

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

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OPAL-RT
TECHNOLOGIES

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 ...



Strong International Footprint



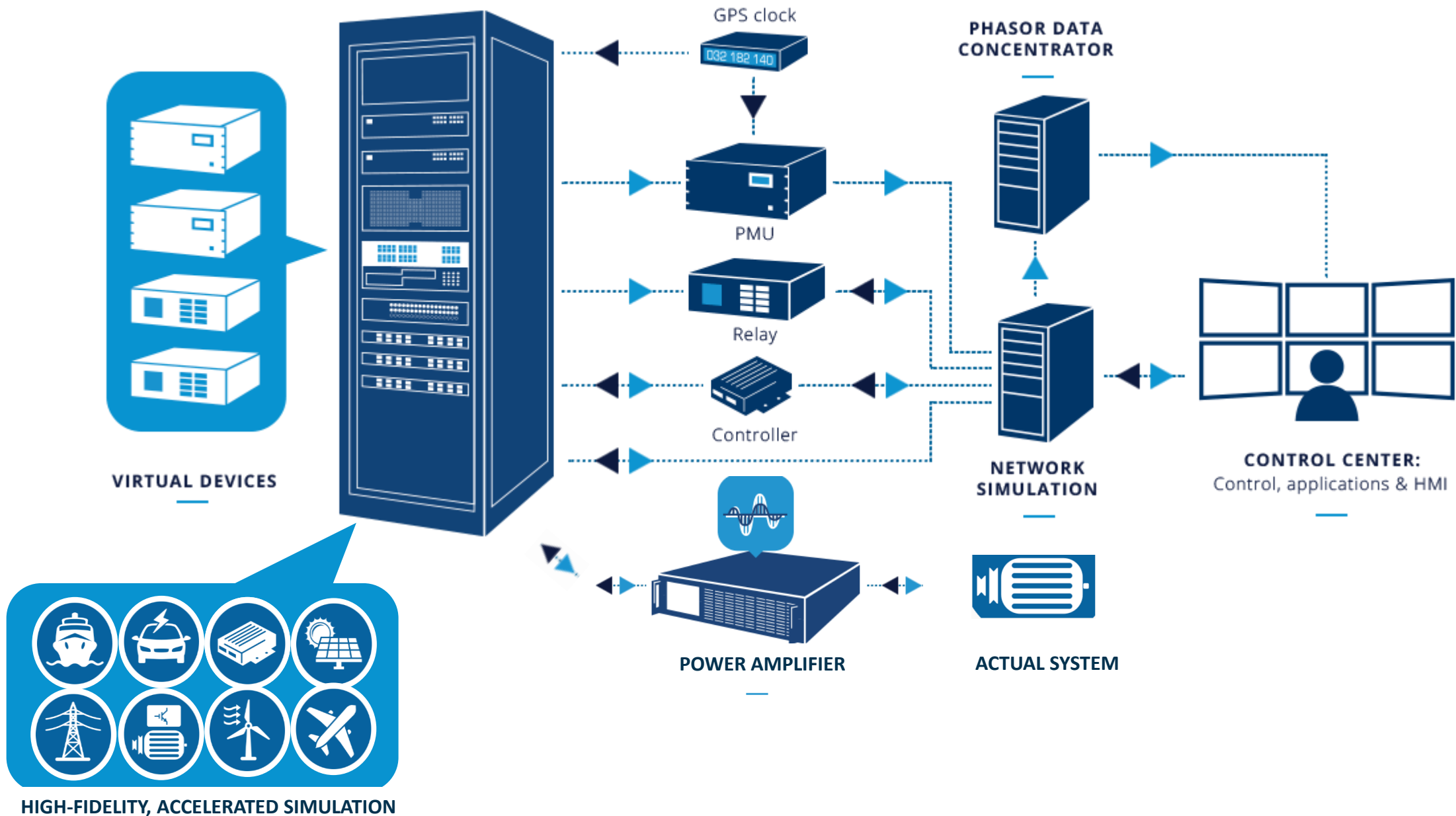
International subsidiaries, offices and Excellence Centers:

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

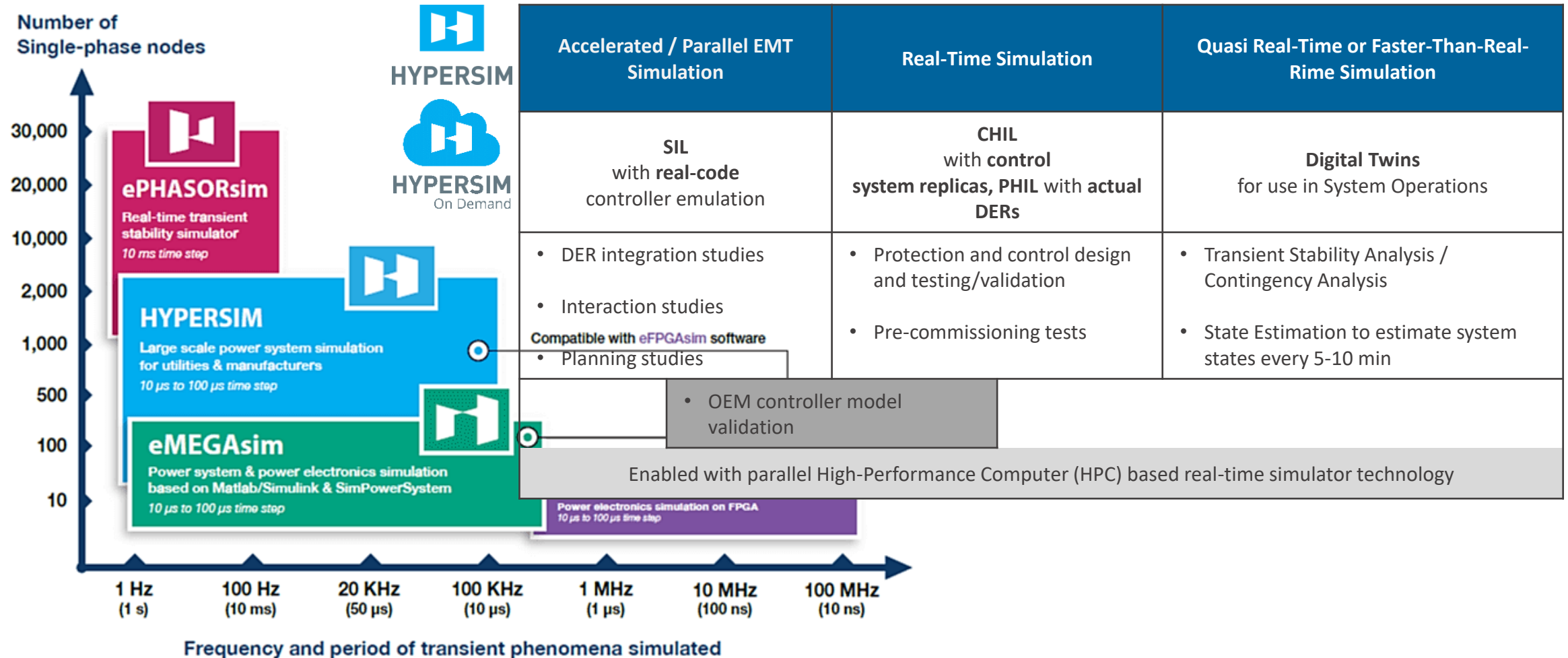
Distributors:

- 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



HYPERSIM – Graphical User Interface and Workflow

C:\Users\ShijiaLi\OneDrive - Opal-RT Technologies\Documents\HYPERSIM\Photovoltaic_Generation_System\Photovoltaic_Generation_System.ecf - HYPERSIM master.o2396 [/shijiali/hyworks-1]

File Home Options View Design HYPERSIM

ScopeView Preferences Targets Dashboards Project UCM Simulink Import Network I/O Interface Sensor Summary Clear Load Append Save As Topology Analysis Netlist Impedance Set Initial Conditions Disable Breakers/Faults Task Manager Analyze Load Flow Map Tasks Generate Code Start Stop Settings User Manual Diagnostic

Photovoltaic_Generation_System.ecf:1 x Photovoltaic_Generation_System.ecf:2

Distribution-Connected Photovoltaic Generation System Example

This example demonstrates the implementation of PVGS using average converter model (page 1) and switching function converter model (page 2)

Simulation of PV generation on a typical distribution system - Average Converter Based Model (Page 1)

Voltage levels

- 154 kV
- 22.9 kV
- 3.3 kV
- 480 V

0-2 seconds- Qref = 0 pu, Pref = 0.3 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment Off.
2-2.5 seconds- Qref = 0.3 pu, Pref = 0.3 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment Off.
2.5-4 seconds- Qref = 0.3 pu, Pref = 1 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment Off.
4-5 seconds- Qref = 0.3 pu, Pref = 1 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment On.
5-6.5 seconds- Qref = 0.3 pu, Pref = 0.5 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment On.
6.5-7.5 seconds- Qref = 0.3 pu, Pref = 0.8 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment On.
7.5-8 seconds- Qref = 0 pu, Pref = 0.8 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment On.
8-10 seconds- Qref = 0 pu, Pref = 0.3 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment Off.
10-15 seconds- Qref = -0.3 pu, Pref = 0.3 pu, Temp= 25 °C, Irr=800 W/m^2, Curtailment Off.
15-18 seconds- Qref = -0.3 pu, Pref = 0.3 pu, Temp= 25 °C, Irr=1000 W/m^2, Curtailment Off.
18-22 seconds- Qref = -0.3 pu, Pref = 0.3 pu, Temp= 35 °C, Irr=1000 W/m^2, Curtailment Off.

