
MATLAB EXPO 2018
KOREA

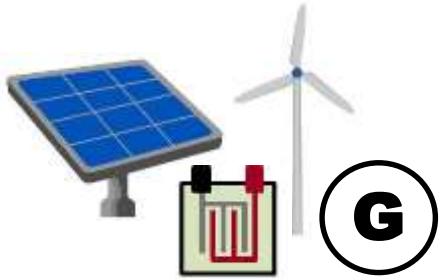
MATLAB EXPO 2018

Realtime Simulation of Large-Scale Power System Using Multi-Core Realtime Machine

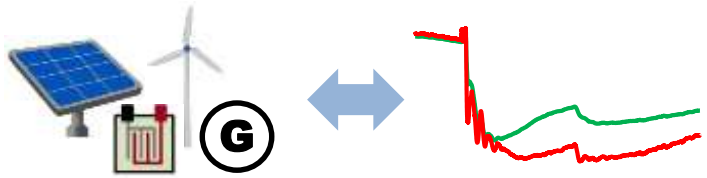
강효석 과장 / Ph.D

Renewable/Microgrid Series Topics

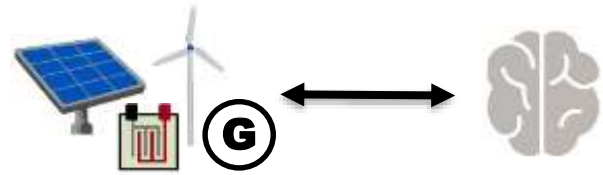
Distributed and Renewable Systems
Modeling and Simulation



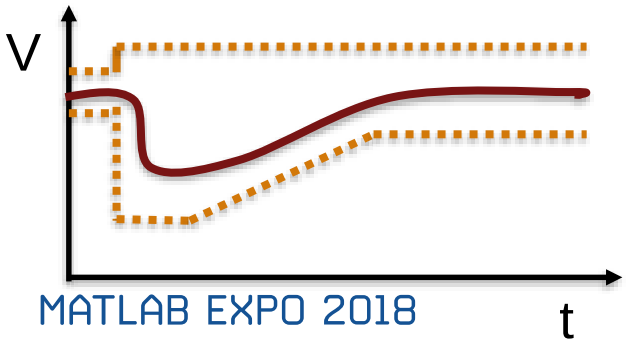
Addressing Validation Requirements
Integrated Workflows



Energy Management Systems
Supervisory Control Design

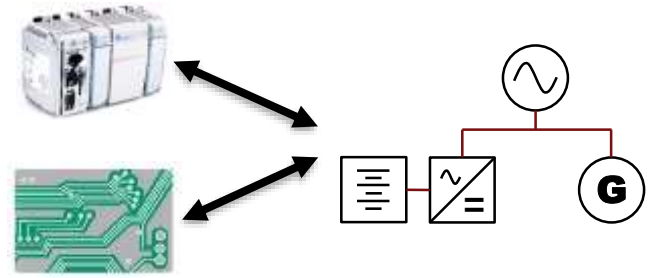


Testing Grid Codes and IEEE Standards
Validating Controls



Deploy Vendor Agnostic Algorithms
C and PLC Code Generation

Grid Integration Studies
Real-Time Testing of Controllers



Sandia National Laboratories Simulates Hawaii Microgrid and Photovoltaic Systems

An array of solar panels.

Challenge

Evaluate the battery capacity and control systems required for reliable operation of a new solar power generation facility

Solution

Use Simulink and Simscape PowerSystems to model and simulate microgrid distribution systems with photovoltaic sources

Results

- Model development time cut by 80%
- Costs reduced through battery right-sizing
- Simulation accuracy verified with real data

"MATLAB, Simulink, and Simscape Power Systems enable mechanical, power, and controls engineers to work together using the same tools, which helps in a multidisciplinary environment like ours."

Ben Schenkman
Sandia

Hydro-Québec Models Wind Power Plant Performance

Turbines on a wind farm.

Challenge

Plan the integration of new wind farms into the power system, predict power output, and ensure safe, reliable operation

Solution

Use MathWorks products to simulate individual wind turbines and wind farms and to generate C code for multiprocessor simulation of entire power systems

Results

- Simulation speed increased to real time
- Equipment needs accurately predicted
- Dynamic simulations enabled

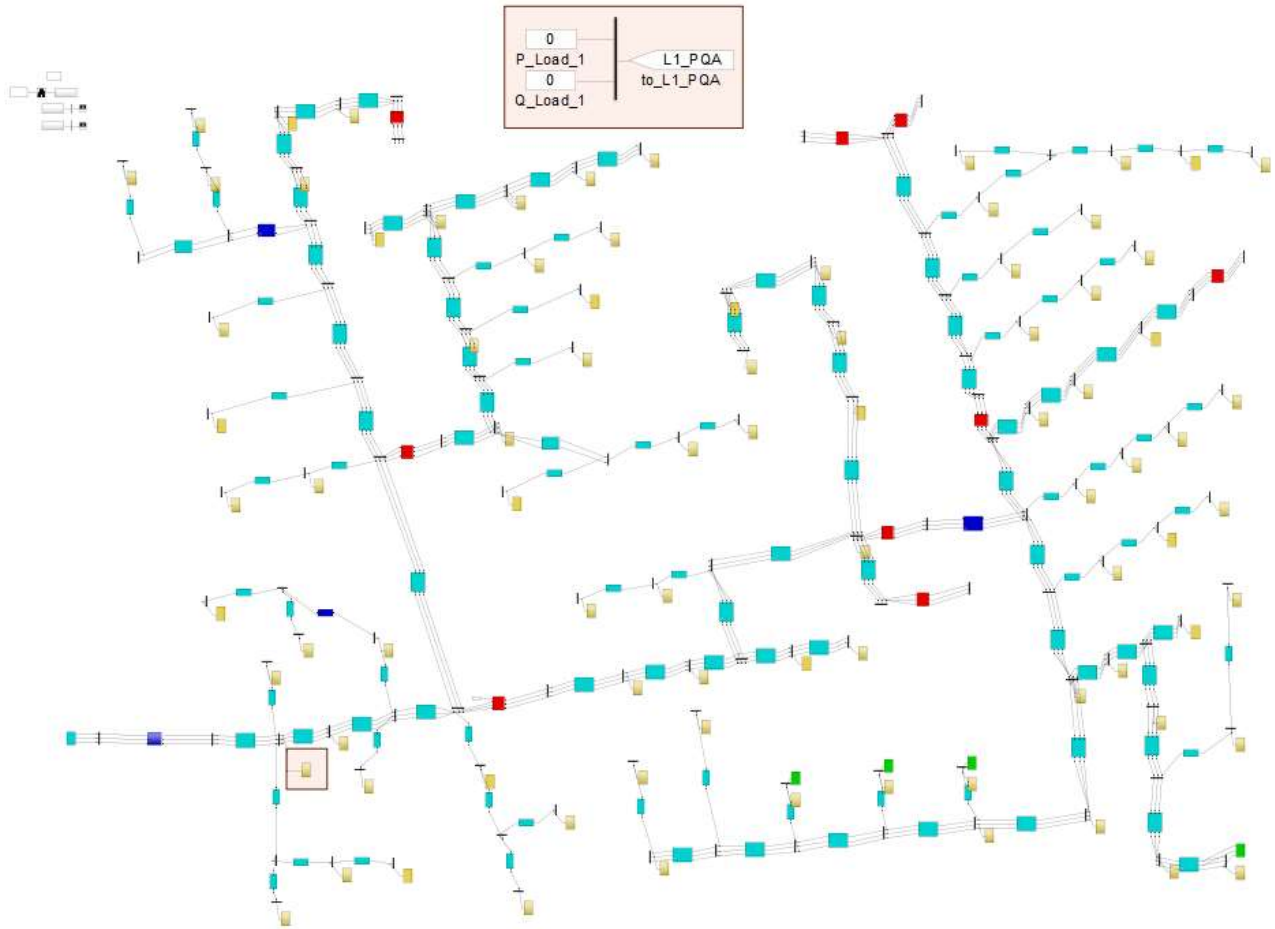
"Accurate modeling is essential not only for planning investments but also to detect situations that can cause an outage. With MathWorks tools, we can simulate power electronics, mechanics, and control systems in one environment, and our models respond like the turbines we have in the field."

Richard Gagnon
Hydro-Québec

IEEE 123 Node – Single Core

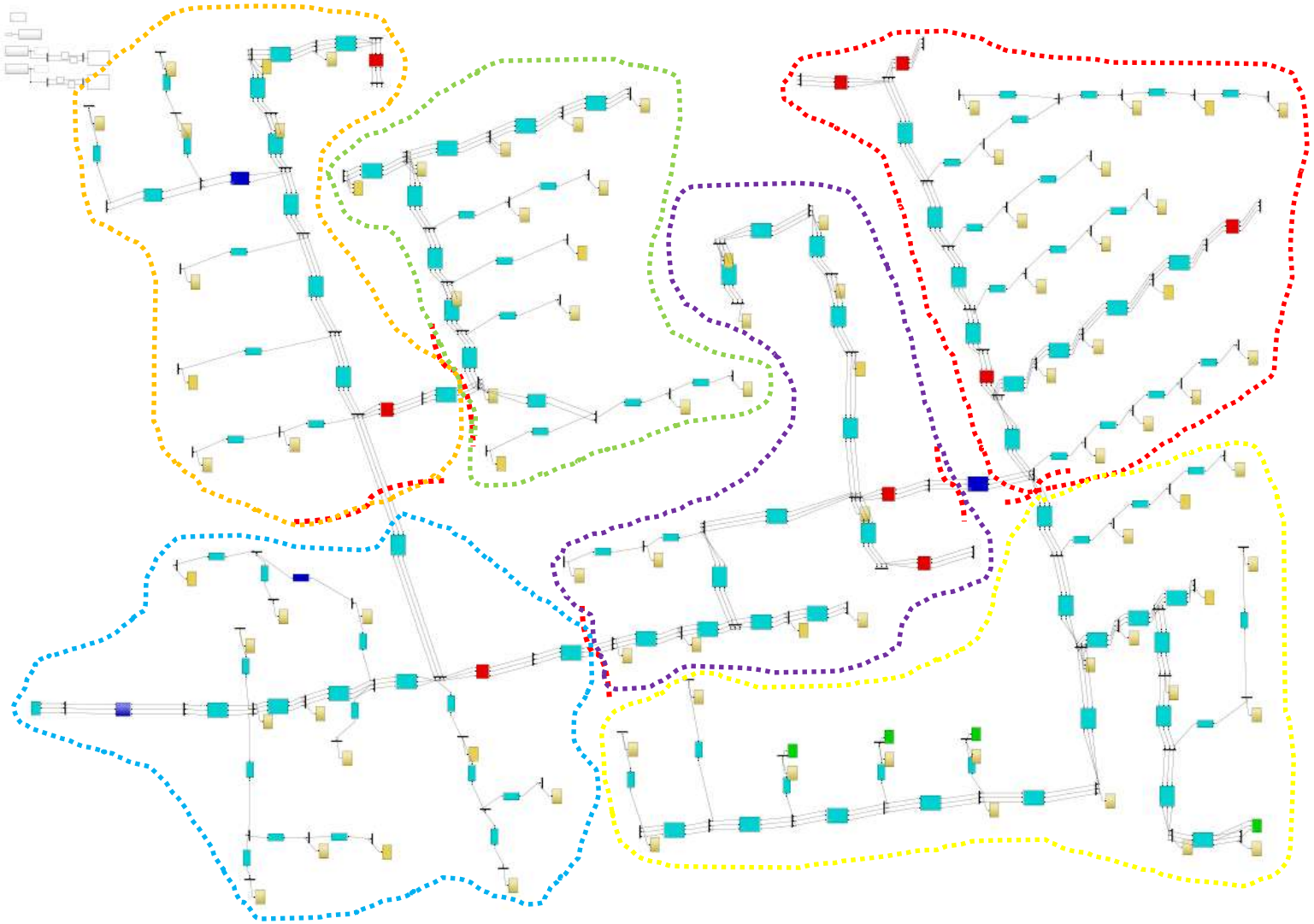
Requirement: Computing time have to be satisfied within 50 *μs* each step time for real-time simulation.

Problem: Overrun is occurred about real-time simulation on single core.



IEEE_123_Phasor – Single Core	Tunable parameters	Inlined parameters
Minimum achievable sample time	474.45 µs	470.58 µs

IEEE 123 Node Distribution Network



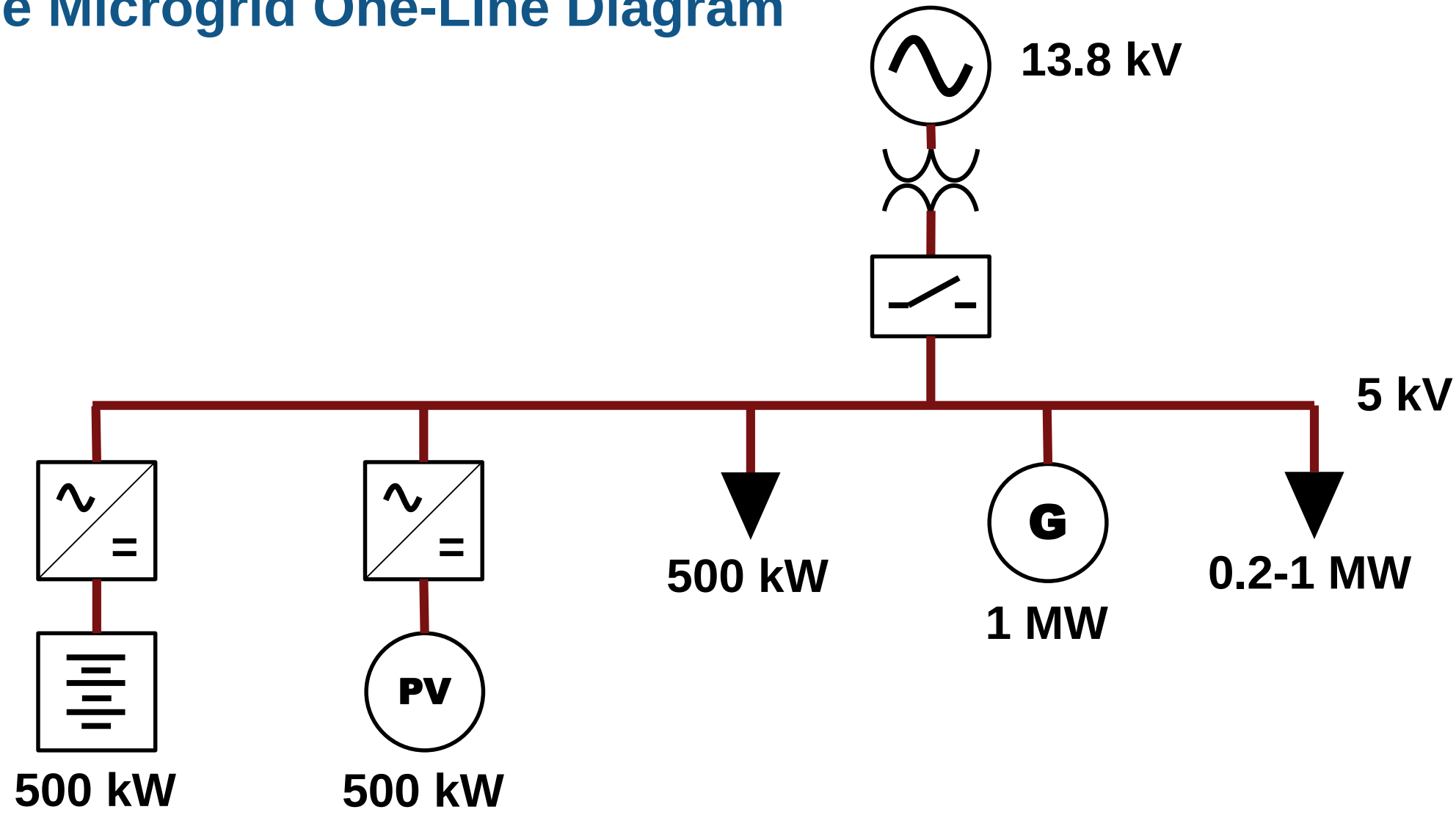
Solution:

- Divide large-scale grid according to computing time
- Assign concurrent execution (Multicore) tasks to individual networks

