Large EMT & Phasor-domain Simulation on the Cloud with HYPERSIM & ePHASORSIM

Evaluating the Performance of Special Protection and Control Systems

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OPAL-RT TECHNOLOGIES

WAMPACS AS STRATEGIC ELEMENT TO INCREASE NETWORK STABILITY

- Conception and testing of WAMPACS is challenging considering:
  - Ever **larger** power systems in number of nodes
  - **Bidirectional** energy exchange between transmission and distribution
  - Mixed balanced and **unbalanced** network areas
  - Potential **volume of data** and **complexity of the communication system**
  - High penetration of **inverter-based energy resources**
  - Private **blackbox** control system and models for DER integration
  - Selection between **EMT and Phasor** (RMS) or hybrid domain simulation techniques
  - Model and data **interoperability** between simulation tools

VISION: HIGH ACCURACY DIGITAL TWIN AS A RESPONSE TO HIGH DER INTEGRATION

Simulation of very large scale generation, transmission and distribution power grid
<Analysis and prediction>

Risk evaluation
Best scenarios

SCADA

Automatic Control

Operator Support

State-Estimator

AI Based Special Control and Protection Sysem

Dynamic Stability Assessment

Ts ≈ 5 minutes

Restart scenario

On-line model validation

Test scenarios
State initialization

Analysis

ePHASORSIM

HYPERSIM

Cloud-based simulation service for operation (control-center-in-the-loop / CCIL)

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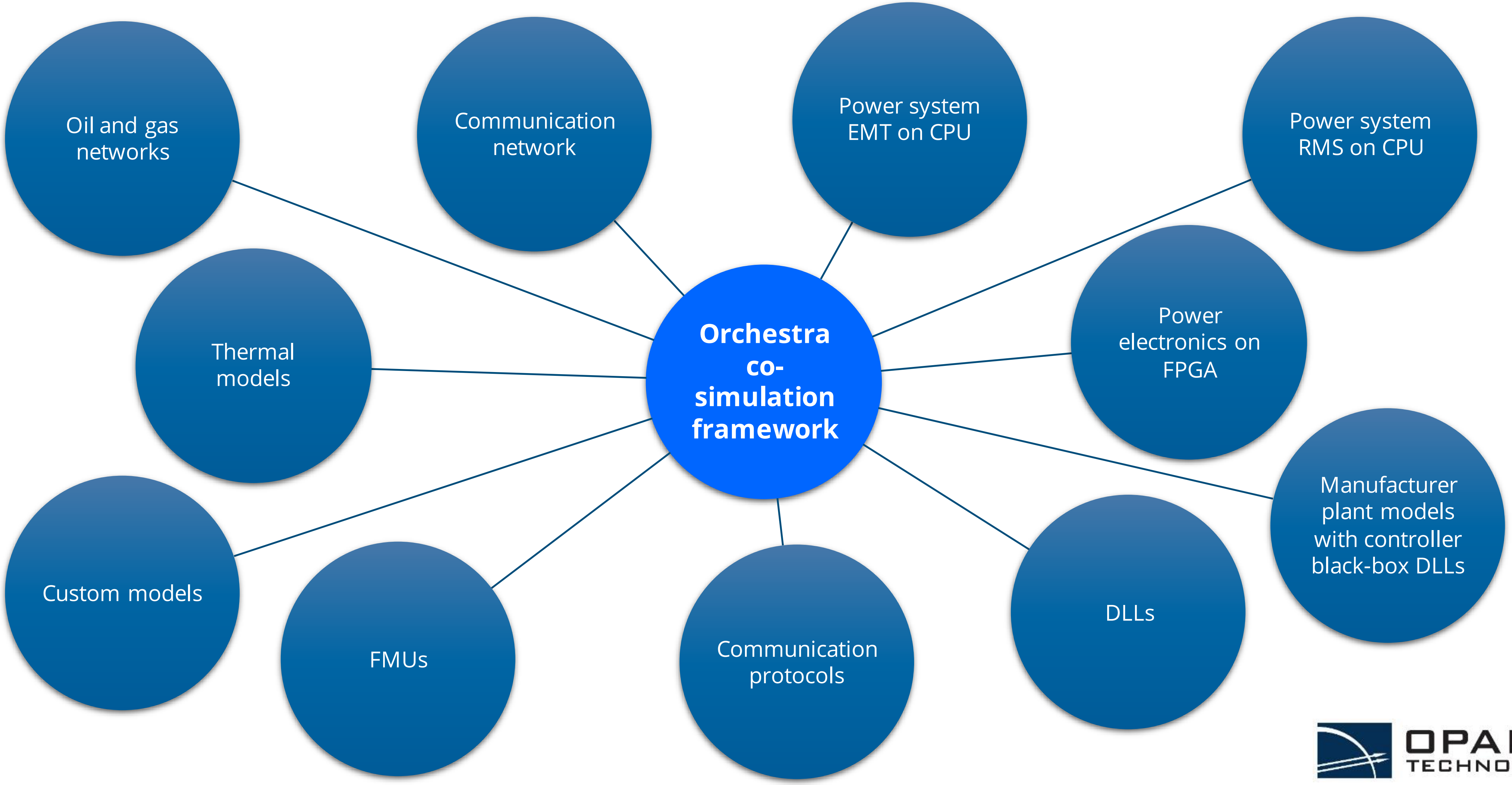
MULTI-DOMAIN MULTI-RATE CO-SIMULATION