OPAL-RT TECHNOLOGIES

HYPERSIM® Real-Time Power System Simulator

Photovoltaic_Generation_System.ecf* Sensor file = Photovoltaic_Generation_System.csv Ts = 50.0 μs Target = [10.64.114.226]

Update server name to : 127.0.0.1:17524

Notification of network change in MasterRoot Nodes -> 127.0.0.1:17524

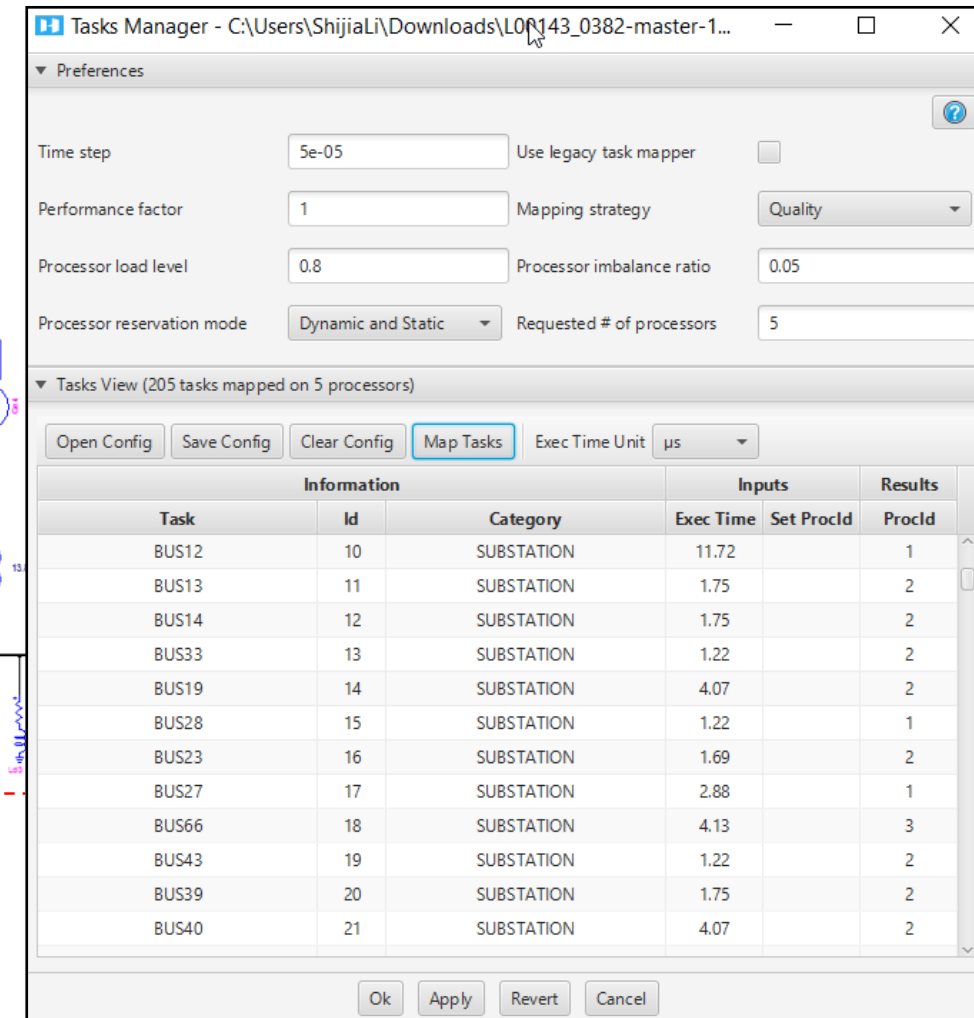
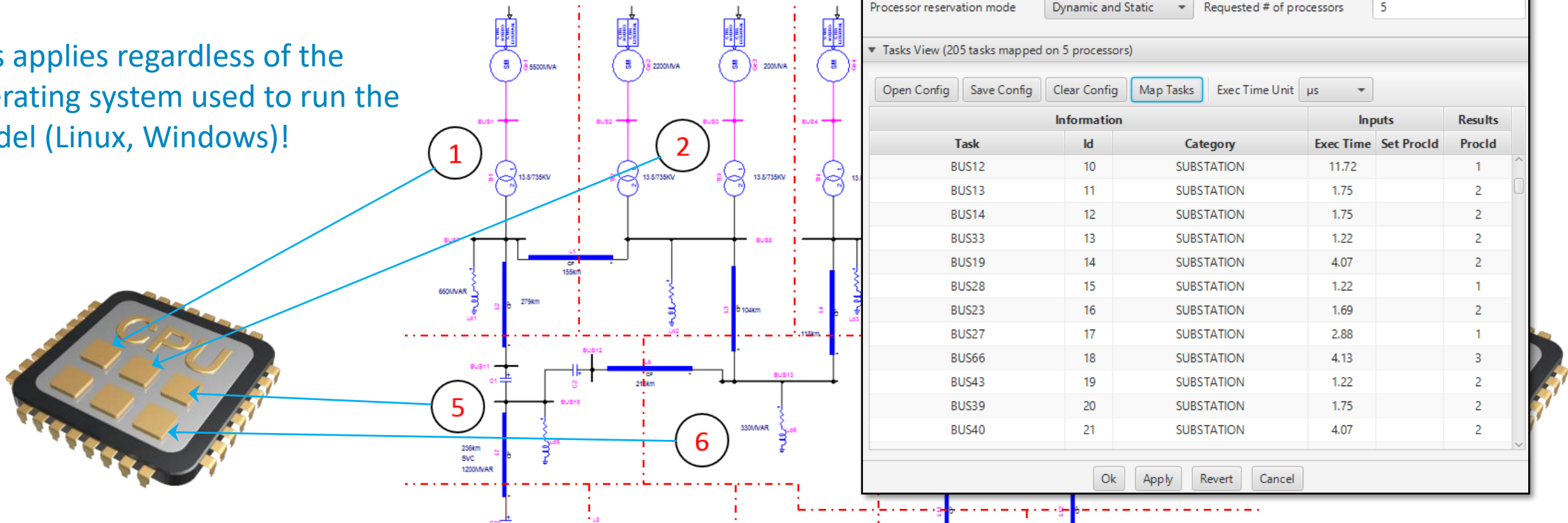
HypConsole Photovoltaic_Generation_System.ecf [1]* Photovoltaic_Generation_System.simout [1]*

5

HYPERSIM - Automatic Model Decoupling

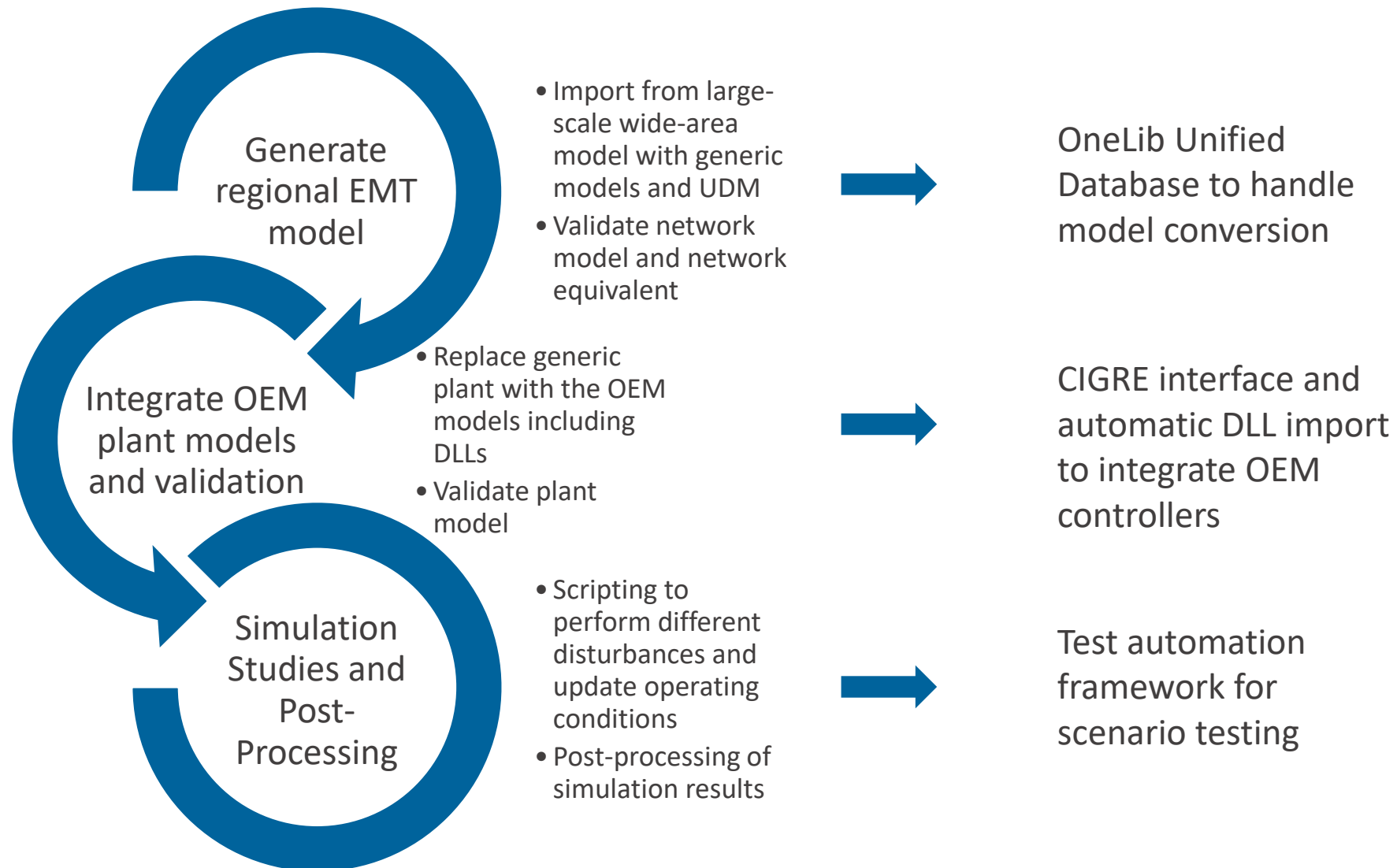
HYPERSIM will automatically split the model into several tasks and distribute them across available processors for maximum performance

