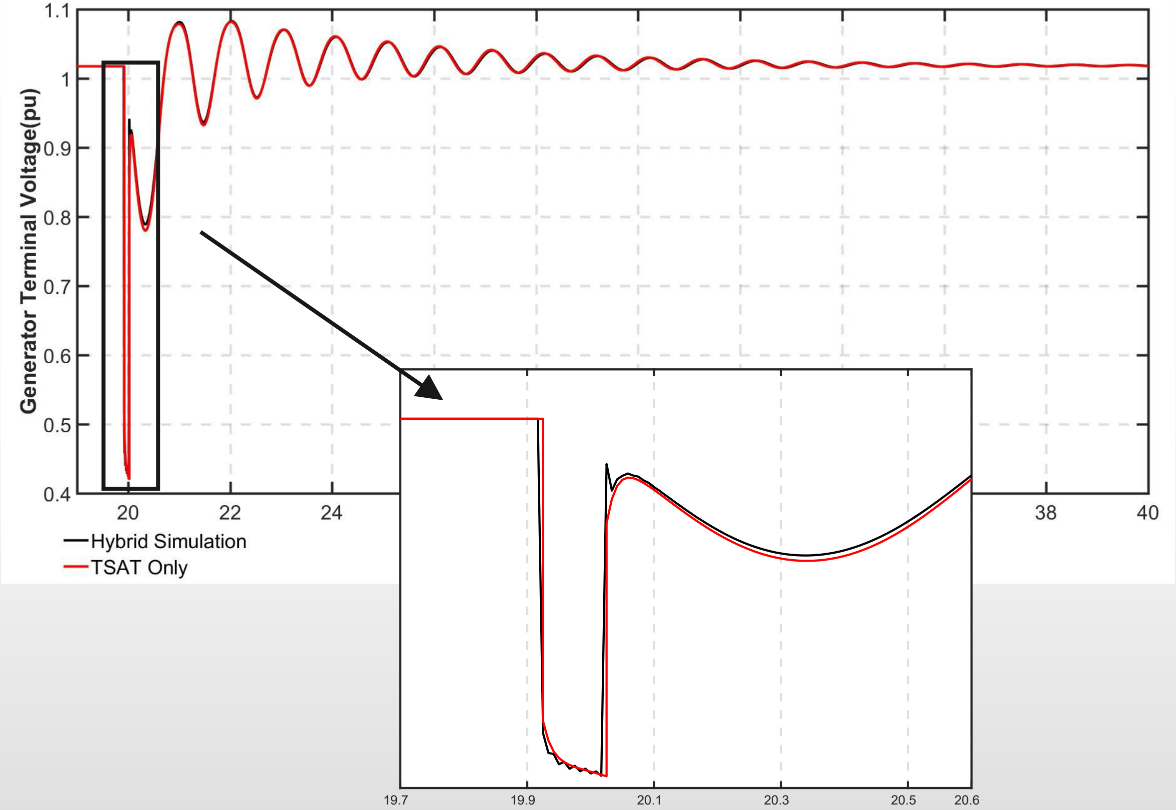


A disturbance in one tool affects the other

Simulation Results