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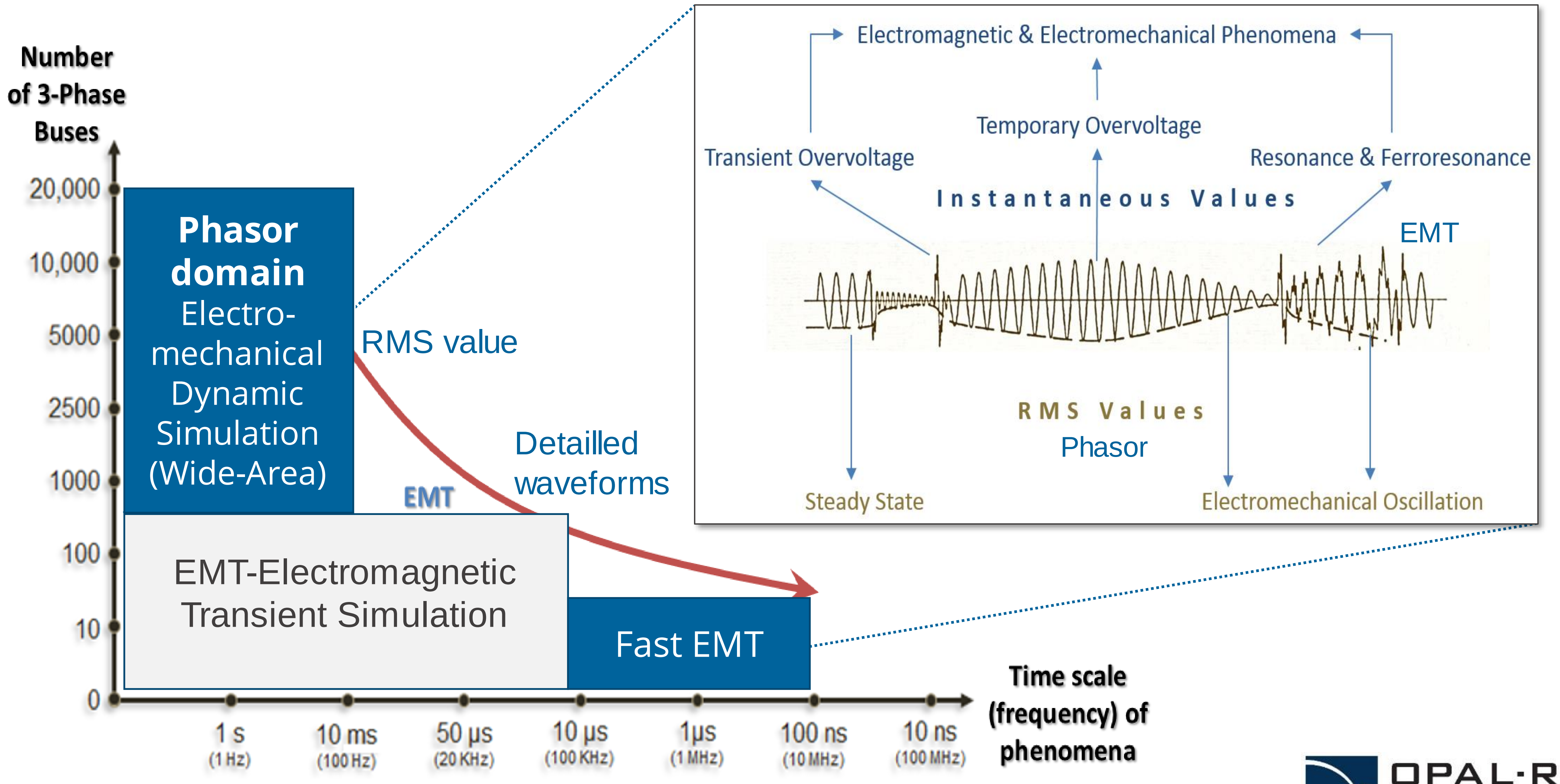
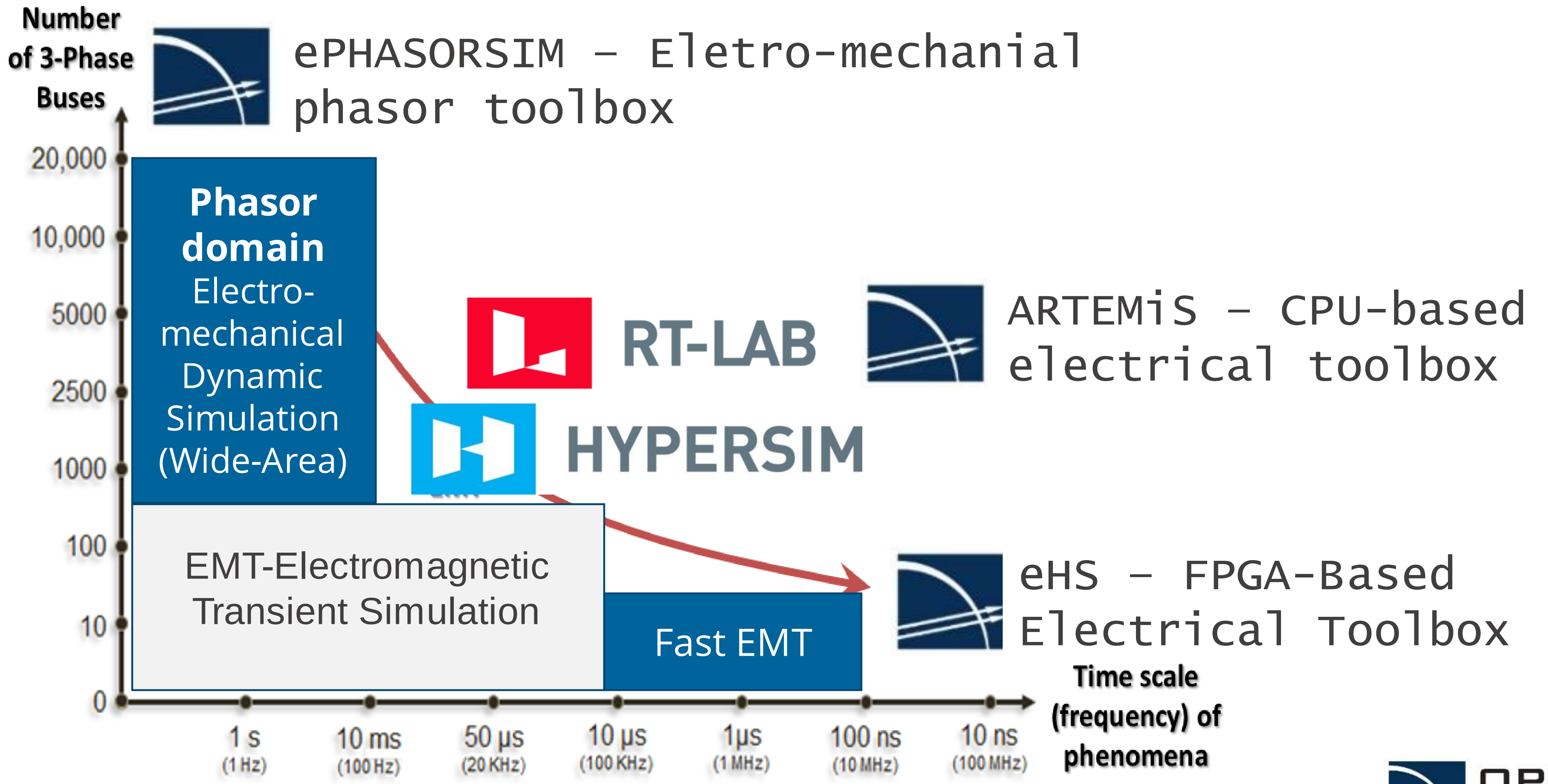
Etienne Leduc,
Offering Manager, Power system simulation tools

- Type of simulation vs tools
- Cloud-based HIL test of WAMPAC and Cybersecurity
- EMT vs PHASOR simulation for critical cases
- Need for faster simulation of larger systems
    - Towards 1-Million-node grid simulation in real-time
    - Closer to the Power Grid Digital-Twin dream!