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

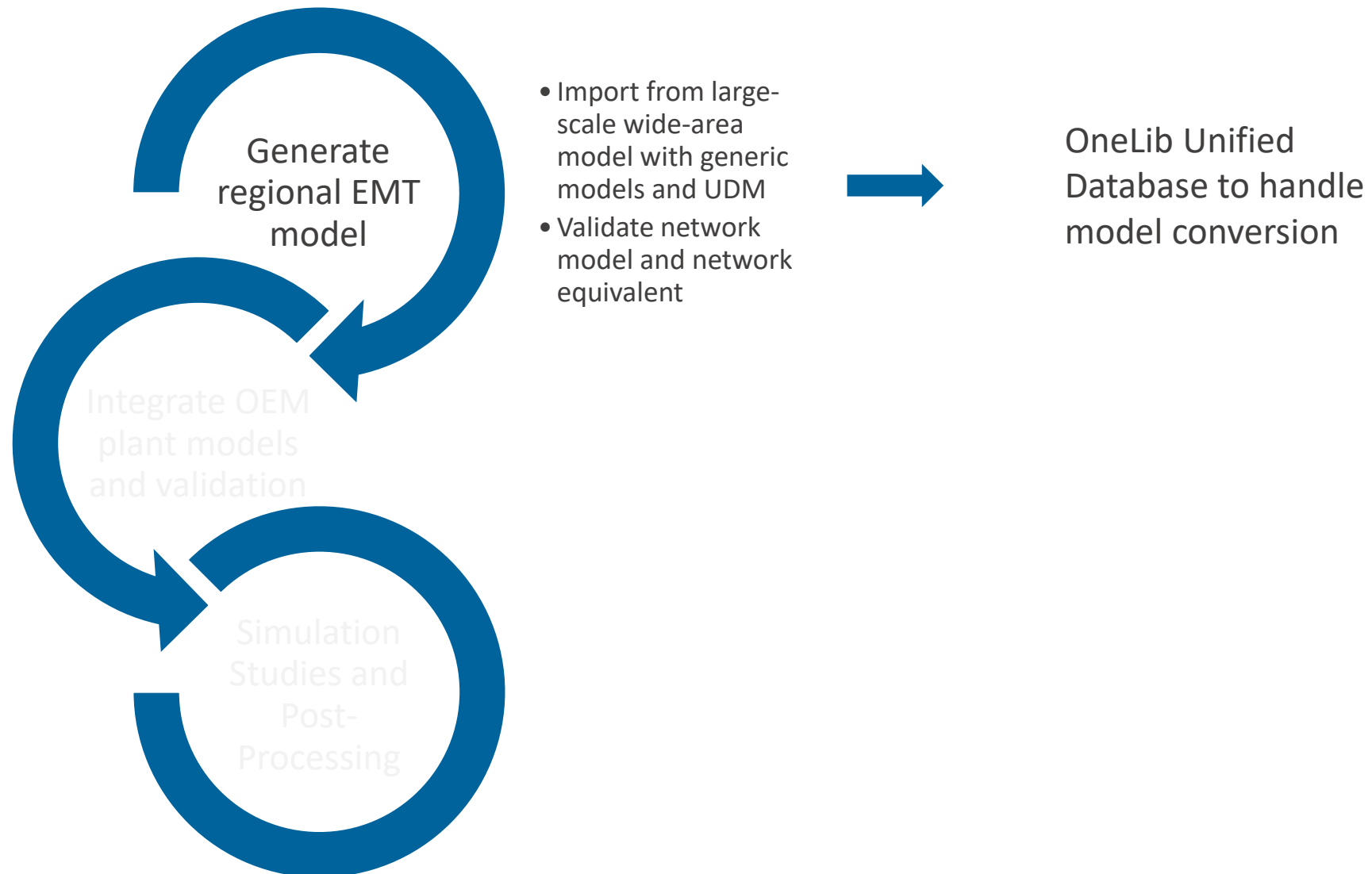


HYPERSIM - Study workflow and features for IBR integration

Study Workflow – Current Process & Mapping to HYPERSIM



Study Workflow – Current Process & Mapping to HYPERSIM



OPAL-RT's Unified Database for Network Model Conversion

Third-Party Software

EMTP
(available today not through DB)

PSCAD
(available today)

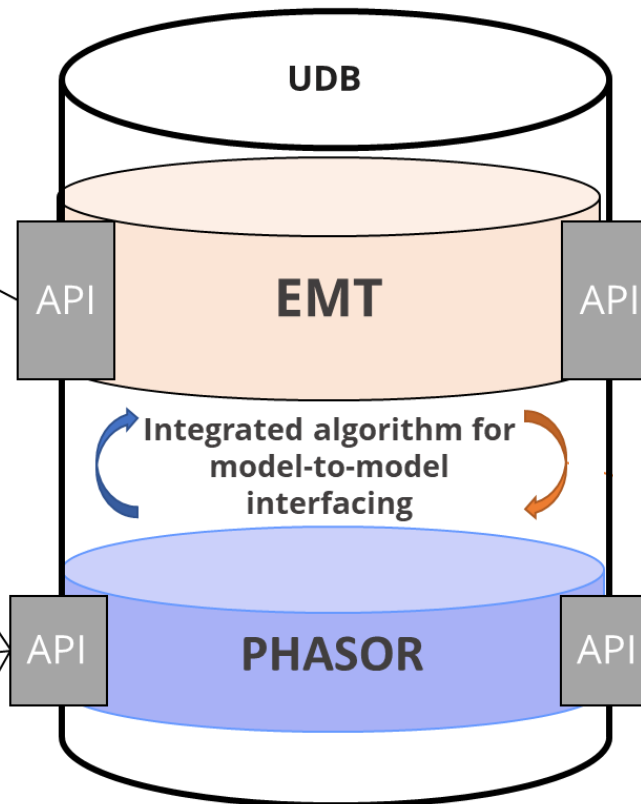
PSSE PowerFactory
(available today)

CYMDIST
(available today not through DB)

GridLAB-D
(ongoing)

CIM/CGMES, ETAP
(under consideration)

OPAL-RT Software



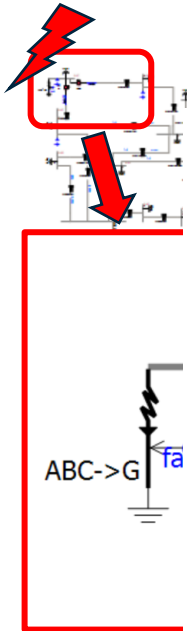
eHS – FPGA-based electrical toolbox
Currently supported: PLECS, PSIM

HYPERSIM – Power system simulator
Currently supported: EMTP, PSSE, PSCAD
Ongoing: PowerFactory, GridLAB-D
Under consideration: CYMDIST, CIM/CGMES

