

# 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



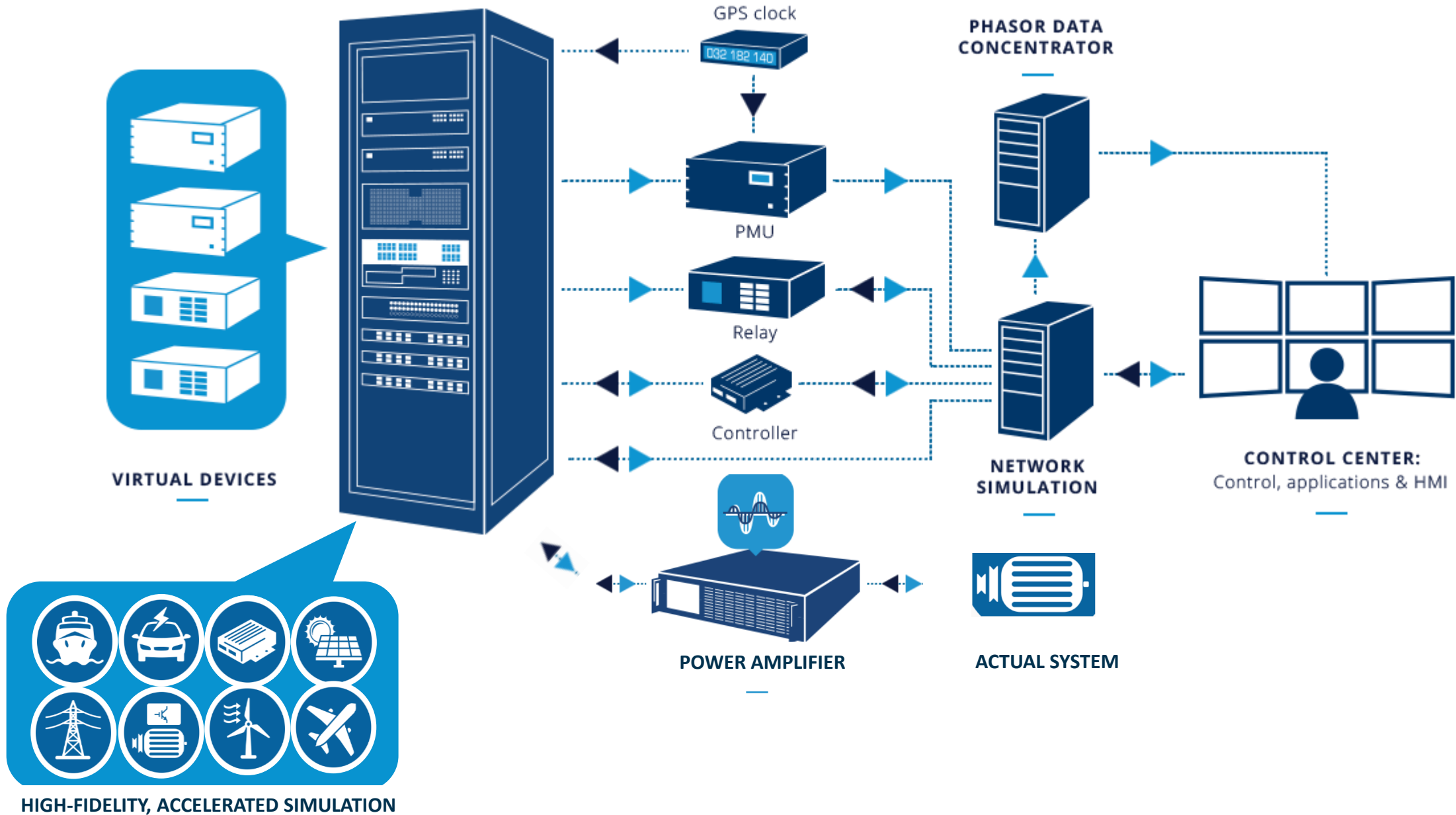
### International subsidiaries, offices and Excellence Centers:

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

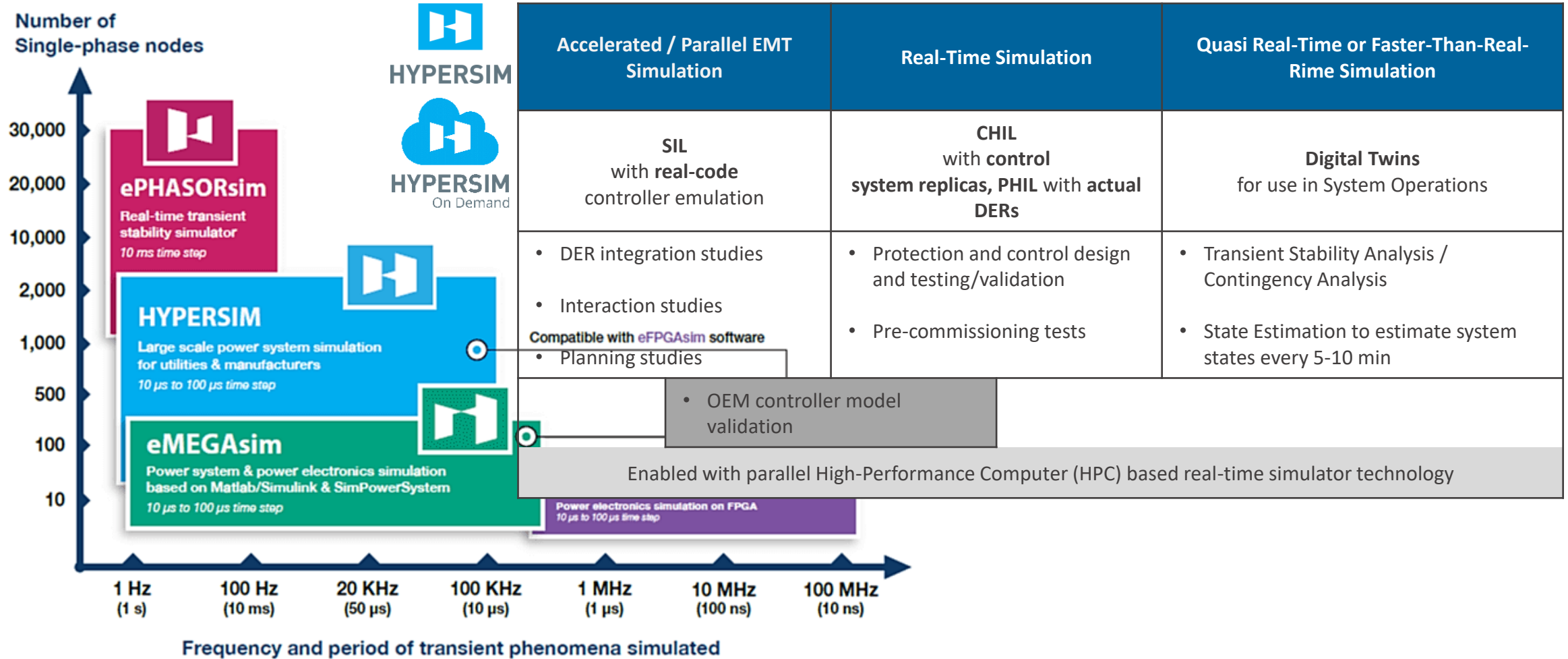
### Distributors:

- 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 Save Append Save As Topology Analysis Set Initial Conditions Netlist Disable Breakers/Faults Impedance 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)