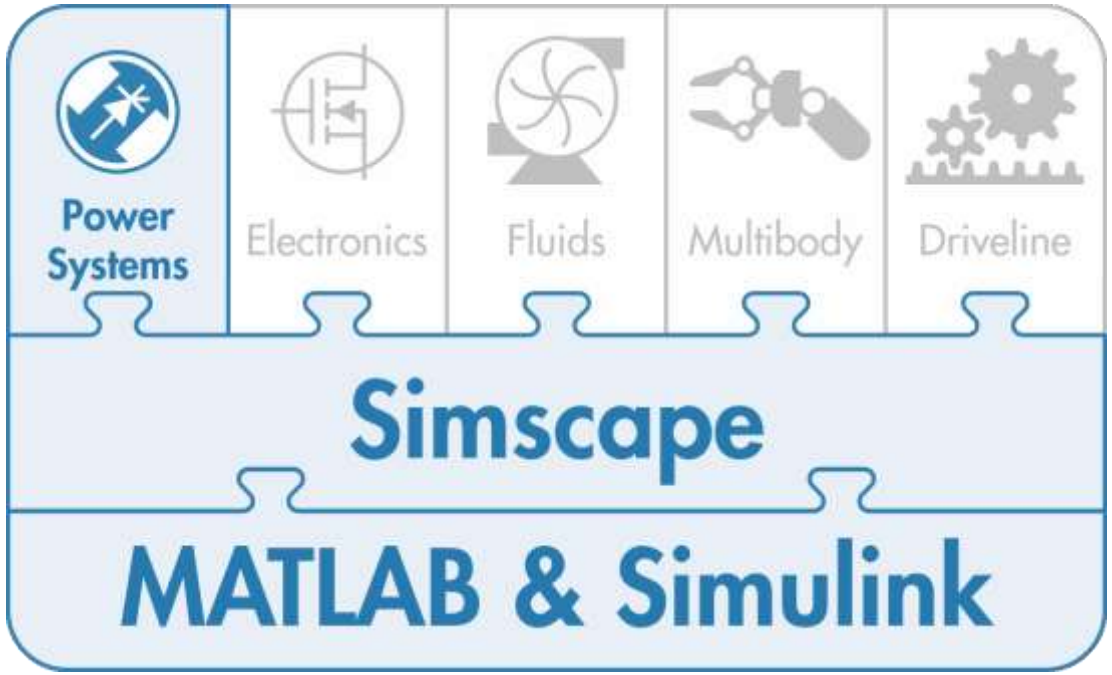
Agenda

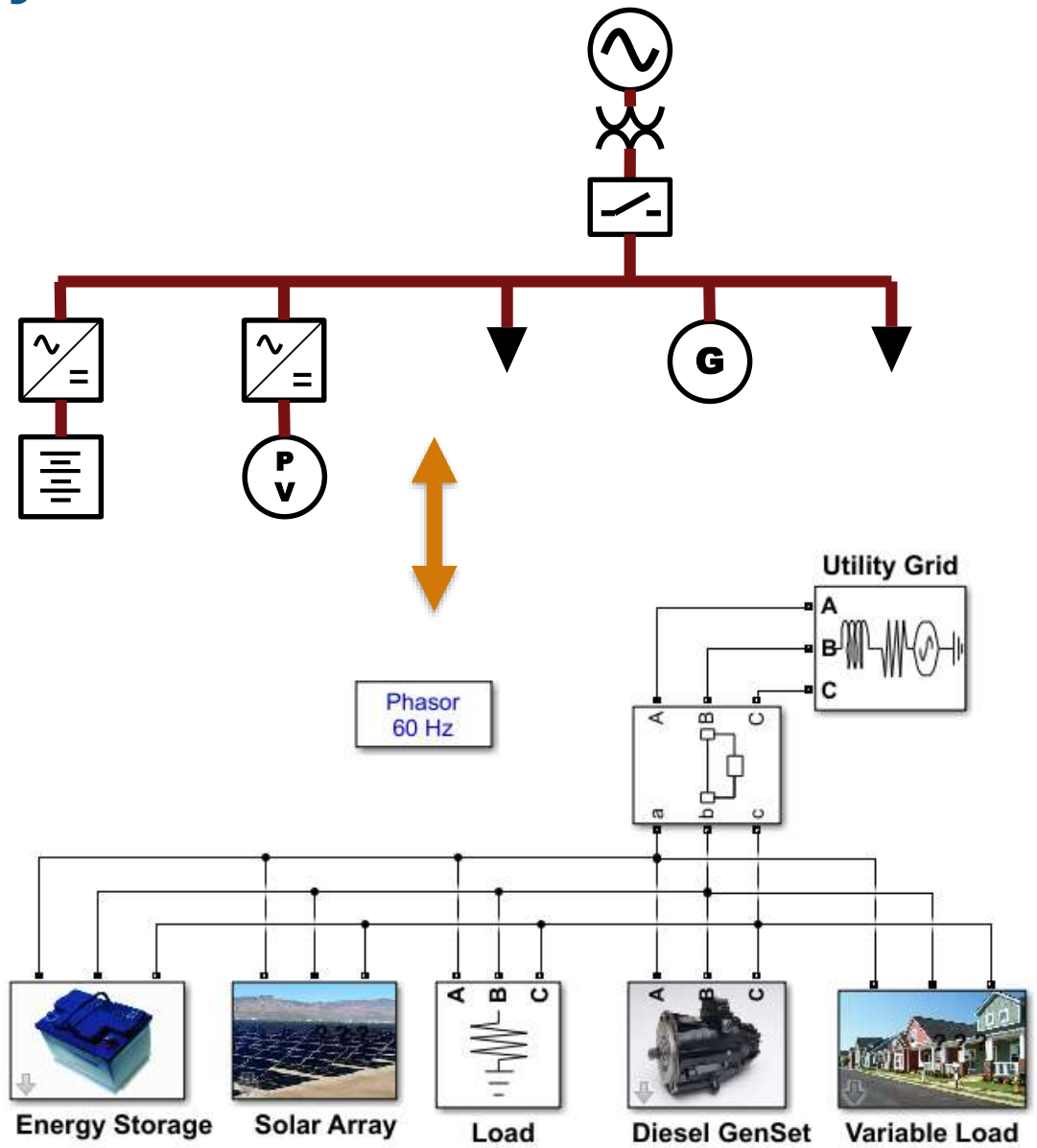
- Microgrid One-Line Diagram – Desktop Simulation
  - Introduction to Simscape Power Systems
  - Hybrid Phasor-EMT Simulation
- Large-Scale Grid System – Real-time Simulation
  - Introduction to Simulink Real-time
  - Case Study 1: Reactive Power Management of Wind Farm
  - Case Study 2: IEEE 123 Node Distribution Network
- What's New about Simscape Power Systems?

Example Microgrid One-Line Diagram

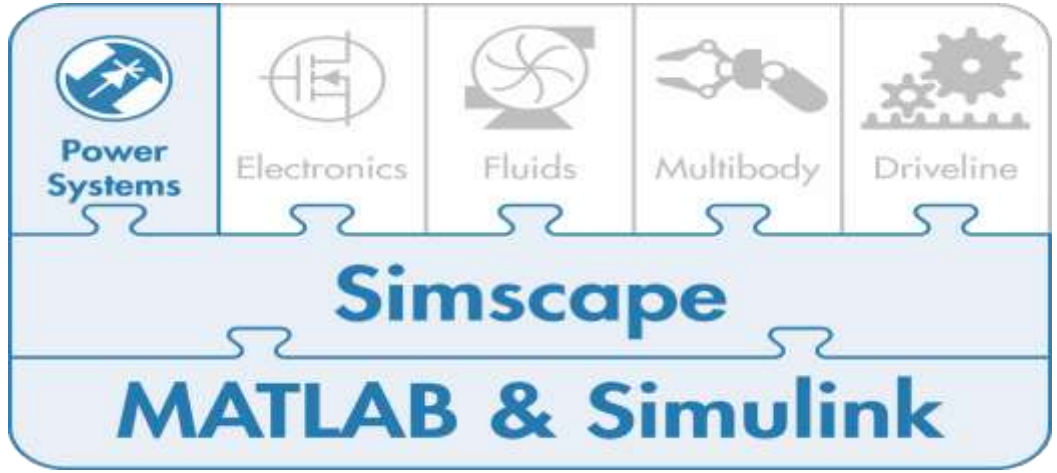


Introduction to Simscape Power Systems

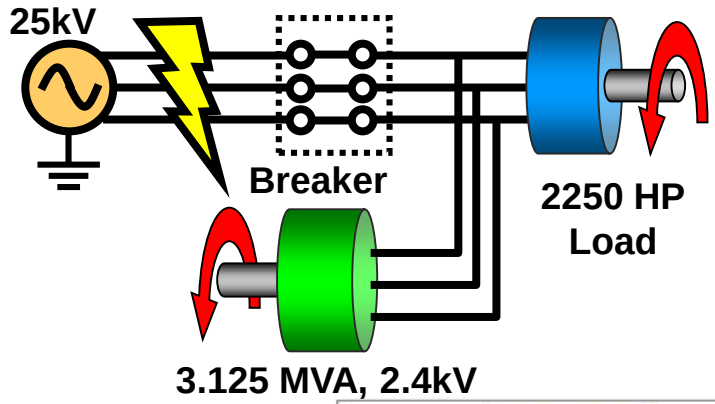


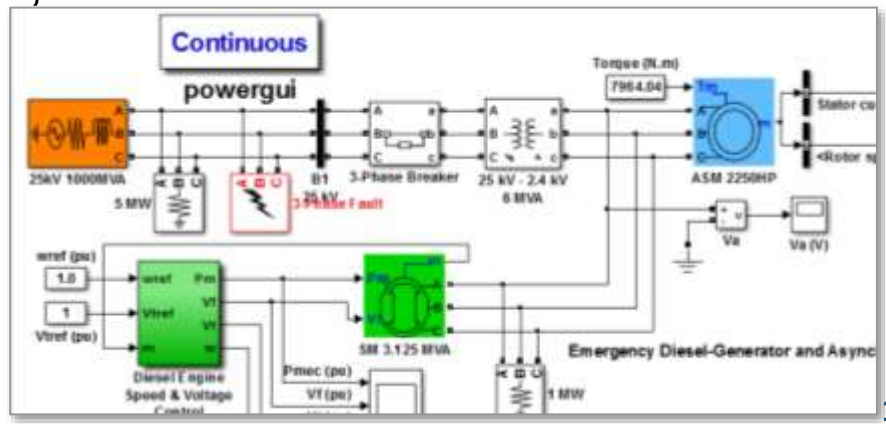


Simscape Power Systems Feature



- Enables physical modeling (acausal) of electrical power systems
- Tight integration with Simulink
- Optimized for system design
- Key features:
  - Comprehensive block libraries, including AC/DC electric drives
  - Discrete and phasor simulation
  - Ideal switching algorithm
  - Steady-state, load flow, FFT, and other analyses