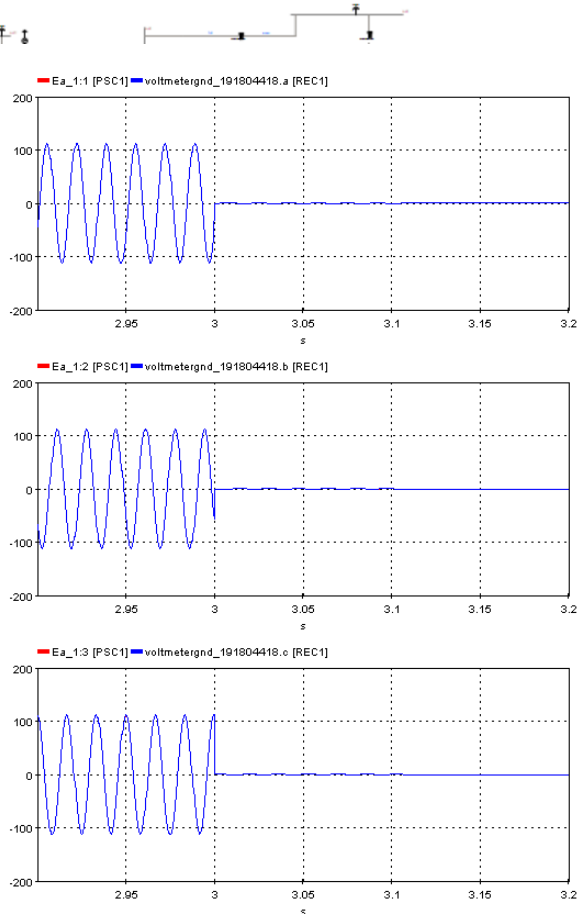
ePHASORSIM – CPU-based electromechanical toolbox
Currently supported: PSSE, PowerFactory
Supported not through DB: CYMDIST
Under consideration: ETAP, CIM/CGMES

IEEE 118 Bus Model Import and Validation in HYPERSIM

Fault



PSCAD Schematic

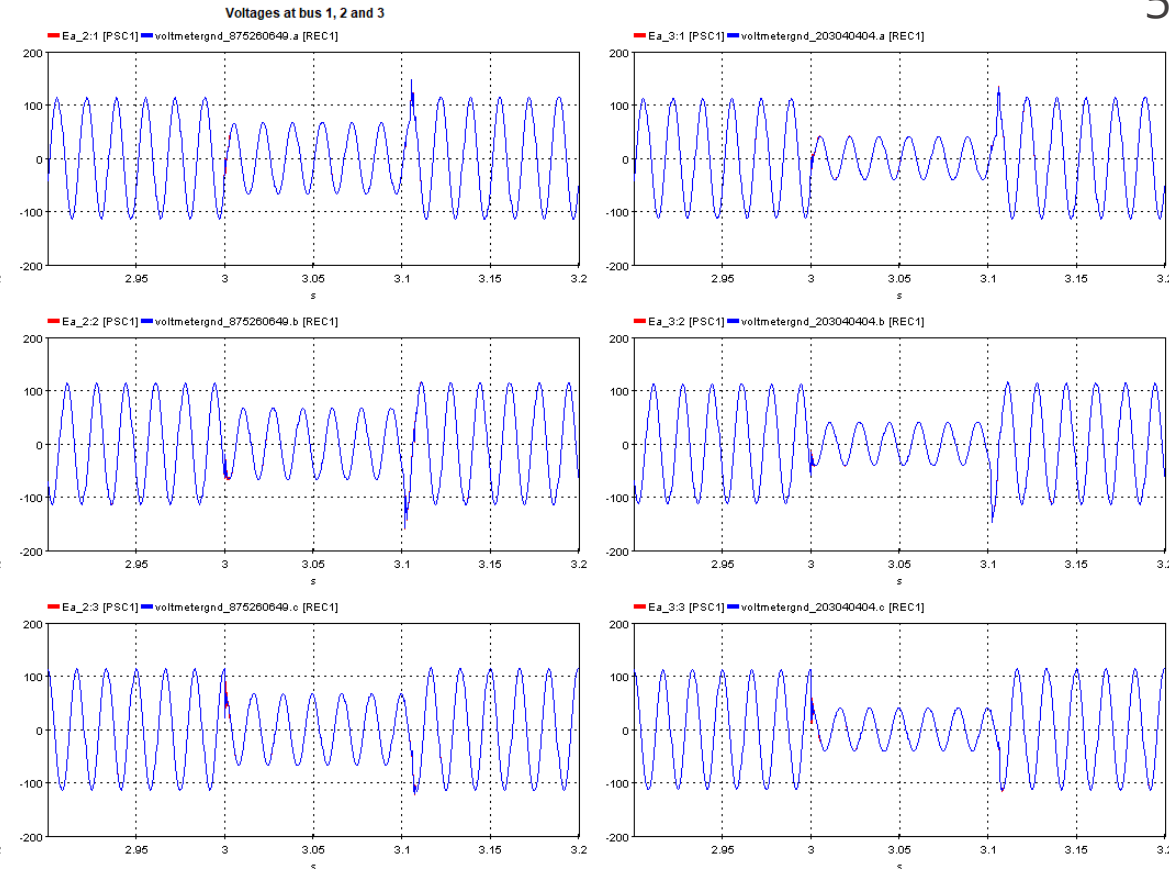


[PSC1] noname - Thu Aug 17 12:04:37 EDT 2023 - C:\Git\example-pscad-import-ieee-39\PSCAD_Import_39_Bus\PSCAD_ref_model\ieee_118_bus.if15_x86
[REC1] SIGNAL_GROUP_1_ieee_118_bus_20230817_135830 - Thu Aug 17 14:24:30 EDT 2023 - C:\Users\DianeDesjardins\OneDrive - Opal-RT Technologies\Documents\Demos\ERCOT\118bus_UBD\ieee_118_bus_hyp\Recordings

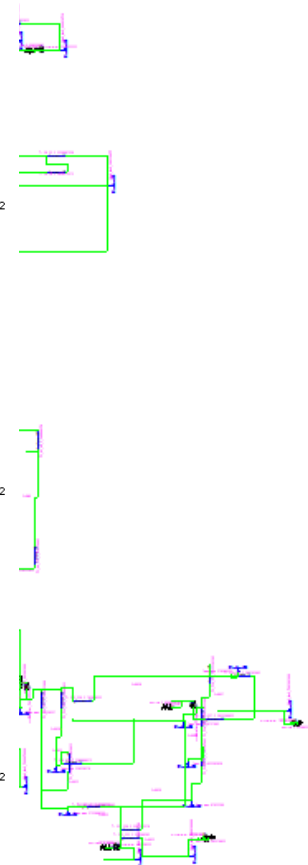
Fault



HYPERSIM Schematic



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



Import of a Simple Solar Farm in HYPERMIM

C:\Users\ShijiaLi\Downloads\Simple Solar Farm\SimpleSolarFarm.ecf - HYPERMIM master.o2396 [/shijiali/hyworks-1]

File Home Options View Design HYPERMIM

ScopeView Preferences Targets Dashboards Project UCM Simulink Import Network I/O Interface Sensor Summary Clear Load Append Save As Control Center Recording Manager Topology Analysis Netlist Impedance Set Initial Conditions Disable Breakers/Faults Task Manager Analyze Load Flow Map Tasks Generate Code Start Stop Settings User Manual Diagnostic

Tools Import/Export Sensors & I/Os Data Logger Network Simulation Help

SimpleSolarFarm.ecf x

Parts

Parts by Library

- Control Exciters
- Control Governors
- Control Interfaces
- Control Logic Operations
- Control Math Operations
- Control Measurements
- Control Miscellaneous
- Control Nonlinear And Dela
- Control Protection Relays
- Control Sources
- Control Stabilizers
- Network FACTS and HVDC
- Network Filters
- Network Lines and Cables
- Network Loads
- Network Machines
- Network Measurements
- Network Renewable Energy
- Network RLC

SimpleSolarFarm.ecf* Sensor file = SimpleSolarFarm.csv [Not found] Ts = 15.0 μ s Target = [localhost]

