Accelerating Large-scale IBR integration Studies in Real-time using HYPERSIM

Shijia Li
Team Lead – Power Systems
Electrical Engineering and Expertise Department
OPAL-RT Technologies

ESIG 2024 Spring Technical Workshop
March 25, 2024

OPAL-RT TECHNOLOGIES

Introduction

About OPAL-RT Technologies

- Founded in 1997 in Montreal, QC, Canada
- 350+ employees, growing sustainably
- 1000+ customers in all industries around the world
- 20% of annual revenue re-invested in R&D
- 40% academic, 60% industries
- 90% revenue from electrical and power electronics sectors
- Markets
  - HIL, RCP, real-time laboratories
  - …and fast off-line and on-line close-to-real-time (cloud) simulation
  - for education, R&D and all industries: energy, power electronic, automobile, off-highway vehicle, aerospace, ships, trains ...

2017 PROFIT 500 CANADA'S FASTEST-GROWING COMPANIES

LISTED IN les affaires 300 QUEBEC'S 2017 MOST IMPORTANT SMEs

MERCURIADES 2016

LISTED IN les affaires 300 QUEBEC'S 2016 MOST IMPORTANT SMEs

HSBC International BUSINESS AWARDS

Strong International Footprint

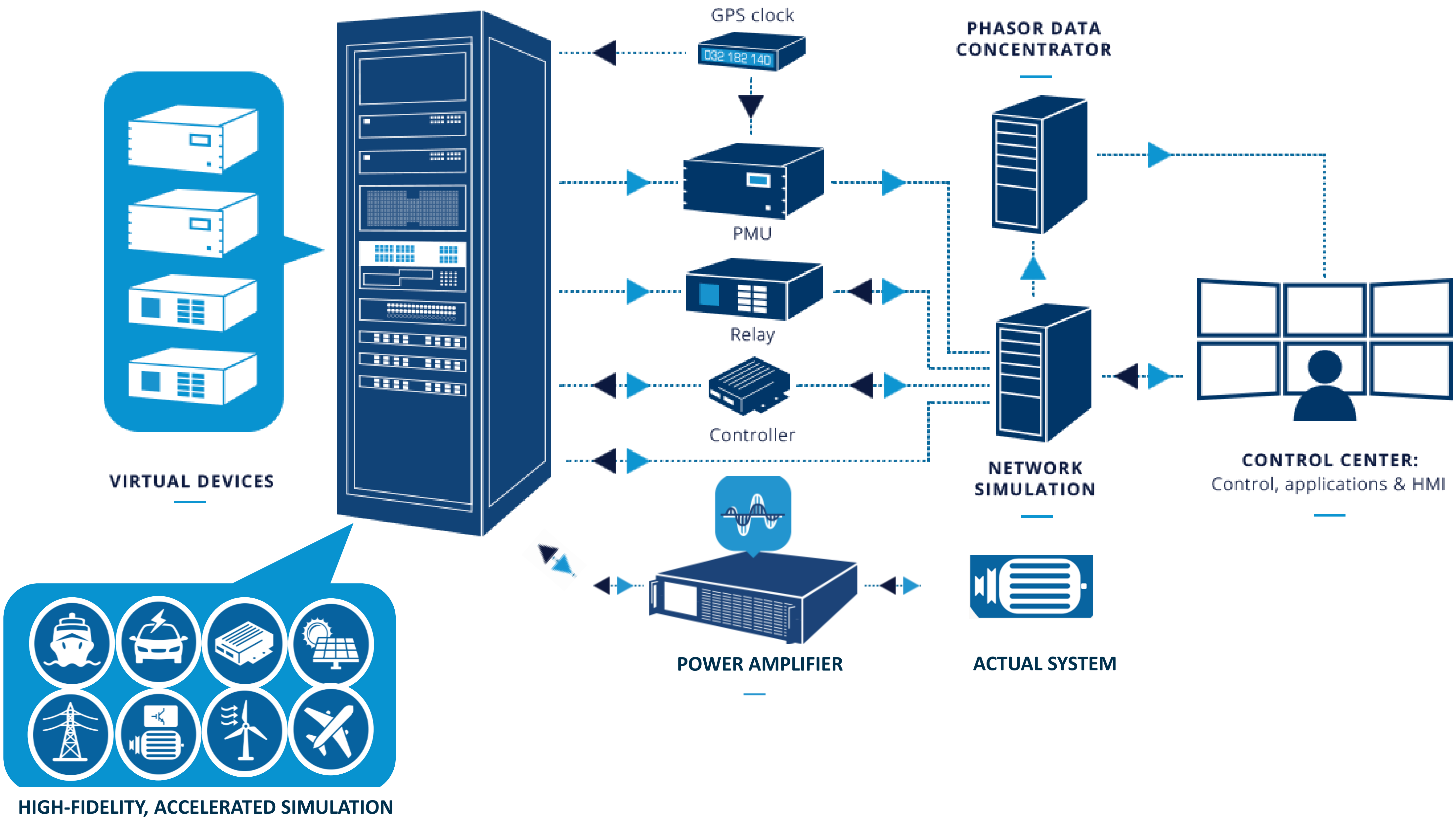
International subsidiaries, offices and Excellence Centers:

- USA (Michigan, Colorado), Germany, France (Paris and Lyon), India, China, Brazil, Australia

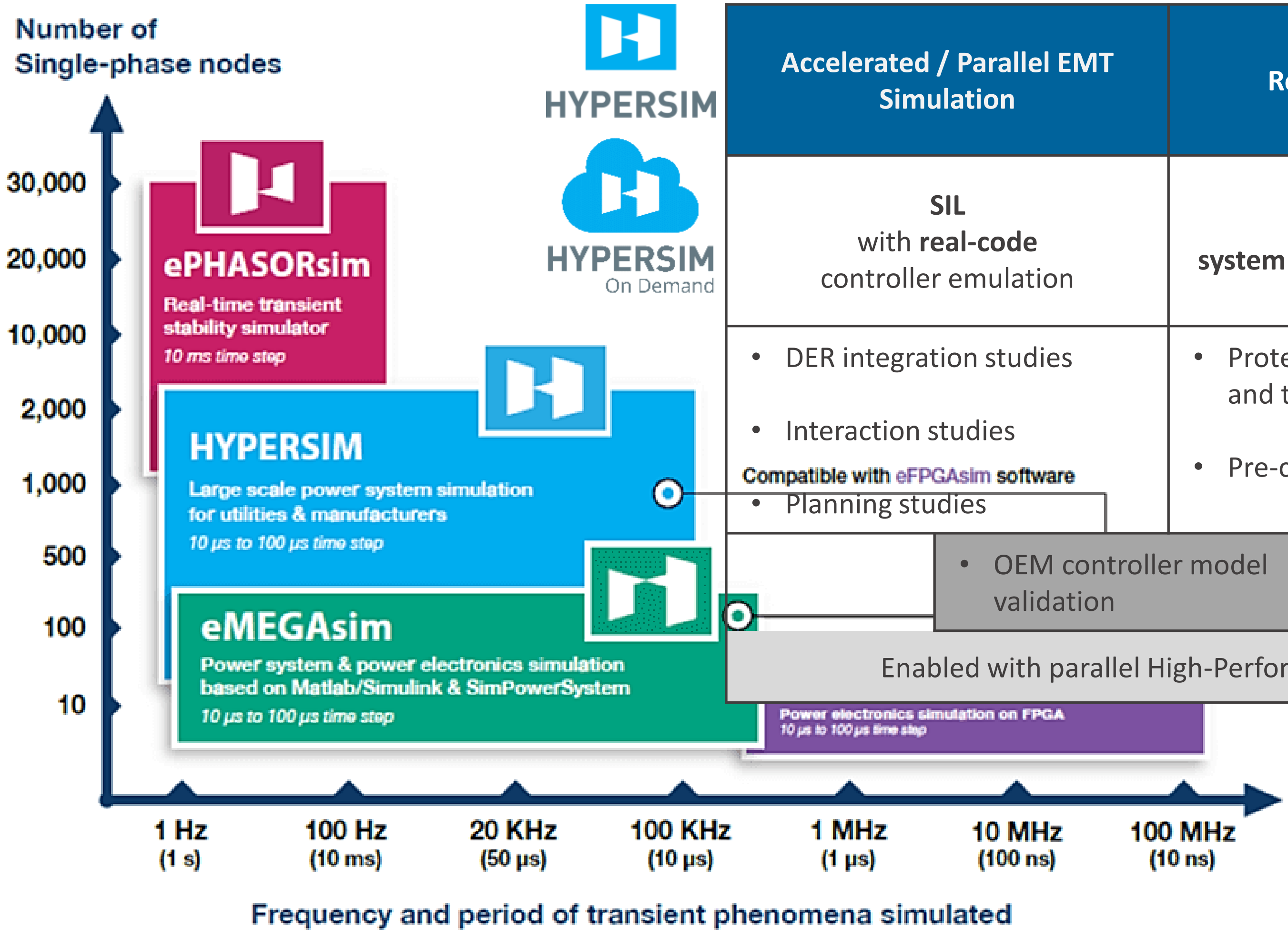
Distributors:

- China, Australia, Japan, Korea, Singapore, Israel, Ukraine, Kazakhstan, Oman, Pakistan, Qatar, Turkey, United Arab Emirates , Kingdom of Saudi Arabia

Use Cases for Real-Time Simulation

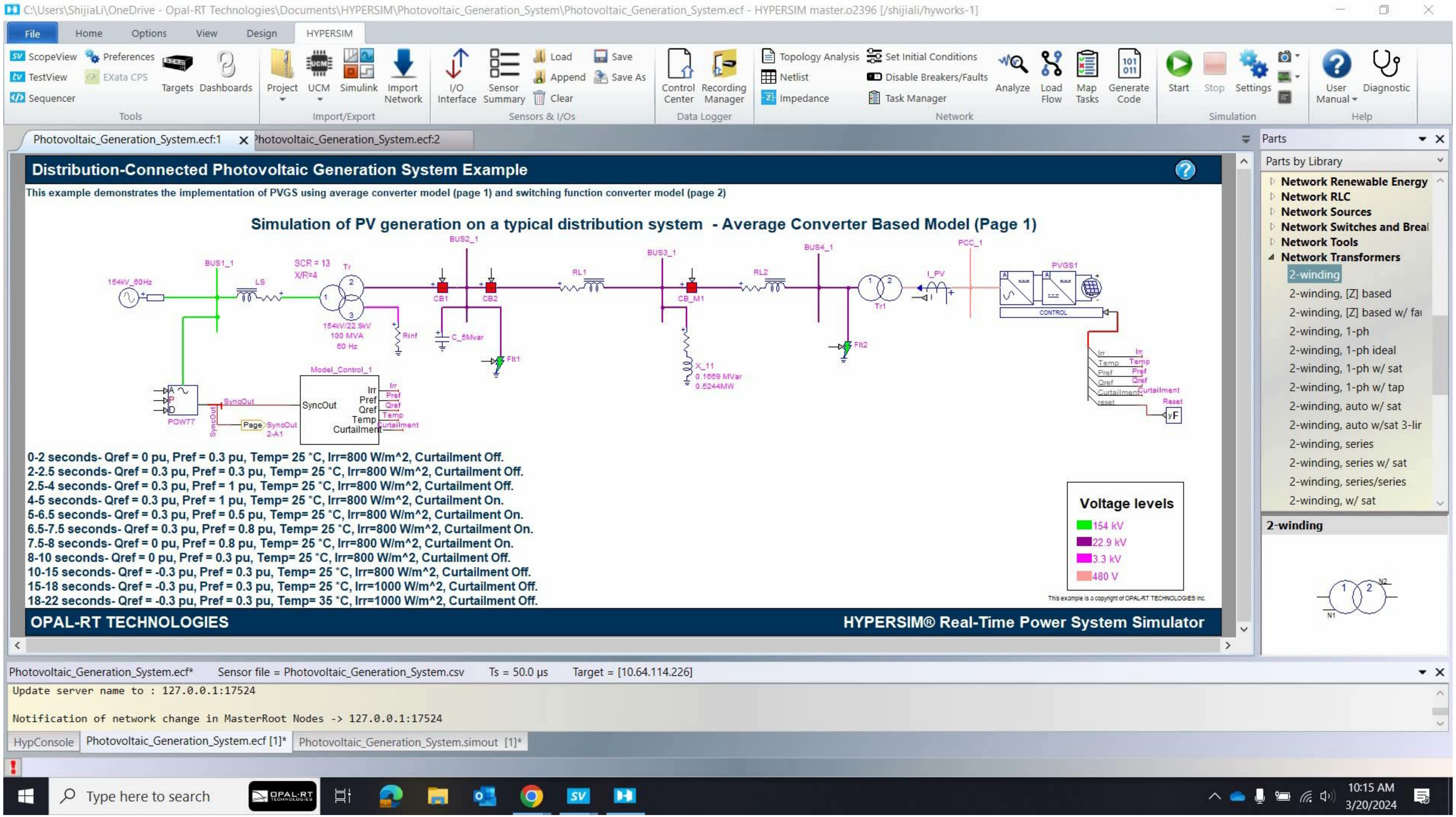


OPAL-RT's Suite of Simulation solutions



Accelerated / Parallel EMT Simulation	Real-Time Simulation	Quasi Real-Time or Faster-Than-Real-Rime Simulation
SIL with **real-code** controller emulation	**CHIL** with **control system replicas, PHIL** with **actual DERs**	**Digital Twins** for use in System Operations
• DER integration studies • Interaction studies • Planning studies	• Protection and control design and testing/validation • Pre-commissioning tests	• Transient Stability Analysis / Contingency Analysis • State Estimation to estimate system states every 5-10 min
• OEM controller model validation		
Enabled with parallel High-Performance Computer (HPC) based real-time simulator technology		

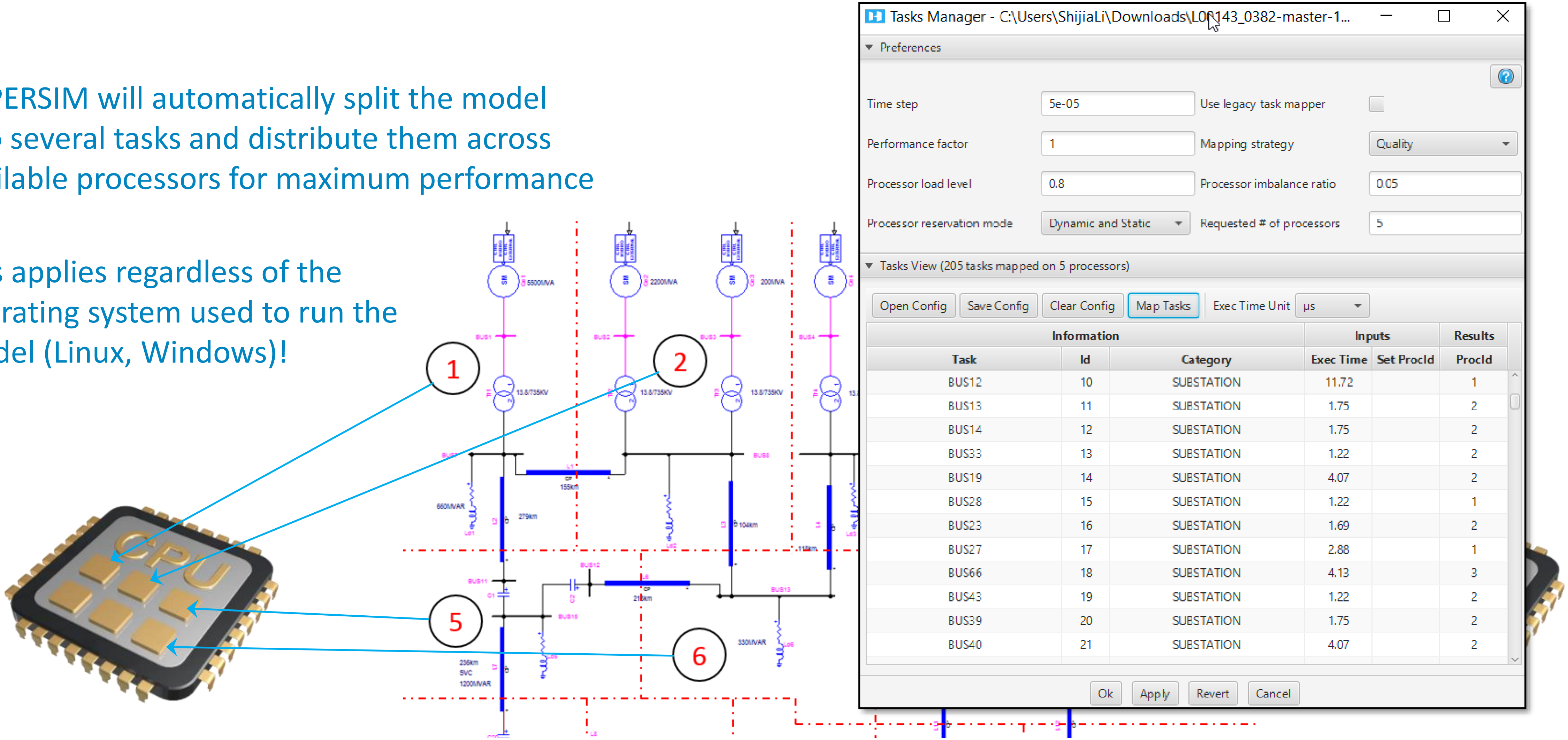
HYPERSIM – Graphical User Interface and Workflow



HYPERSIM - Automatic Model Decoupling

HYPERSIM will automatically split the model into several tasks and distribute them across available processors for maximum performance