**Simulation Parameters:**

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

**Voltage levels**

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

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

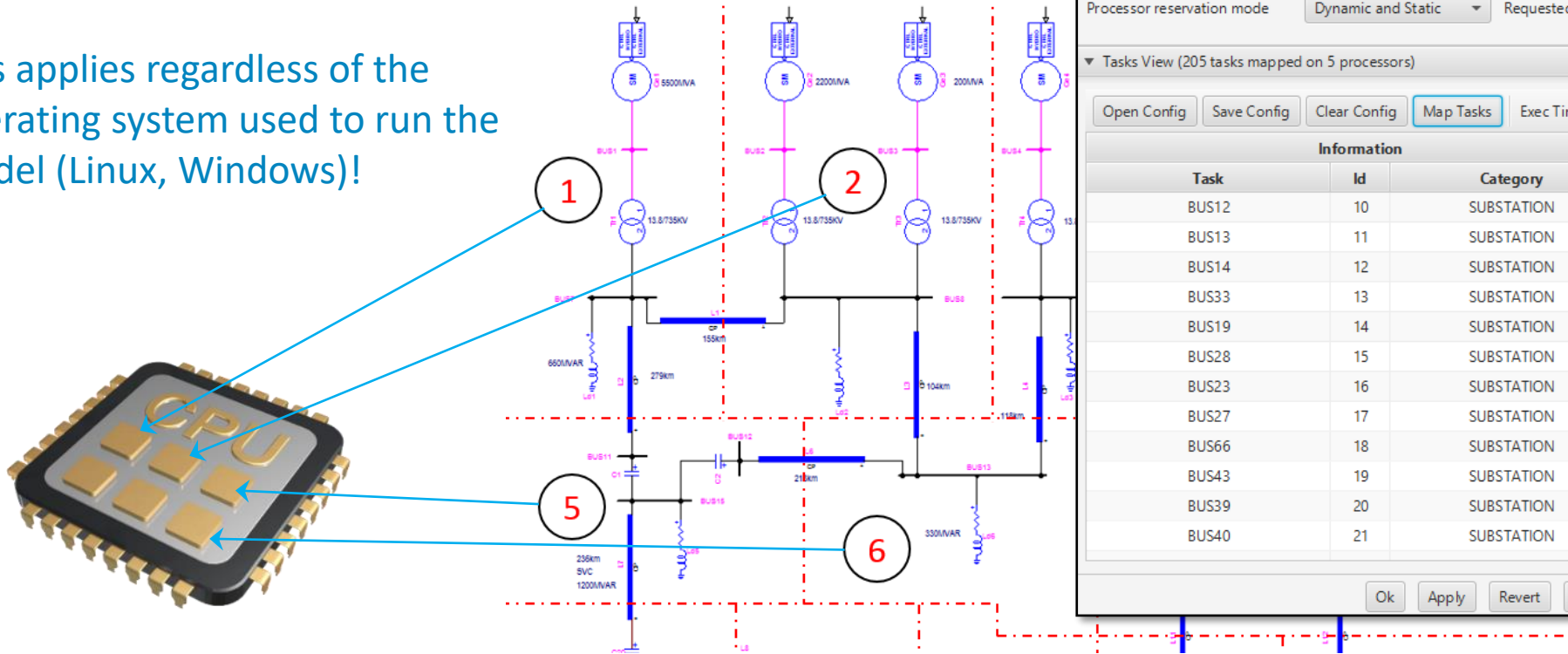
HypConsole Photovoltaic\_Generation\_System.ecf [1]\* Photovoltaic\_Generation\_System.simout [1]\*

Type here to search 10:15 AM 3/20/2024

# 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)!



Tasks Manager - C:\Users\ShijiaLi\Downloads\LOM143\_0382-master-1...

▼ Preferences

Time step: 5e-05 Use legacy task mapper:

Performance factor: 1 Mapping strategy: Quality

Processor load level: 0.8 Processor imbalance ratio: 0.05

Processor reservation mode: Dynamic and Static Requested # of processors: 5

▼ Tasks View (205 tasks mapped on 5 processors)

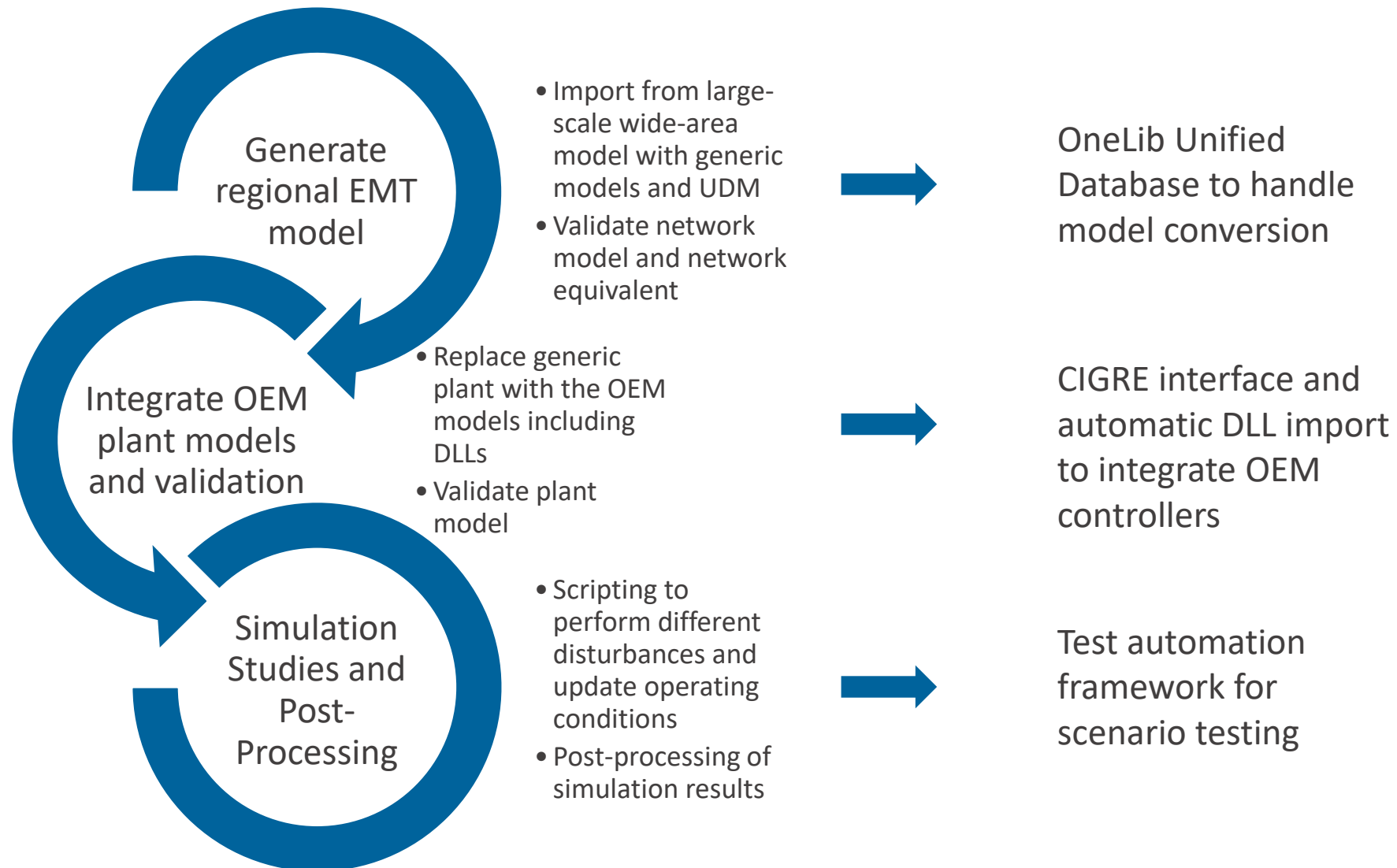
Open Config Save Config Clear Config Map Tasks Exec Time Unit:  $\mu$ s

Information			Inputs		Results
Task	Id	Category	Exec Time	Set ProclD	ProclD
BUS12	10	SUBSTATION	11.72		1
BUS13	11	SUBSTATION	1.75		2
BUS14	12	SUBSTATION	1.75		2
BUS33	13	SUBSTATION	1.22		2
BUS19	14	SUBSTATION	4.07		2
BUS28	15	SUBSTATION	1.22		1
BUS23	16	SUBSTATION	1.69		2
BUS27	17	SUBSTATION	2.88		1
BUS66	18	SUBSTATION	4.13		3
BUS43	19	SUBSTATION	1.22		2
BUS39	20	SUBSTATION	1.75		2
BUS40	21	SUBSTATION	4.07		2