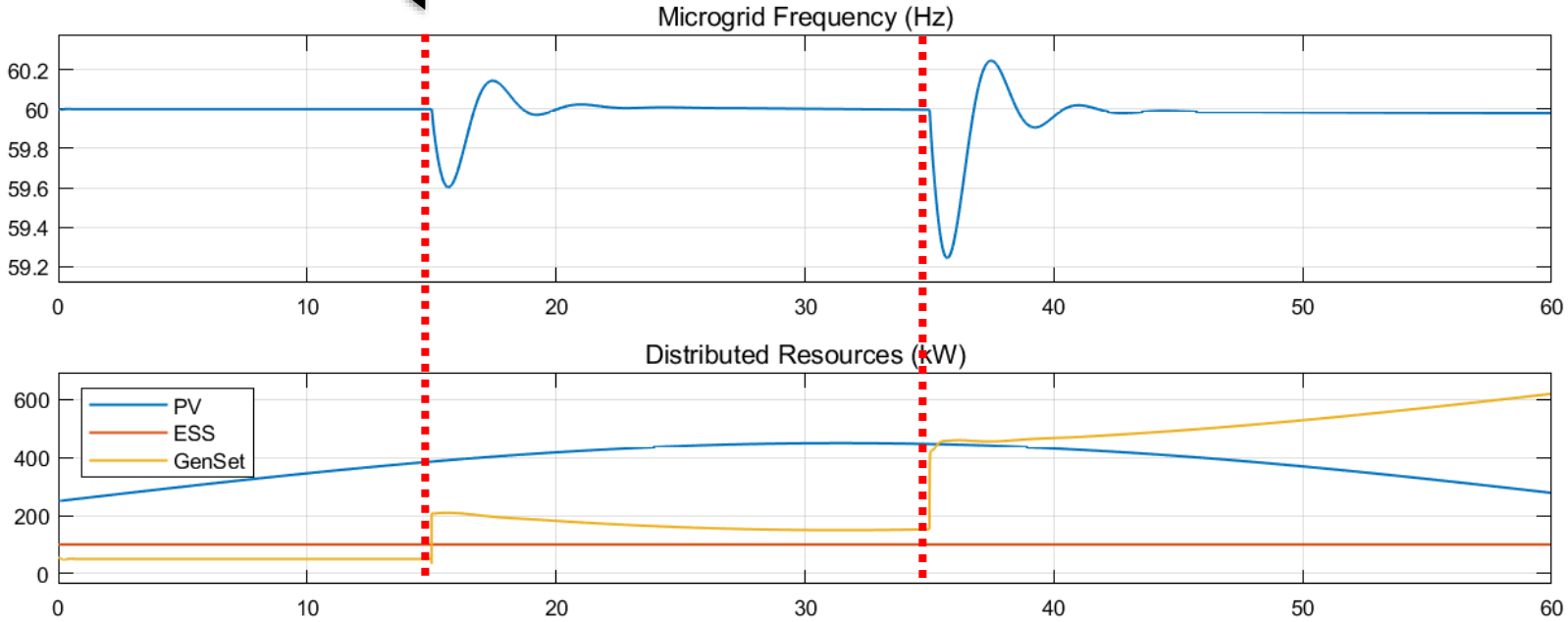


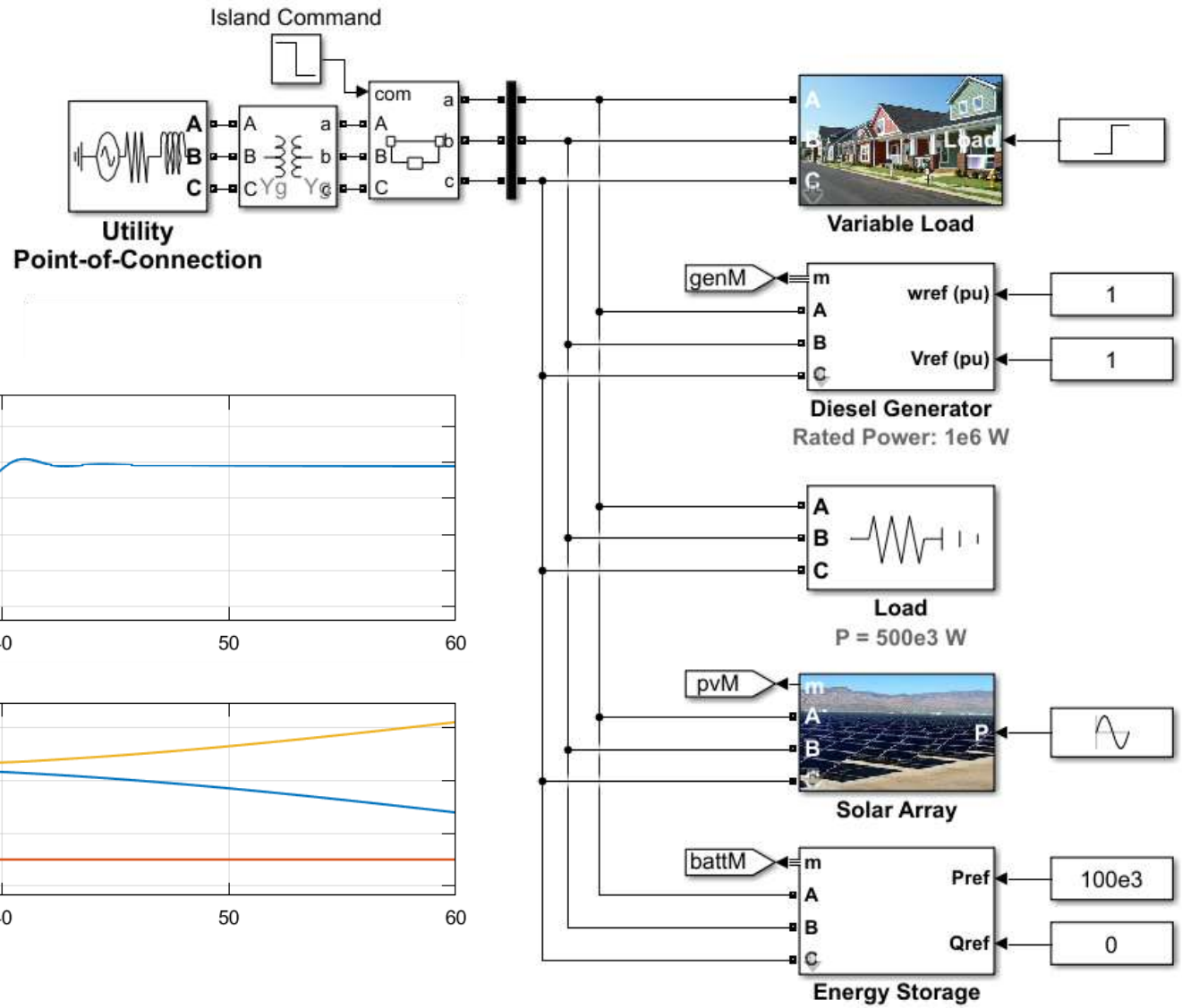


Implementing Microgrid One-Line Diagram in Simulink

Island Microgrid at 15 seconds

Add 300 kW Load at 35 seconds

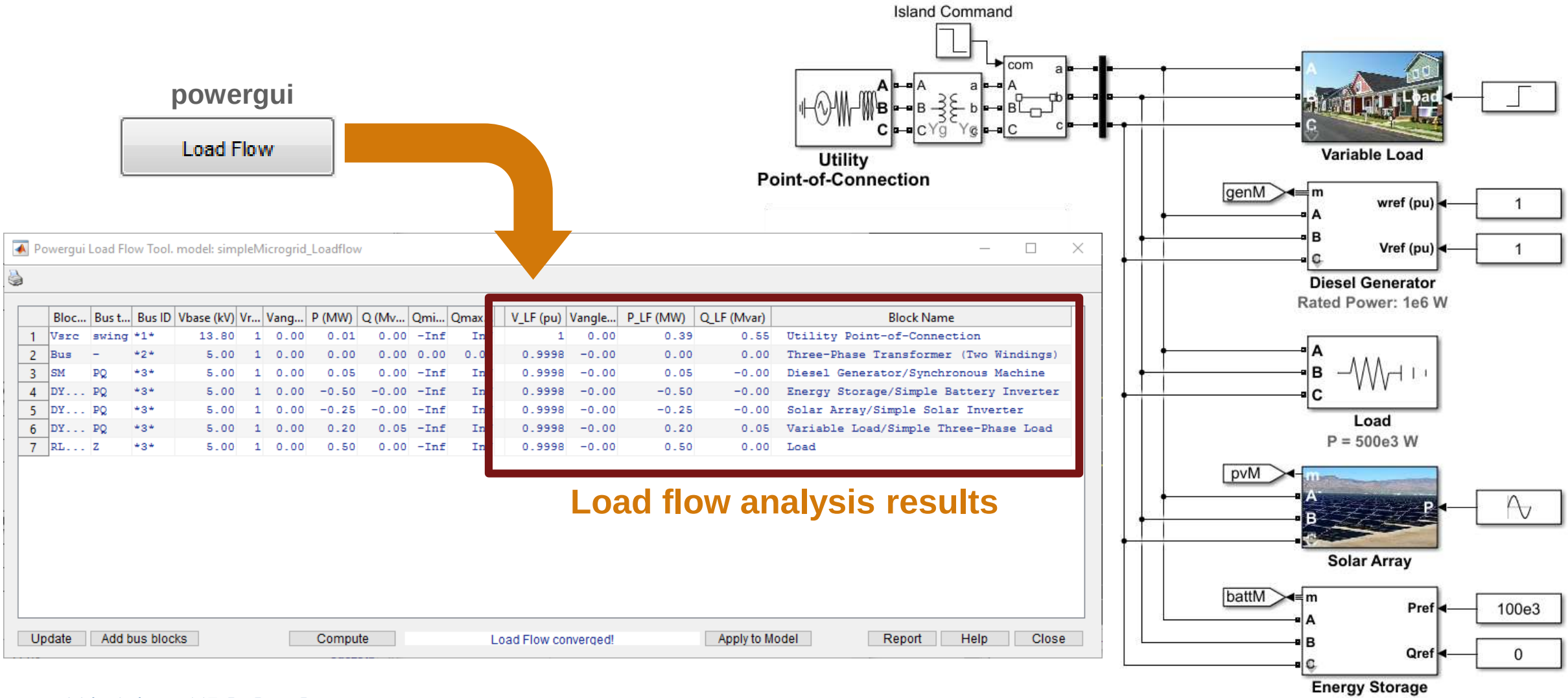




Load Flow Analysis of Schematic

powergui

Load Flow



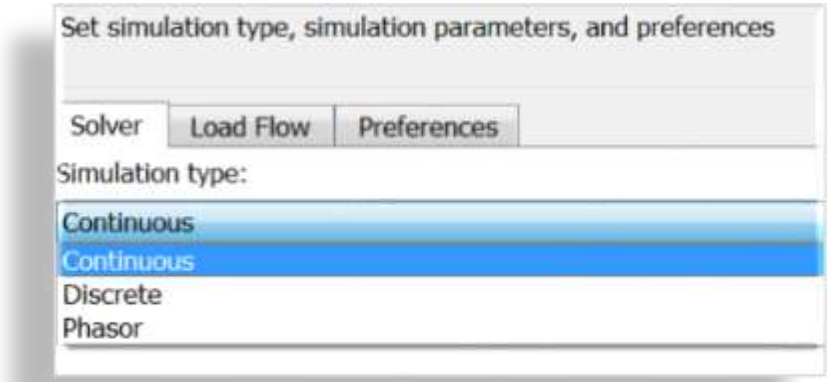
Powergui Load Flow Tool. model: simpleMicrogrid_Loadflow

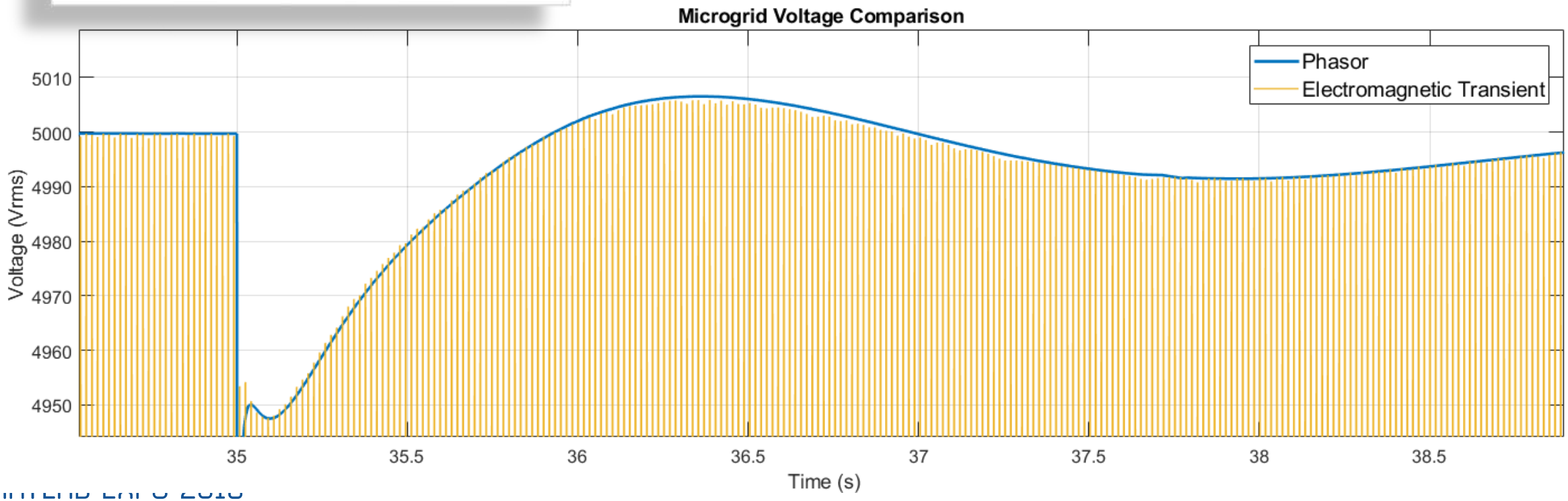
	Bloc...	Bus t...	Bus ID	Vbase (kV)	Vr...	Vang...	P (MW)	Q (Mv...	Qmi...	Qmax	V_LF (pu)	Vangle...	P_LF (MW)	Q_LF (Mvar)	Block Name
1	Vsrc	swing	*1*	13.80	1	0.00	0.01	0.00	-Inf	In	1	0.00	0.39	0.55	Utility Point-of-Connection
2	Bus	-	*2*	5.00	1	0.00	0.00	0.00	0.00	0.0	0.9998	-0.00	0.00	0.00	Three-Phase Transformer (Two Windings)
3	SM	PQ	*3*	5.00	1	0.00	0.05	0.00	-Inf	In	0.9998	-0.00	0.05	-0.00	Diesel Generator/Synchronous Machine
4	DY...	PQ	*3*	5.00	1	0.00	-0.50	-0.00	-Inf	In	0.9998	-0.00	-0.50	-0.00	Energy Storage/Simple Battery Inverter
5	DY...	PQ	*3*	5.00	1	0.00	-0.25	-0.00	-Inf	In	0.9998	-0.00	-0.25	-0.00	Solar Array/Simple Solar Inverter
6	DY...	PQ	*3*	5.00	1	0.00	0.20	0.05	-Inf	In	0.9998	-0.00	0.20	0.05	Variable Load/Simple Three-Phase Load
7	RL...	Z	*3*	5.00	1	0.00	0.50	0.00	-Inf	In	0.9998	-0.00	0.50	0.00	Load

Update | Add bus blocks | Compute | Load Flow converged! | Apply to Model | Report | Help | Close

Load flow analysis results

Phasor and Electromagnetic Transient(EMT) Comparison





Hybrid Phasor-EMT Simulation

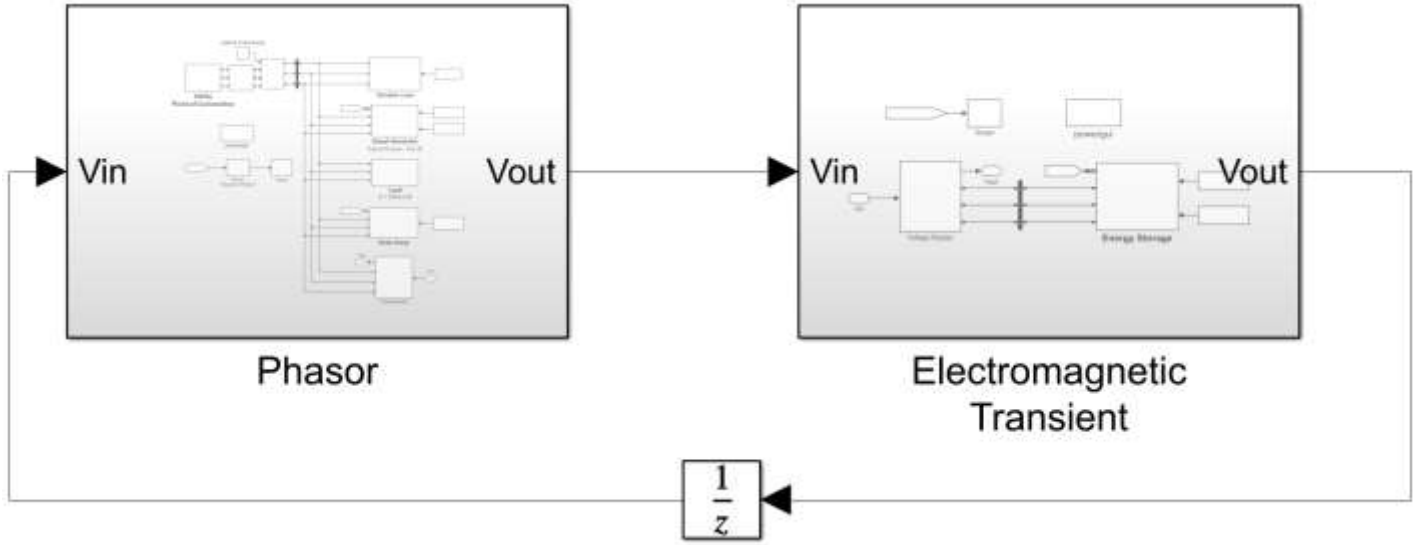
Phasor
60 Hz

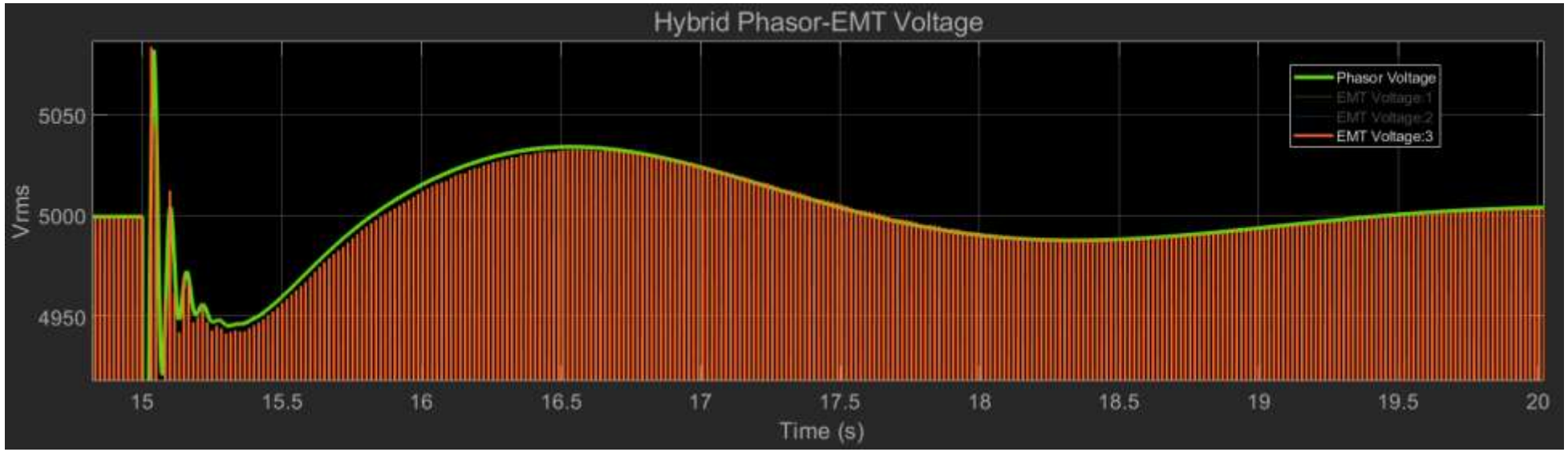
powergui

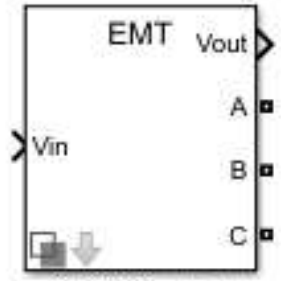
Discrete
0.0001 s.