SIMULATION TOOL OVERVIEW



SIMULATION TOOL OVERVIEW

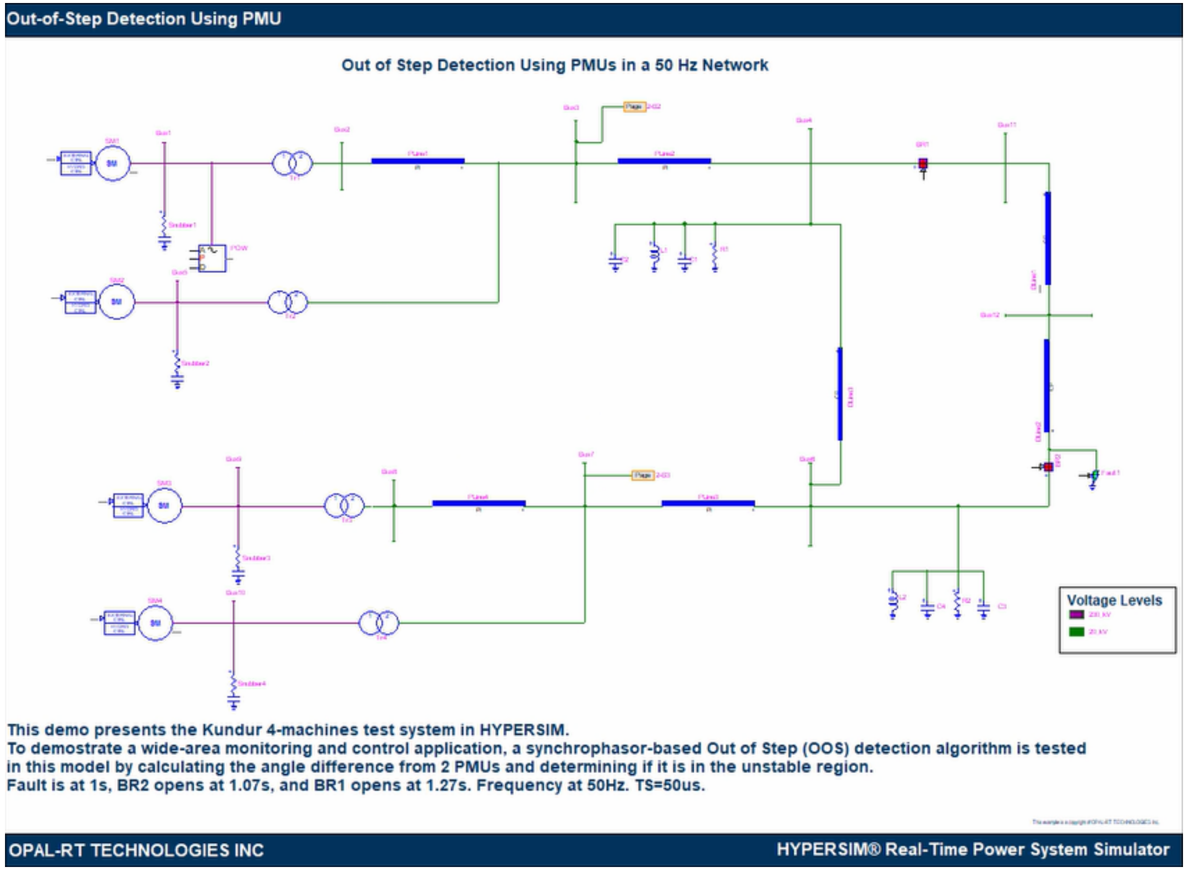


WIDE RANGE OF SUPPORTED COMMUNICATION PROTOCOLS

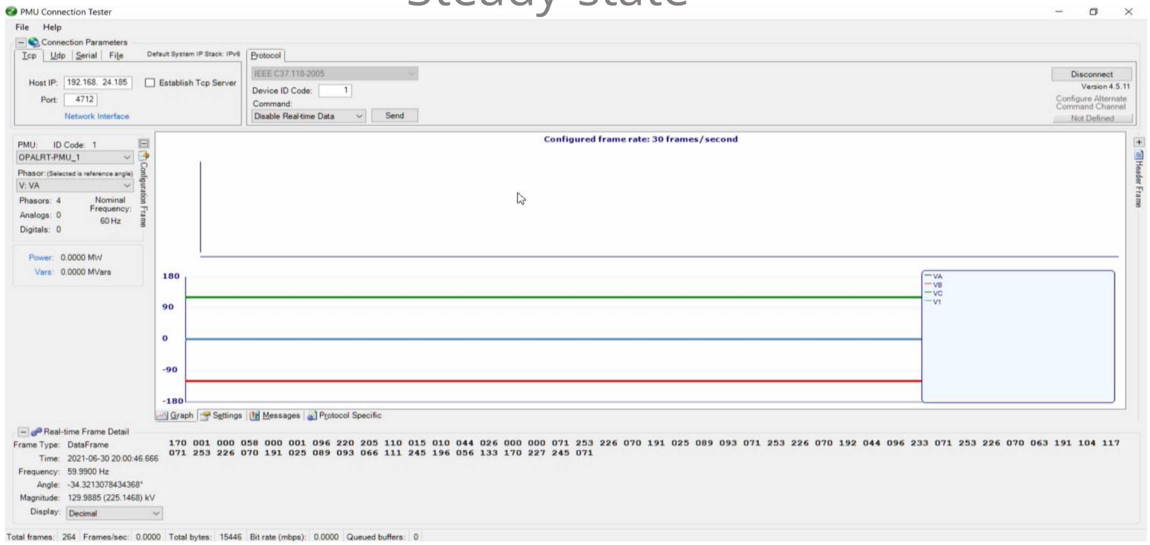
- C37.118 slave/master
- IEC 61850 GOOSE/SV/MMS, LE and NLE + Data integrity manipulation
- DNP3 slave/master
- Modbus slave/master
- IEC 60870-5-104 slave
- OPC-UA
- IRIG-B, 1PPS, or the IEEE 1588 PTP standard power profiles
- ABB PS935
- EtherCAT slave/master
- And more…

USE CASE #1: WINDOWS-BASED HIL USING 2 LAPTOPS

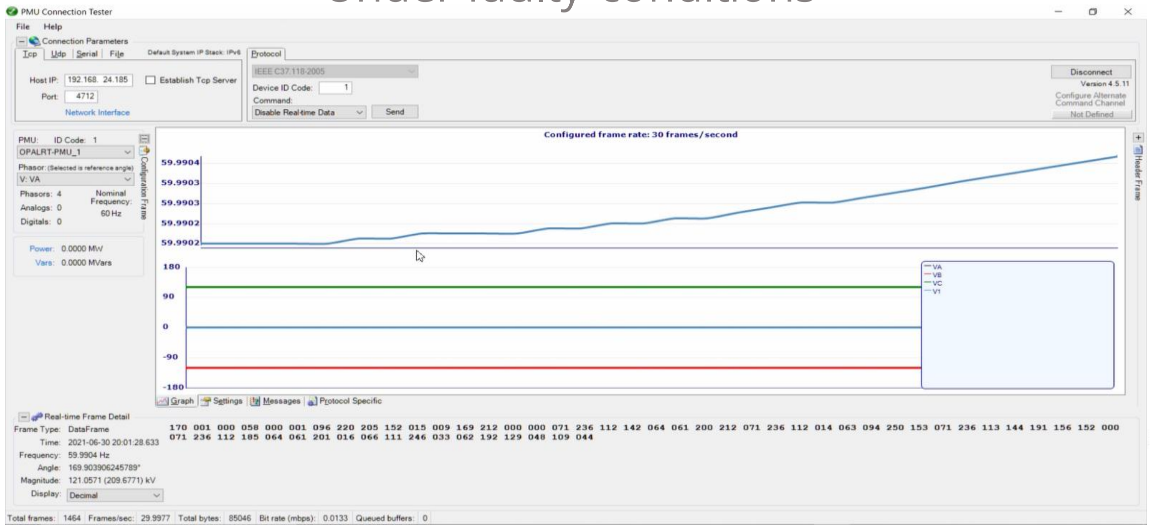
PC #1: 4 machine model with PMU and C37.118
PC #2: PMU connection tester
Both running on Windows OS



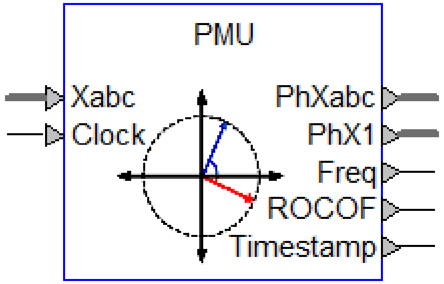
Steady-state



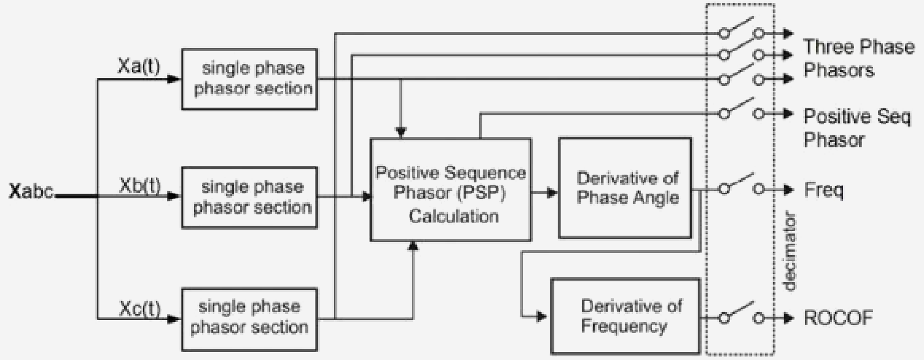
Under faulty conditions



USE CASE #1: IEEE-Compliant PMU



▼ PMU

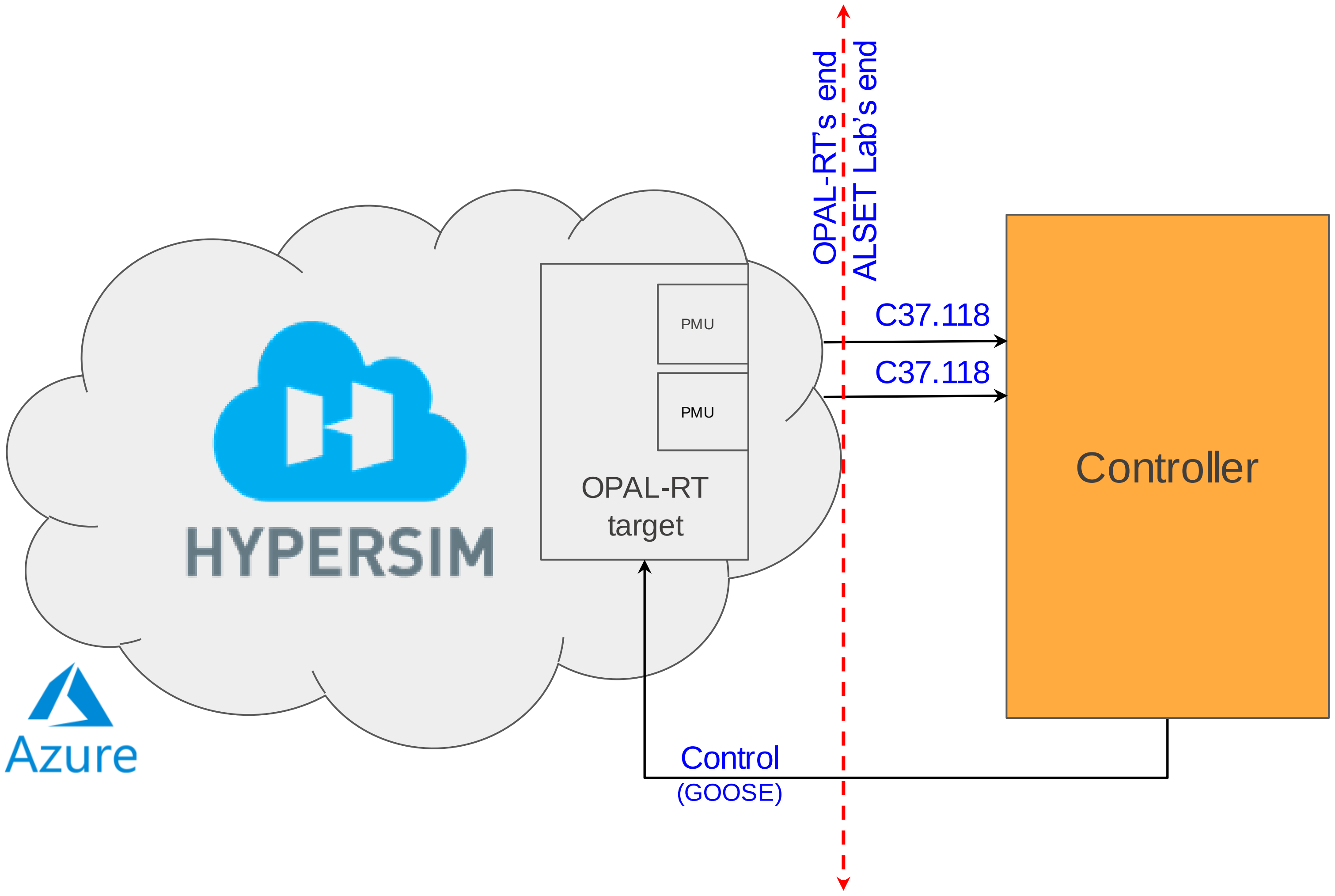


This Phasor Measurement Unit (PMU) block is based on the Discrete Fourier Transform (DFT) algorithm.[1] The input is a bundle including the instantaneous three-phase voltages or currents. The PMU outputs three phase phasors, positive sequence phasor, frequency and rate of change of frequency (ROCOF). The phasors can be configured to be output as magnitude-angle or real-imaginary parts.