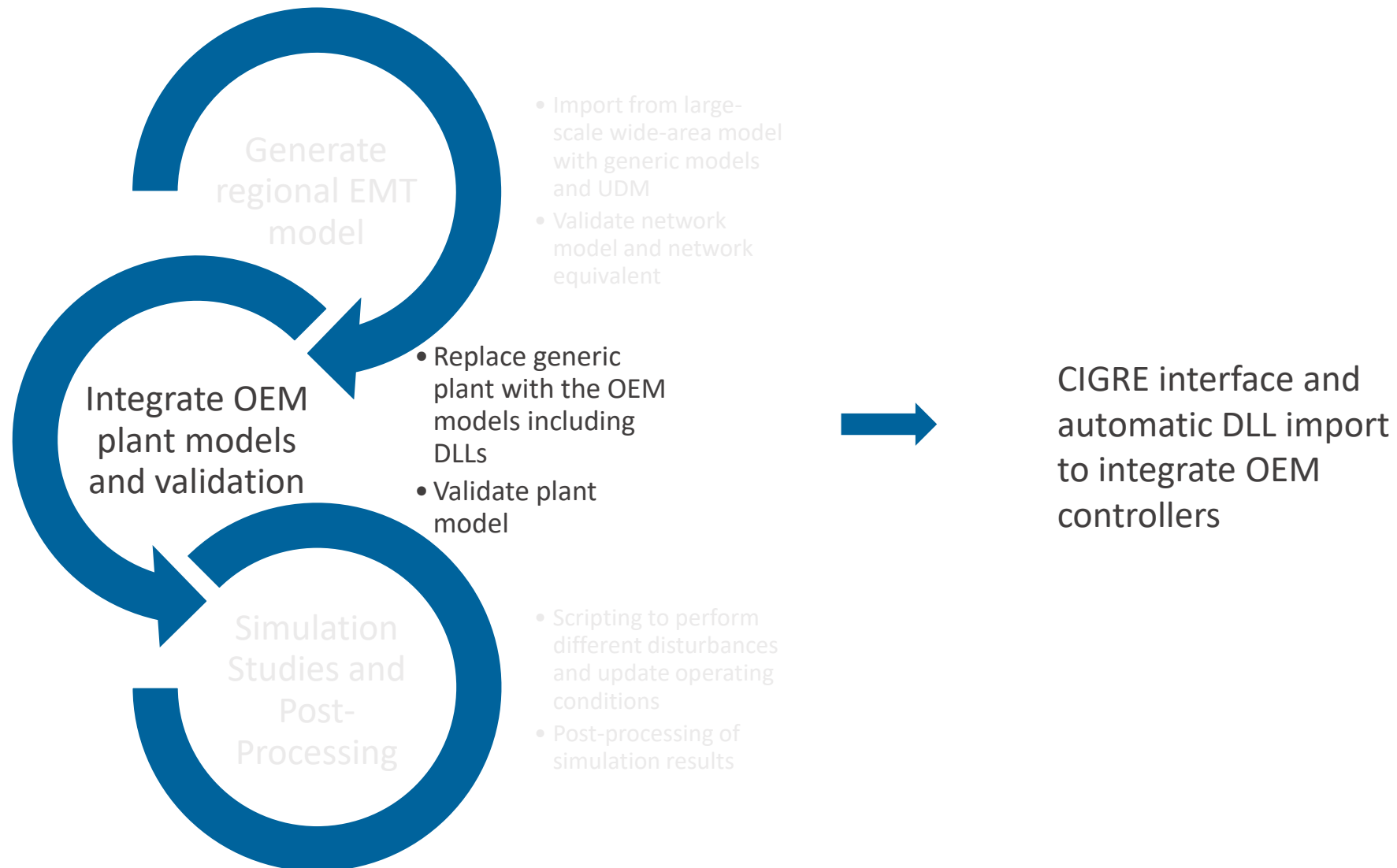
```
create datapointFile  
  
Creating datapoint file : C:/Users/ShijiaLi/Downloads/Simple Solar Farm/SimpleSolarFarm_hyp/configurationsIO/dataPoints.xml  
  
Creating datapoint.xml 0 ms
```