powergui

Different "powergui" settings per subsystem

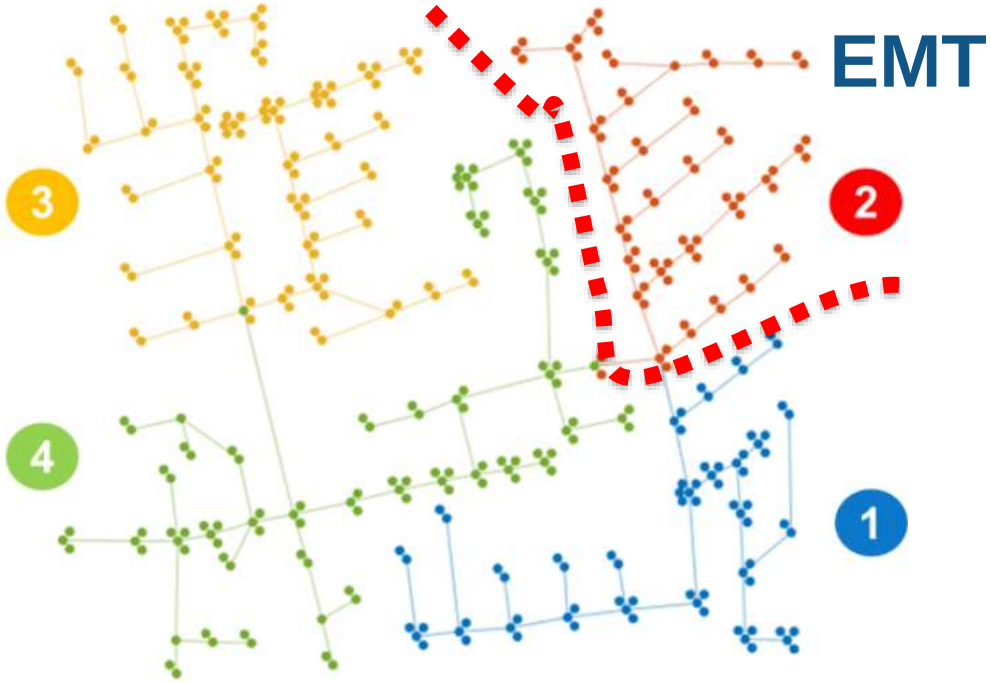


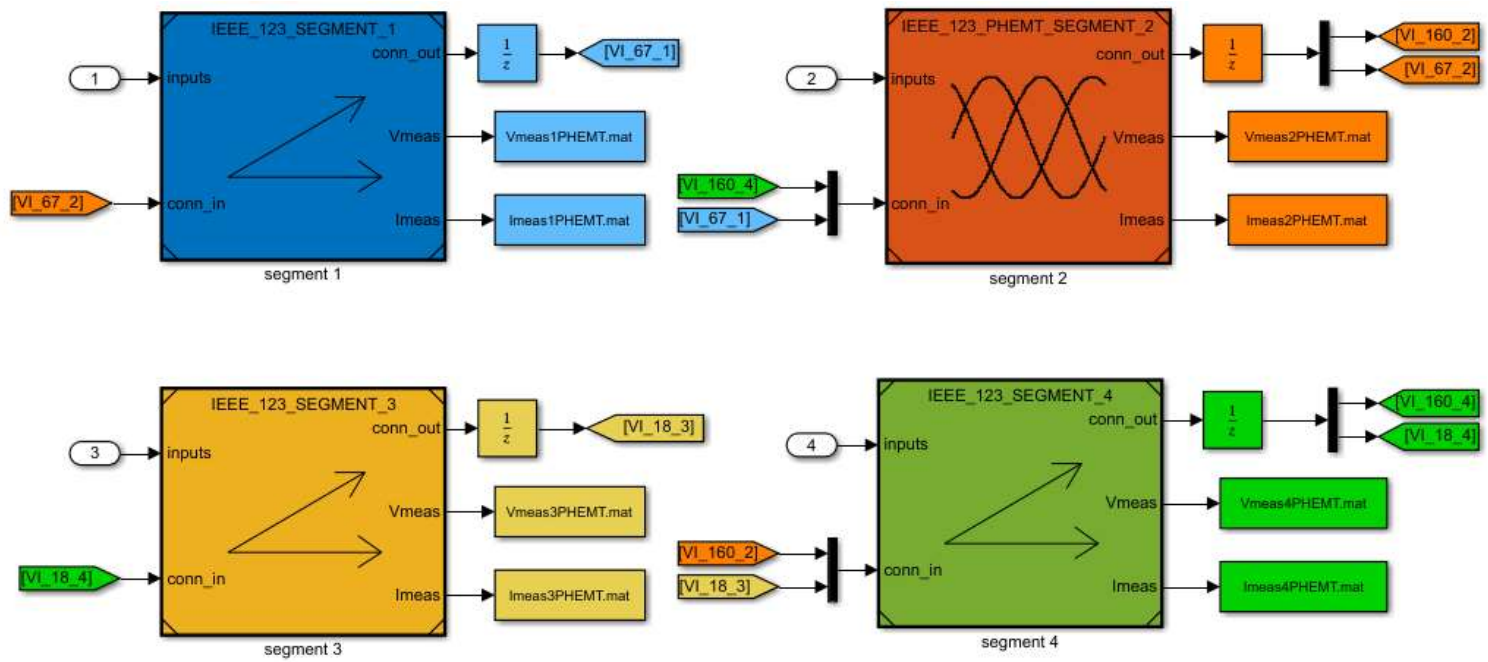




Hybrid Phasor-EMT Simulation

Scaling up simulation size – IEEE 123 Node Distribution Feeder with Hybrid Phasor-EMT



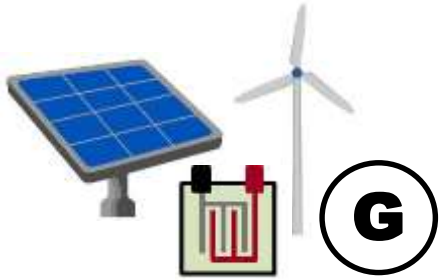


Agenda

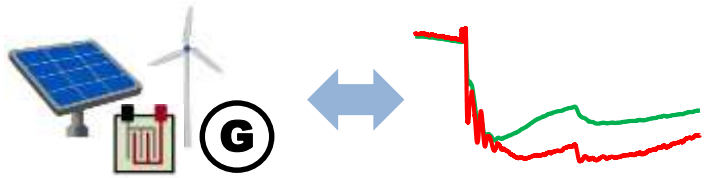
- Microgrid One-Line Diagram – Desktop Simulation
  - Introduction to Simscape Power Systems
  - Hybrid Phasor-EMT Simulation
- Large-Scale Grid System – Real-time Simulation
  - Introduction to Simulink Real-time
  - Case Study 1: Reactive Power Management of Wind Farm
  - Case Study 2: IEEE 123 Node Distribution Network
- What's New about Simscape Power Systems?

Renewable/Microgrid Series Topics

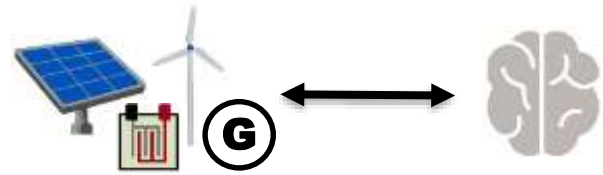
Distributed and Renewable Systems
Modeling and Simulation



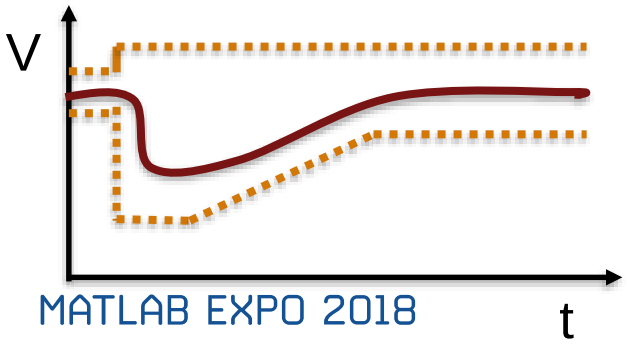
Addressing Validation Requirements
Integrated Workflows



Energy Management Systems
Supervisory Control Design

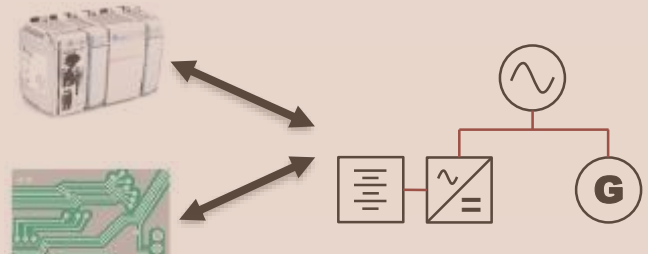


Testing Grid Codes and IEEE Standards
Validating Controls



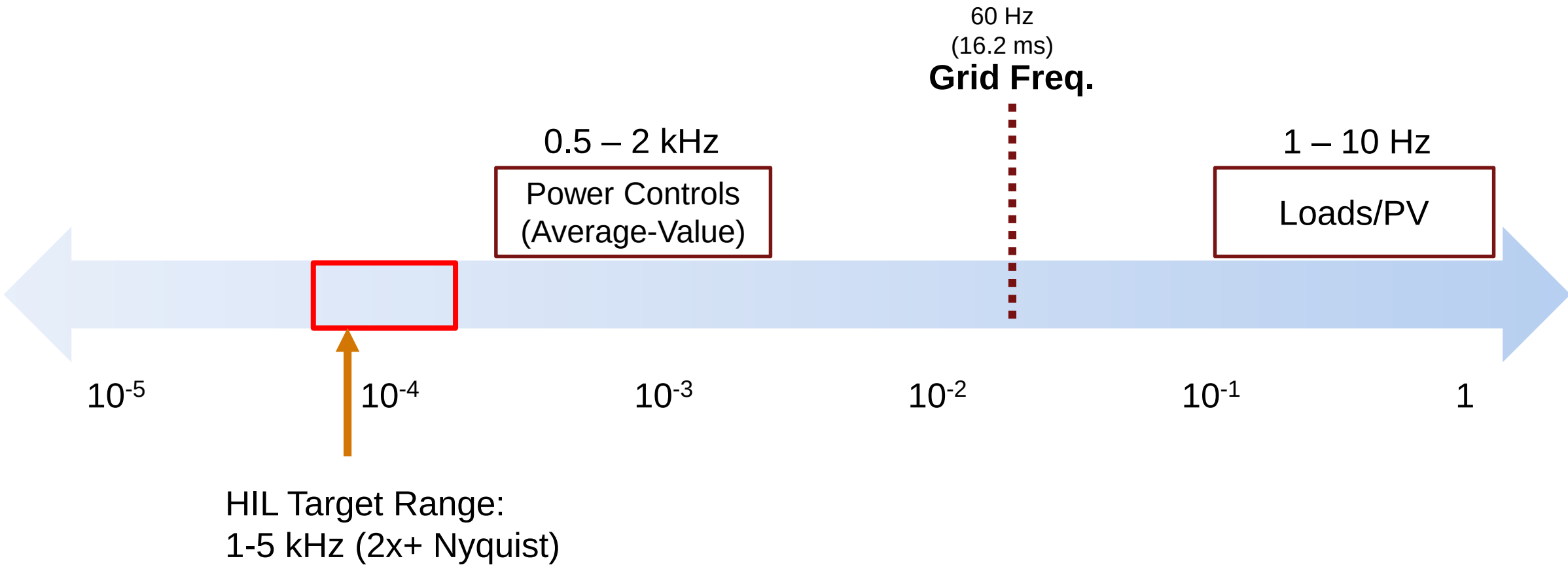
Deploy Vendor Agnostic Algorithms
C and PLC Code Generation

Grid Integration Studies
Real-Time Testing of Controllers



Why Simscape Power Systems and Simulink Real-Time?

Balance of Model Fidelity and Computational Complexity



What is Simulink Real-Time?

From desktop simulation to real time

Creation of real-time applications from Simulink models and loading them onto dedicated target computer hardware in 3 automated steps:

1. Code Generation
2. Compile and Link
3. Download and Ready to Run

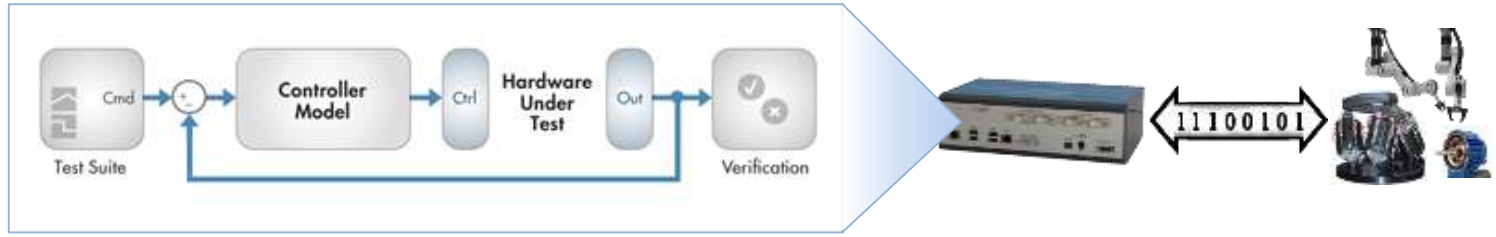
What is Simulink Real-Time?

Connect to your physical system

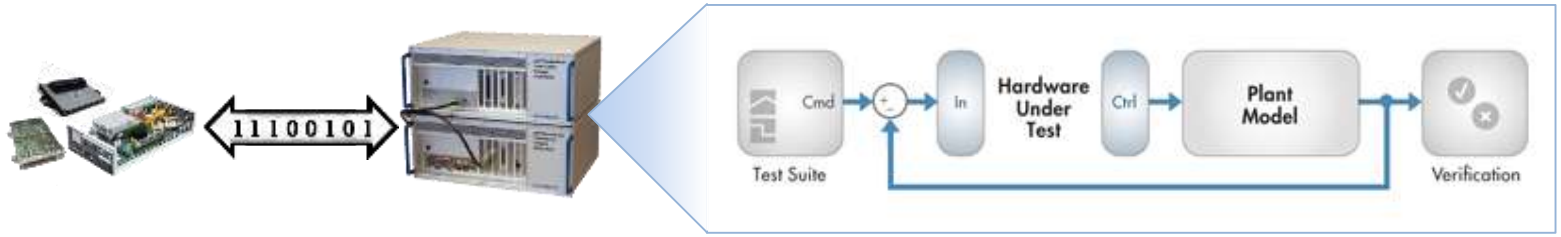
- Support for a broad range of I/O types and communication protocols
- Easy drag and drop and configuration within a Simulink model

Real-Time Simulation and Testing Tasks

- Rapid Control Prototyping



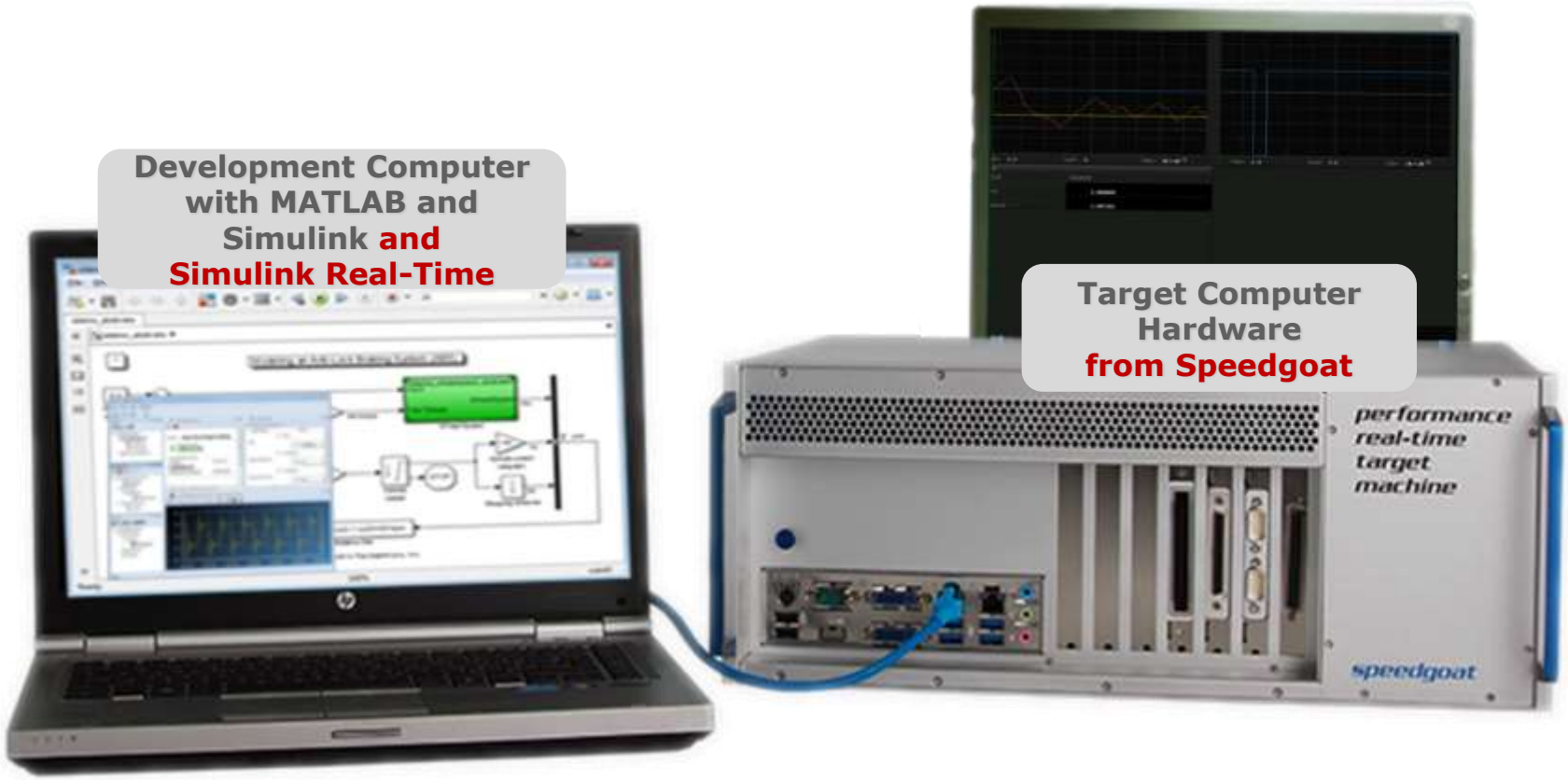
- Hardware-in-the-loop simulation (HIL)



- Parametric evaluation and performance assessment
  - System robustness
  - Human factors
  - Calibration

What Hardware is used with Simulink Real-Time?