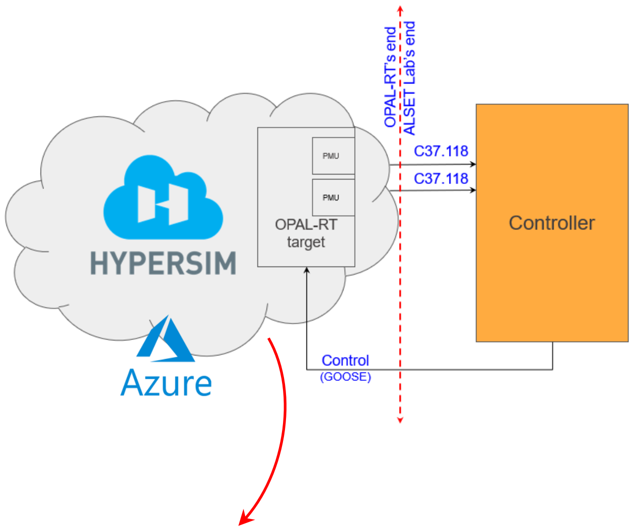
1. IEEE Standard for Synchrophasor Measurements for Power Systems," in *IEEE Std C37.118.1-2011 (Revision of IEEE Std C37.118-2005)*, vol., no., pp.1-61, Dec. 28 2011

F0	50	Hz
PMU class	P	
Reporting rate [S/cycle]	1	S/c
Output format	Mag-Ang	
Clock type	Internal Clock	

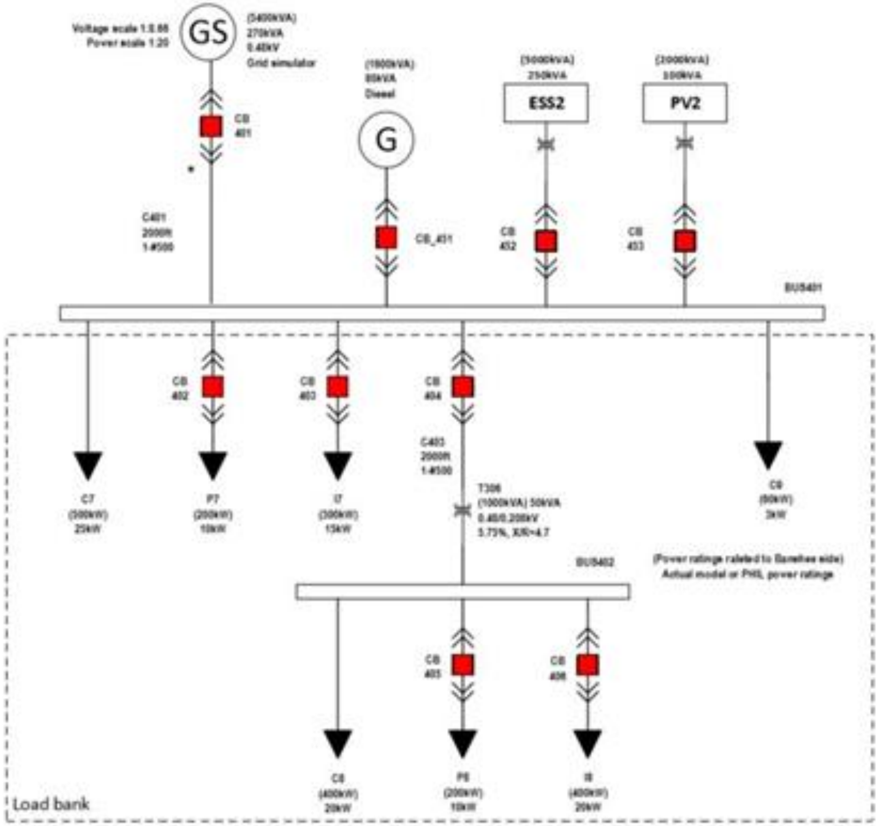
USE CASE #2: CLOUD-BASED HIL – CONCEPT



USE CASE #2: CLOUD-BASED HIL: MODEL



Construction of the Microgrid Model: Details of the sources



DER type	Location	Power rating (kVA)	Voltage rating (kV)	Grid-forming capability
Diesel generator	Feeder 1	4000	13.8	Yes
PV	Feeder 2	5000	0.48	No
BESS	Feeder 2	3000	0.48	Yes
CHP	Feeder 3	3500	13.8	Yes
Diesel generator	Feeder 4	80	0.48	Yes
PV	Feeder 4	100	0.48	No
BESS	Feeder 4	250	0.48	Yes

HYPERSIM running the microgrid model on Azure VM

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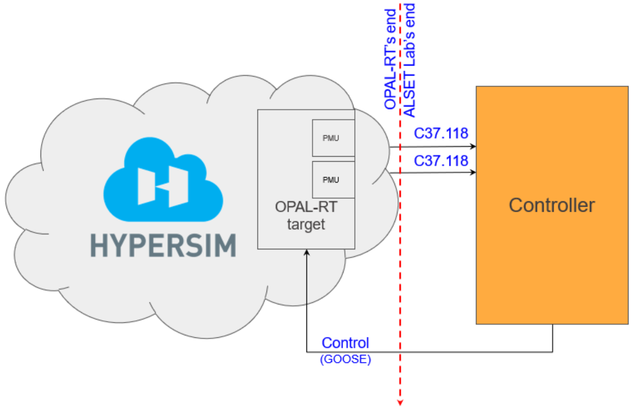
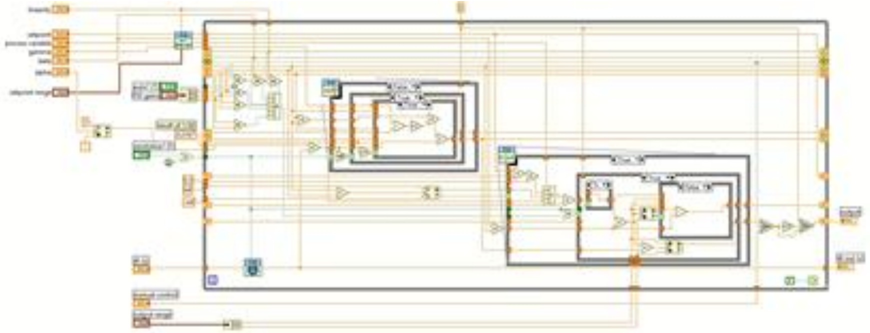
USE CASE #2: CLOUD-BASED HIL: CONTROLLER

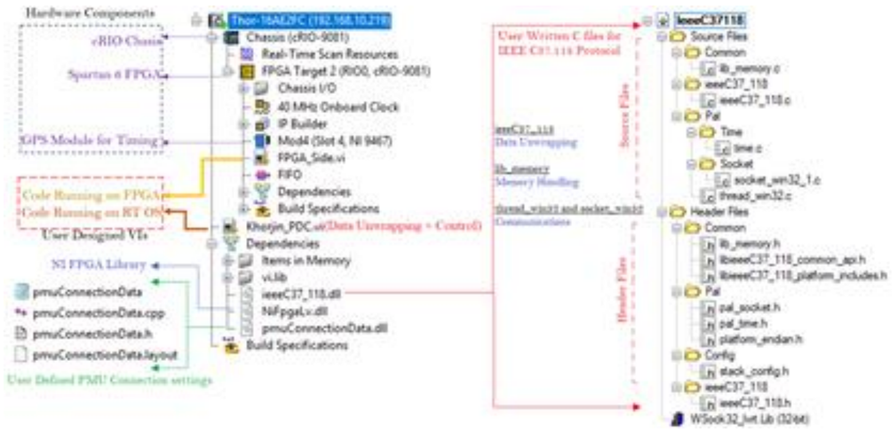




Controller VI on LabView

■Controller is being run on an NI cRIO-9081 hardware connected to ALSET Lab Network.