HypConsole SimpleSolarFarm.ecf [1]* SimpleSolarFarm.simout [1]*

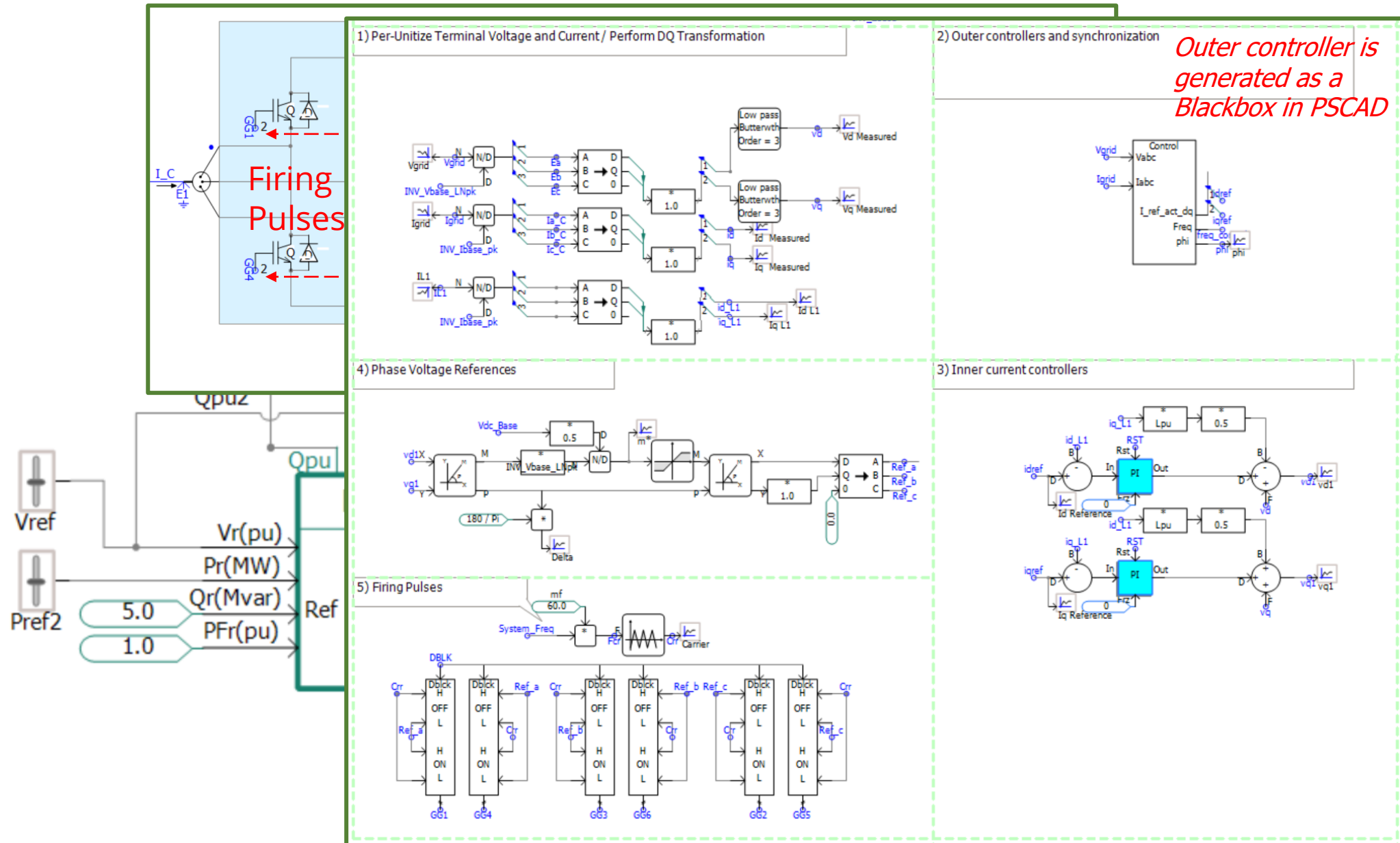
Type here to search

10:10 AM
3/19/2024

Study Workflow – Current Process & Mapping to HYPERSIM



Solar Farm Import with Blackbox Controller in HYPERSIM



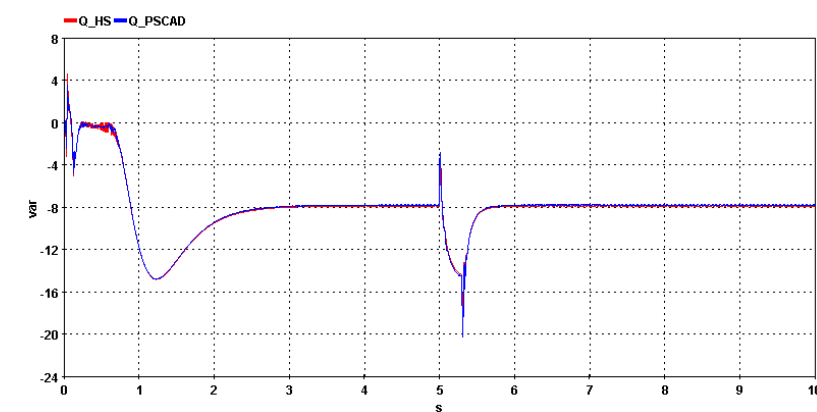
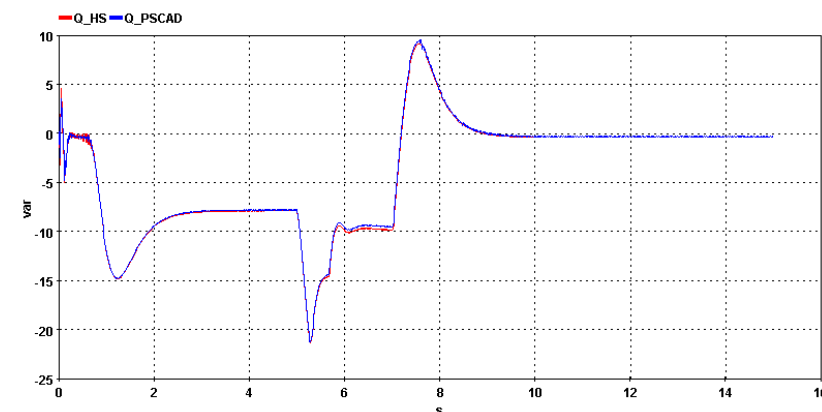
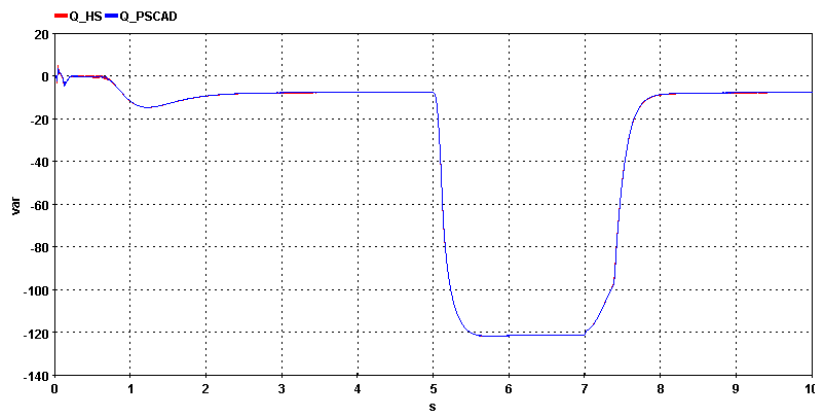
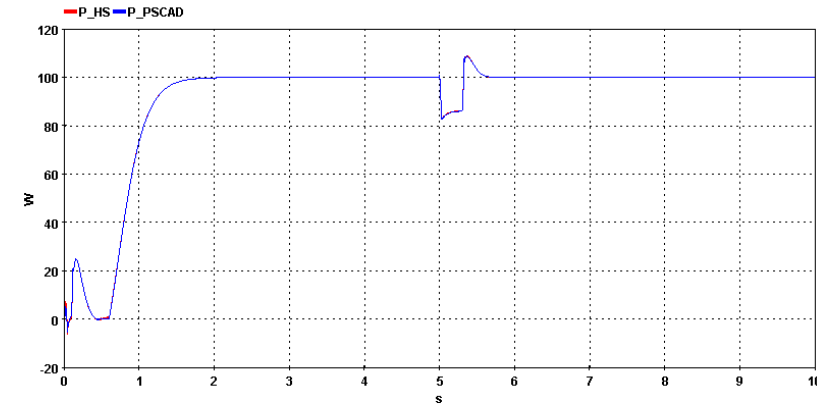
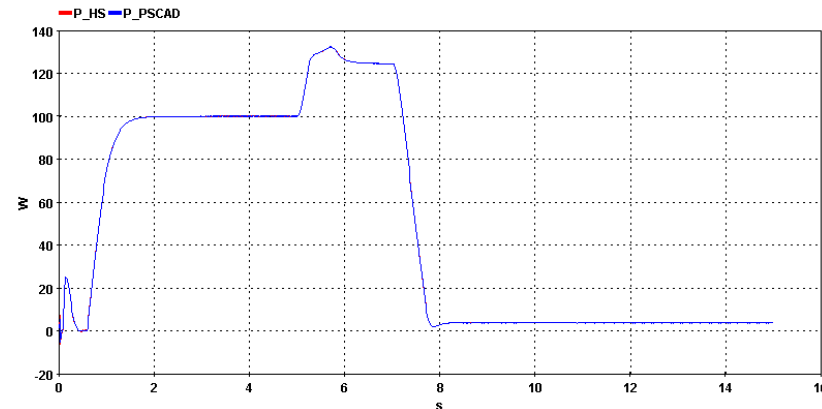
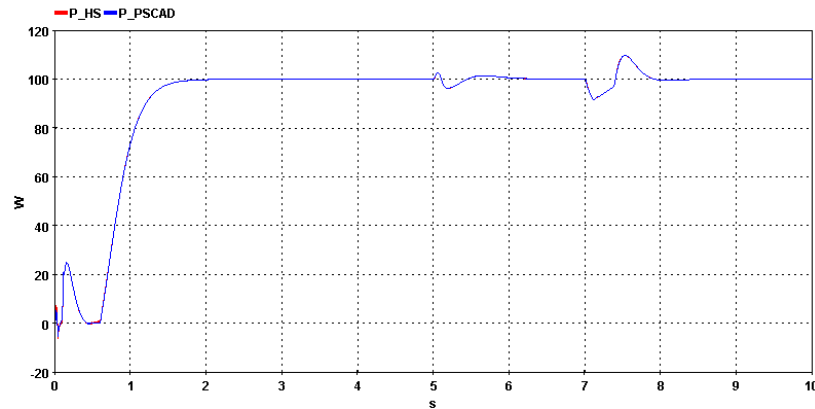
Solar Form Import Validation with Blackbox Controller

Comparison of validation results between PSCAD and HYPERSIM

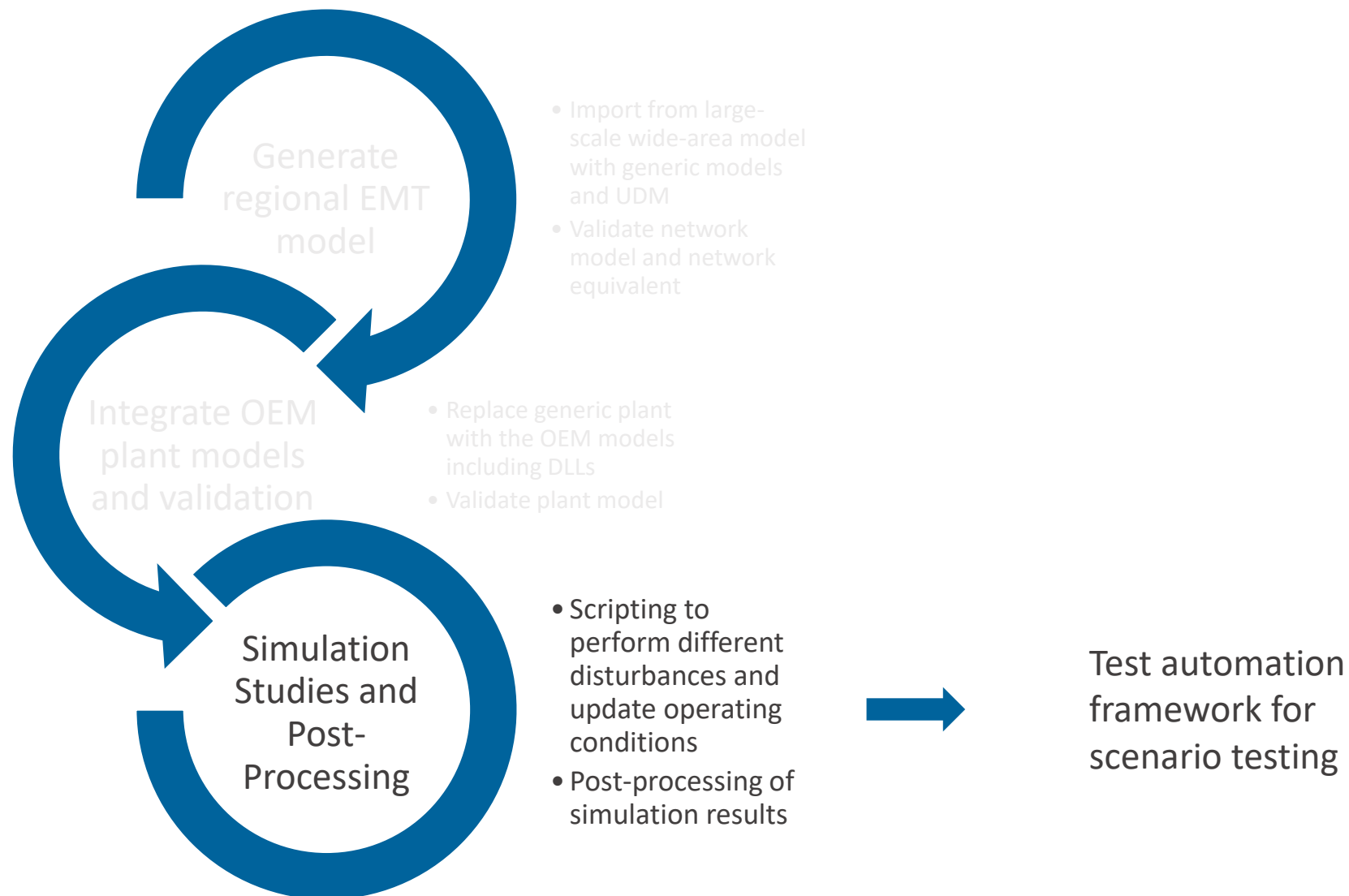
Overvoltage (DIP=1.1)

Under frequency (DIP=0.96)