Development computer + target computer



Speedgoat Provides Real-Time Target Machines

Made for use with Simulink Real-Time

Speedgoat develops and sells Real-Time target machines consisting of

- An industrial computer (Real-time target machine)
- I/O modules
- Software drivers, cables and tools to connect with a prototype

Simulink Real-Time and Speedgoat target computer hardware are expressly designed to work together

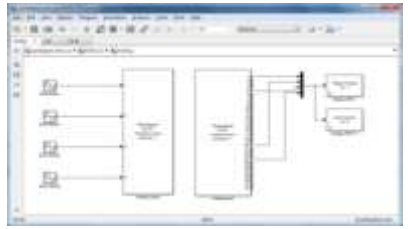
Real-time target machine

I/O modules installed in target machine

I/O Cable

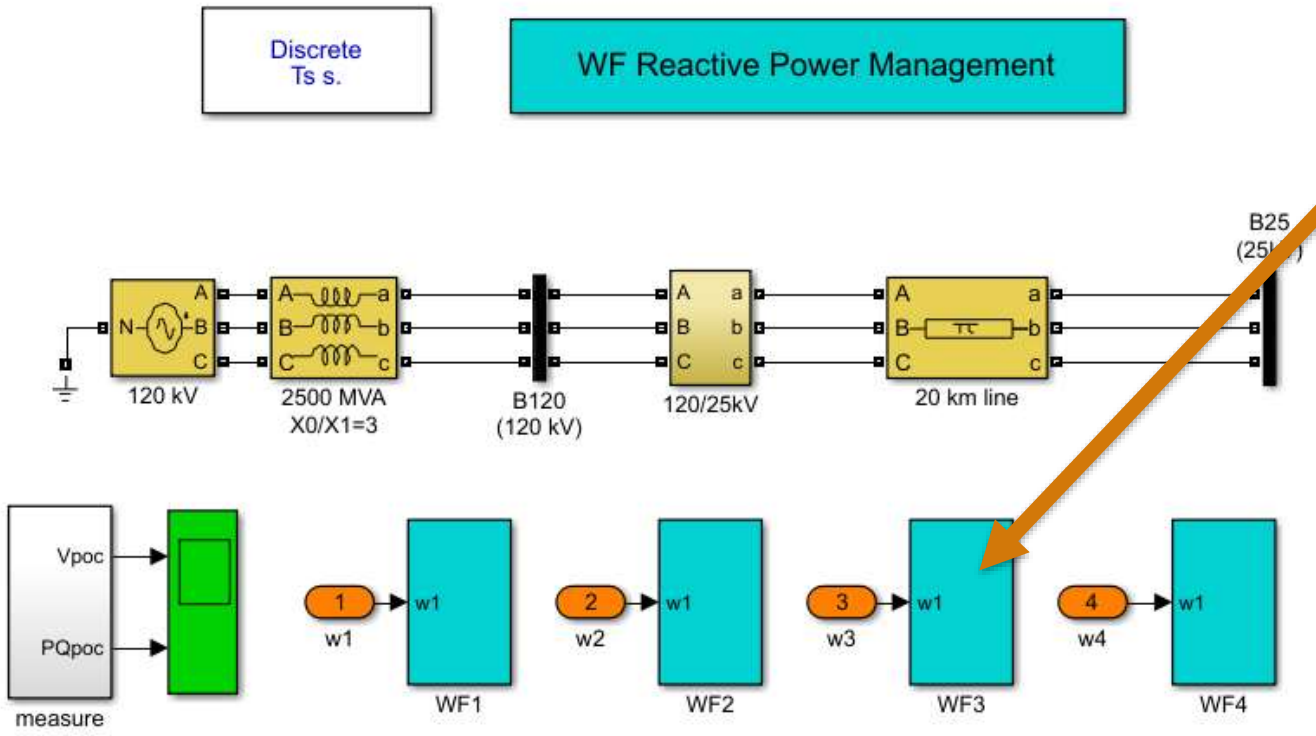
Terminal board

Simulink drivers

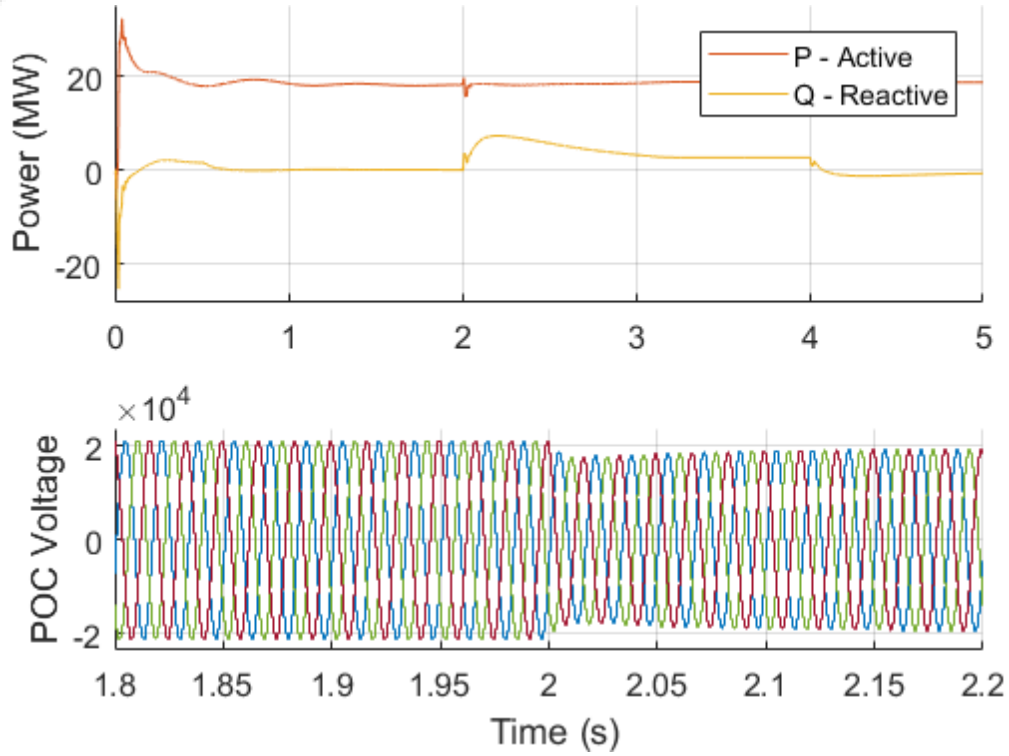


Simulink test models

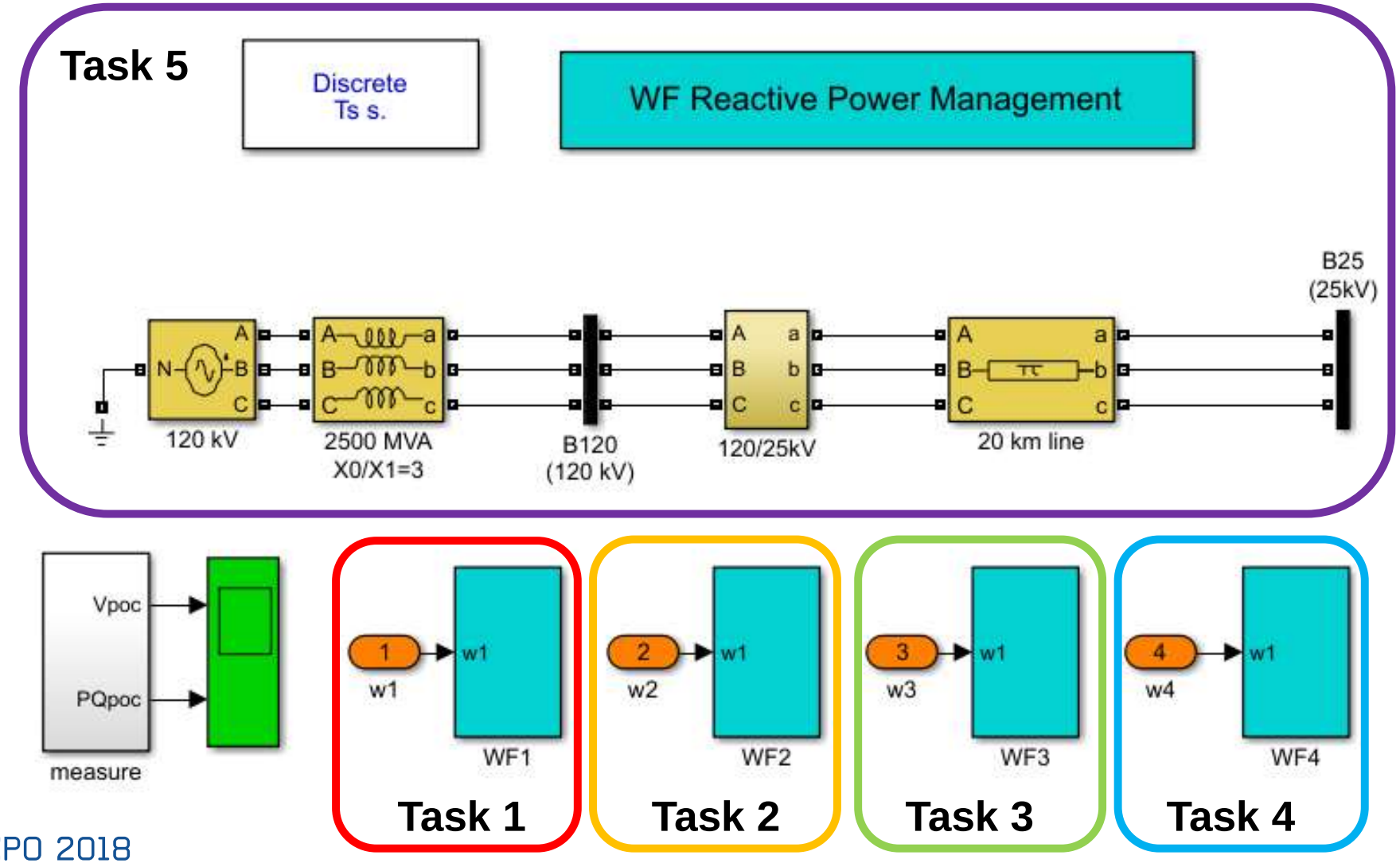
Case Study 1: Reactive Power Management of Wind Farm



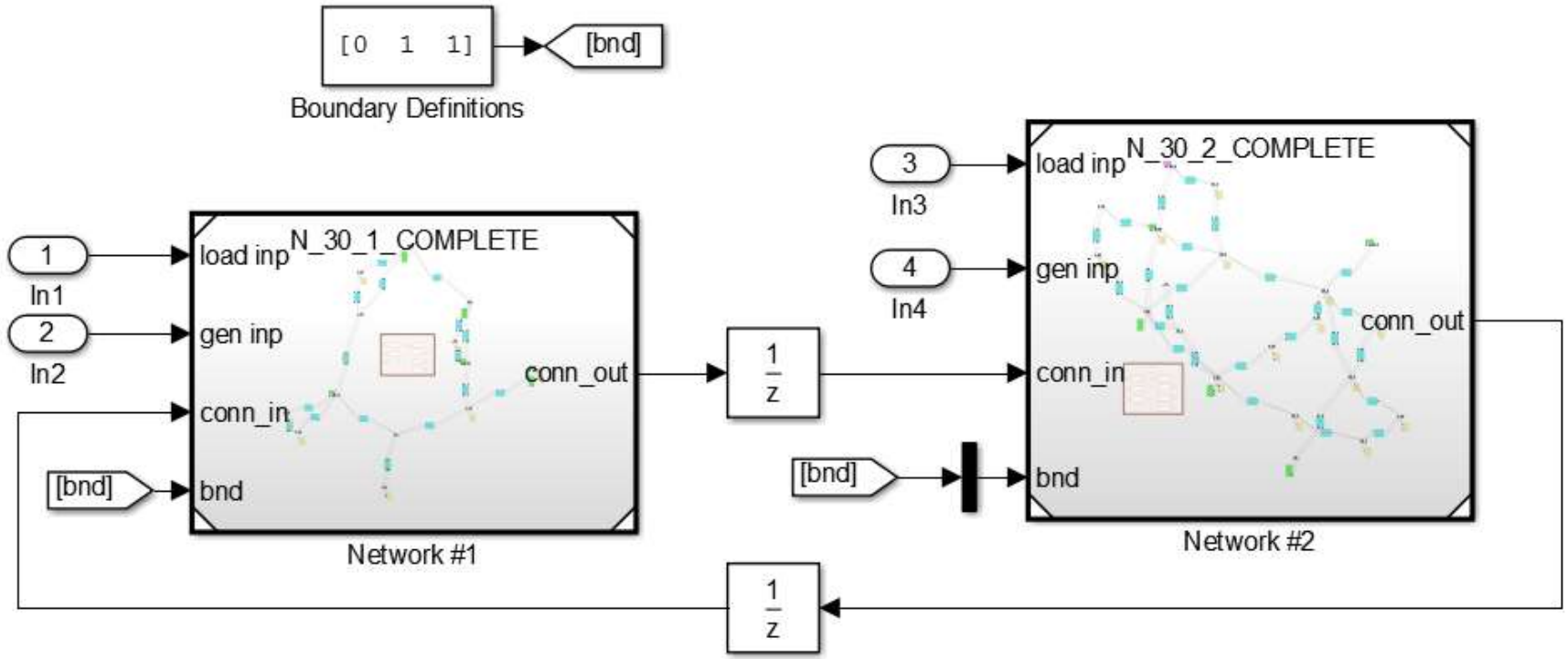
Five DFIG Wind Turbines (Total of 20)