■It unwraps C37.118 data in real-time and takes control action/ switching action based on it

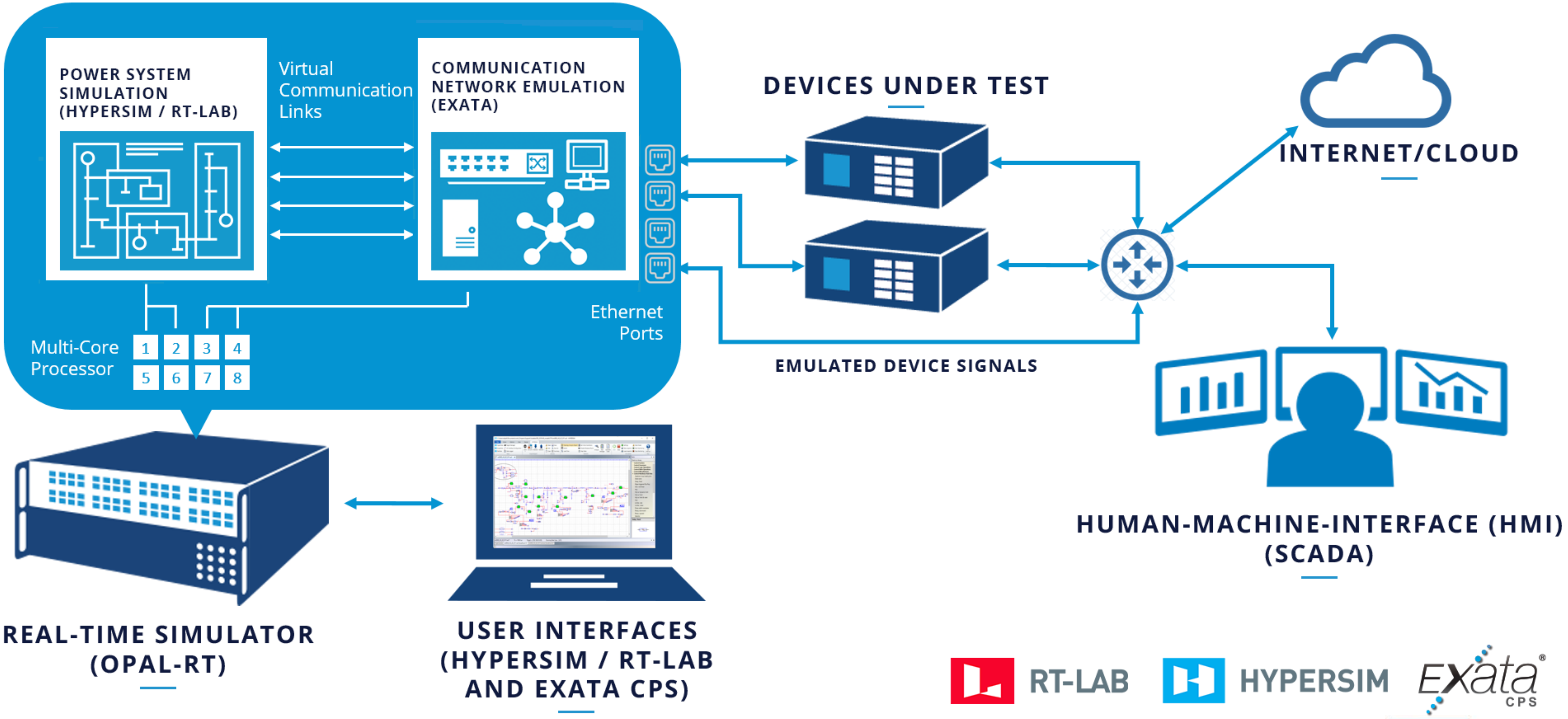


Code structure for Synchrophasor Synchronization Gateway + Controller on cRIO-9081

cRIO-9081 HW in ALSET Lab connected to Network

HYPERSIM/RT-LAB FOR CYBER-PHYSICAL SIMULATIONS

CYBER-PHYSICAL SYSTEM (CPS) CO-SIMULATION



RT-LAB HYPERSIM EXata CPS

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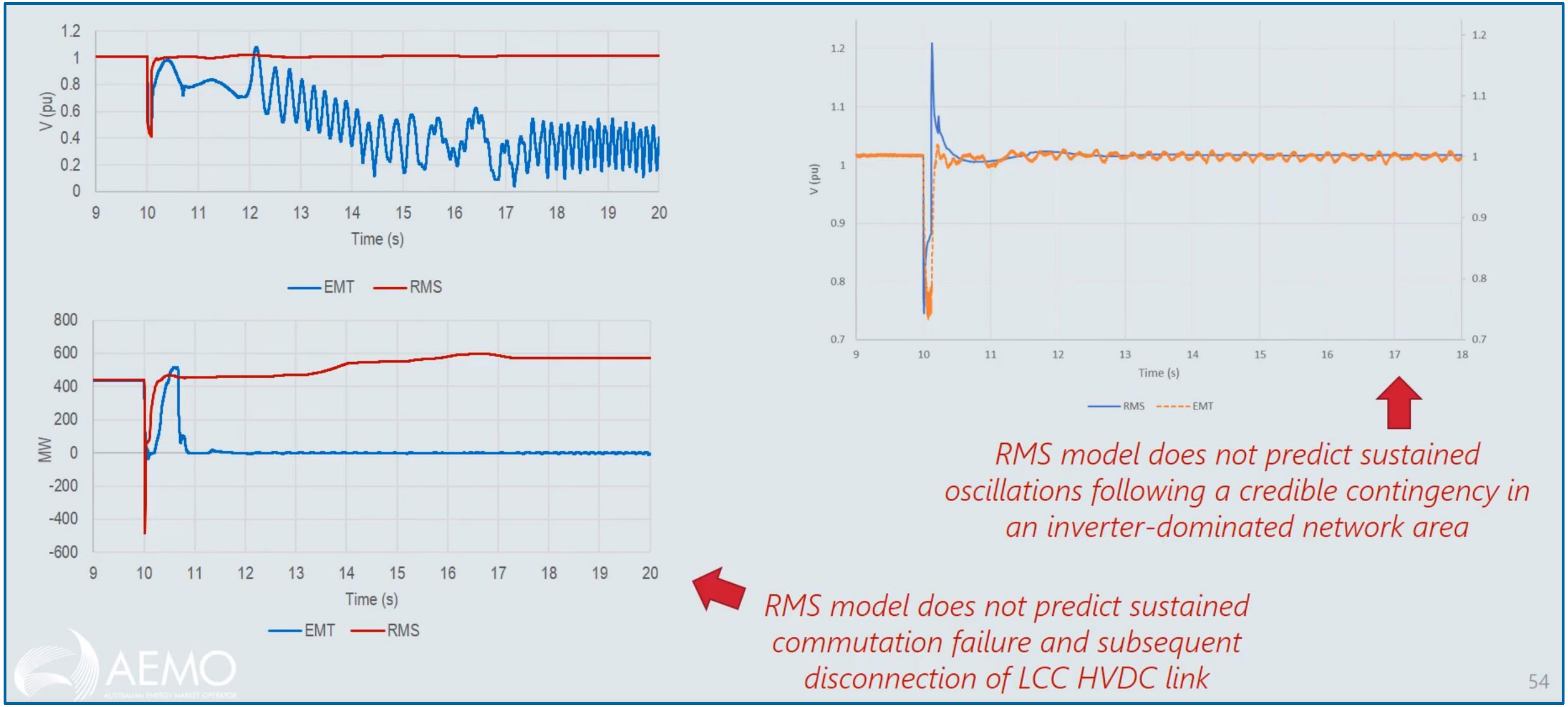
APPLICATION REQUIRING EMT SIMULATION & PARALLEL PROCESSING

- Multi-infeeds with HVDC converters installed near large cities
  - China, India, Brazil …
  - Evaluation of commutation failure risk and power transfer capability following faults
  - Protection and control system interactions
- Power systems with high penetration of renewable energy
  - Large quantities of power electronics-based generation, loads and energy storage systems
  - Low inertia systems: fast responses and impedance resonances
  - Inland and off-shore wind parks, solar plants
  - Microgrids connected or disconnected from the main grid
- HVDC MMC Grids … next slides