Ok Apply Revert Cancel

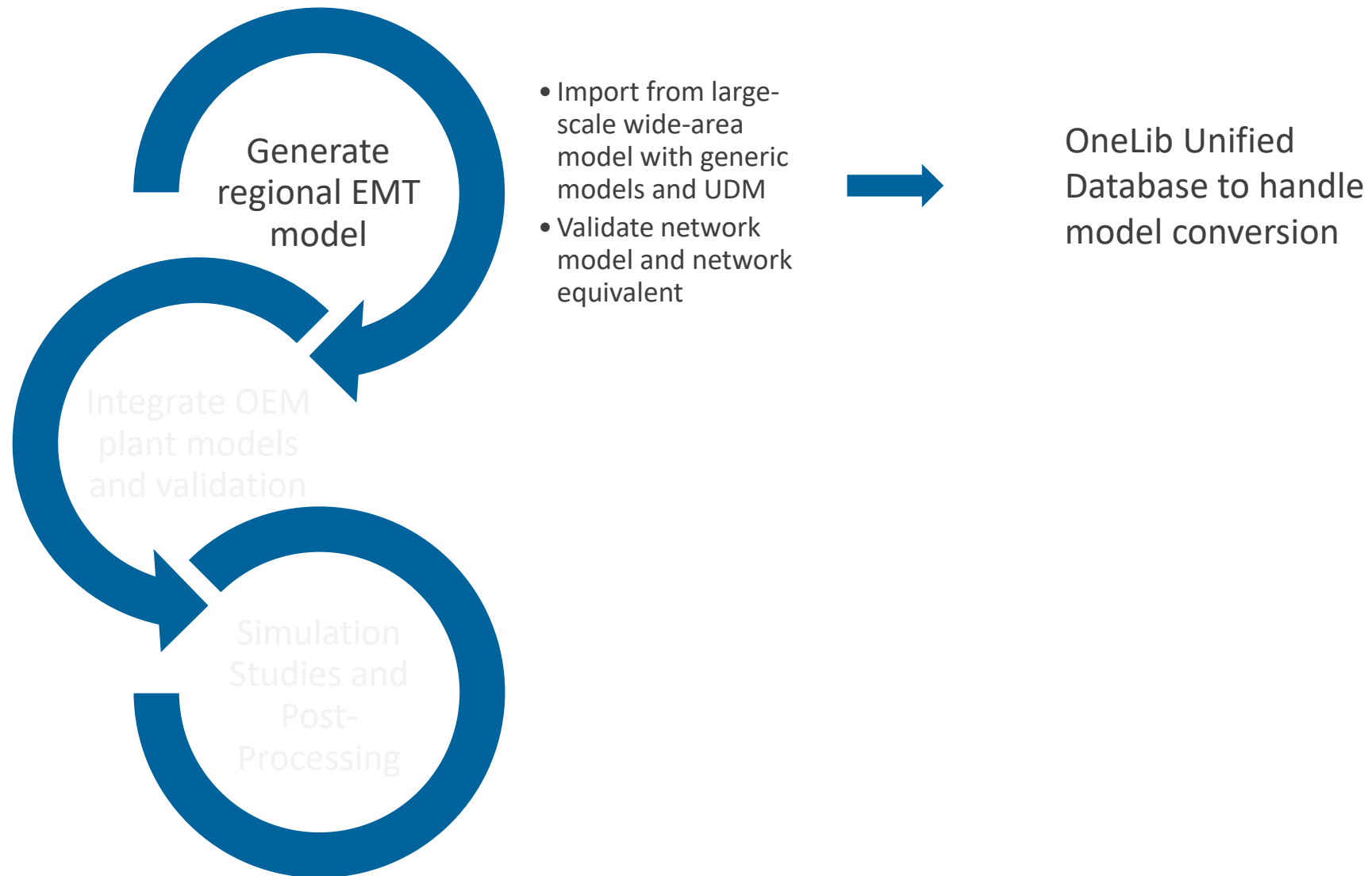
# HYPERSIM - Study workflow and features for IBR integration

# Study Workflow – Current Process & Mapping to HYPERSIM





# Study Workflow – Current Process & Mapping to HYPERSIM



## Third-Party Software

**EMTP**  
(available today not through DB)

**PSCAD**  
(available today)

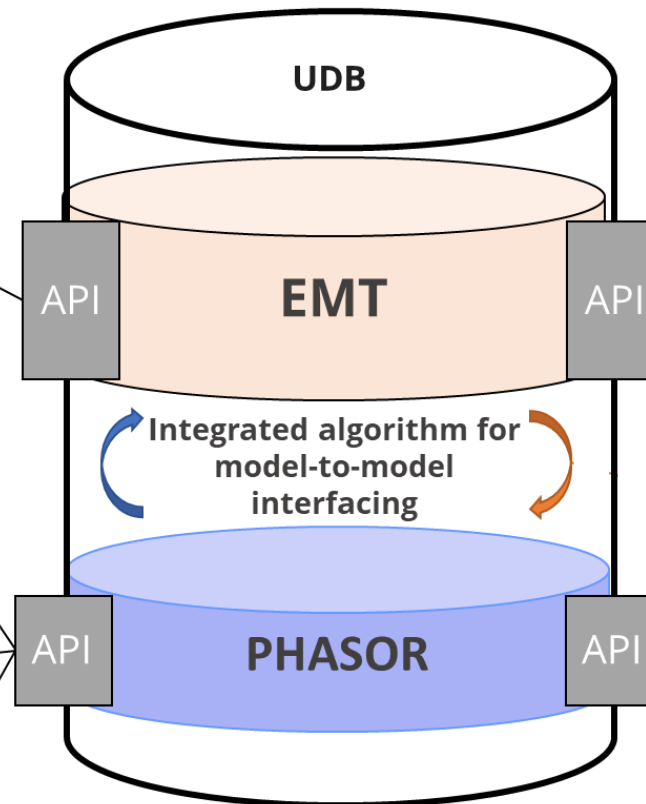
**PSSE PowerFactory**  
(available today)

**CYMDIST**  
(available today not through DB)

**GridLAB-D**  
(ongoing)

**CIM/CGMES, ETAP**  
(under consideration)

## OPAL-RT Software



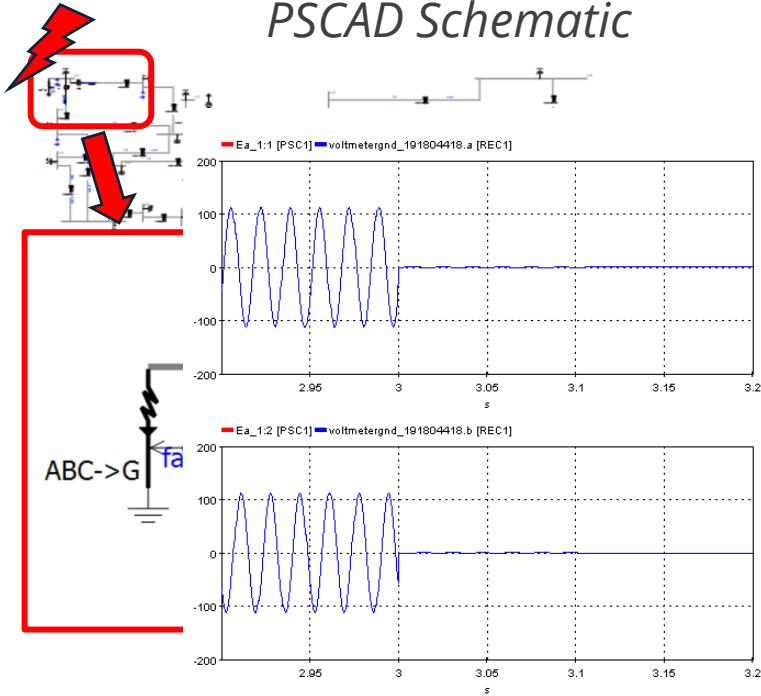
**eHS - FPGA-based electrical toolbox**  
Currently supported: PLECS, PSIM

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

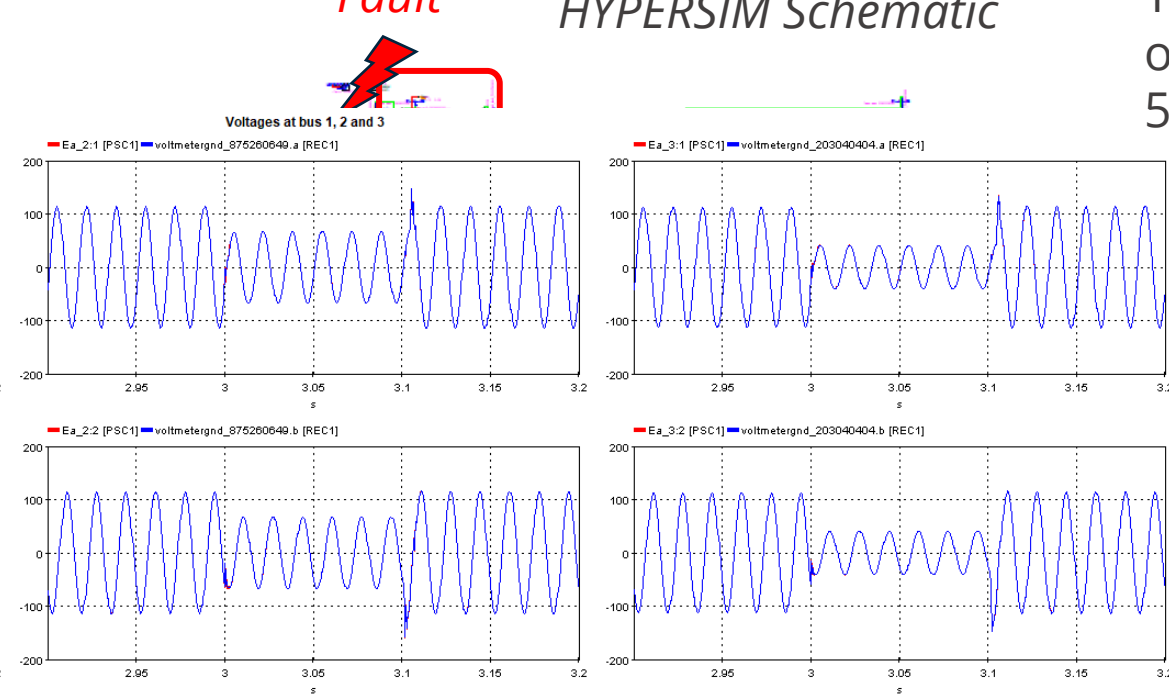
**ePHASORSIM - CPU-based electromechanical toolbox**  
Currently supported: PSSE, PowerFactory  
Supported not through DB: CYMDIST  
Under consideration: ETAP, CIM/CGMES