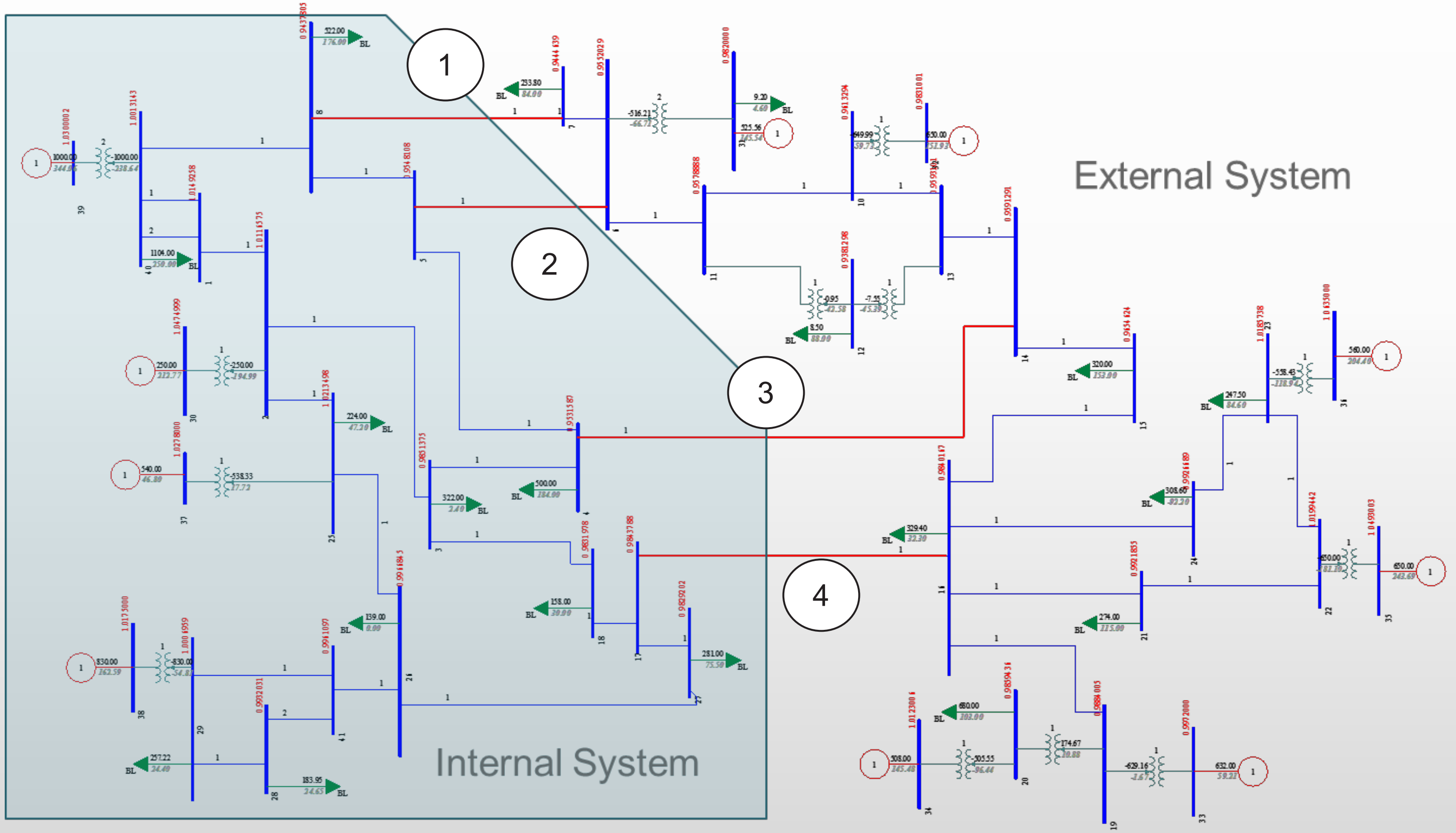
- Study Case 1: IEEE 39-Bus System





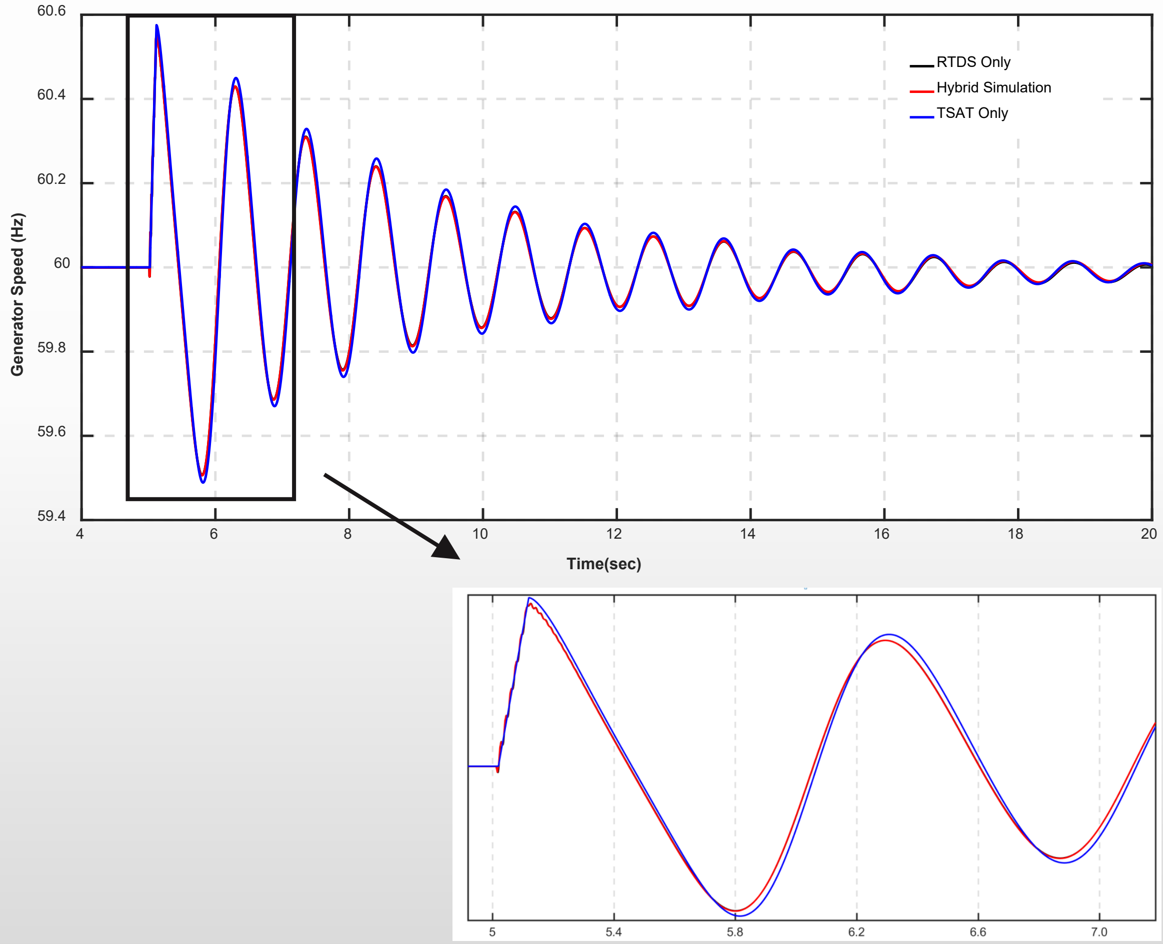