EMT MODELS CRITICAL FOR MODERN POWER SYSTEM



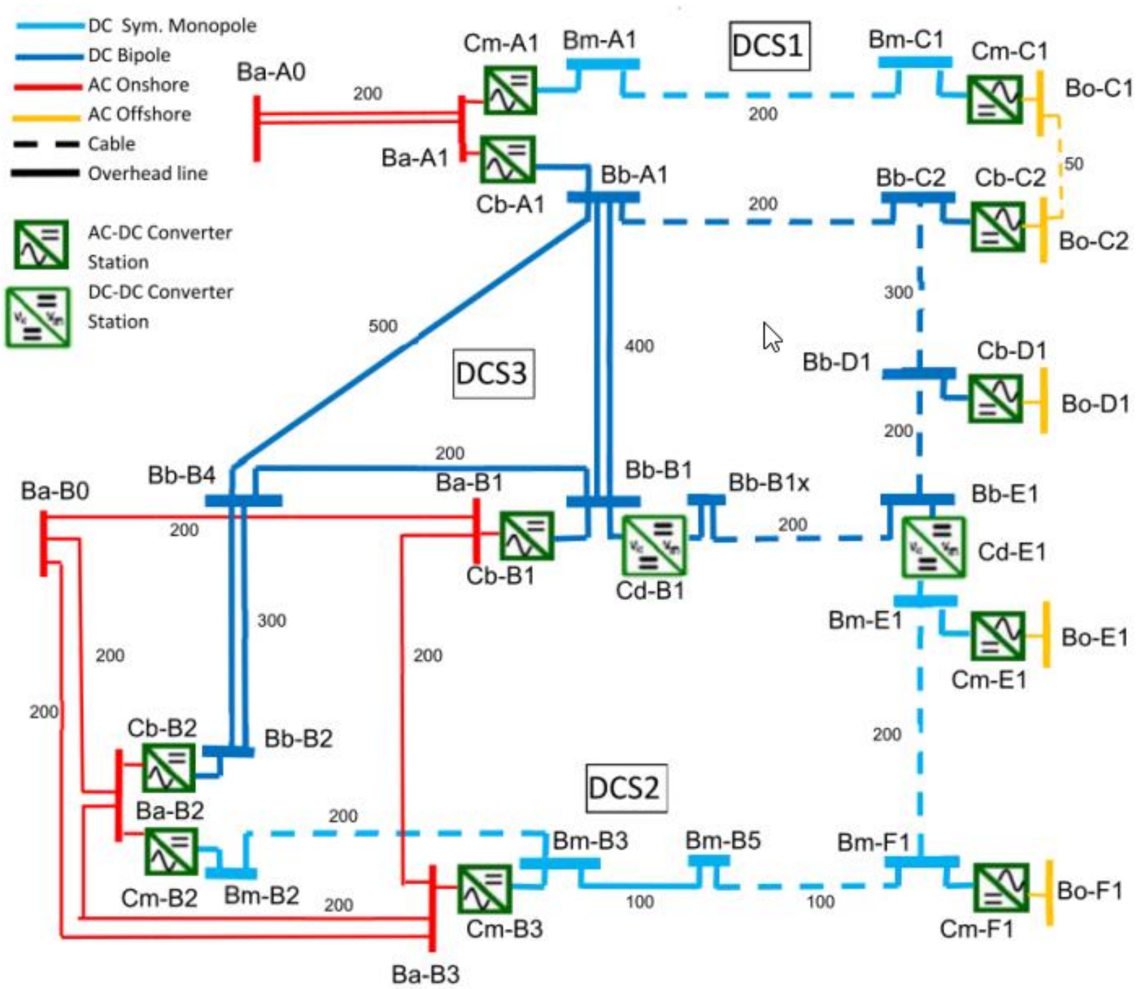
Source: AEMO system strength workshop, https://aemo.com.au/en/learn/energy-explained/system-strength-workshop

NEED FOR FASTER SIMULATION

- Power systems are becoming more complex
- Several power electronics systems can interact together, affecting global system performance and power transfer capability
- The accuracy of simplified phasor domain models is questionable for such systems
- EMT simulation may be needed to evaluate the performance of low-inertia systems
- Analysis of hundreds of contingencies becomes impractical for large systems unless fast parallel simulation is used
- Because EMT simulation requires very small time steps (10 to 50 us)

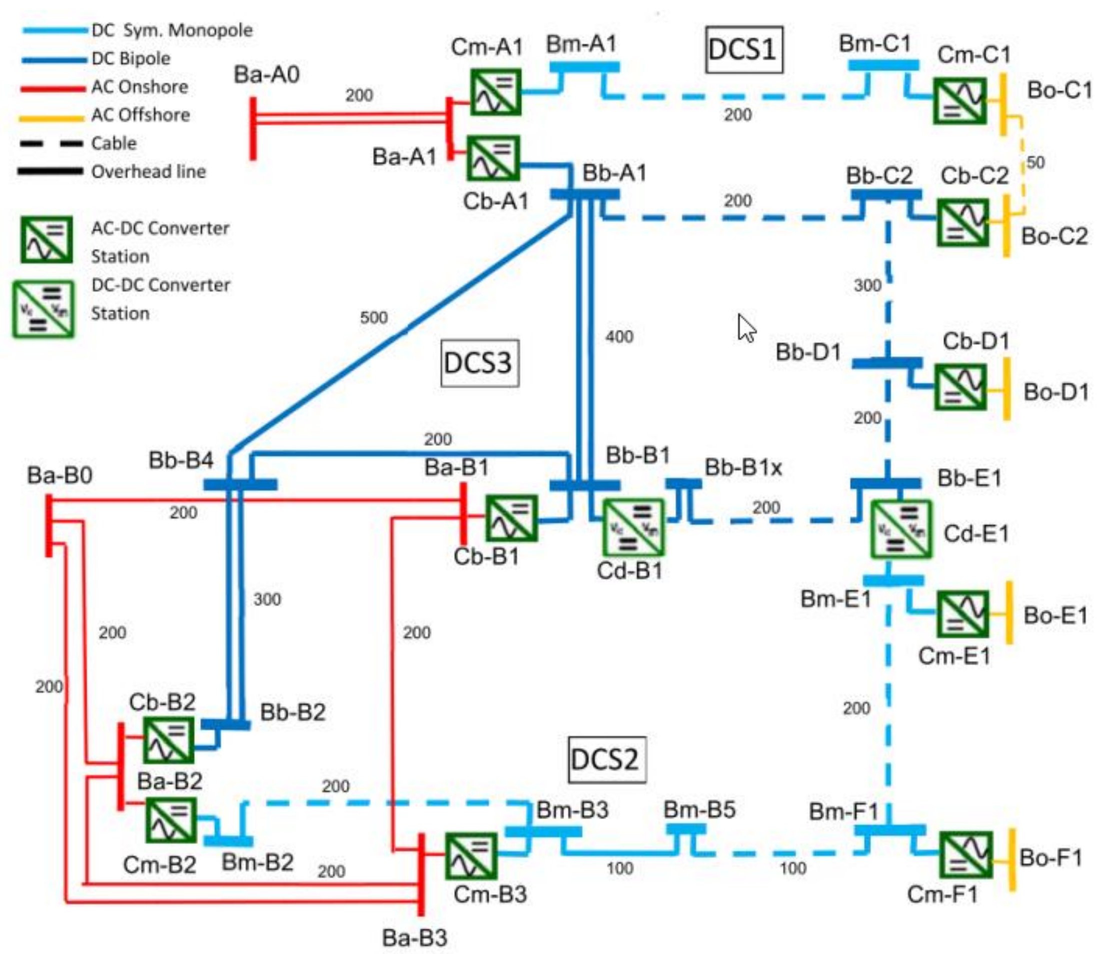
USE CASE #3: COMPLEX SYSTEM SIMULATION ON CLOUD

Example: CIGRE B4 DC Grid Benchmark



- 13 MMC-HVDC and DC-DC converters
- Phasor-type simulation accuracy is questionable due to fast controller responses and low inertia of the global system
- Hundreds of contingencies must be analysed to determine power transfer capabilities
  - N-1 contingencies (line, transformer or generator out-of-service)
  - Different fault types and clearing times