# IEEE 118 Bus Model Import and Validation in HYPERSIM

Fault



Fault

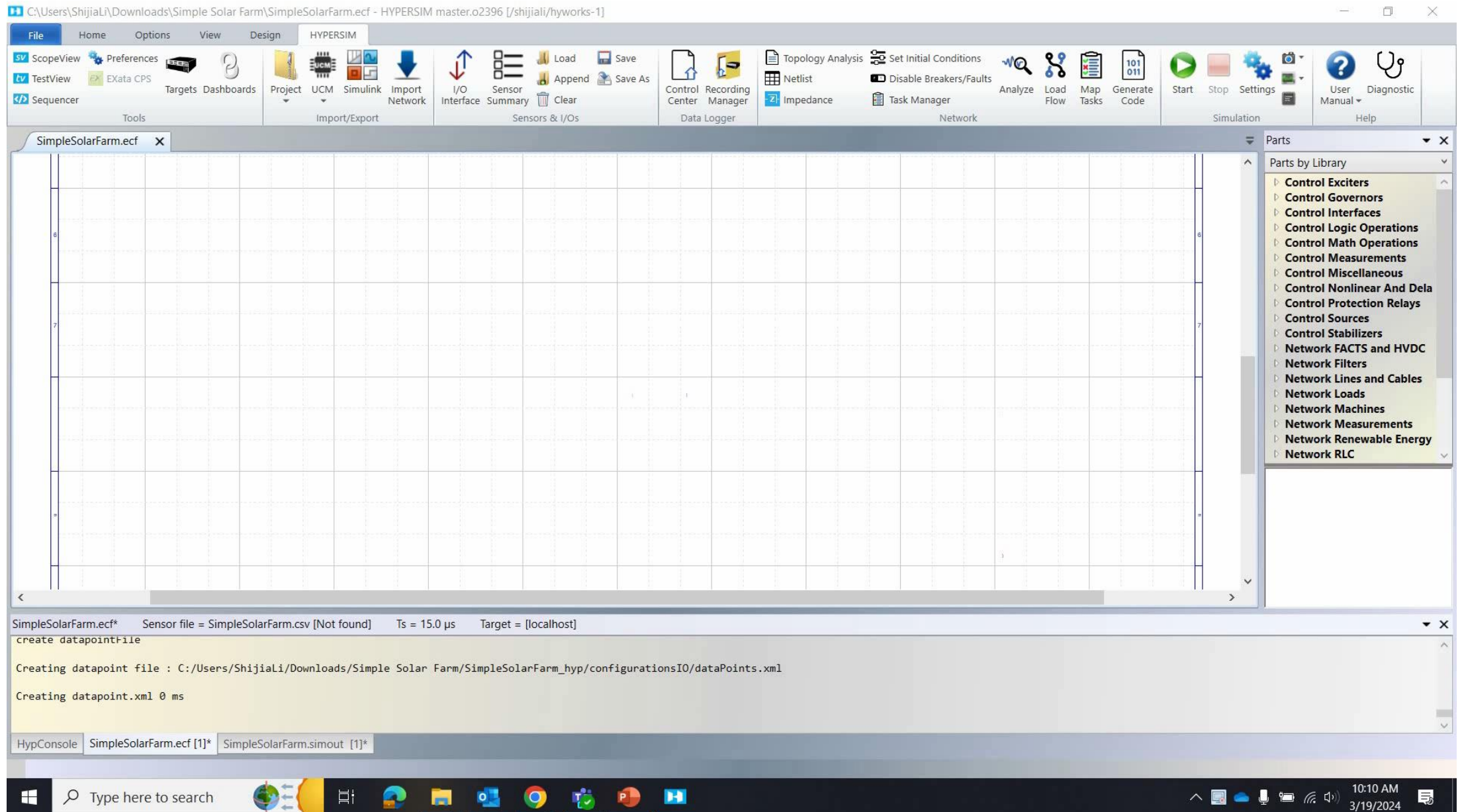


HYPERSIM Schematic

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

[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\_UDB\ieee\_118\_bus\_hyp\Recordings

# Import of a Simple Solar Farm in HYPERMIM



The screenshot displays the HYPERMIM software interface. The title bar shows the file path: `C:\Users\ShijiaLi\Downloads\Simple Solar Farm\SimpleSolarFarm.ecf - HYPERMIM master.o2396 [/shijiali/hyworks-1]`. The ribbon menu includes tabs for File, Home, Options, View, Design, and HYPERMIM. The HYPERMIM ribbon contains various tool groups: Tools (ScopeView, Preferences, TestView, Sequencer, Targets, Dashboards, Project, UCM, Simulink, Import Network), Sensors & I/Os (I/O Interface, Sensor Summary, Clear), Data Logger (Control Center, Recording Manager, Impedance), Network (Topology Analysis, Netlist, Set Initial Conditions, Disable Breakers/Faults, Task Manager), Simulation (Start, Stop, Settings), and Help (User Manual, Diagnostic).

The main workspace shows a grid with a vertical axis labeled 6, 7, and 9. On the right, the 'Parts' panel is open, displaying a list of components categorized by library:

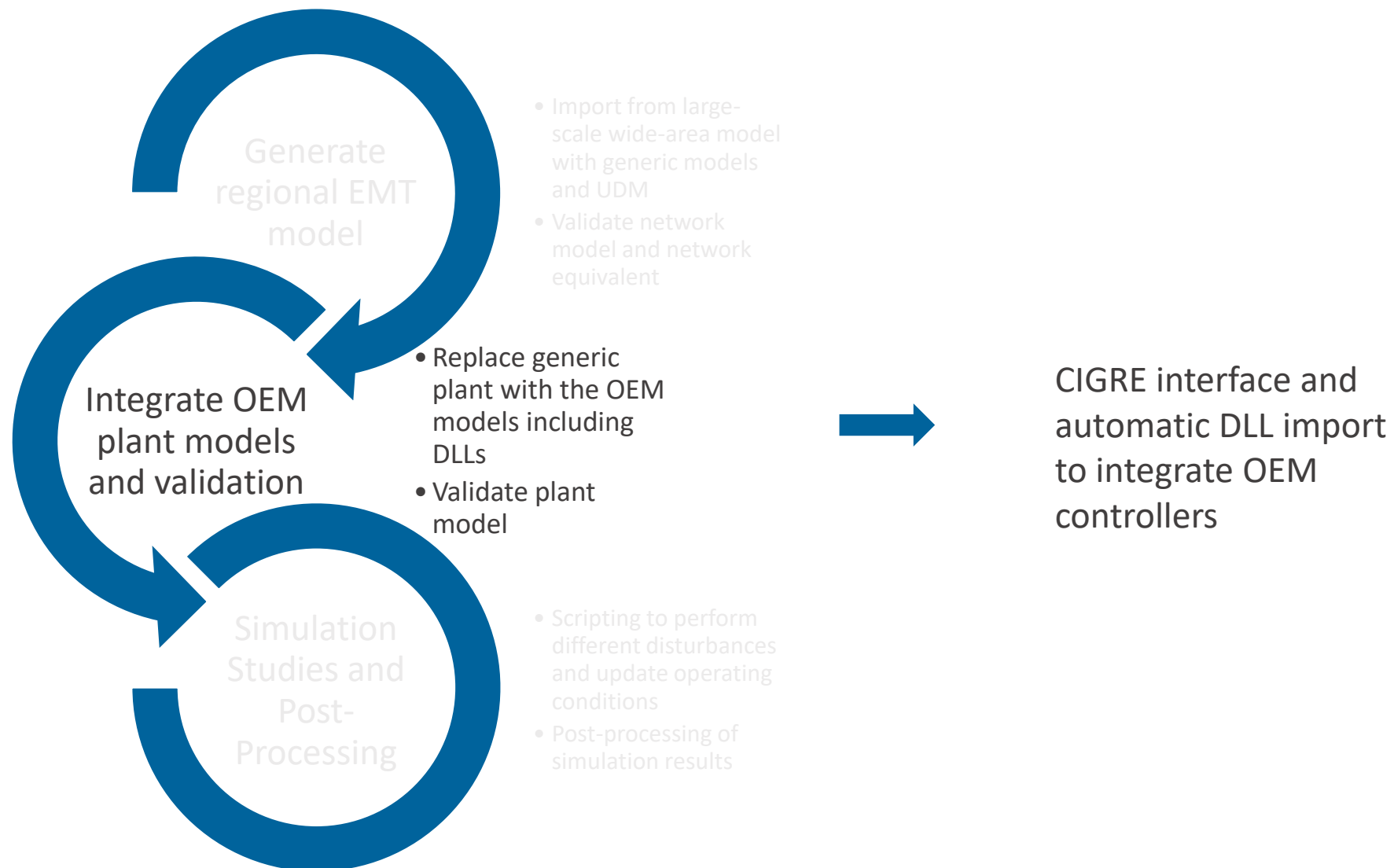
- Control Exciters
- Control Governors
- Control Interfaces
- Control Logic Operations
- Control Math Operations
- Control Measurements
- Control Miscellaneous
- Control Nonlinear And Dela
- Control Protection Relays
- Control Sources
- Control Stabilizers
- Network FACTS and HVDC
- Network Filters
-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