Simulation Results

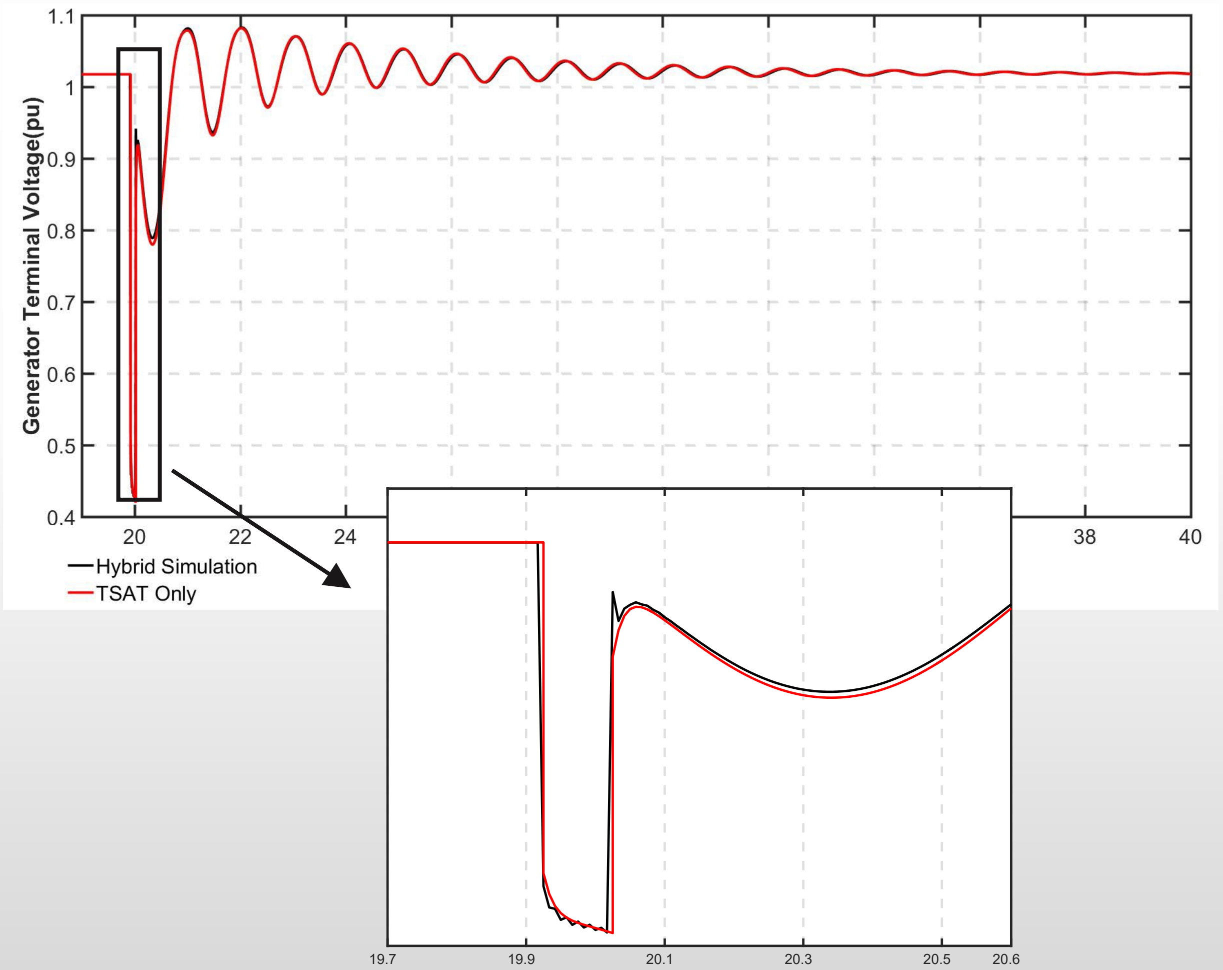
- Study Case 1: IEEE 39-Bus System
- Four boundaries