USE CASE #3: CIGRE B4 DC GRID BENCHMARK – CLOUD PERFORMANCE

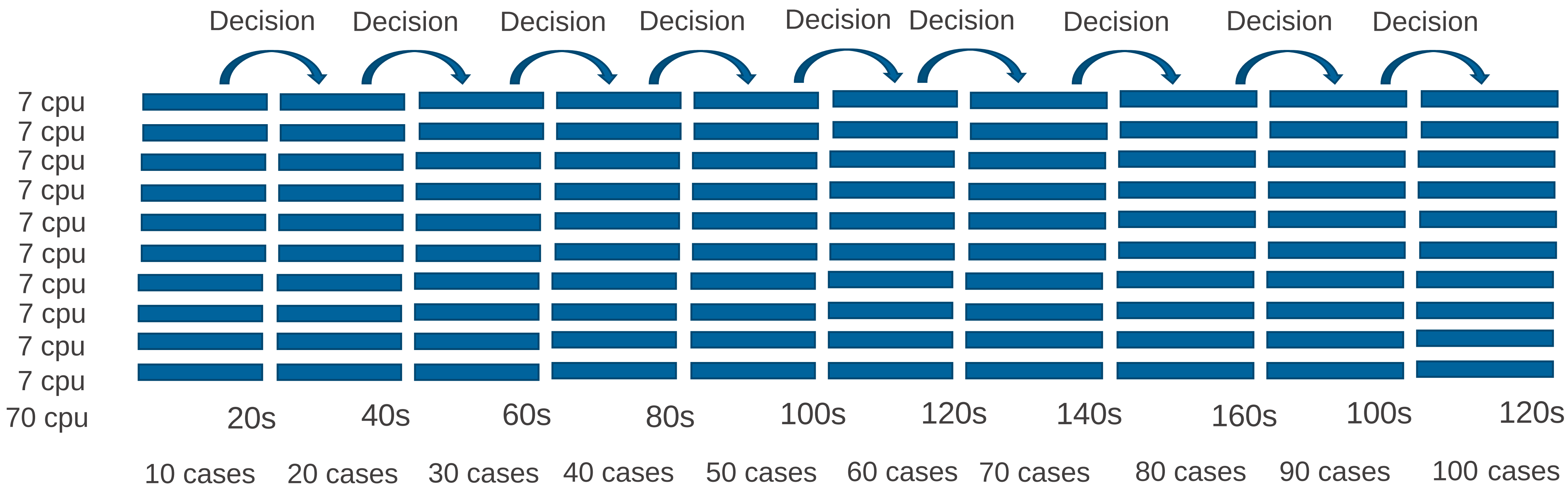


	Typical EMT Off-line Software	HYPERSIM Off-line and real-time Software (on AWS Cloud)
Serial Execution (one CPU core)	1500 to 2500 s	300s
Parallel Execution	> 500s	20s
CPU Cores	9	7
Time Step	25µs	25µs
Simulation Time	25 seconds	25 seconds

More contingencies can be analysed in less time using parallel processing

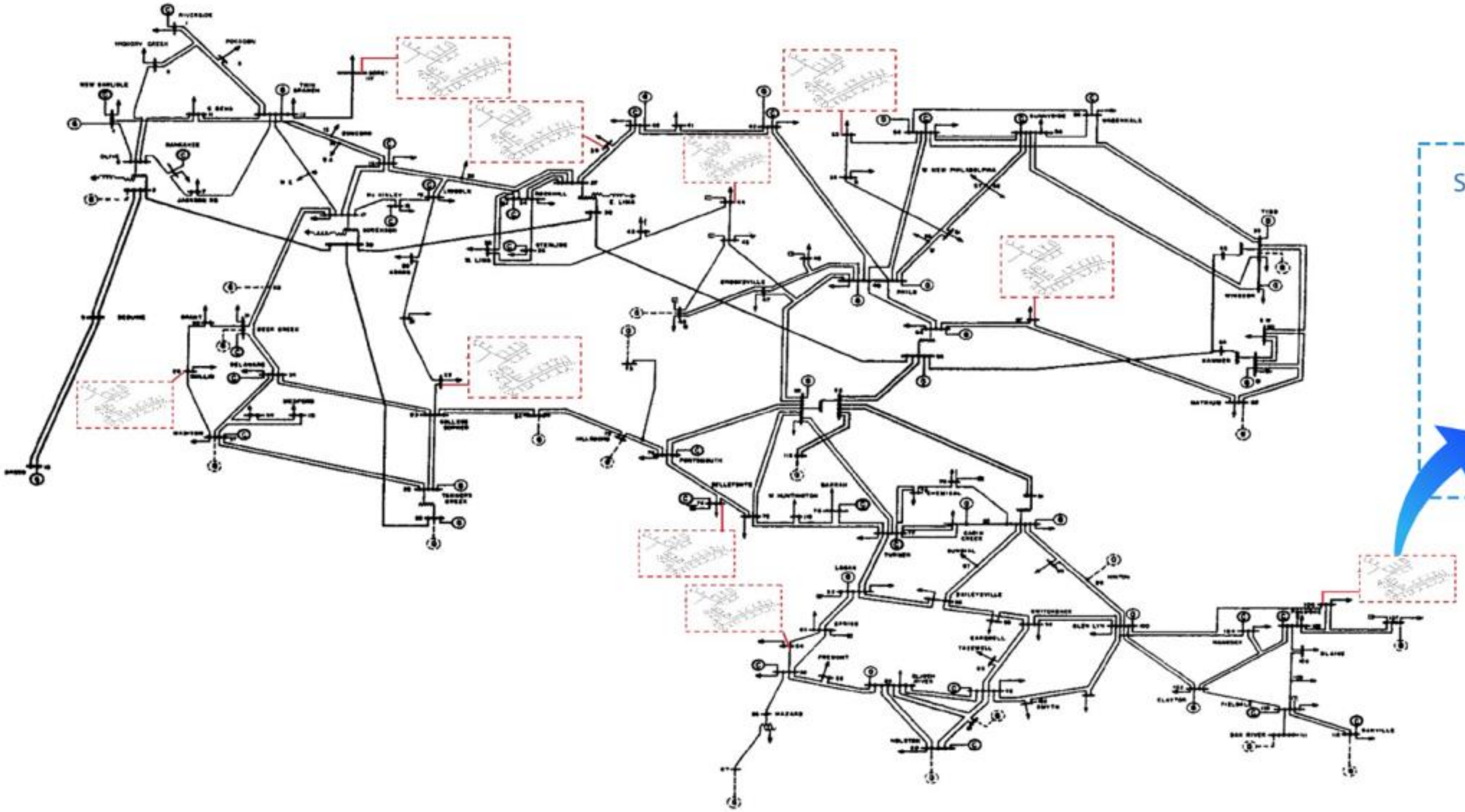
USE CASE #3: INCREASING INTERACTIVITY – DECREASING RESPONSE TIME – MAXIMIZING TEST COVERAGE

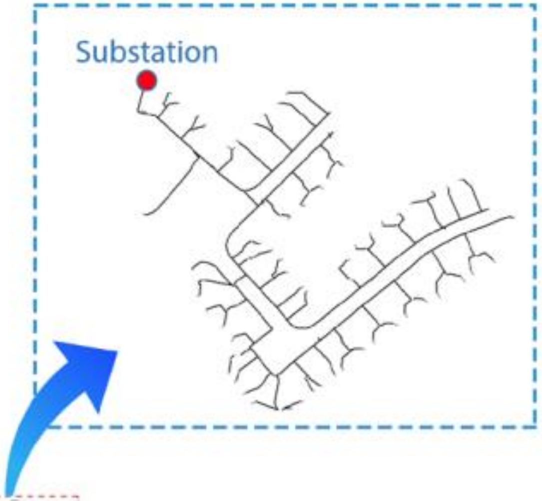
Example of parallel-series execution of several runs to evaluate global system performance and power transfer capability for large number of contingencies in minimum time. The selection of **next** cases could be dependent on the results of **previous** cases.



Using several parallel runs with only one processor per run would take between 300 and 2000 seconds to analyse 100 contingencies with 70 CPUs instead of 100 seconds

USE CASE #4: 1 MILLION T&D NODES WITH ePHASORSIM

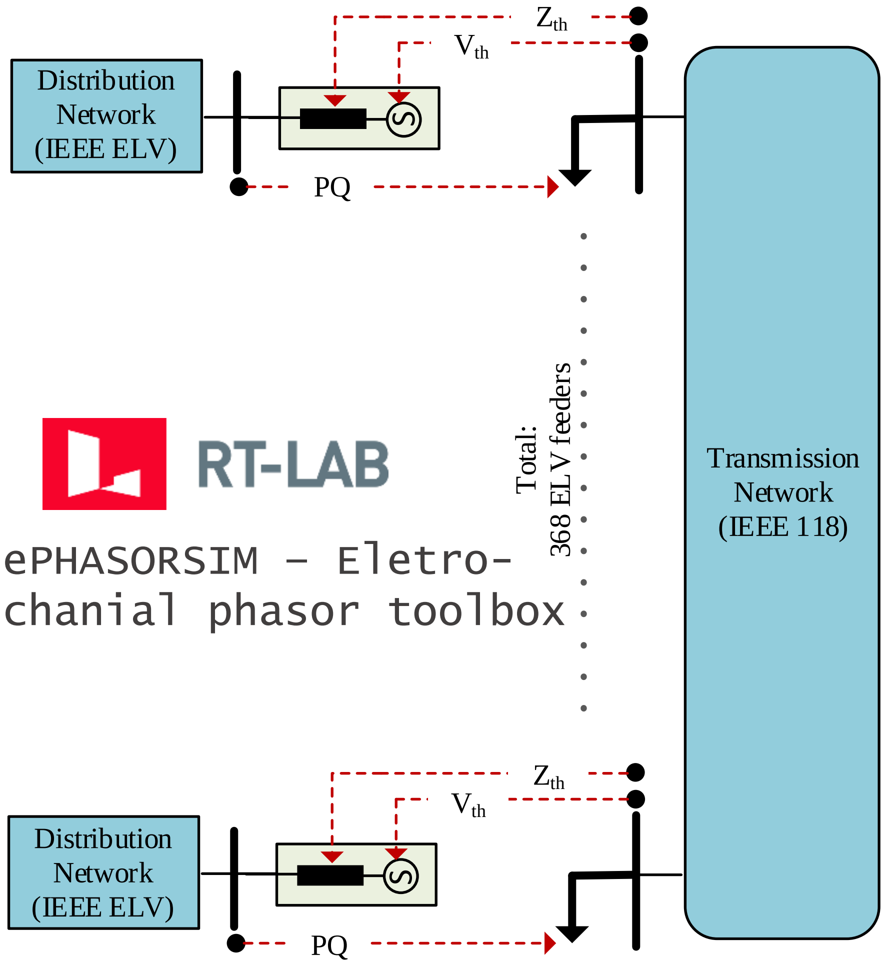




Based on 108,000-node T&D system presented in:
https://blob.opal-rt.com/medias/L00161_0775.pdf