The HypConsole at the bottom shows the following output:

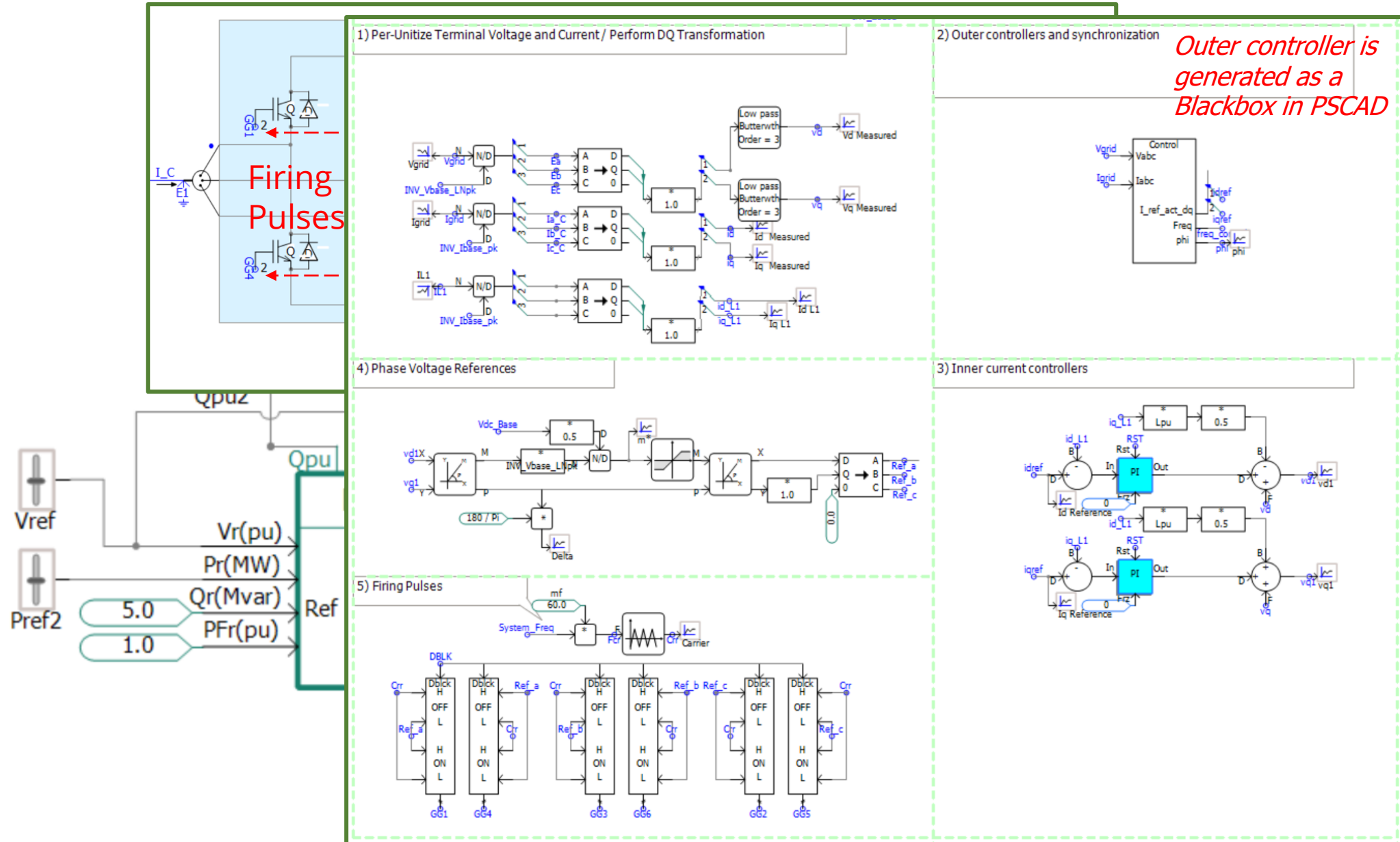
```
SimpleSolarFarm.ecf*   Sensor file = SimpleSolarFarm.csv [Not found]   Ts = 15.0 μs   Target = [localhost]
create datapointFile
Creating datapoint file : C:/Users/ShijiaLi/Downloads/Simple Solar Farm/SimpleSolarFarm_hyp/configurationsIO/dataPoints.xml
Creating datapoint.xml 0 ms
```

The taskbar at the bottom shows the Windows Start button, search bar, and several application icons. The system tray displays the time as 10:10 AM on 3/19/2024.