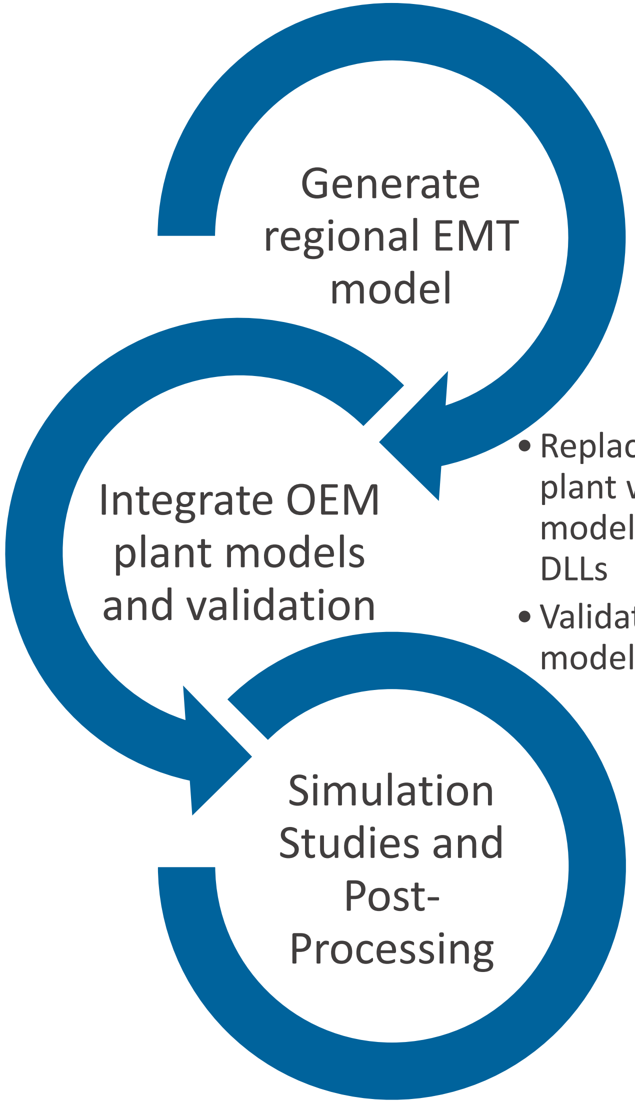
This applies regardless of the operating system used to run the model (Linux, Windows)!



HYPERSIM - Study workflow and features for IBR integration

OPAL-RT TECHNOLOGIES

Study Workflow – Current Process & Mapping to HYPERSIM



- Import from large-scale wide-area model with generic models and UDM
- Validate network model and network equivalent

→ OneLib Unified Database to handle model conversion

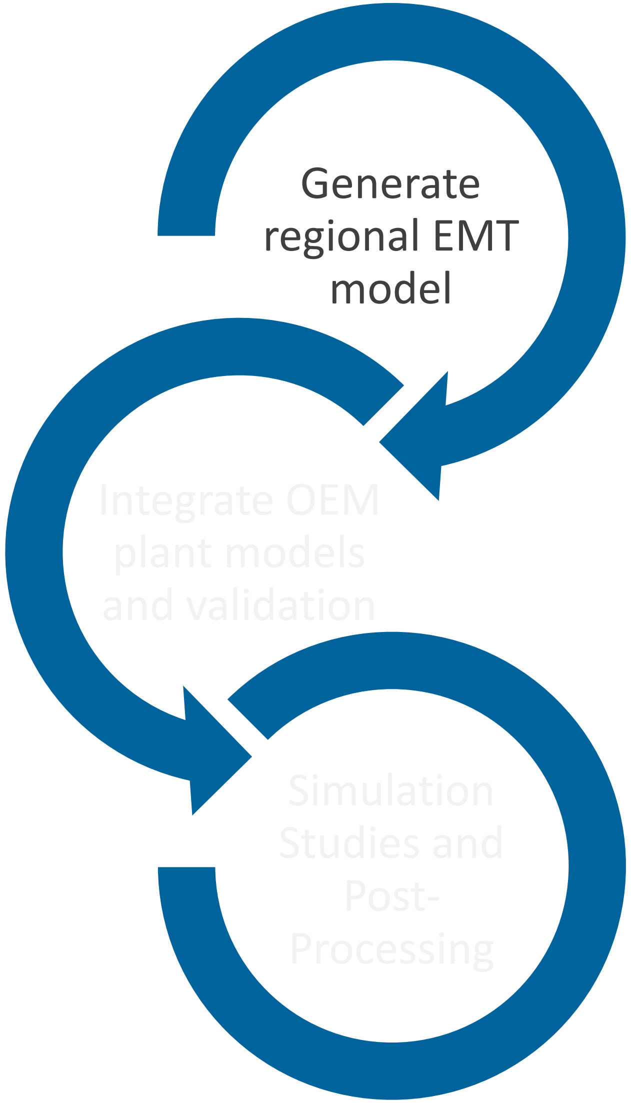
- Replace generic plant with the OEM models including DLLs
- Validate plant model

→ CIGRE interface and automatic DLL import to integrate OEM controllers

- Scripting to perform different disturbances and update operating conditions
- Post-processing of simulation results

→ Test automation framework for scenario testing

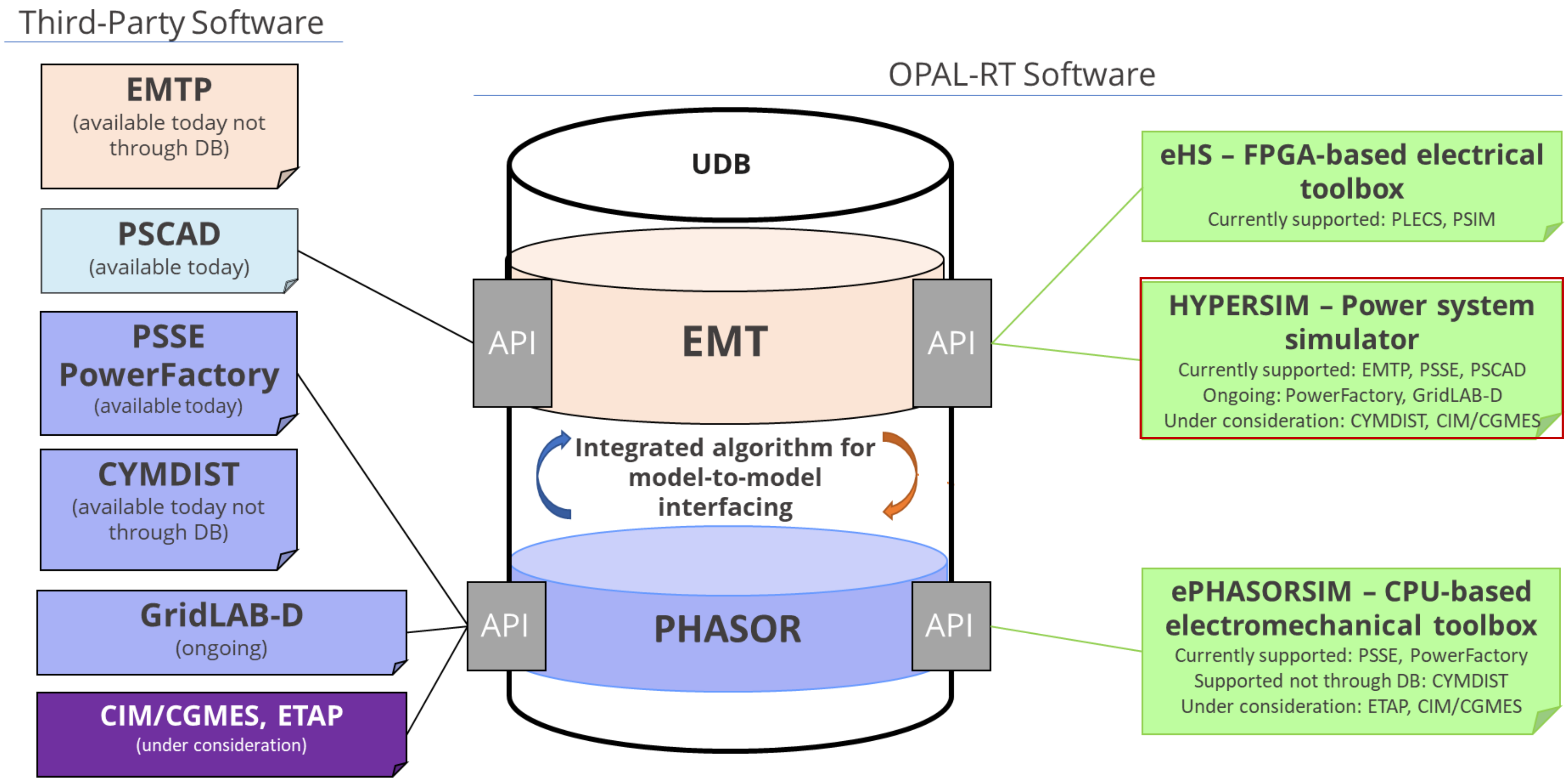
Study Workflow – Current Process & Mapping to HYPERSIM



- Import from large-scale wide-area model with generic models and UDM
- Validate network model and network equivalent