USE CASE #4: 1 MILLION T&D NODES WITH ePHASORSIM

- 1Million nodes integrated transmission and distribution model in ePHASORSIM
  - Transmission system: IEEE 118 bus transmission network (PSS/E model)
  - Distribution system: IEEE European Low Voltage (ELV) distribution feeder
  - 368 of the ELV feeders connected at different load buses of IEEE 118.
  - Each load bus containing 4-5 ELV feeders to achieve 1 Million node synthetic model
- One solver for transmission system, and 368 solvers for distribution systems.
- Distribution systems represented as lumped constant power load in transmission system, and transmission system represented as voltage source in distribution system
- Thevenin equivalent of transmission system and power consumption of the distribution system at point of common coupling (PCC) are exchanged every time-step to maintain the integration

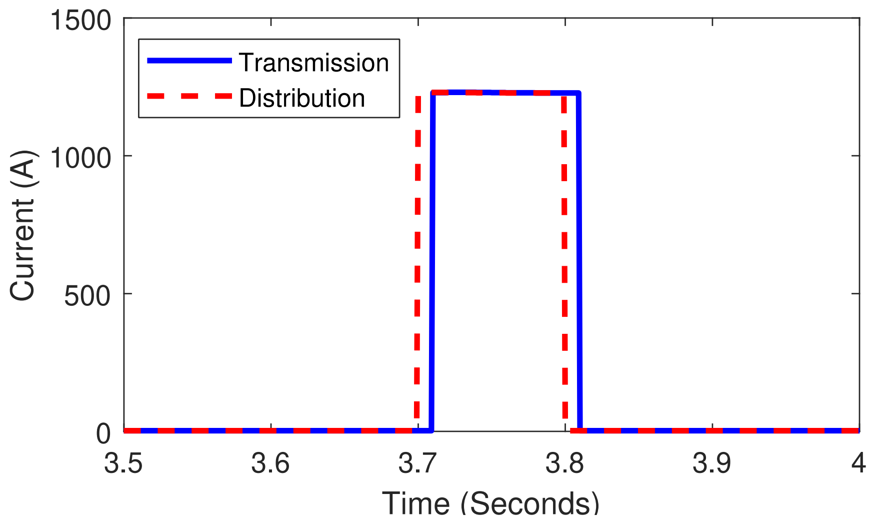


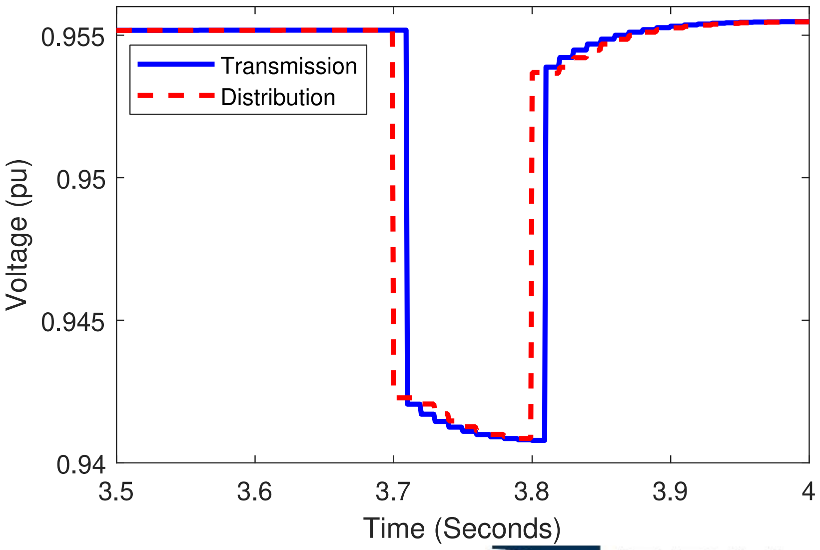
RT-LAB

+ ePHASORSIM – Eletro-mechanial phasor toolbox

USE CASE #4: 1 MILLION T&D NODES WITH ePHASORSIM

- Objective:
  - To capture interactions between transmission and distribution systems.
- ePHASORSIM: transmission system as positive sequence network, distribution system as three-phase system
- Test case 1: Fault at distribution system and capture the response in transmission system. All fault current should come from the transmission system for proper integration.
  - A 3 phase line to ground fault created at one of the distribution network.
  - The positive sequence current at the PCC is very close for the load representing the feeder and the current in the distribution system.
  - Similarly, the voltage at the PCC for the transmission bus and the distribution are very close





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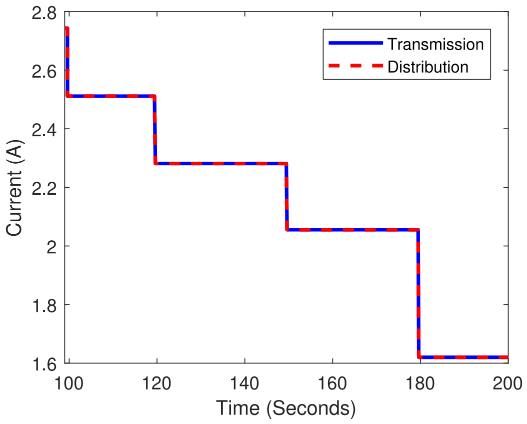
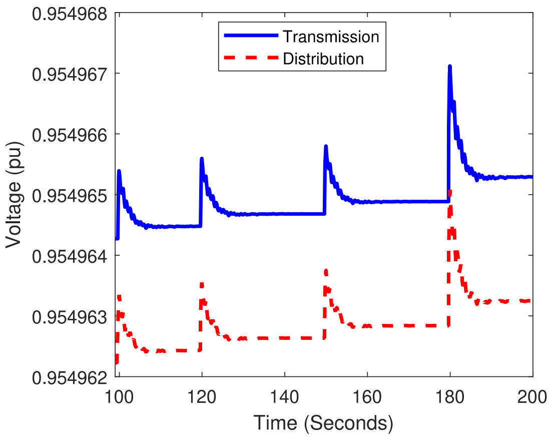
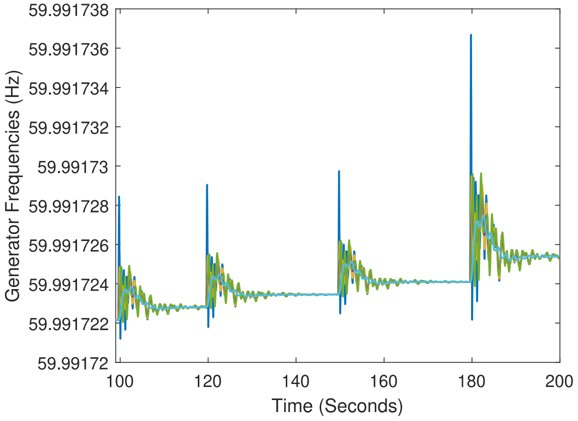
USE CASE #4: 1 MILLION T&D NODES WITH ePHASORSIM

- Test case 2:
  - Power injection at the distribution level to represent energy resources such as PVs
  - A negative load in a distribution system was created to represent an energy source.
  - The power injection for the energy source was controlled with a step function to understand the response at the transmission level
  - The current and voltage at the PCC were compared to insure the proper interconnection.
  - The change in the transmission system was minimal as the maximum change in the injection was 50% of the total distribution load (0.05MW), which was much less than what transmission system was supplying (~4 GW)
  - The corresponding response at the transmission level was noticed at different intervals as the power injection changes in the distribution system (10%, 20%, 30%, and 50%)
  - The negative load can be replaced with DER models, or data for further studies







CONCLUSION

- Co-simulation EMT/RMS or with communication networks or manufacturer plant models with controller black-box DLLs becomes necessary in several cases
- The migration of simulation software to the cloud is essential for data management, model analytics, grid data analytics and grid data processing
- Leveraging clusters of high-performance multi-core computers to not only parallelize model execution but also testing of several contingencies at the same time will be crucial to achieve update of transient stability assessment every 5 to 10 minutes
- OPAL-RT's portfolio and roadmap are tailored to address WAMPACS existing and future needs

Thank you for your attention!

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