# Study Workflow – Current Process & Mapping to HYPERSIM



# Solar Farm Import with Blackbox Controller in HYPERSIM



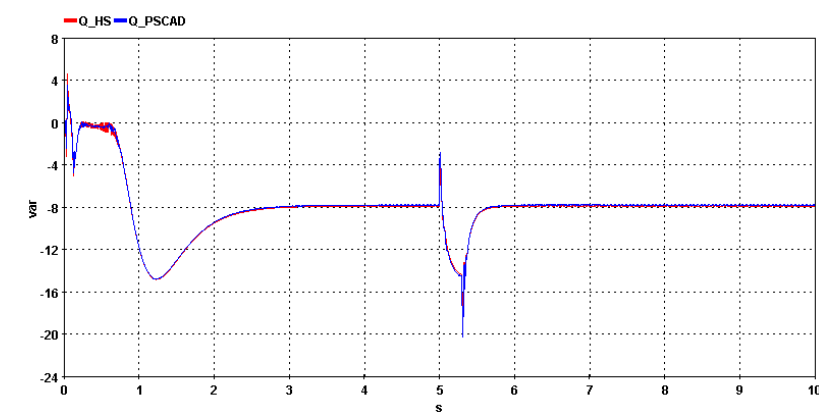
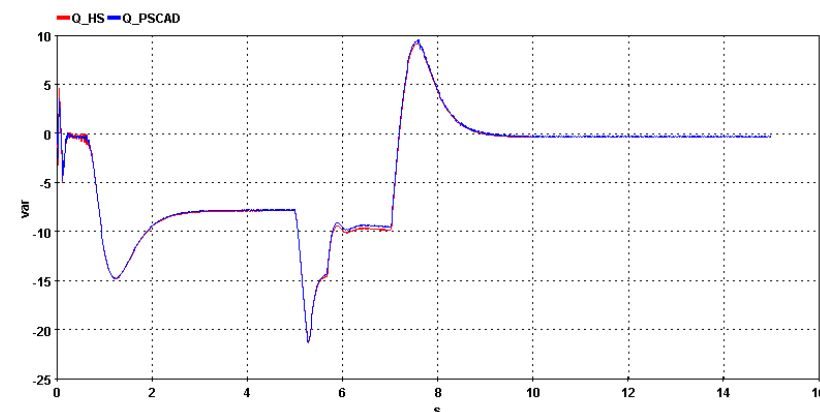
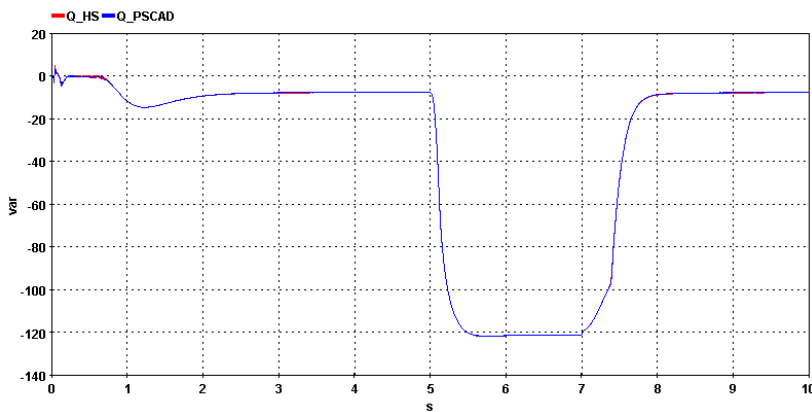
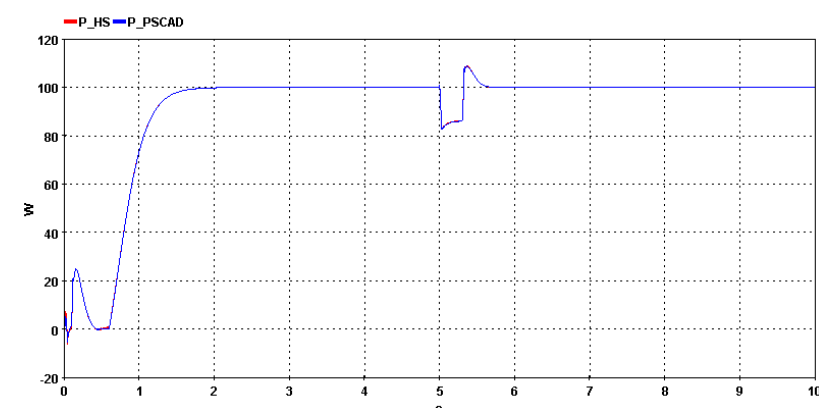
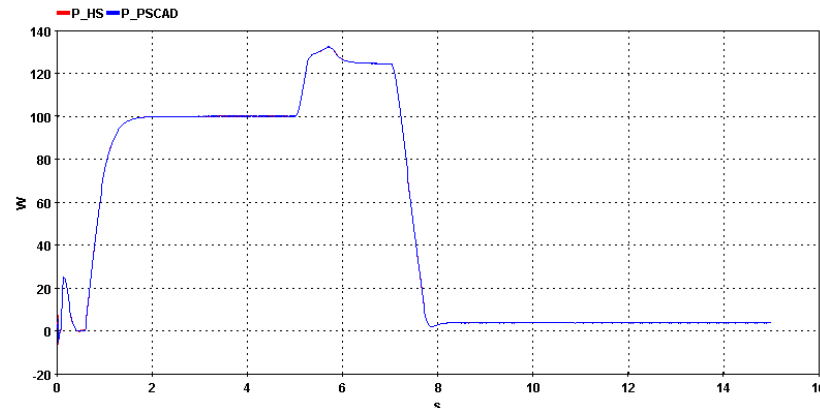
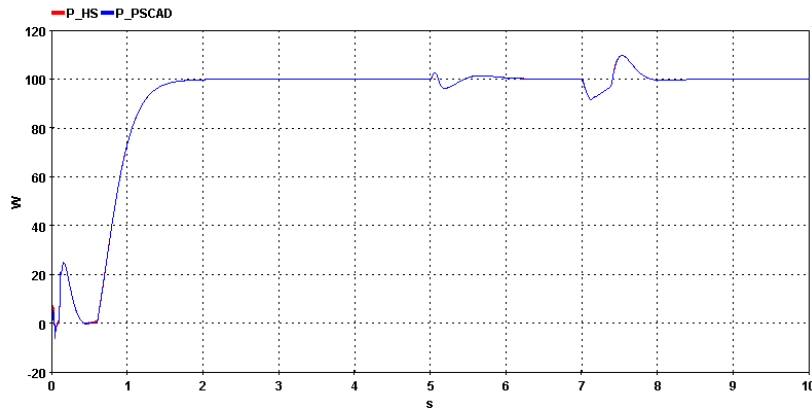
# Solar Form Import Validation with Blackbox Controller

## Comparison of validation results between PSCAD and HYPERSIM

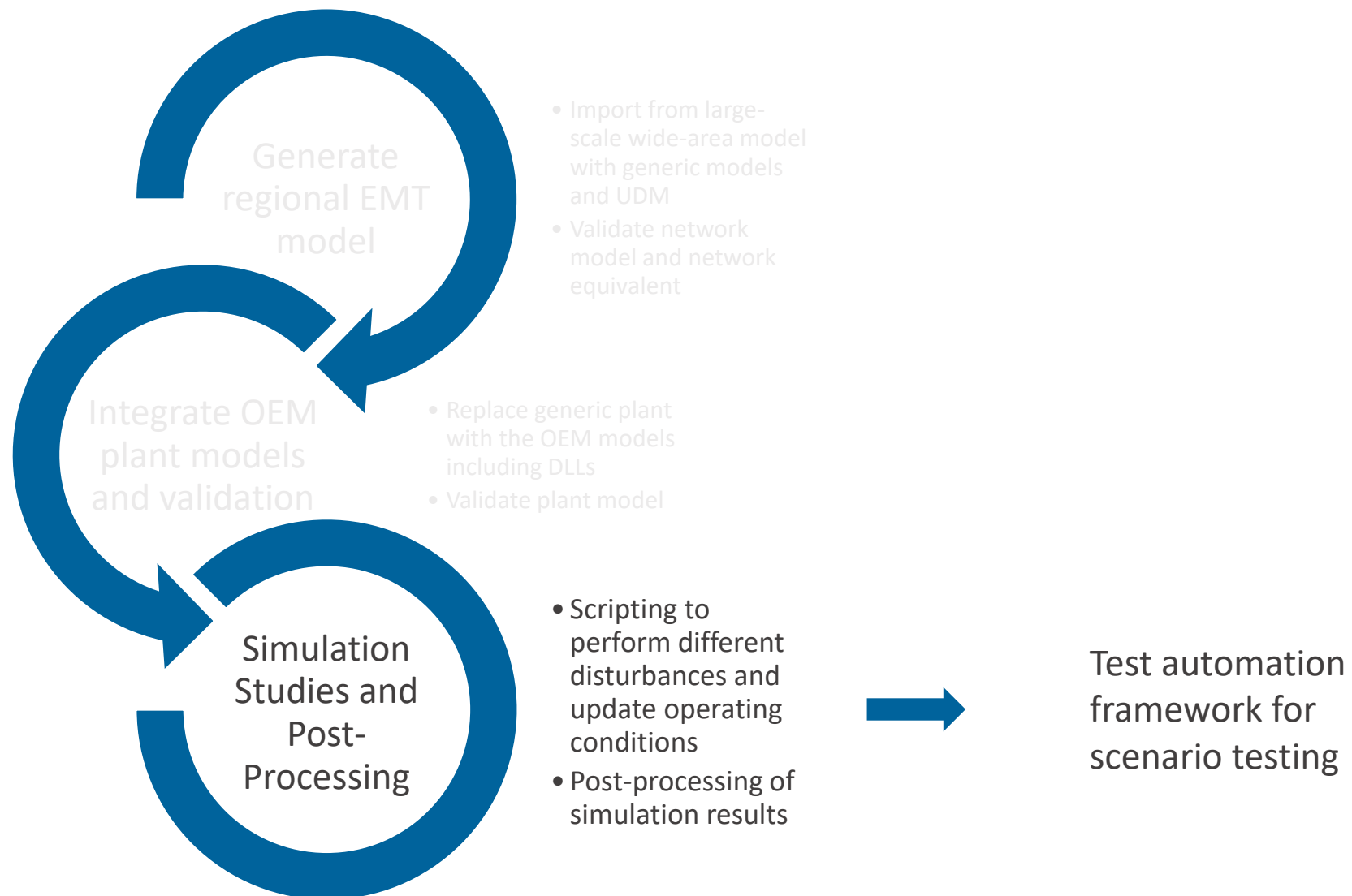
### Overvoltage (DIP=1.1)

### 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.calculationStep')

print('calcStep = ' + calcStep)

print('code directory : ' + HyWorksApi.getPreference('simulation.codeDirectory'))

print('mode : ' + HyWorksApi.getPreference('simulation.architecture'))