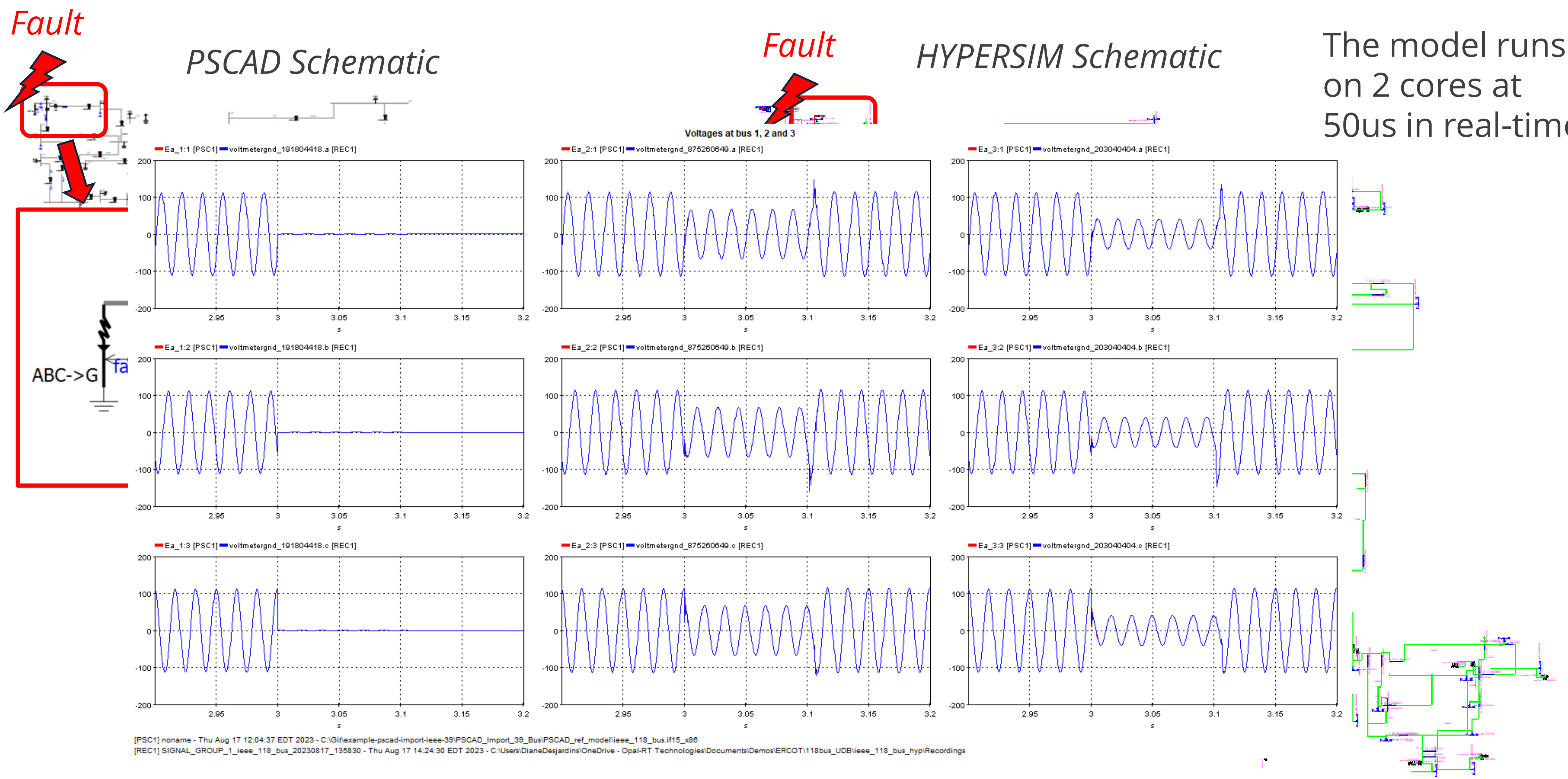
OneLib Unified Database to handle model conversion

OPAL-RT's Unified Database for Network Model Conversion

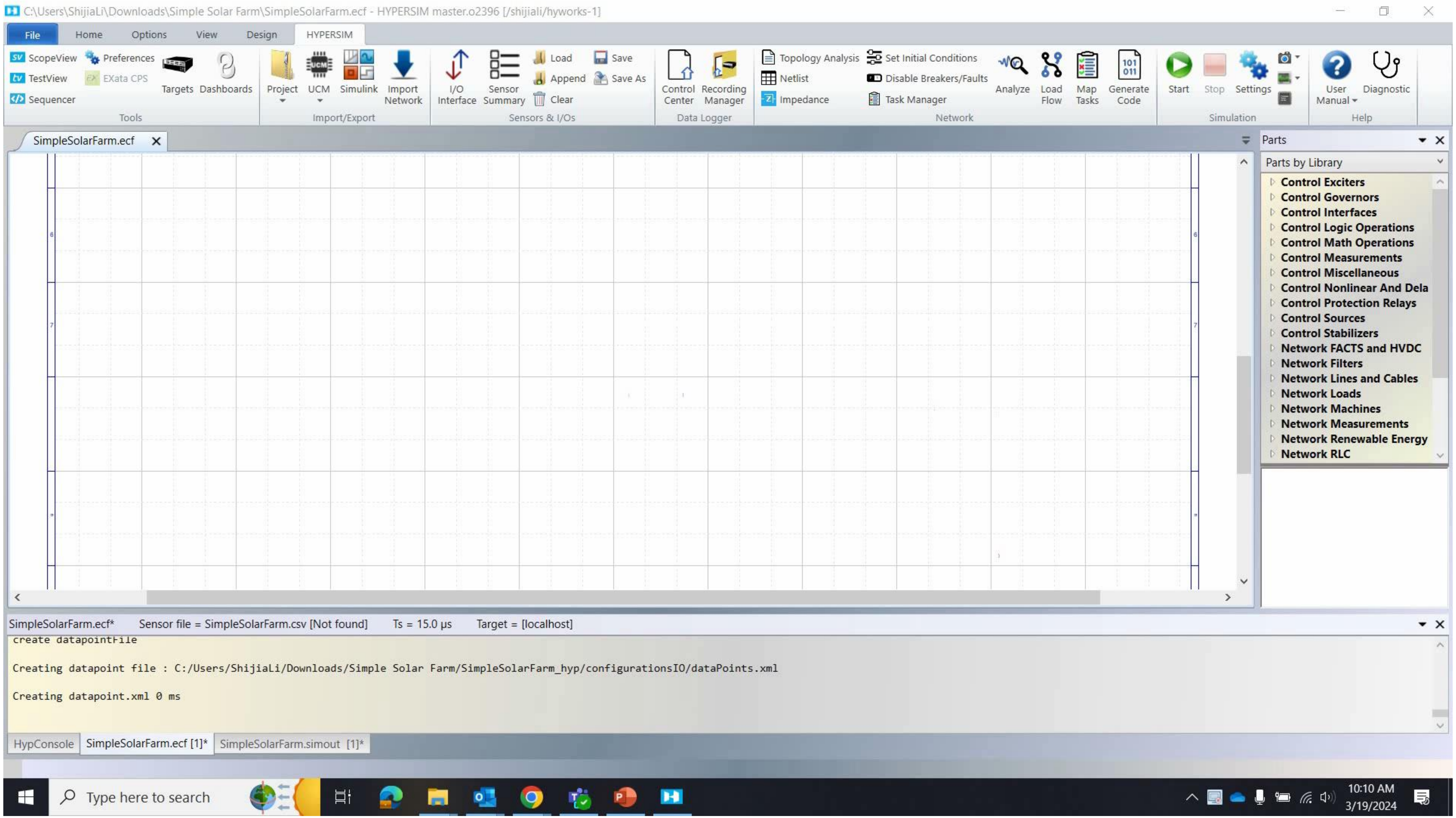


IEEE 118 Bus Model Import and Validation in HYPERSIM

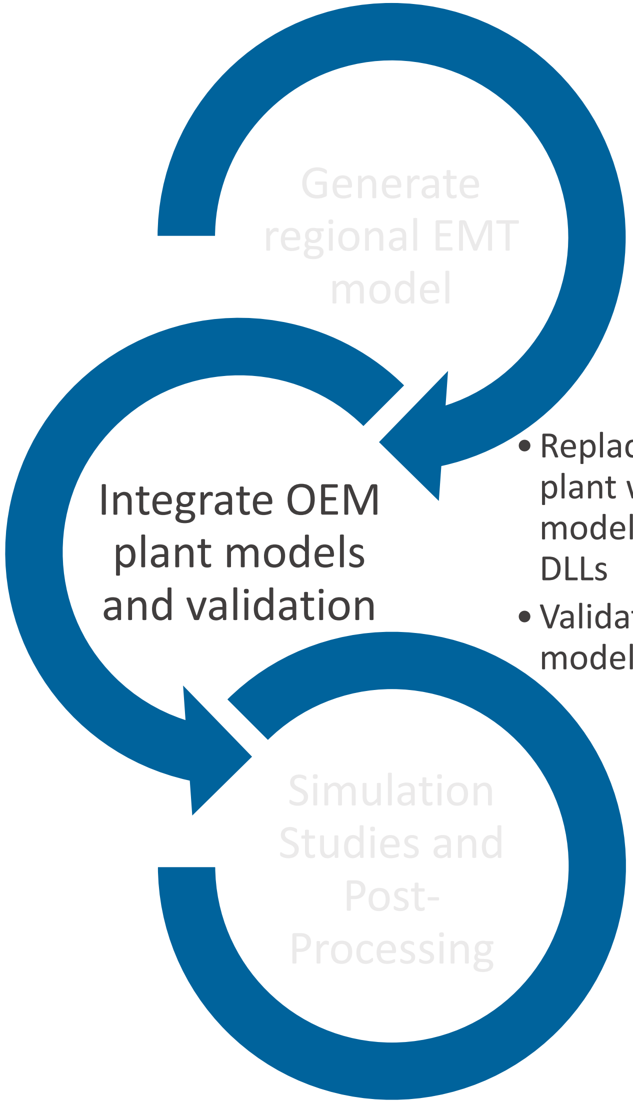
The model runs on 2 cores at 50us in real-time