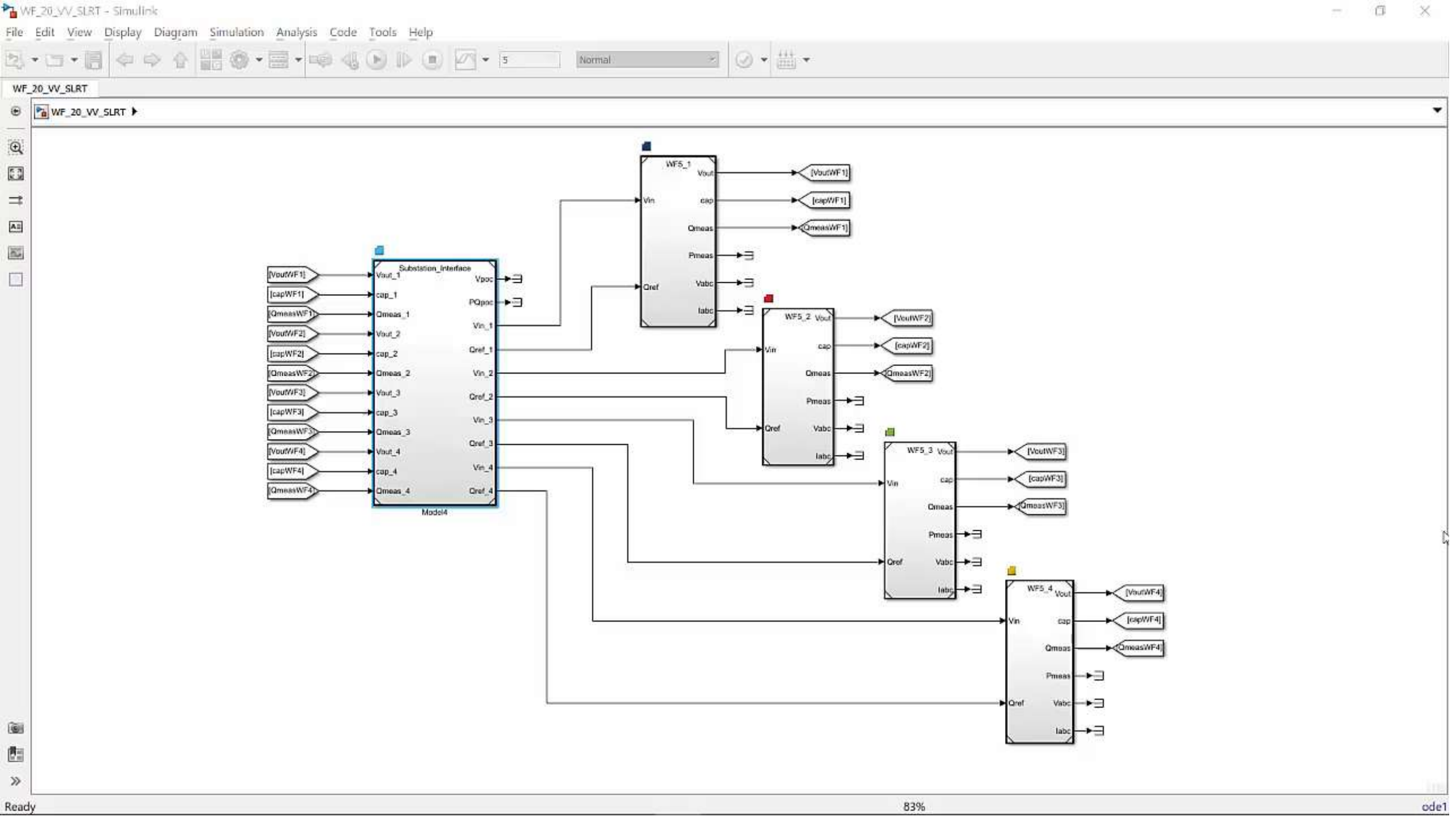
Leveraging Multi-core Real-time Machines to Improve Sample Time



Model Reference for Sub-Networks



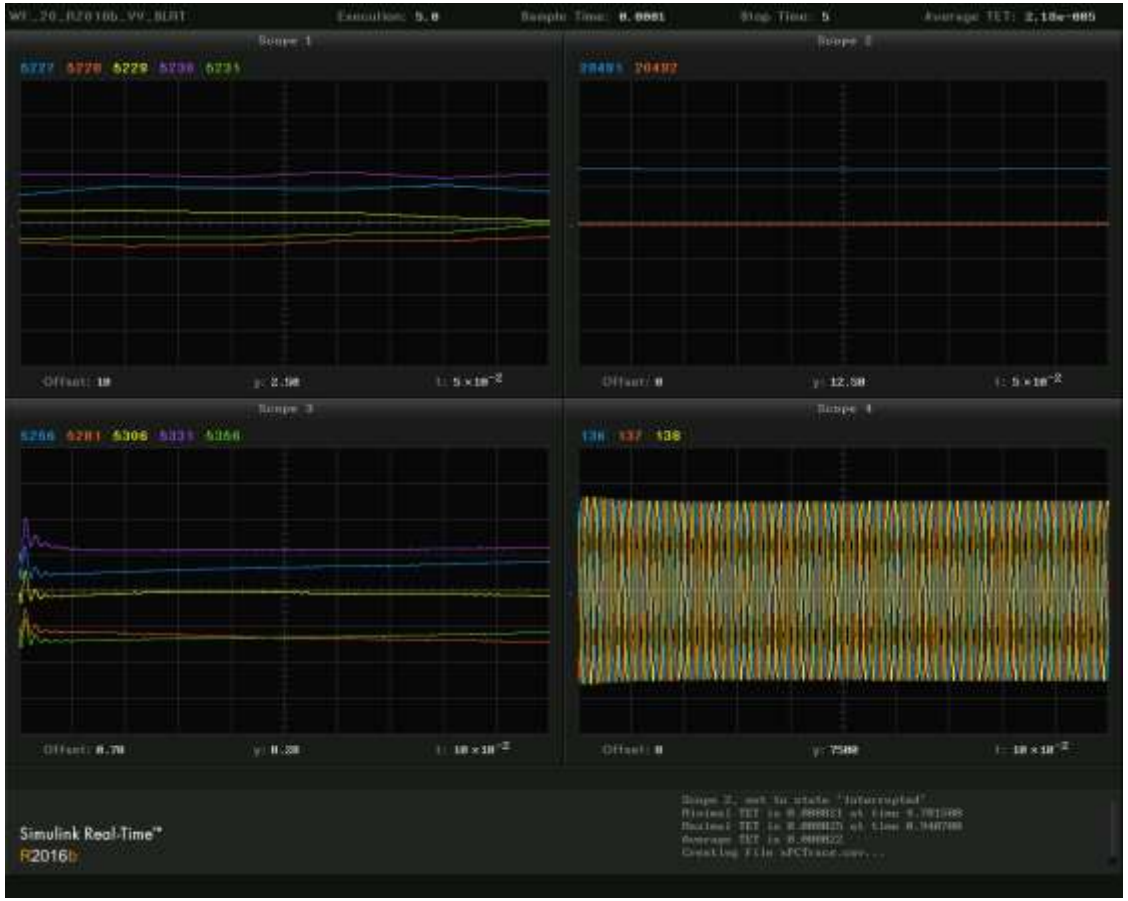
- Model Reference for improved memory management and parallel build to facilitate the creation of ‘larger’ networks.
- Replay of Synchrophasor data through an electrical network segment
- Simulink Real Time concurrent execution

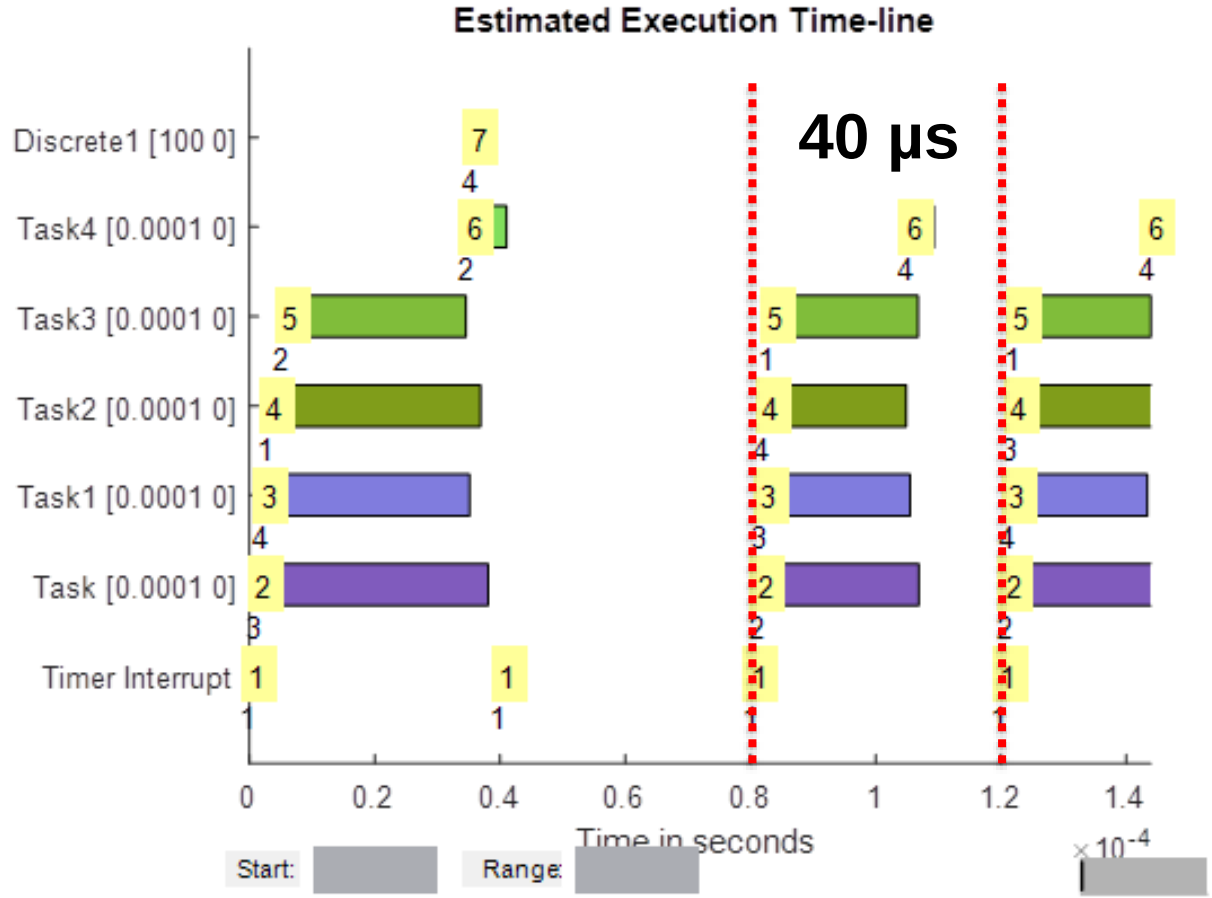

WF_20_VV_SLRT - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
Normal
WF_20_VV_SLRT
WF_20_VV_SLRT
Substation_Interface
Vout_1
cap_1
Qmeas_1
Vout_2
cap_2
Qmeas_2
Vout_3
cap_3
Qmeas_3
Vout_4
cap_4
Qmeas_4
Vpoc
PQpoc
Vin_1
Qref_1
Vin_2
Qref_2
Vin_3
Qref_3
Vin_4
Qref_4
Model4
[VoutWF1]
[capWF1]
[QmeasWF1]
[VoutWF2]
[capWF2]
[QmeasWF2]
[VoutWF3]
[capWF3]
[QmeasWF3]
[VoutWF4]
[capWF4]
[QmeasWF4]
WF5_1
WF5_2
WF5_3
WF5_4
Vin
Qref
Vout
cap
Qmeas
Pmeas
Vabc
Iabc
Ready
83%
ode1


Execution: 25.0
Sample Time: 0.00025
Stop Time: 25
Scope 1
Wind Speeds (Farm 2)
Scope 2
20401 20402
PQ at POC
Pmeas (Farm 2)
Vabc (Farm 1)

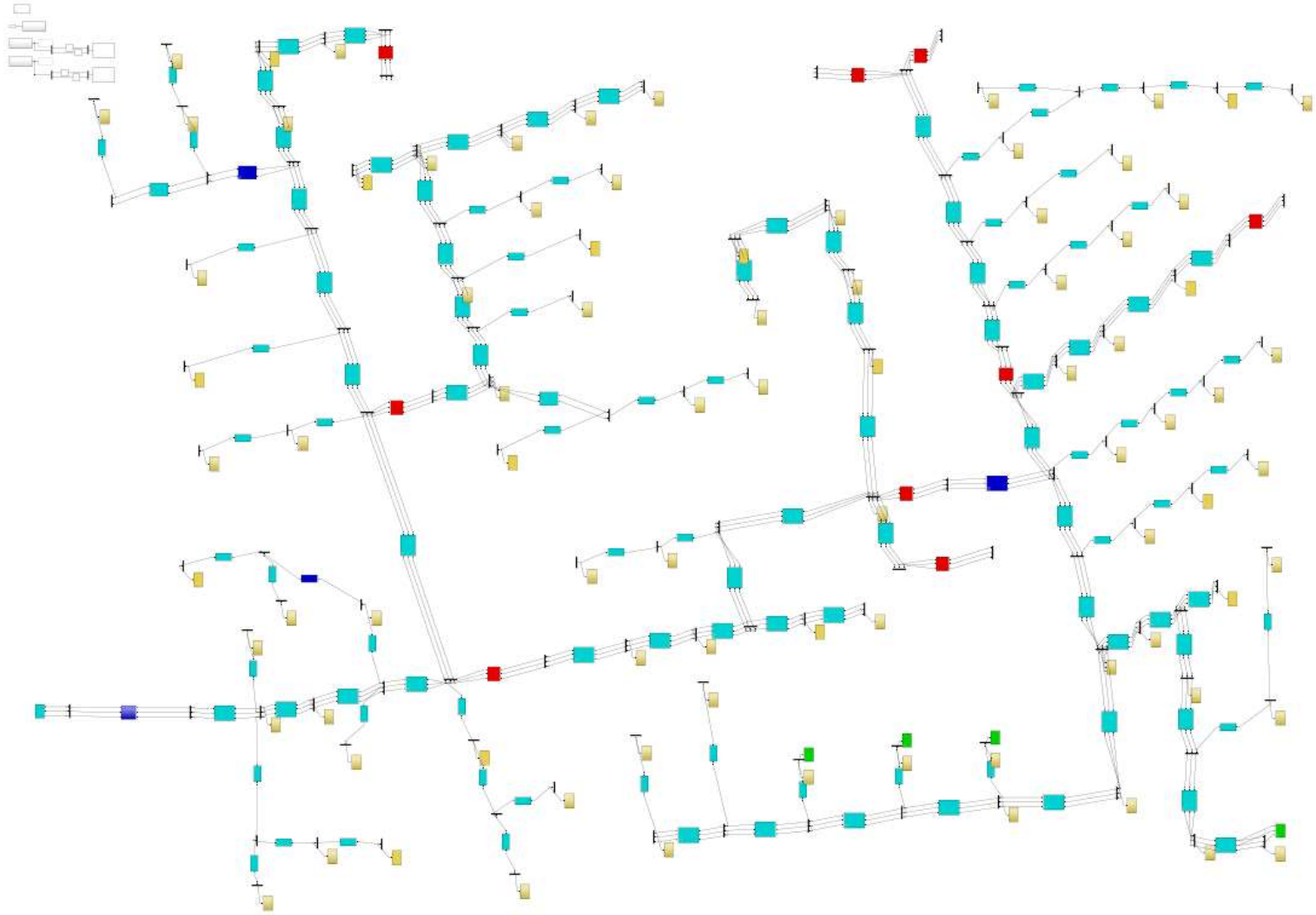
Wind Farm Real-Time Case Study

Speedgoat with Intel quad-core i7 (4 GHz)