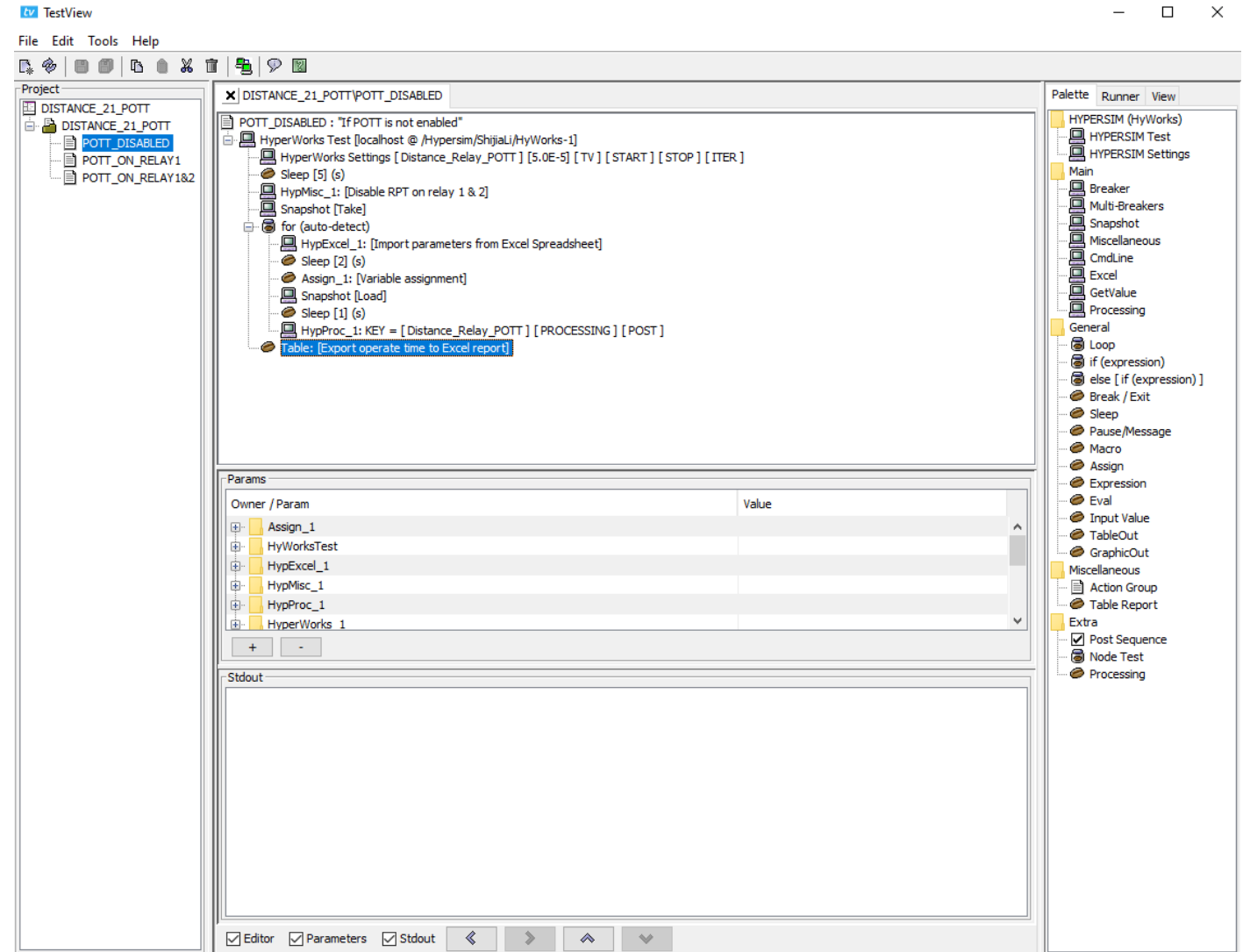
HyWorksApi.mapTask()
HyWorksApi.genCode()
HyWorksApi.startLoadFlow()
HyWorksApi.startSim()
print('startSim done')

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

HyWorksApi.setComponentParameter('Ge7', 'baseVolt', str(float(volt[0])))

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

## Test View for Automation



The screenshot displays the TestView application window. The main area shows a test sequence for 'POTT\_DISABLED'. The sequence includes:

- 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)
- HypProc\_1: KEY = [Distance\_Relay\_POTT] [PROCESSING] [POST]
- Table: [Export operate time to Excel report]

The interface also features a 'Params' table and a 'Stdout' area.

Owner / Param	Value
Assign_1	
HyWorksTest	
HypExcel_1	
HypMisc_1	
HypProc_1	
HyperWorks_1	

The 'Stdout' area is currently empty.

# 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

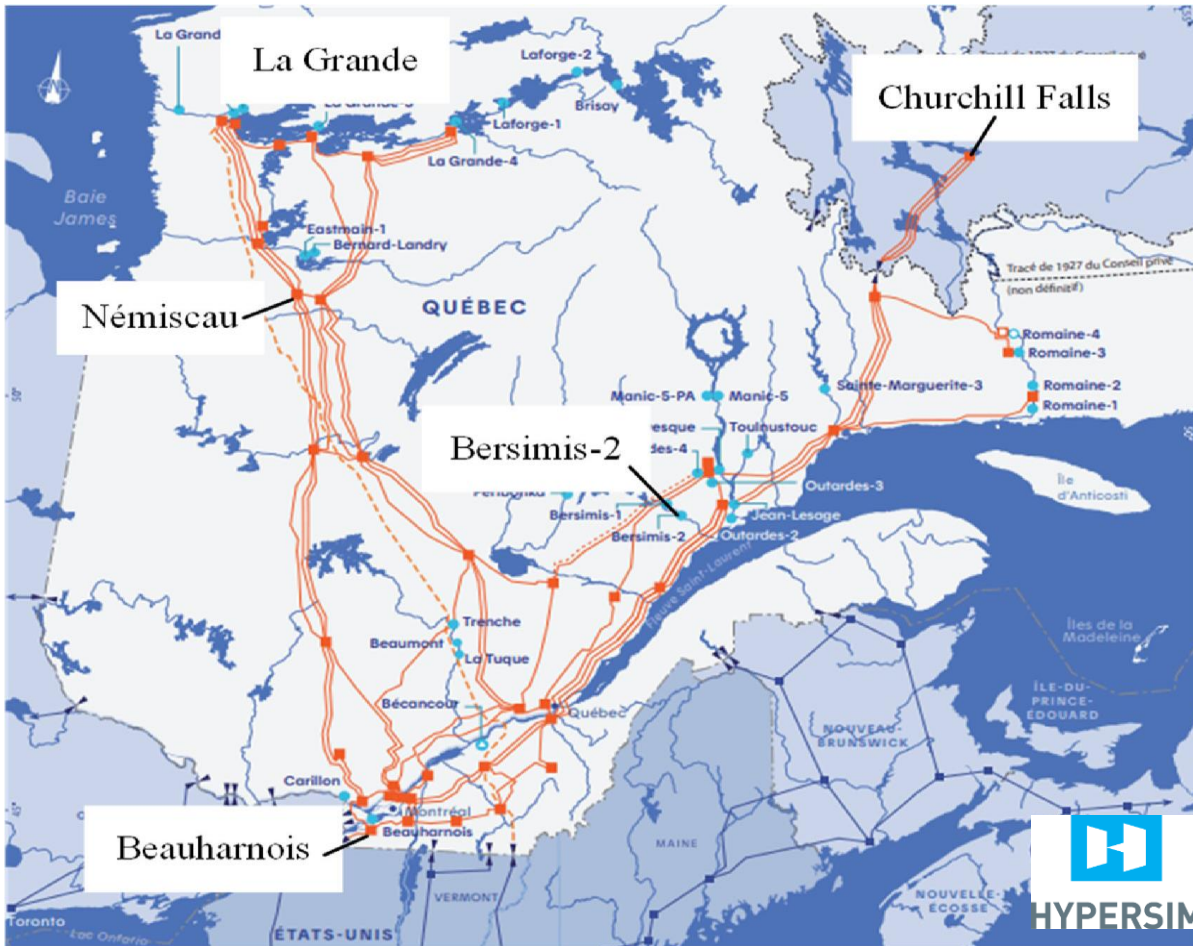
MODEL BENCHMARK	
Approximate number of components (3-phase)	
Buses (3-phase)	4,000
Lines, loads, switched shunts reactors ...	6,700
Transformers and synchronous machines	2,000
Inverter-based generation plants	150
Controllers using real-code (precompiled DLLs)	300+
FACTS and HVDC converters	70
Protection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