Import of a Simple Solar Farm in HYPERSIM



Study Workflow – Current Process & Mapping to HYPERSIM



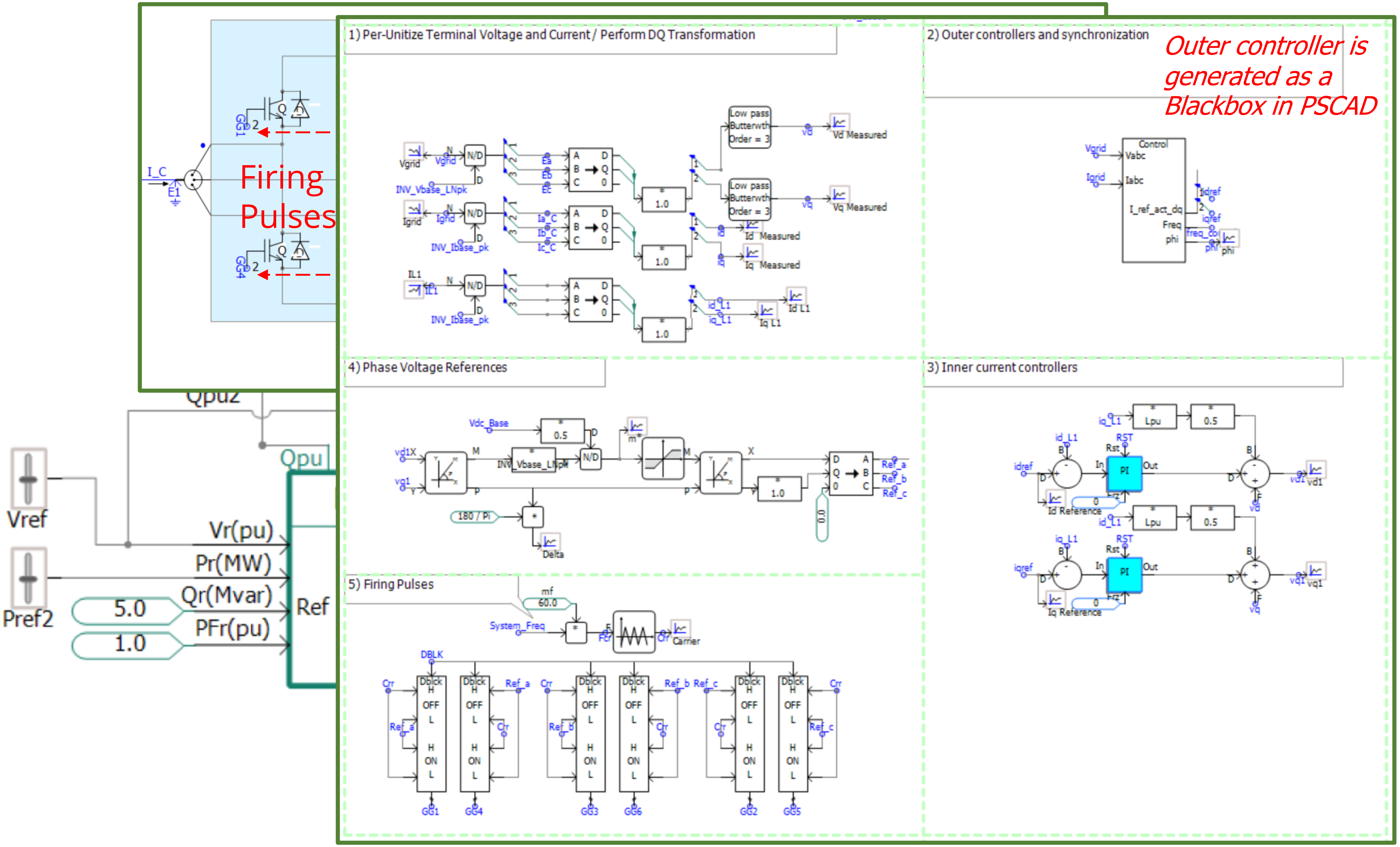
- Import from large-scale wide-area model with generic models and UDM
- Validate network model and network equivalent

- Replace generic plant with the OEM models including DLLs
- Validate plant model

- Scripting to perform different disturbances and update operating conditions
- Post-processing of simulation results

→ CIGRE interface and automatic DLL import to integrate OEM controllers

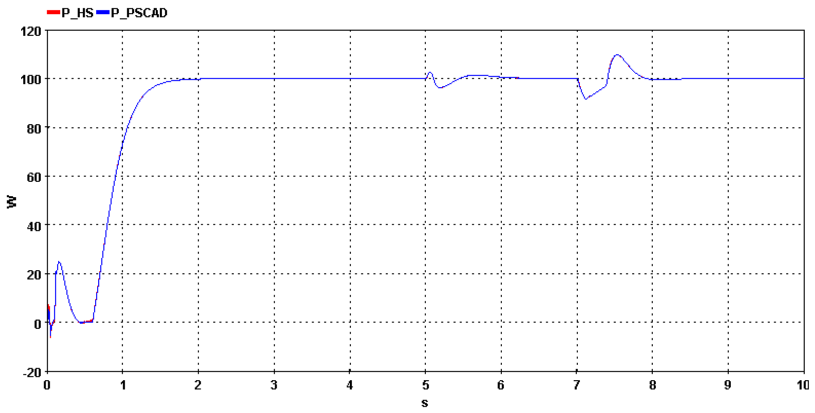
Solar Farm Import with Blackbox Controller in HYPERSIM

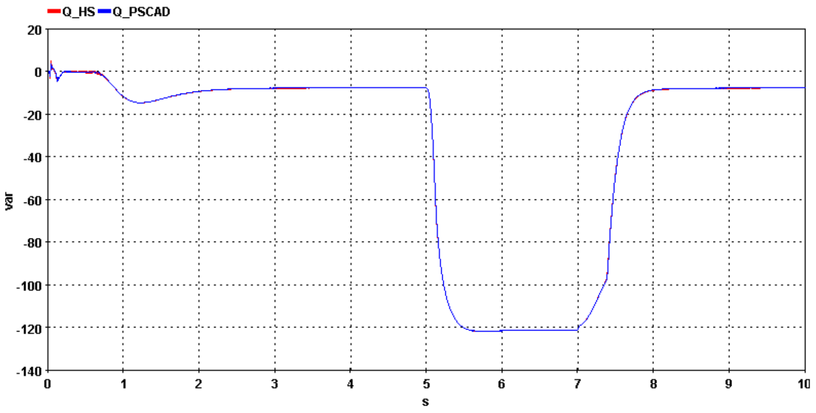


Solar Form Import Validation with Blackbox Controller

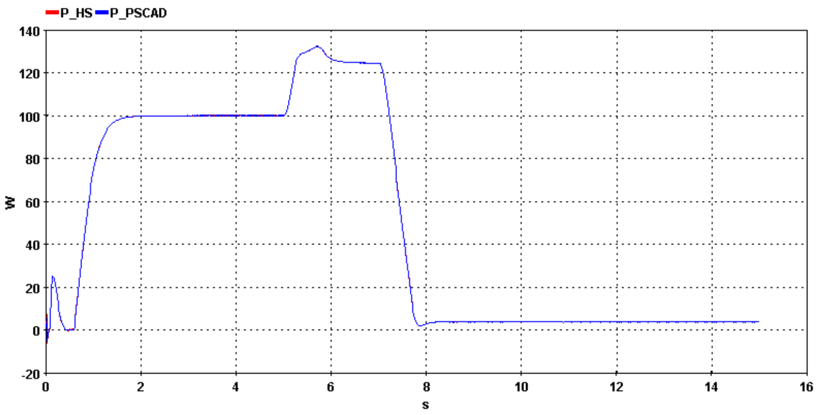
Comparison of validation results between PSCAD and HYPERSIM