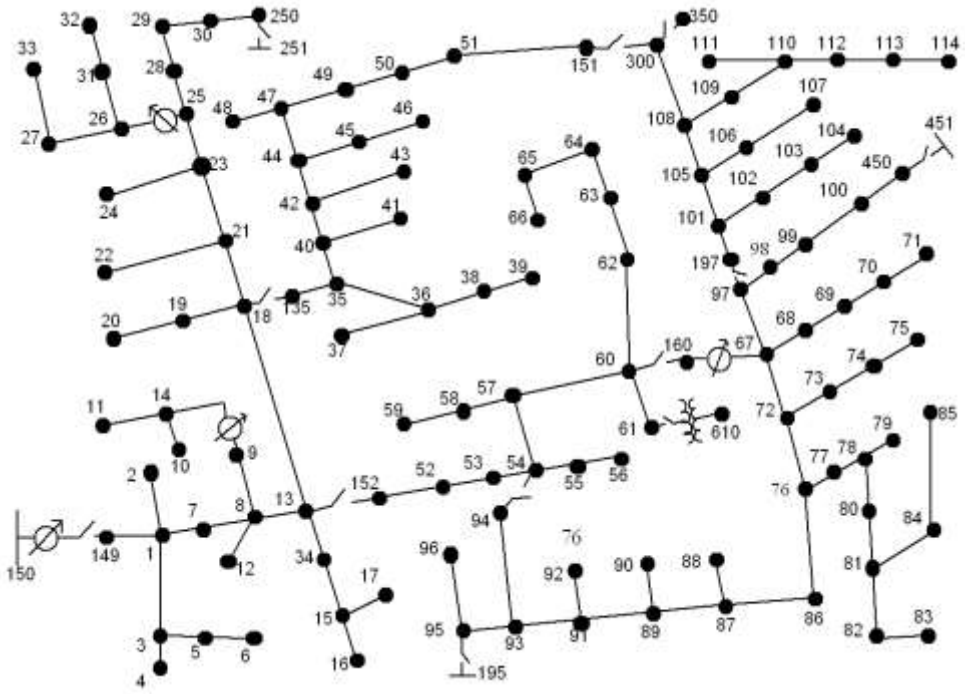




Case Study 2: IEEE 123 Node Distribution Network

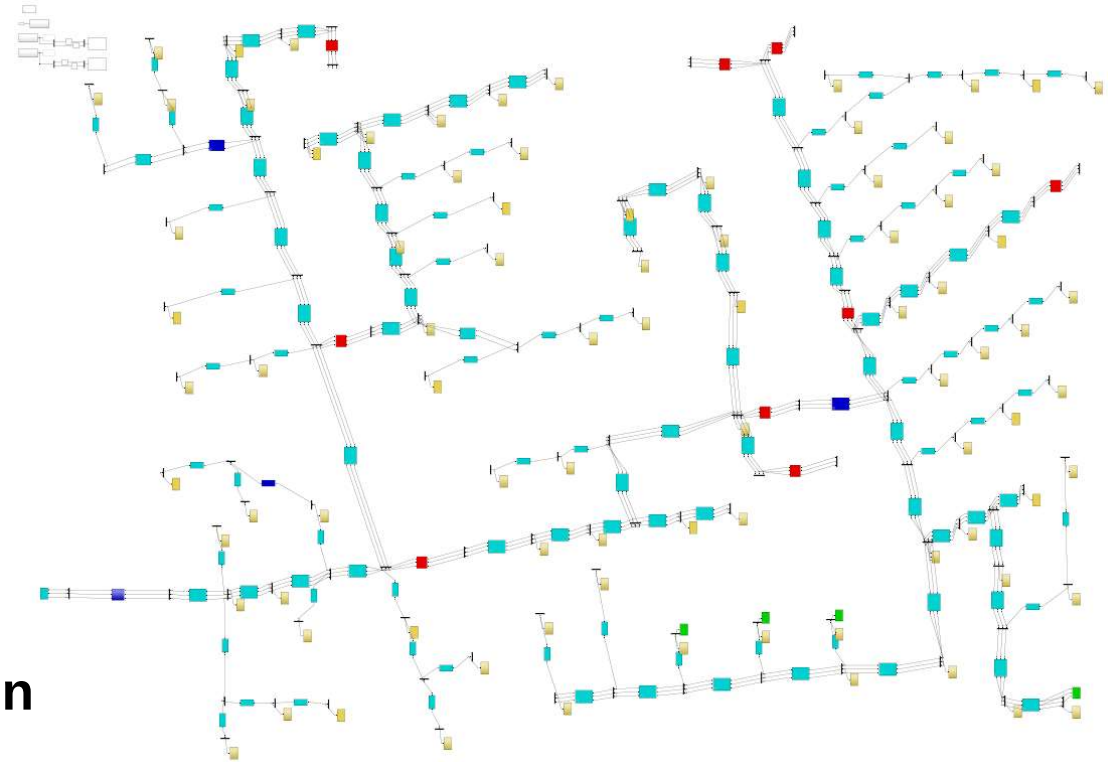


Large-Scale Distribution Network



IEEE 123 Node Test Feeder *

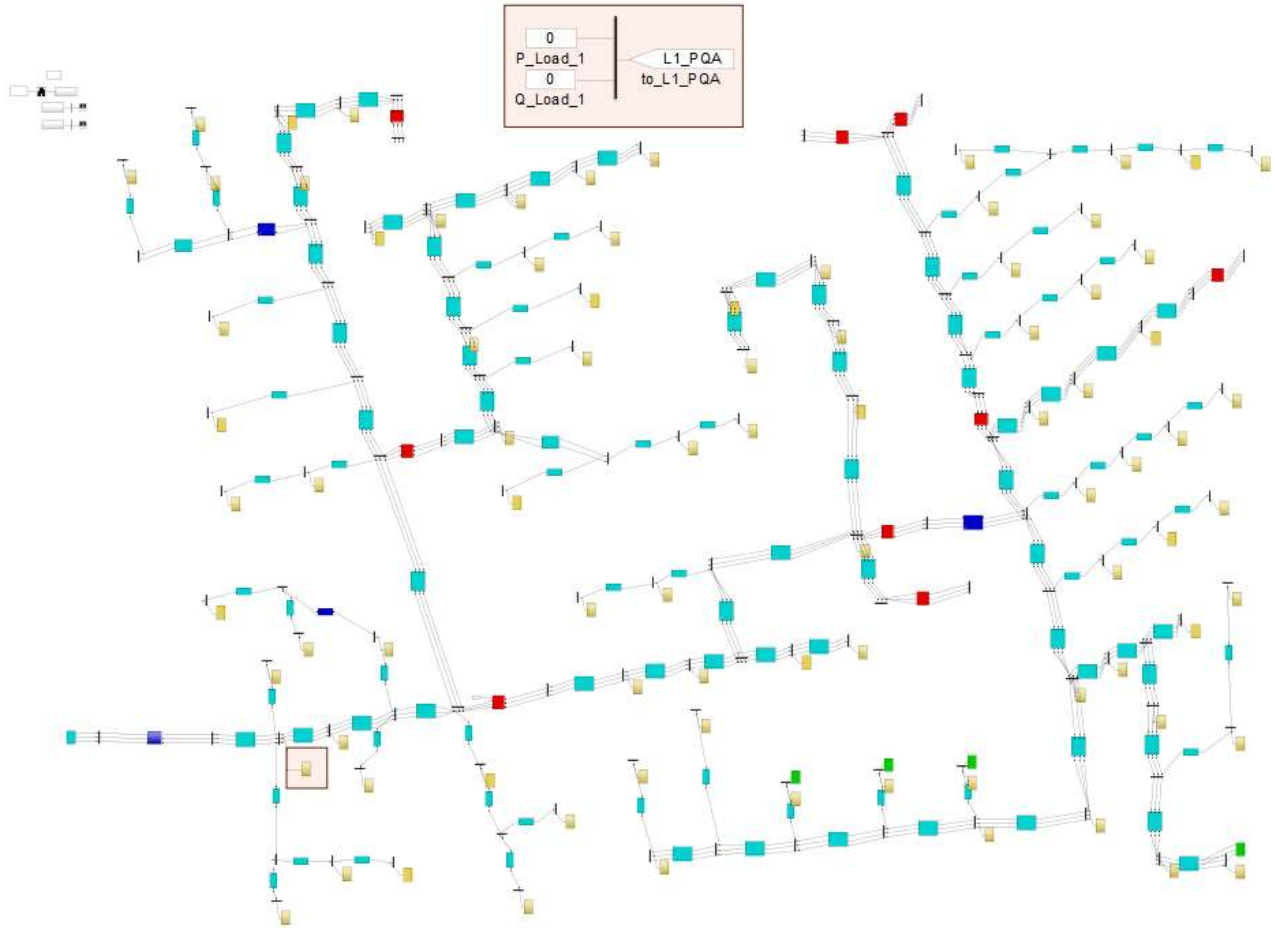
Auto Conversion



Simscape Power System Model

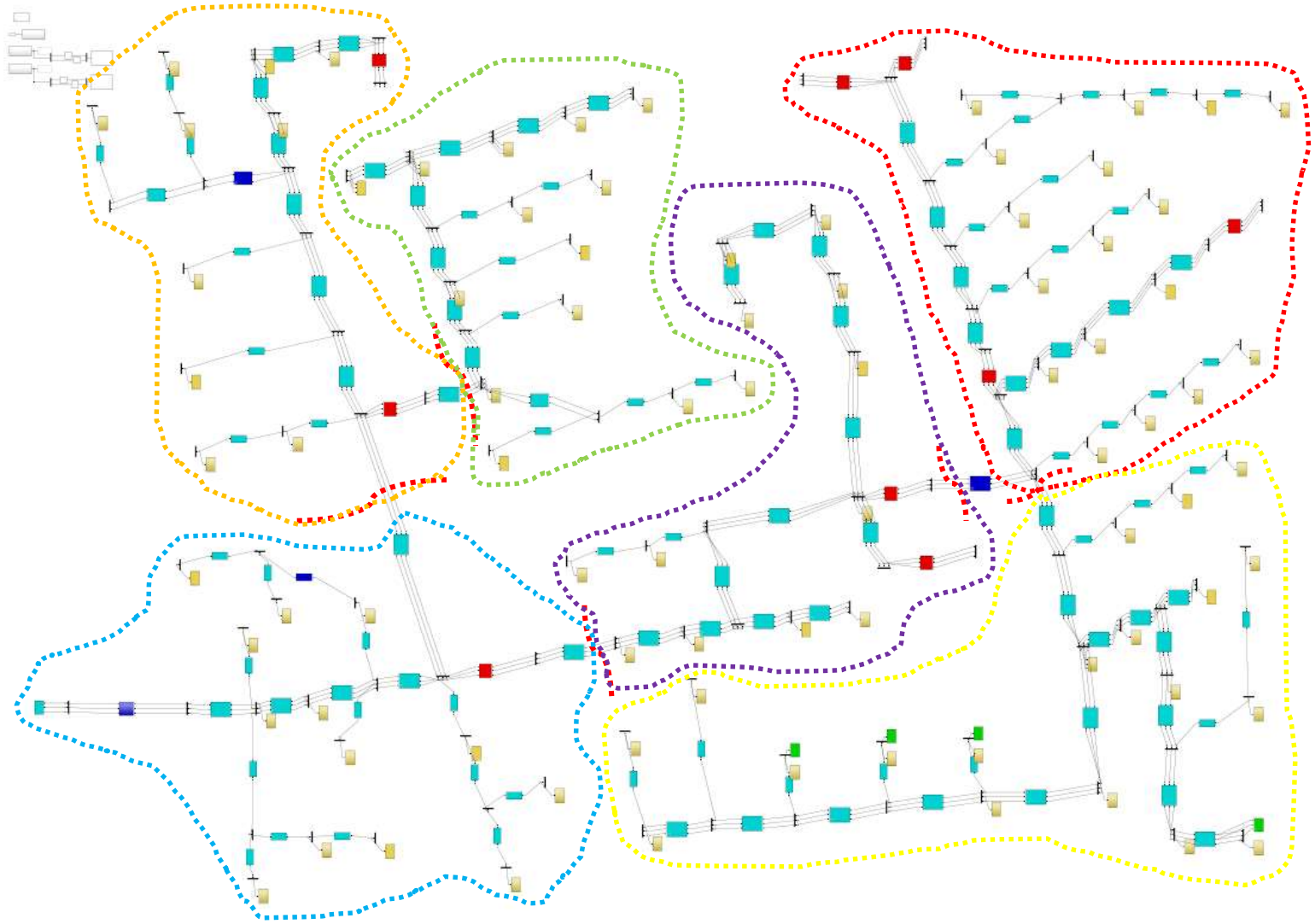
* : IEEE POWER ENGINEERING SOCIETY

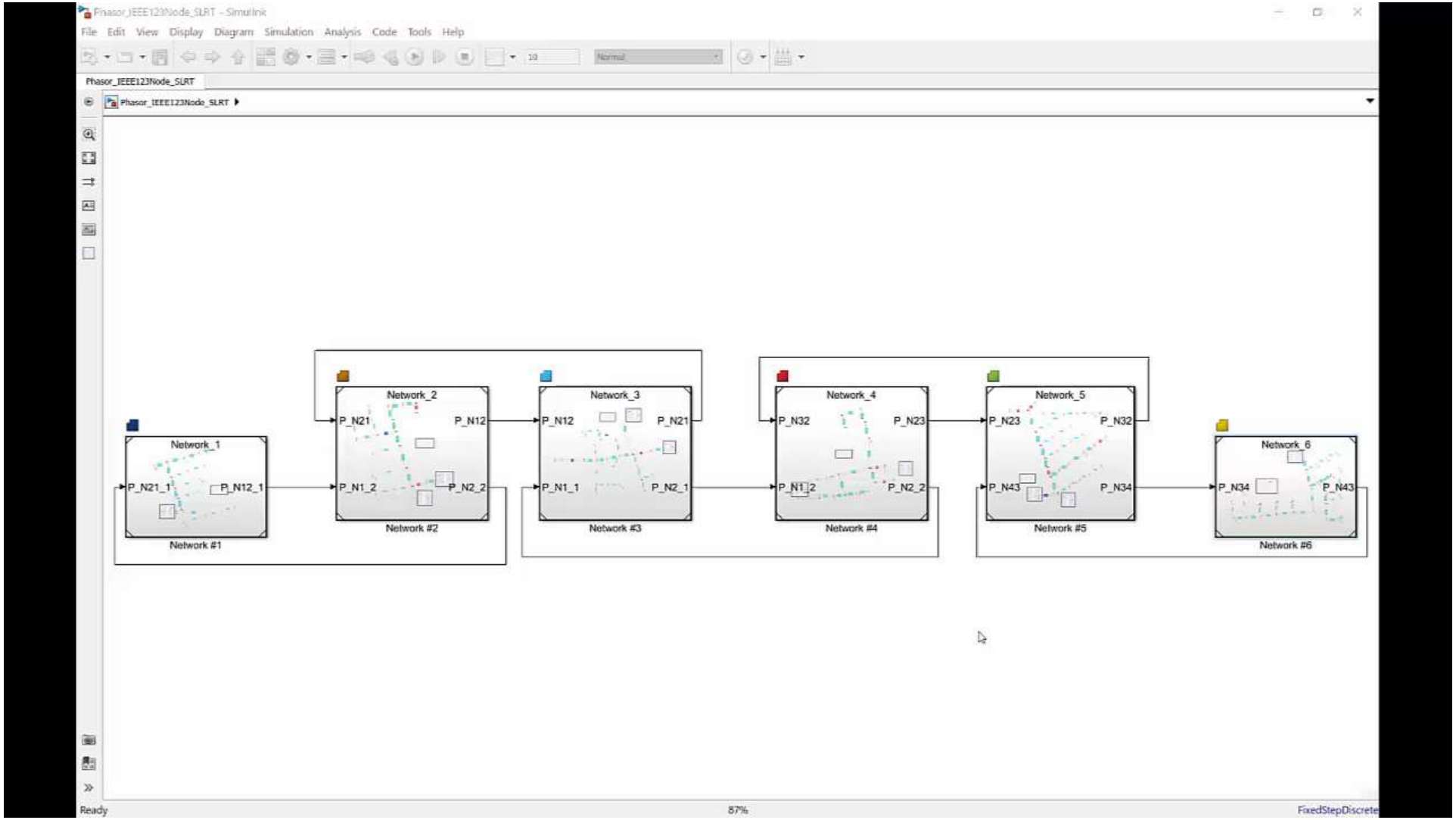
IEEE 123 Node – Single Core



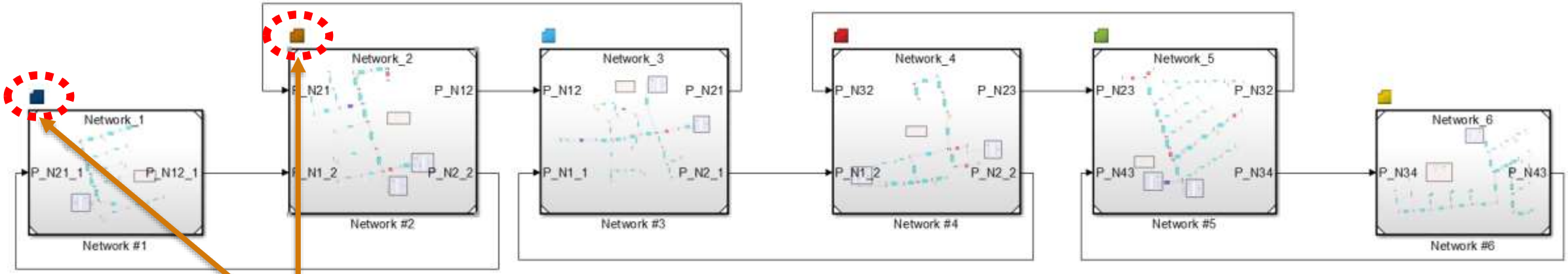
IEEE_123_Phasor – Single Core	Tunable parameters	Inlined parameters
Minimum achievable sample time	474.45 µs	470.58 µs