3ph fault



Study Workflow – Current Process & Mapping to HYPERSIM



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.archi

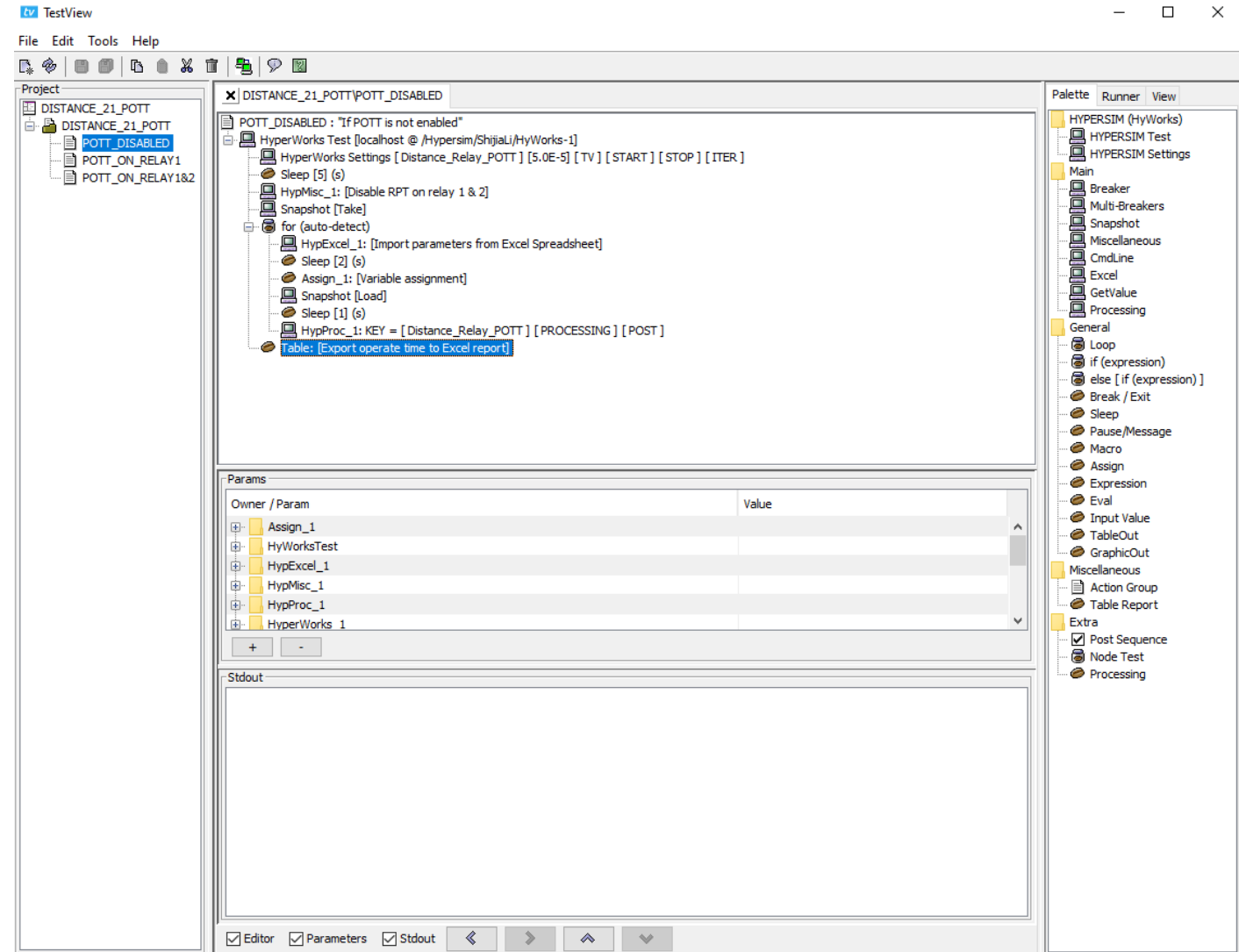
HyWorksApi.mapTask()
HyWorksApi.genCode()
HyWorksApi.startLoadFlow()
HyWorksApi.startSim()
print('startSim done')

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

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

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

Test View for Automation



The screenshot displays the TestView application interface. The main window is titled "TestView" and contains a "Project" pane on the left, a "Test Sequence" pane in the center, and a "Params" table at the bottom. The "Project" pane shows a tree structure with folders like "DISTANCE_21_POTT" and "POTT_DISABLED". The "Test Sequence" pane shows a sequence of steps: "POTT_DISABLED: 'If POTT is not enabled'", "HyperWorks Test [localhost @ /Hypersim/ShijiaLi/HyWorks-1]", "HyperWorks Settings [Distance_Relay_POTT] [5.0E-5] [TV] [START] [STOP] [ITER]", "Sleep [5] (s)", "HypMisc_1: [Disable RPT on relay 1 & 2]", "Snapshot [Take]", "for (auto-detect)", "HypExcel_1: [Import parameters from Excel Spreadsheet]", "Sleep [2] (s)", "Assign_1: [Variable assignment]", "Snapshot [Load]", "Sleep [1] (s)", and "HypProc_1: KEY = [Distance_Relay_POTT] [PROCESSING] [POST]". The "Params" table lists parameters for "Assign_1", "HyWorksTest", "HypExcel_1", "HypMisc_1", "HypProc_1", and "HyperWorks_1".

Owner / Param	Value
Assign_1	
HyWorksTest	
HypExcel_1	
HypMisc_1	
HypProc_1	
HyperWorks_1	

HYPERSIM - Benchmarks & Use cases

- 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

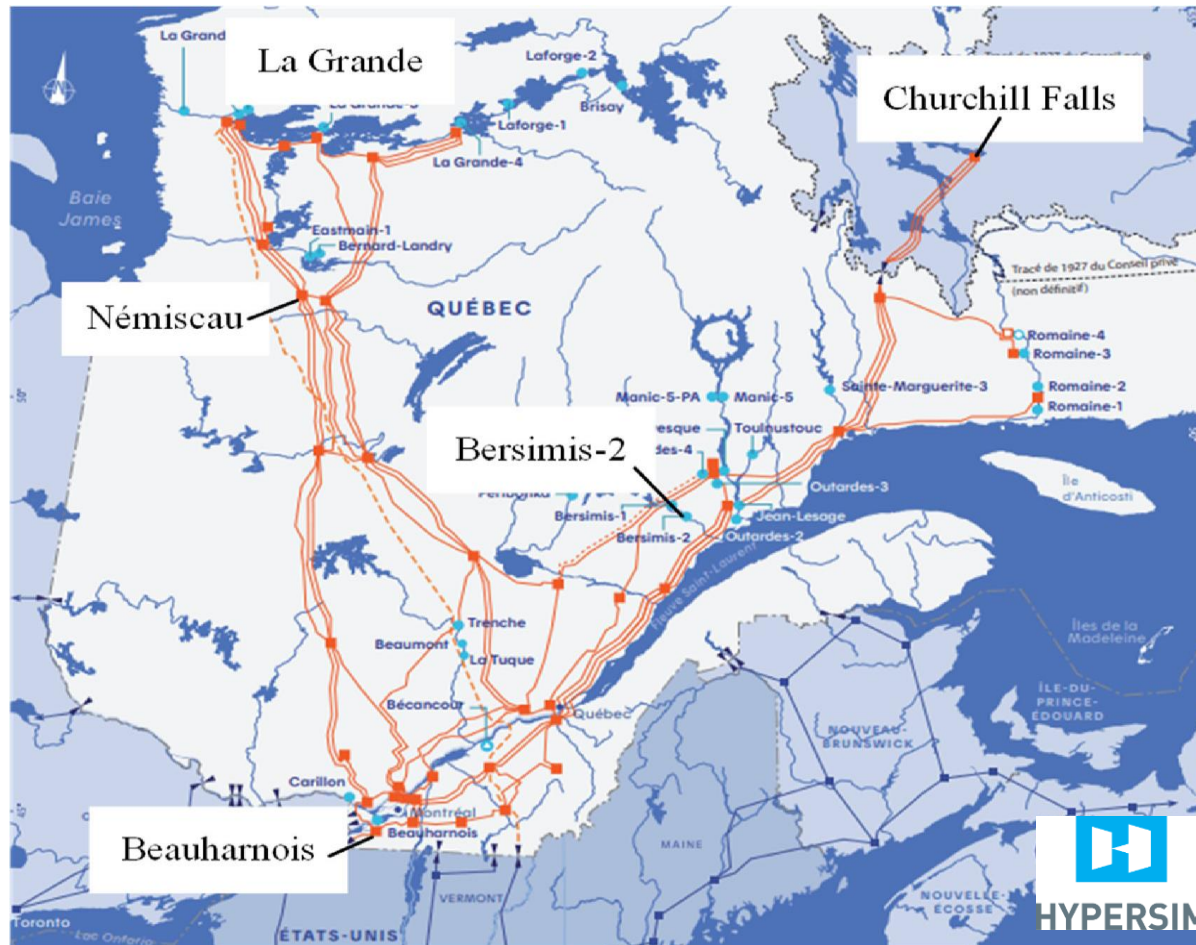
MODEL BENCHMARK Approximate number of components (3-phase)	
Buses (3-phase)	4,000
Lines, loads, switched shunts reactors ...	6,700
Transformers and synchronous machines	2,000
Inverter-based generation plants	150
Controllers using real-code (precompiled DLLs)	300+
FACTS and HVDC converters	70
Protection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