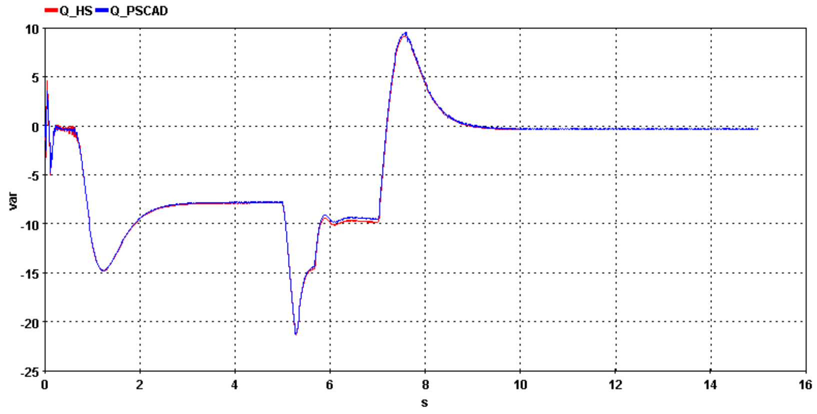
Overvoltage (DIP=1.1)



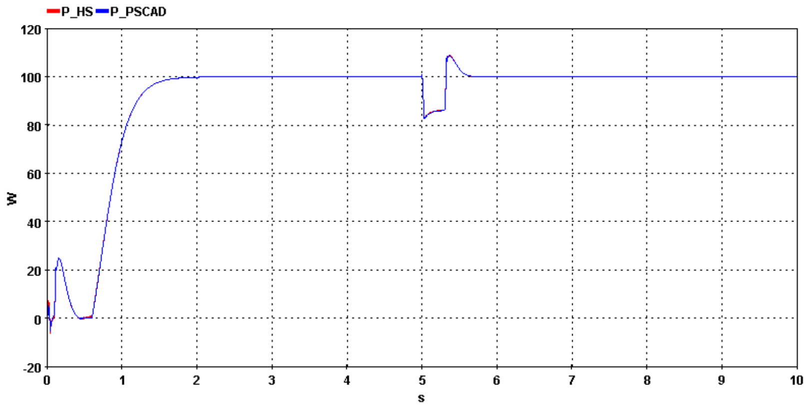


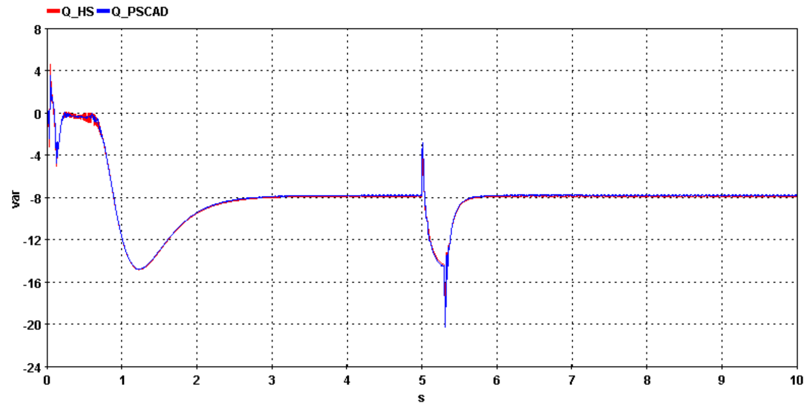
Under frequency (DIP=0.96)



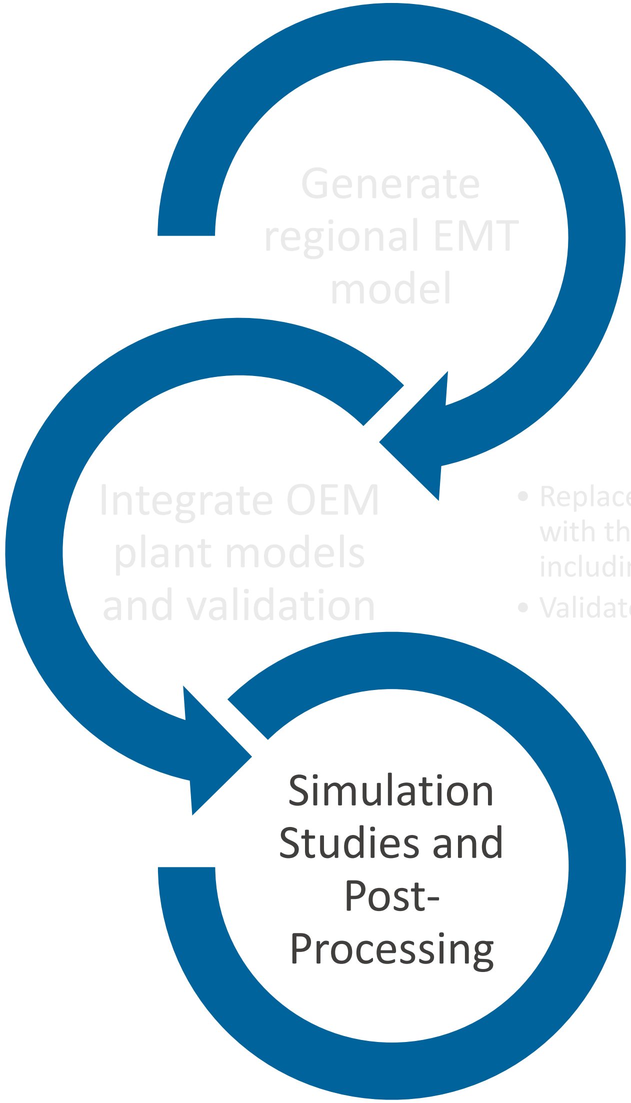


3ph fault





Study Workflow – Current Process & Mapping to HYPERSIM



- Import from large-scale wide-area model with generic models and UDM
- Validate network model and network equivalent

- Replace generic plant with the OEM models including DLLs
- Validate plant model

- Scripting to perform different disturbances and update operating conditions
- Post-processing of simulation results

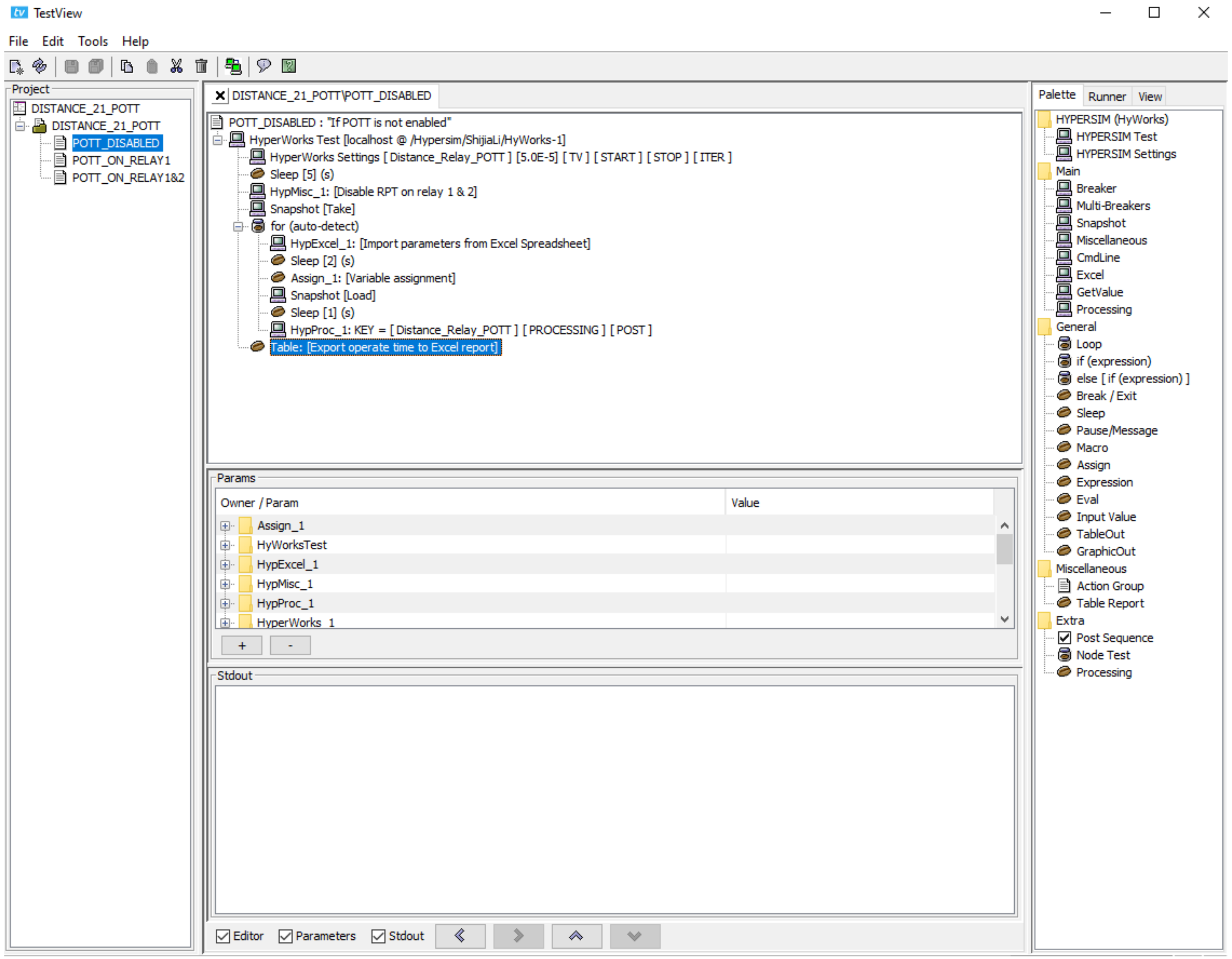
→ Test automation framework for scenario testing