Simulation Results

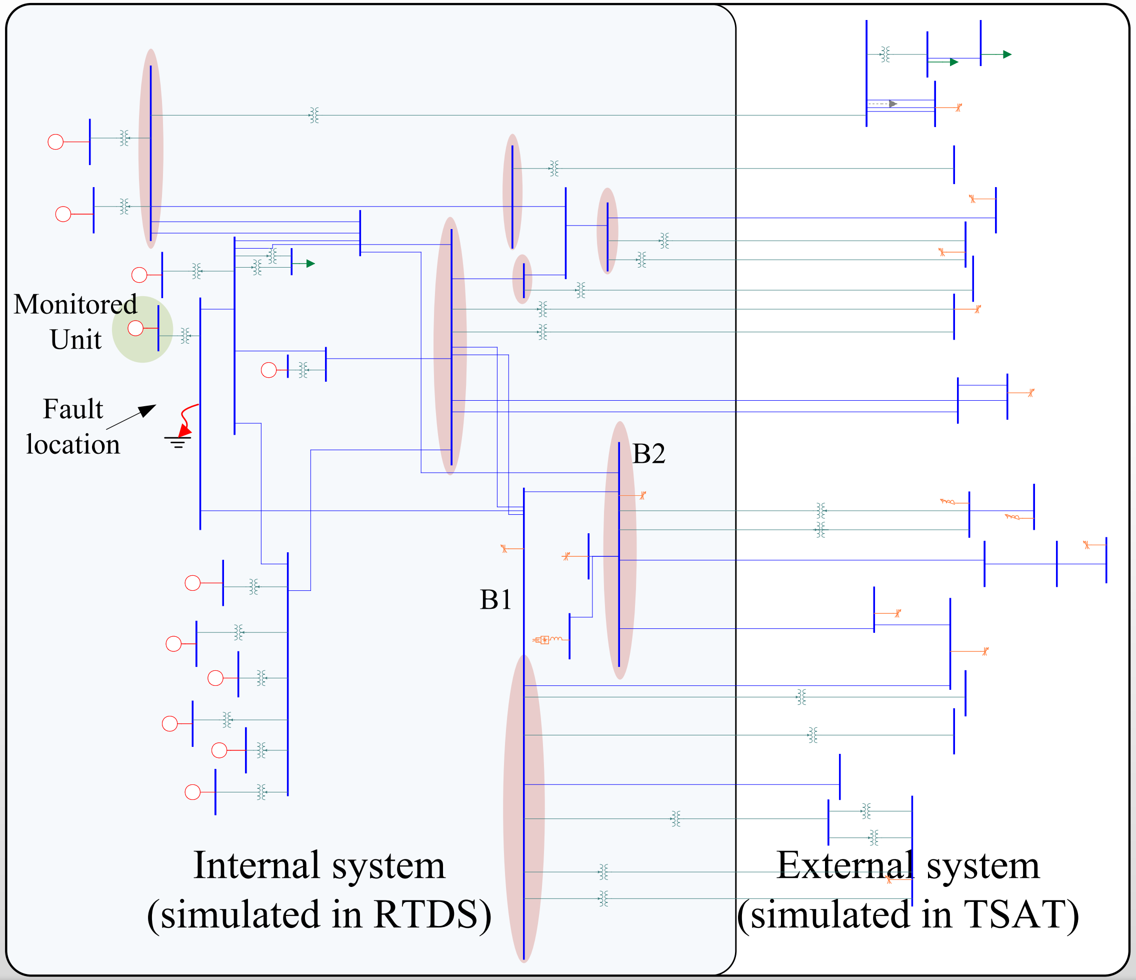
- Study Case 1: IEEE 39-Bus System, 4 boundaries