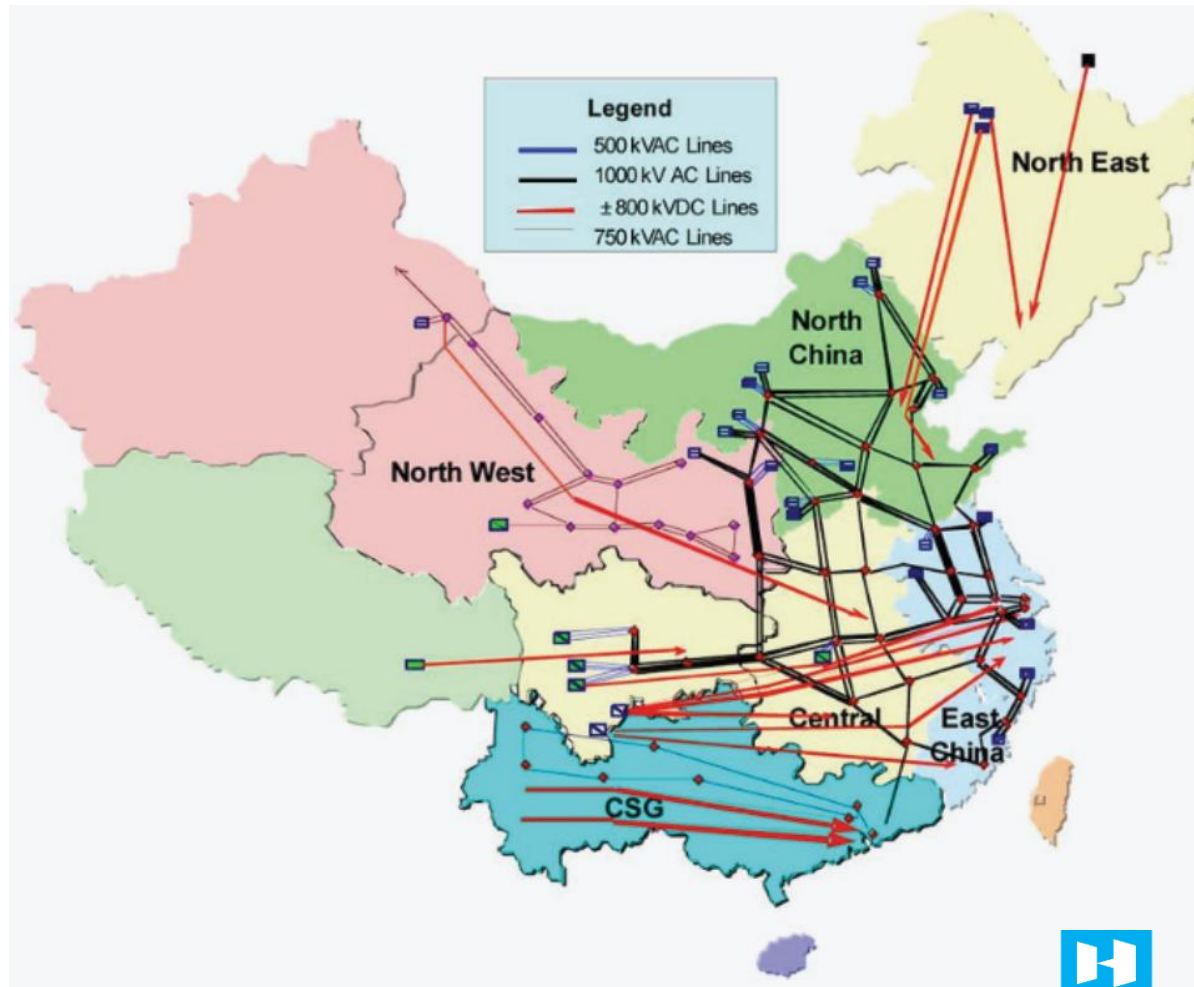


Complex components	Quantity
Three-phase buses	1 666
Electrical machines	111
Lines and cables	432
Three-phase transformers	338
Governors	86
Excitation systems	81
Stabilizers	54
Static compensators	10
Wind power plants	6
HVDC converters	6
Dynamic loads	165

## SIMULATION TIME FOR A 15 Second EVENT

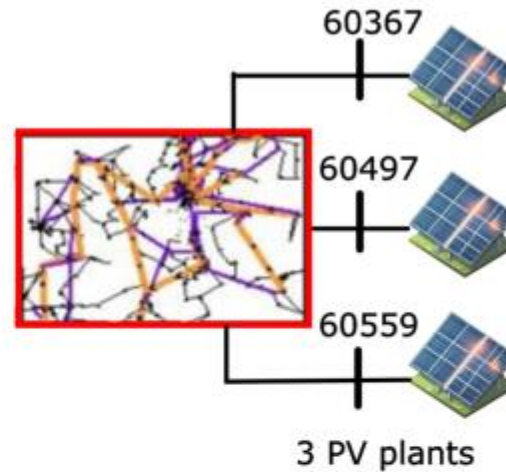
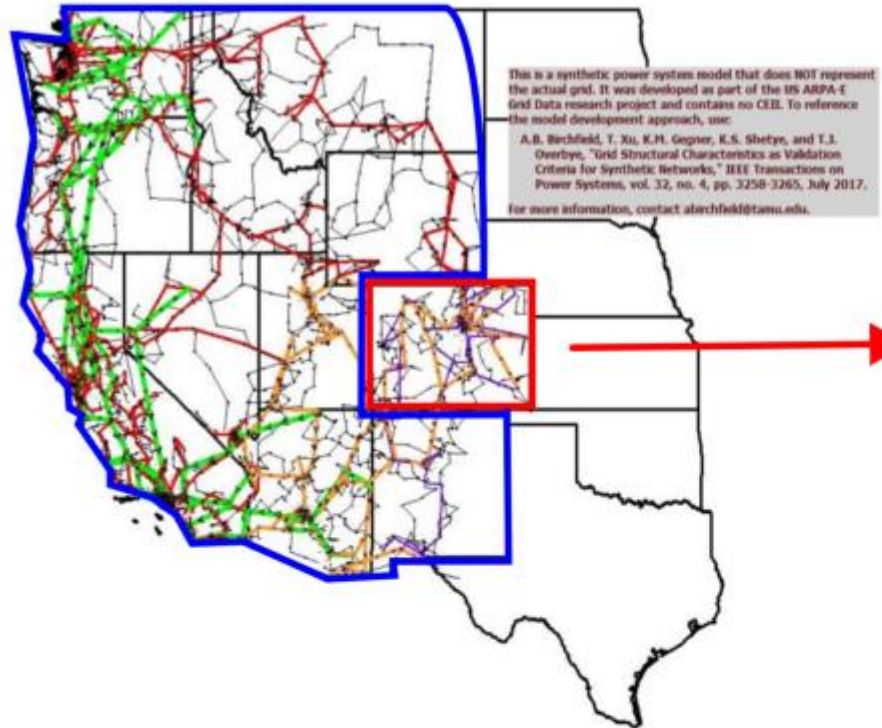
Nbre of CPU	Measured Tstep (s)	Theoretical Tstep with 100% efficiency (s)	Actual efficiency
1	2565		
4	786	641	82%
56	15	46	305%

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.



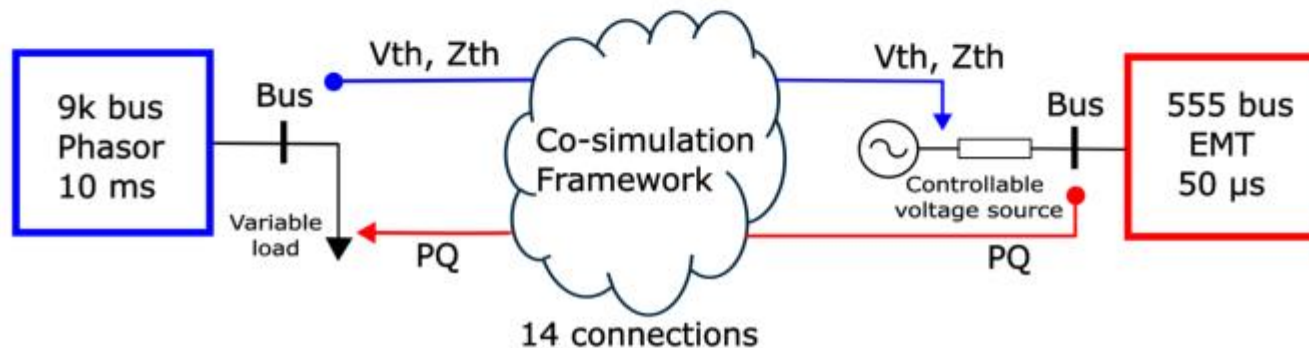
Components	Quantity
3-phase nodes	8500
Generators	350
Sources	1300
Transmission lines	4500
HVDC links connected to replicas	10
Switches	800
3-ph breakers	1200
Dynamic loads	1500
RLC	5700
Filters	200
Transformers	900
Control components	37000

- 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

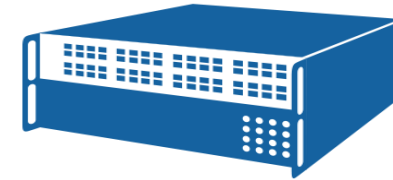
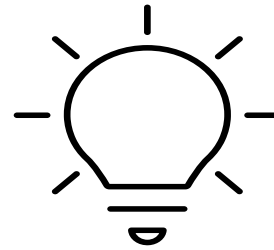
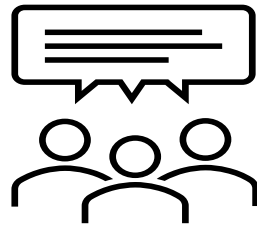
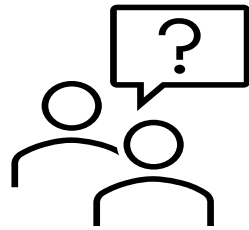


## Power components in EMT:

- 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](mailto:shijia.li@opal-rt.com)

## Thank You!