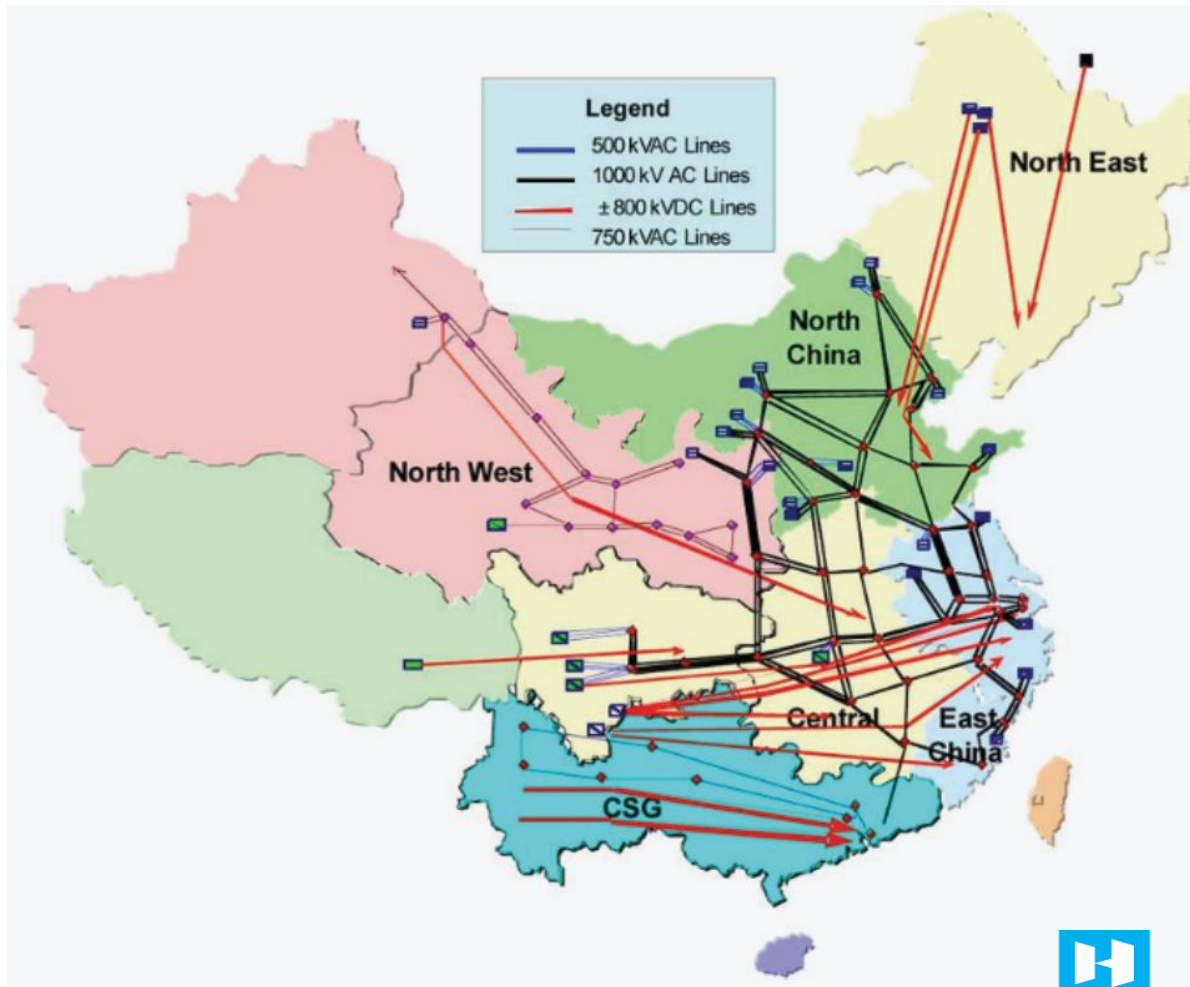


Complex components	Quantity
Three-phase buses	1 666
Electrical machines	111
Lines and cables	432
Three-phase transformers	338
Governors	86
Excitation systems	81
Stabilizers	54
Static compensators	10
Wind power plants	6
HVDC converters	6
Dynamic loads	165

SIMULATION TIME FOR A 15 Second EVENT

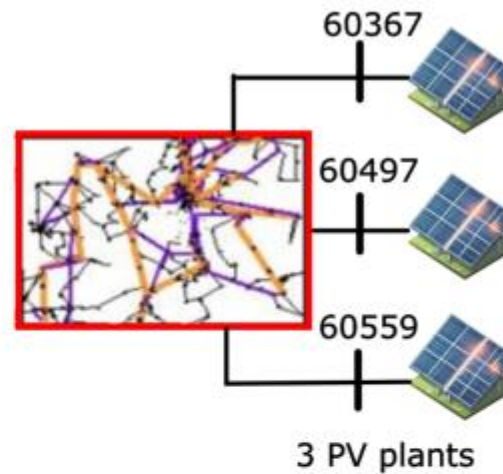
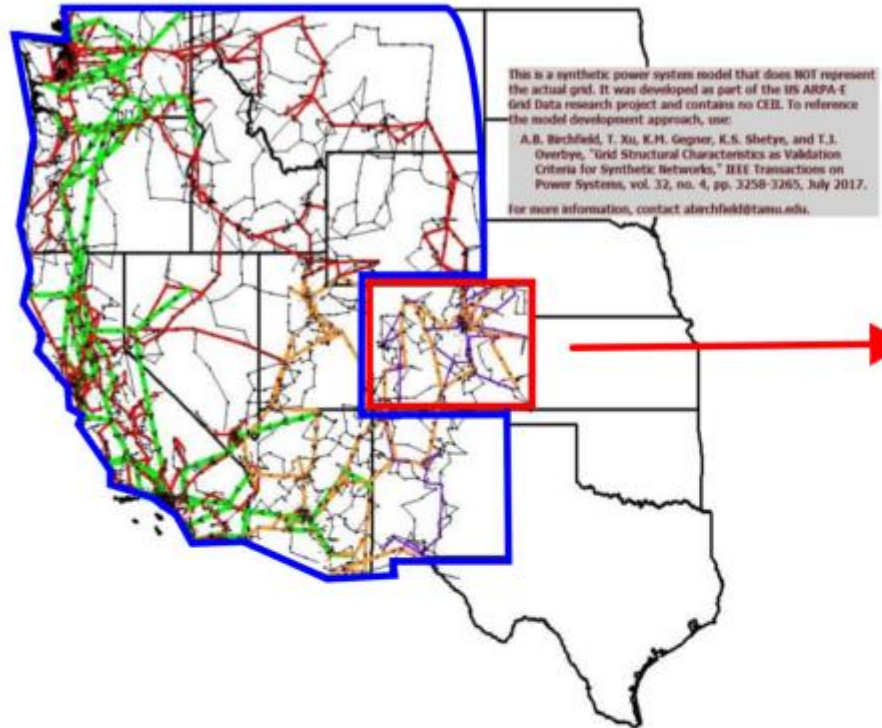
Nbre of CPU	Measured Tstep (s)	Theoretical Tstep with 100% efficiency (s)	Actual efficiency
1	2565		
4	786	641	82%
56	15	46	305%

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.


HYPERMIM

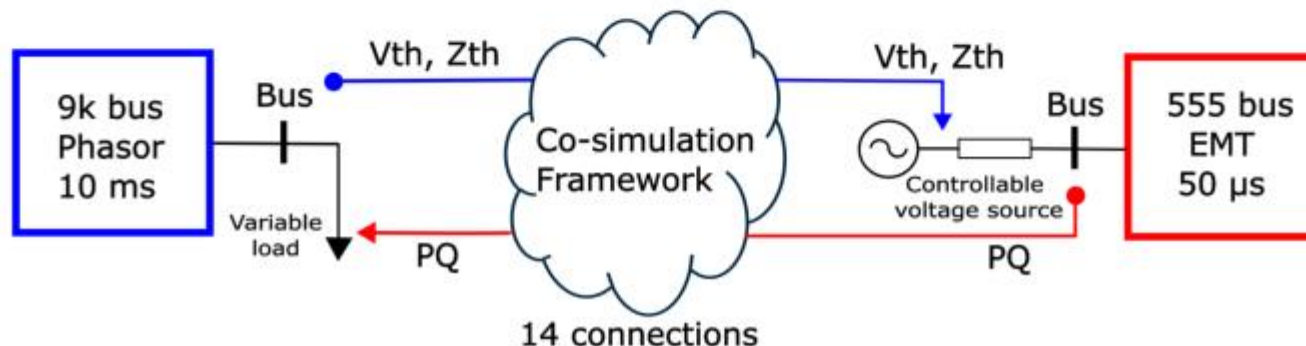
Components	Quantity
3-phase nodes	8500
Generators	350
Sources	1300
Transmission lines	4500
HVDC links connected to replicas	10
Switches	800
3-ph breakers	1200
Dynamic loads	1500
RLC	5700
Filters	200
Transformers	900
Control components	37000

- **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**

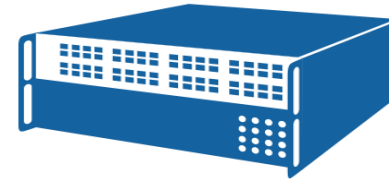
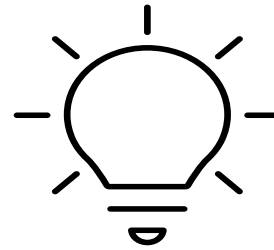
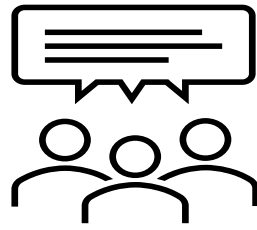
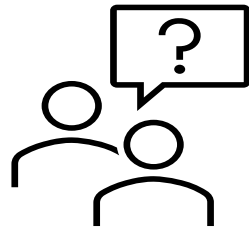


Power components in EMT:

- 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!