Simulation Results

- Study Case 2: A practical system with 5619 buses, 854 generators*

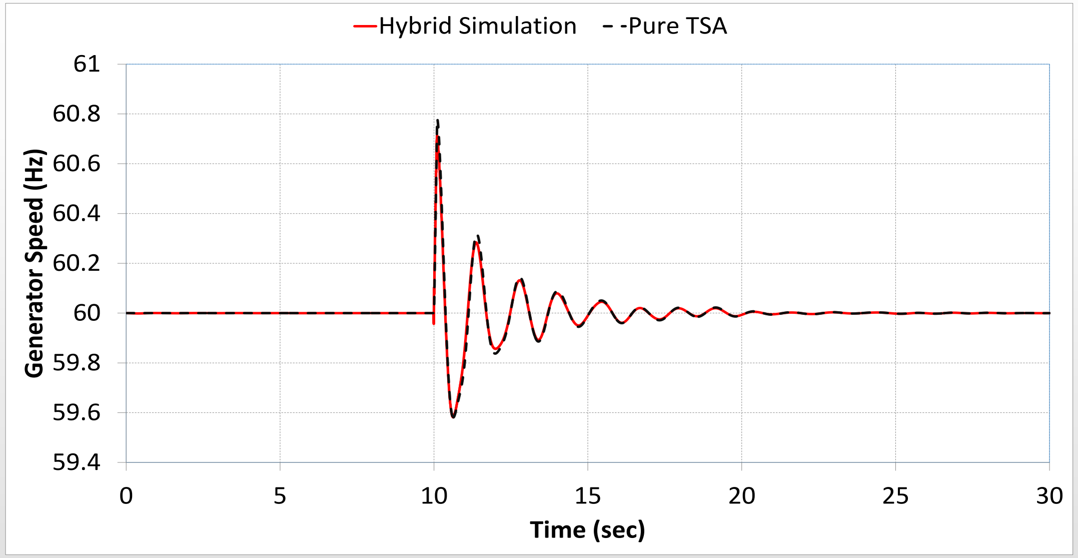


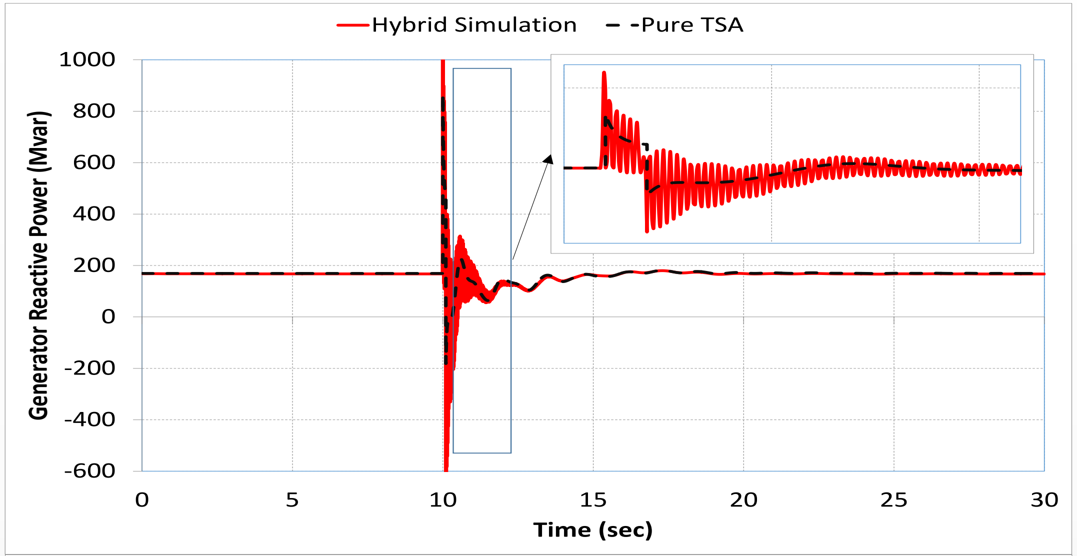
- Boundary number: 7
- Internal System: 25 buses, 11 generators
- EMT: 50μs; TSA: 4ms
- A 100ms fault @ 10s

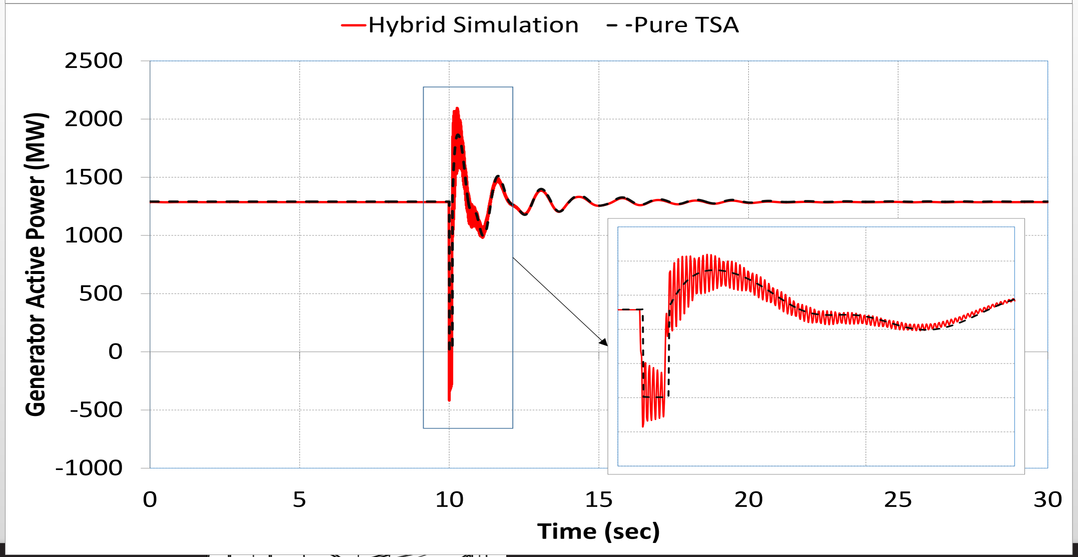
* P. Zadkhast, X. Lin, F. Howell, B. Ko, K. Hur, "Practical challenges in hybrid simulation studies interfacing transient stability and electro-magnetic transient simulations", Electric Power Systems Research, vol. 190, Jan. 2021

Simulation Results

- Study Case 2: A practical system
  - A 100ms fault @ 10s







Conclusions

- Hybrid RTDS-TSAT Simulation takes advantage of
  - Detailed modeling of RTDS electromagnetic transient simulation
  - Bulk power system simulation capability of TSAT
- Facilitates analyzing interactions between low- and high-frequency transients
- Real-time (hardware-in-loop) simulation of modern power systems possible

o Interfacing techniques (Thevenin/Norton, FDNE) critical to keep EMT/TSA transients

o Extra hardware might be needed

o Limited number of interfaces

Thank you

Thank you