Automating Simulation Studies & Post-Processing

Python API

```
import os
import sys
sys.path.append(r'C:\OPAL-RT\HYPERSIM\hypersim-version\Window
# Replace hypersim-version by the version you want to test

import HyWorksApiGRPC as HyWorksApi
import time

HyWorksApi.startAndConnectHypersim()
# This script finds the model next to it, when we launch pyth
designPath = os.path.join(os.getcwd(), 'HVAC_735kV_38Bus.ecf'
HyWorksApi.openDesign(designPath)

HyWorksApi.setPreference('simulation.calculationStep', '50e-6
calcStep = HyWorksApi.getPreference('simulation.calculationSt

print('calcStep = ' + calcStep)

print('code directory : ' + HyWorksApi.getPreference('simulat

print('mode : ' + HyWorksApi.getPreference('simulation.archit

HyWorksApi.mapTask()
HyWorksApi.genCode()
HyWorksApi.startLoadFlow()
HyWorksApi.startSim()
print('startSim done')

volt = HyWorksApi.getComponentParameter('Ge7', 'baseVolt')
print(('baseVolt = ' + volt[0] + volt[1]))

HyWorksApi.setComponentParameter('Ge7', 'baseVolt', str(floa

volt2 = HyWorksApi.getComponentParameter('Ge7', 'baseVolt')
```

Test View for Automation



HYPERSIM - Benchmarks & Use cases

Large-scale Synthetic NEM model with OEM controllers

- A 4000-bus and 300+ Blackbox Controller EMT Benchmark for enabling IBR integration studies
- 30s simulation in 90s wall clock time, 500-core Windows server
  - 50 us time step for the main grid; 10 us or 16.67 us for OEM controller codes

MODEL BENCHMARK Approximate number of components (3-phase)	
Buses (3-phase)	4,000
Lines, loads, switched shunts reactors …	6,700
Transformers and synchronous machines	2,000
Inverter-based generation plants	150
Controllers using real-code (precompiled DLLs)	300+
FACTS and HVDC converters	70
Protection relay models	100

- **About 100 cores for the 4000-bus system**
- **300 cores for the controller codes**

Hydro-Quebec 735 kV Transmission System Model

- Hydro-Quebec 2023 grid: 56 cores, 40us in real-time
- 8 x 8 cores modules Xeon Scalable Gold 6144 @ 3.5GHz, 24.75 MB L3 Cache) on HPE SuperDome Flex

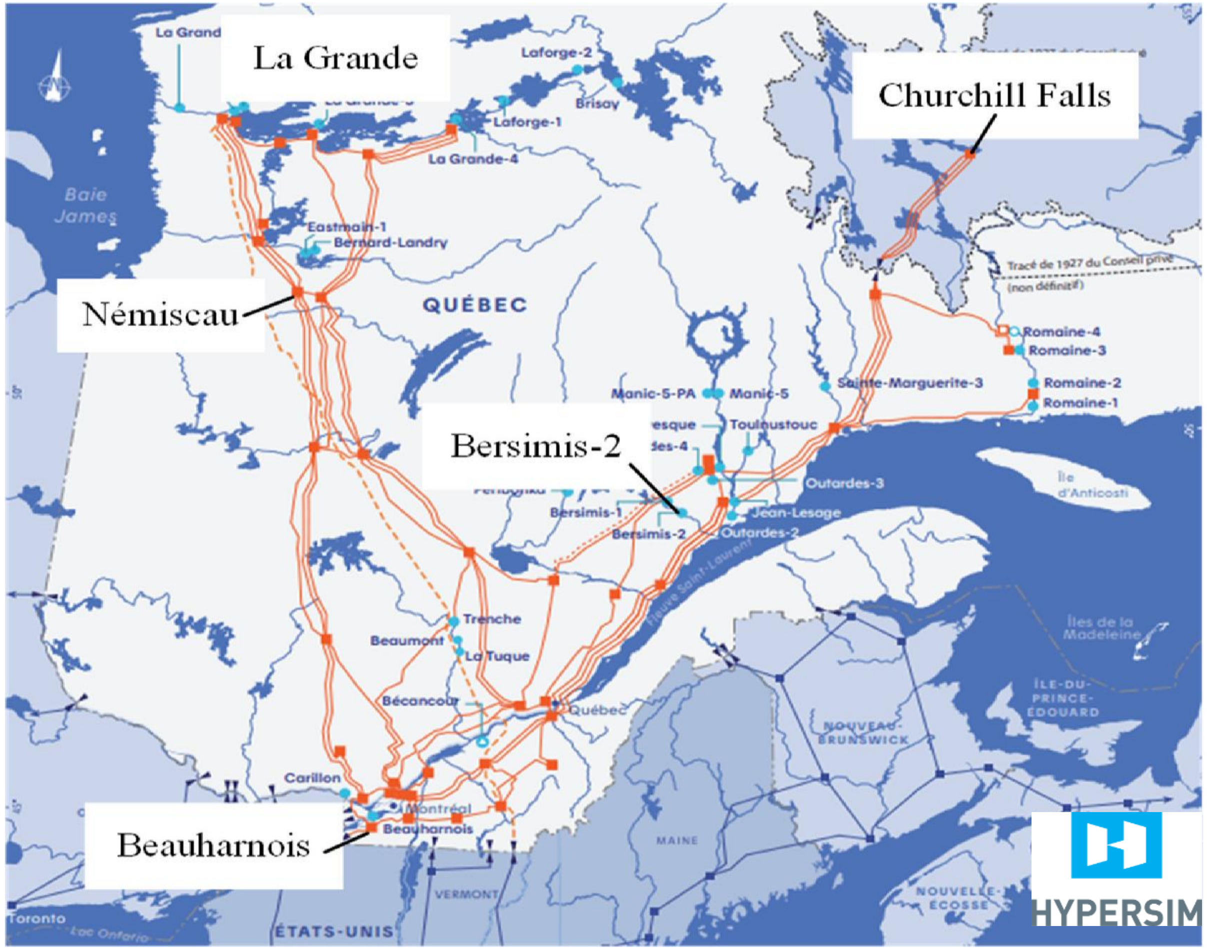


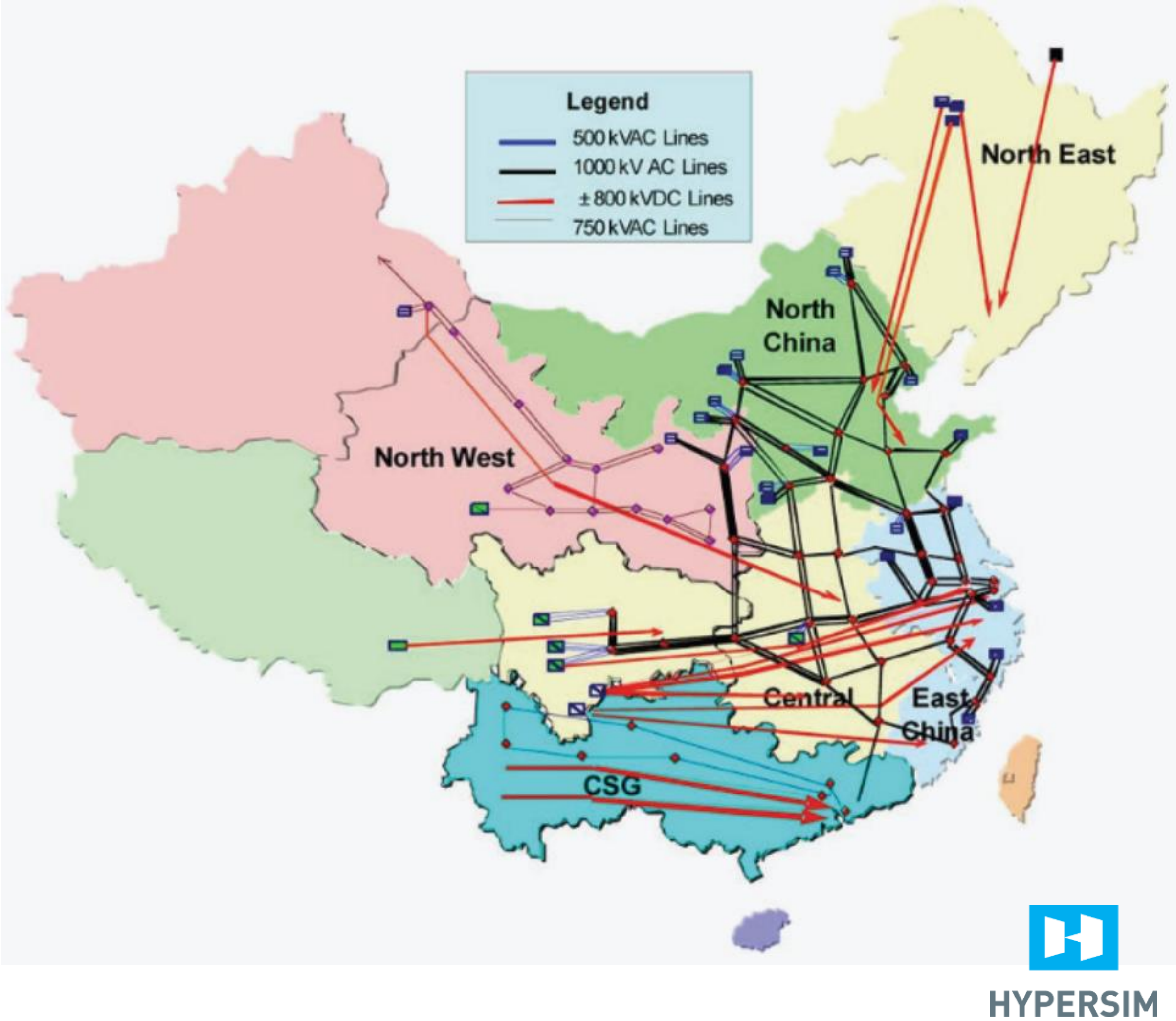
Image Credit: P. Le-Huy, E. Lemieux, F. Guay, Lessons learned in porting offline large-scale power system simulation to real-time for wide-area monitoring, protection and control, Electric Power Systems Research, Volume 223, 2023.

Complex components	Quantity
Three-phase buses	1 666
Electrical machines	111
Lines and cables	432
Three-phase transformers	338
Governors	86
Excitation systems	81
Stabilizers	54
Static compensators	10
Wind power plants	6
HVDC converters	6
Dynamic loads	165

SIMULATION TIME FOR A 15 Second EVENT

Nbre of CPU	Measured Tstep (s)	Theoretical Tstep with 100% efficiency (s)	Actual efficiency
1	2565		
4	786	641	82%
56	15	46	305%

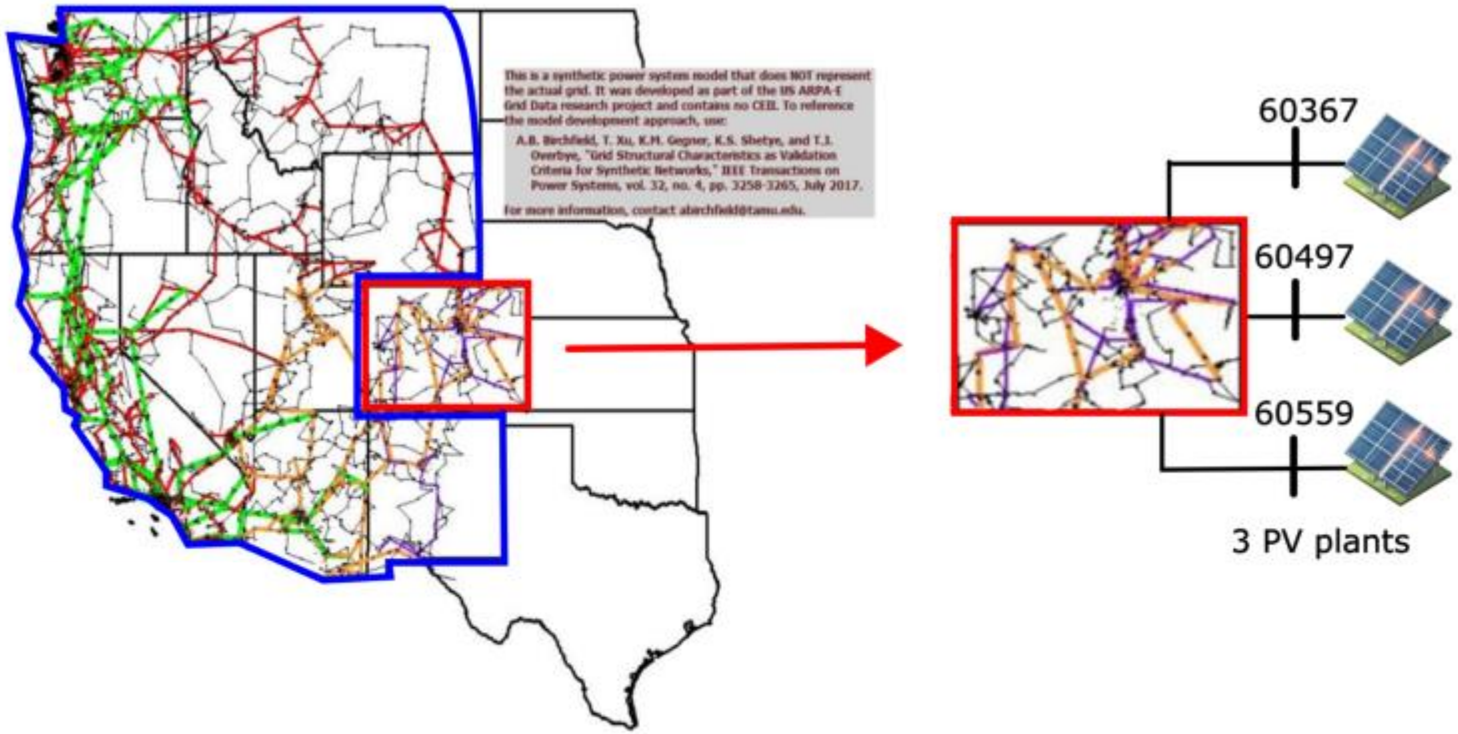
CEPRI – China Large Transmission System Model 500kV+

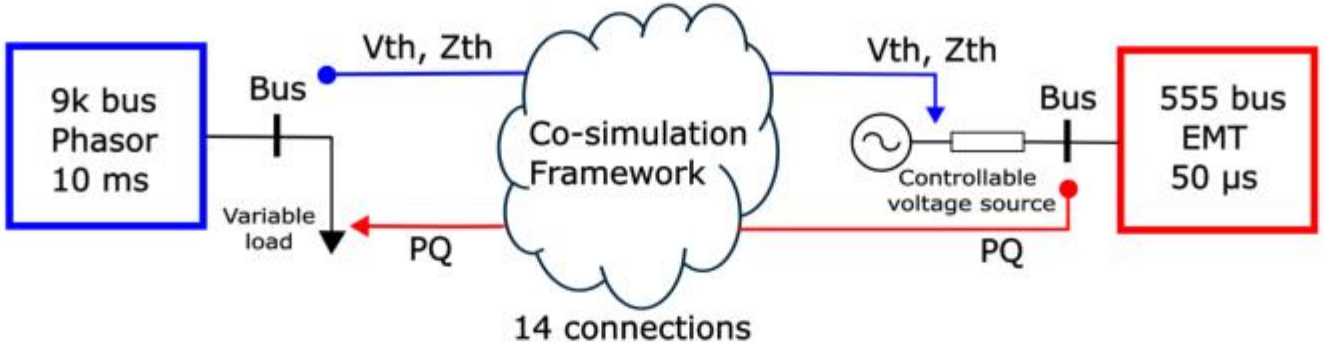


Components	Quantity
3-phase nodes	8500
Generators	350
Sources	1300
Transmission lines	4500
HVDC links connected to replicas	10
Switches	800
3-ph breakers	1200
Dynamic loads	1500
RLC	5700
Filters	200
Transformers	900
Control components	37000

- **300+ cores, 50 us**
- **2 SUPERDOM FLEX (HP) OF 300 cores each (600 cores in total) are now used interfaced with more than 70 OP5607 FPGA-based IO systems and simulators**

Large-scale Phasor-EMT Co-simulation of Synthetic WECC 10000 Bus System



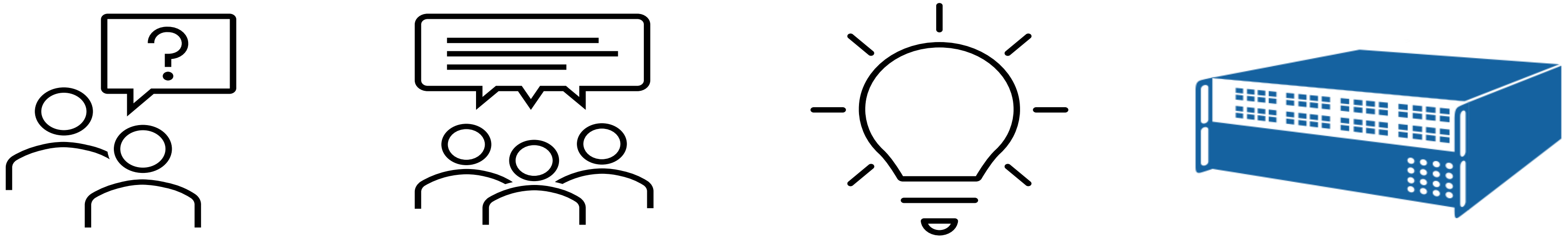


Power components in EMT:

- 555 buses (541 internal + 14 external nodes)
- 599 lines (582 internal + 17 external)
- 268 loads
- 101 generators with controllers
- 159 2-winding transformers
- 16 3-winding transformers
- 24 switched shunts

- Currently under development

Questions?



For attendees interested in using HYPERSIM to try out the tool,
please reach out to me directly or email: shijia.li@opal-rt.com

Thank You!

OPAL-RT TECHNOLOGIES