IEEE 123 Node Distribution Network



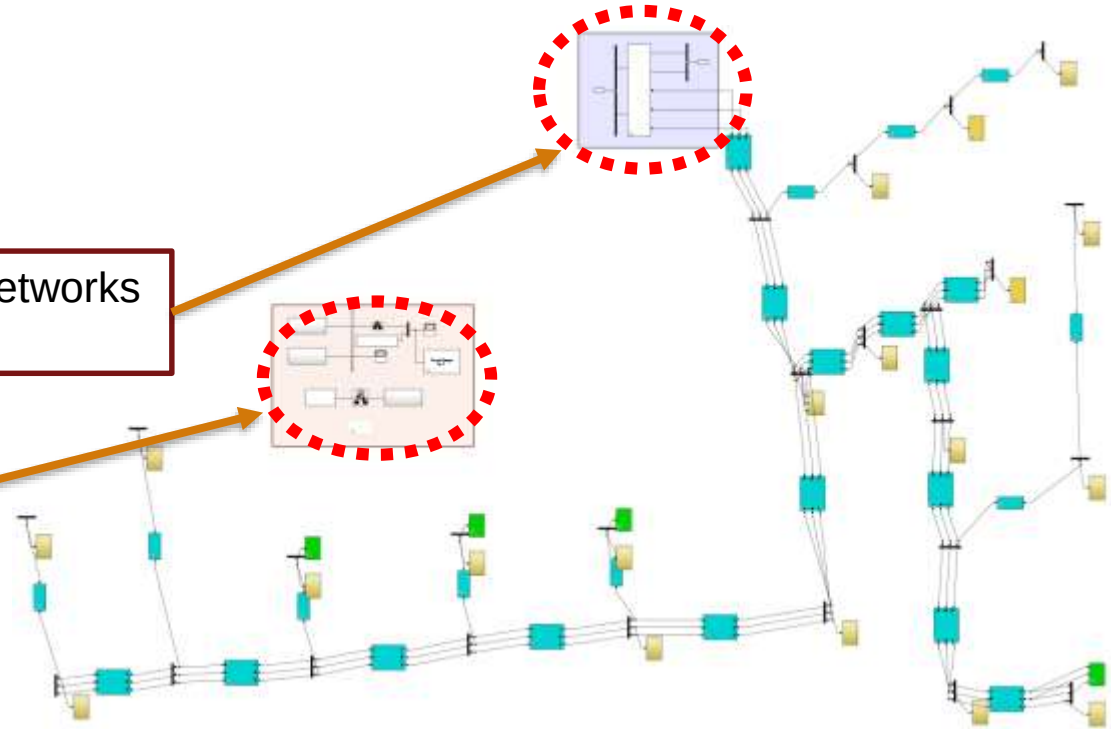

Phasor_IEEE123Node_SLRT - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
Phasor_IEEE123Node_SLRT
Network_1
P_N21_1
P_N12_1
Network #1
Network_2
P_N21
P_N12
P_N1_2
P_N2_2
Network #2
Network_3
P_N12
P_N21
P_N1_1
P_N2_1
Network #3
Network_4
P_N32
P_N23
P_N1_2
P_N2_2
Network #4
Network_5
P_N23
P_N32
P_N43
P_N34
Network #5
Network_6
P_N34
P_N43
Network #6
Ready
87%
FixedStepDiscrete

Real-time IEEE 123 Node on Multi-core



Assign Concurrent Execution (Multicore) Tasks to individual networks

V-I Interface between subnetworks outputs Simulink signals

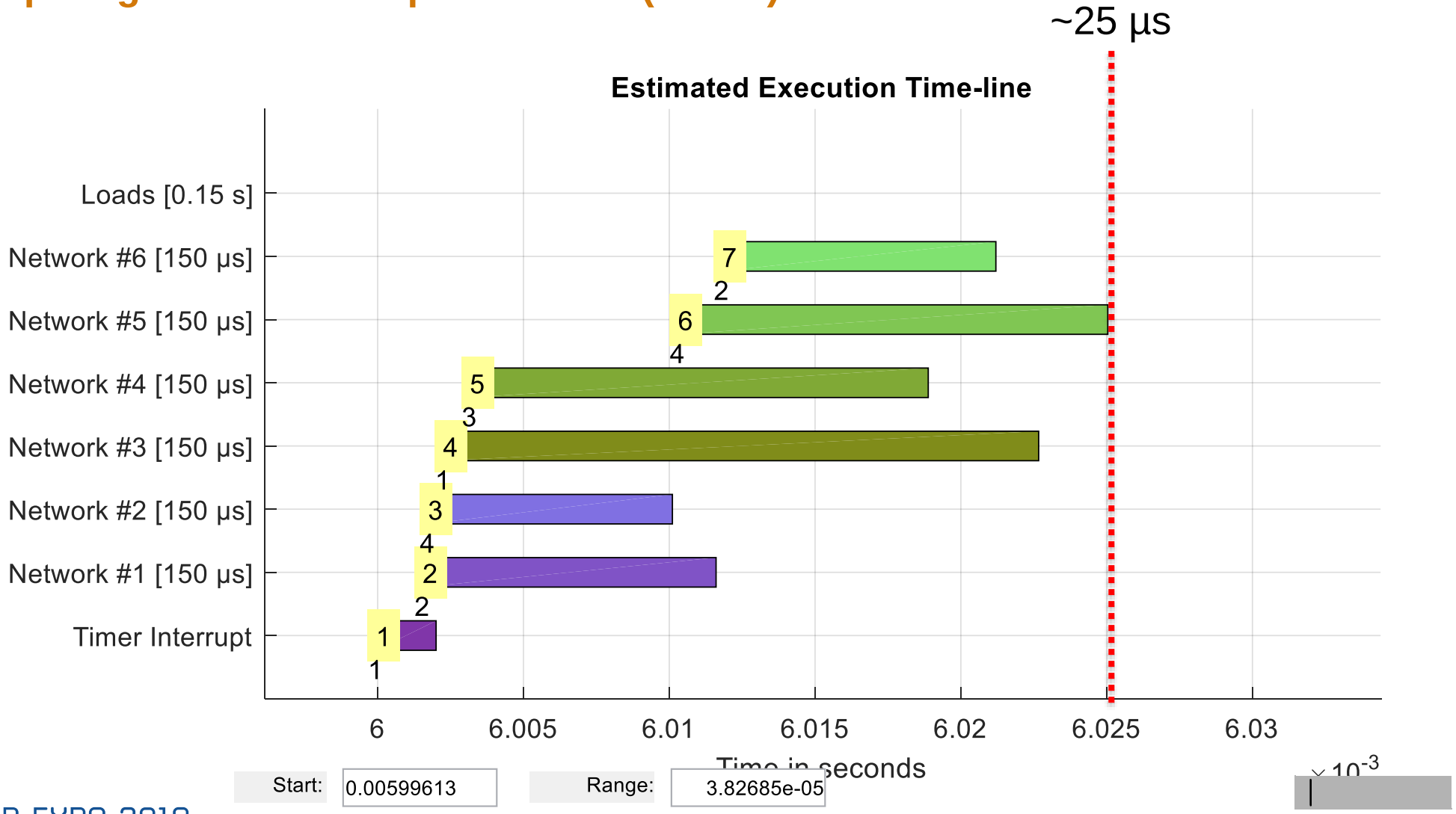


Subnetworks can have different "powergui" solver settings:

- Discrete (EMT)
- Phasor

Task Execution Times (TET) for 150 µs

Speedgoat with Intel quad-core i7 (4 GHz)



Agenda

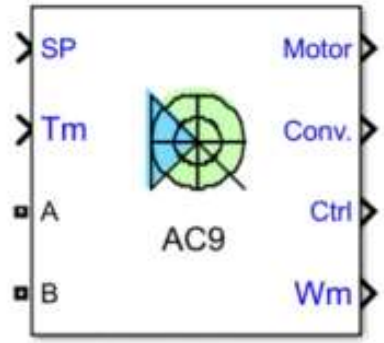
- Microgrid One-Line Diagram – Desktop Simulation
  - Introduction to Simscape Power Systems
  - Hybrid Phasor-EMT Simulation
- Large-Scale Grid System – Real-time Simulation
  - Introduction to Simulink Real-time
  - Case Study 1: Reactive Power Management of Wind Farm
  - Case Study 2: IEEE 123 Node Distribution Network
- What's New about Simscape Power Systems?

Simscape Power Systems ST

New Components

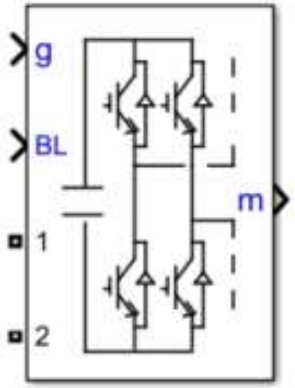
New feature in R2018a

- Single-Phase Induction Motor Drive
  - Design a speed drive with vector control for a single-phase asynchronous motor



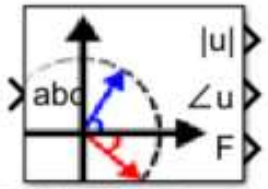
Single-Phase Induction Motor Drive

- Full-Bridge MMC (External DC Links)
  - Convert power using a full-bridge bridge block with external connections to power module DC terminals



Full-Bridge MMC

- PMU (PLL-Based Positive Sequence)
  - Compute the positive-sequence component of a three-phase voltage measurement signal



PMU (PLL-Based, Positive-Sequence)

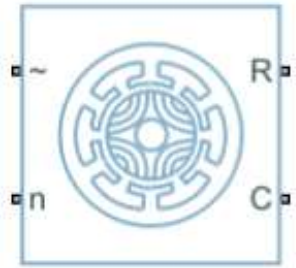
```
>> ac9_example
>> power_MultiCellDrive
>> power_KunderTwoAreaSystem
```

Simscape Power Systems SC

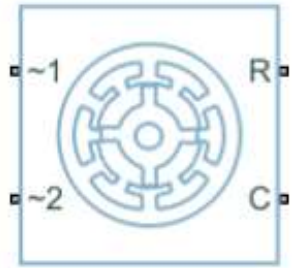
New Components

New feature in R2017b

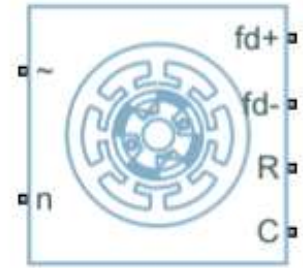
- Reluctance Machines
  - Switched reluctance
  - Synchronous reluctance
- Hybrid Excitation Synchronous Machine
- AC Cable
  - Unbonded, bonded, or cross-bonded cable
  - Flat or a trefoil line formation.
- Incremental Shaft Encoder
- Reluctance with Hysteresis
  - Custom inductances and transformers with magnetic hysteresis



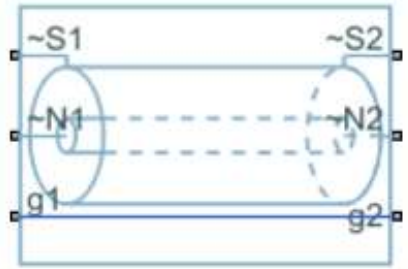
Synchronous Reluctance Machine



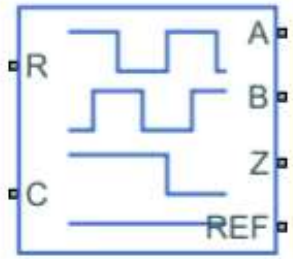
Switched Reluctance Machine



Hybrid Excitation Synchronous Machine



AC Cable



Incremental Shaft Encoder

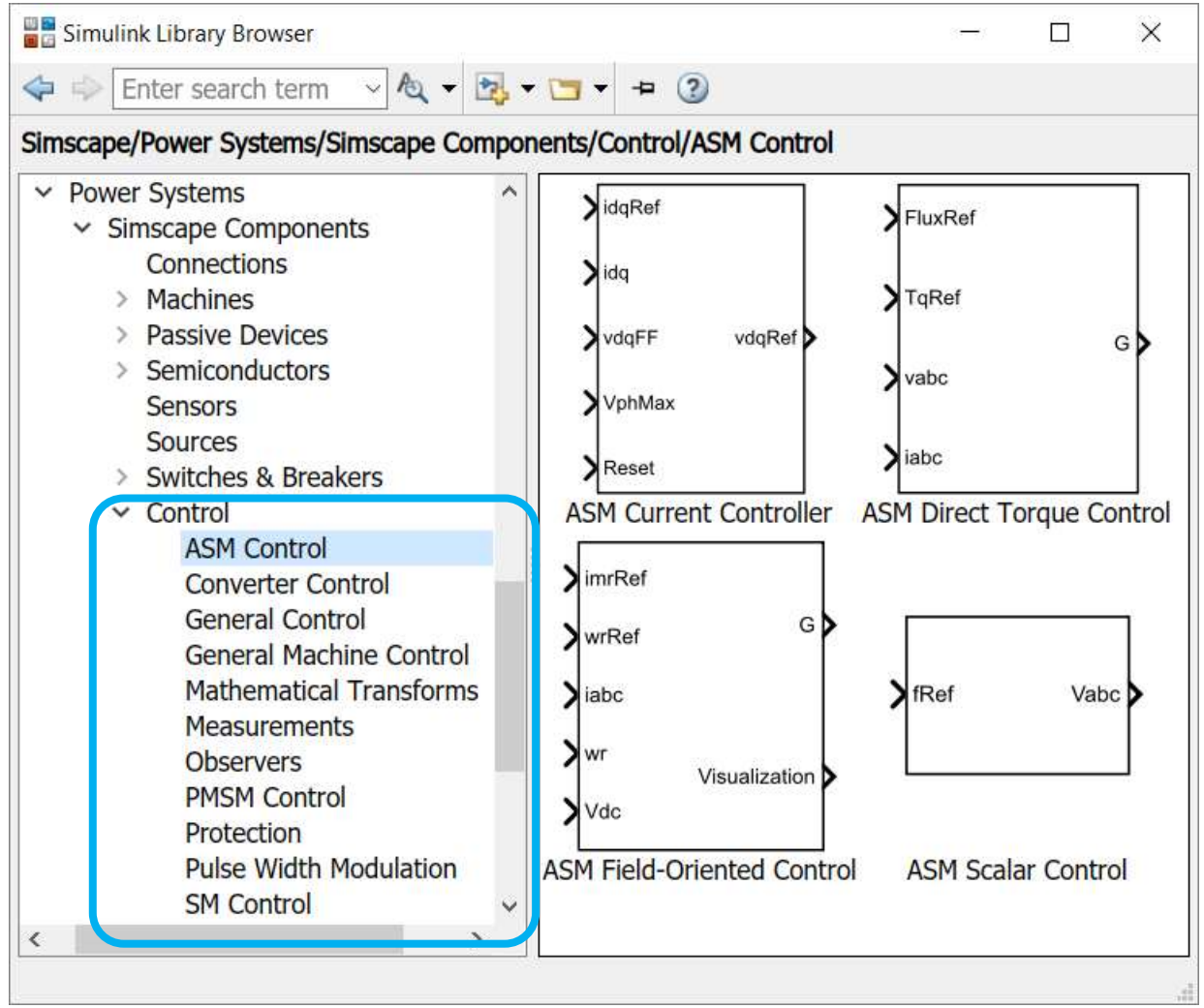
Reluctance with Hysteresis

New feature in R2017b

Simscape Power Systems SC

Expanded Control Libraries

- Save time implementing, testing, and documenting algorithm models
  - Asynchronous, Synchr. machine control
  - PMSM control
  - Converter control
  - Transforms (Clarke, Park, …)
  - PWM Generators
  - Modular and decoupled, customizable, and compatible with Embedded Coder®
  - Open access to the implementation source code.



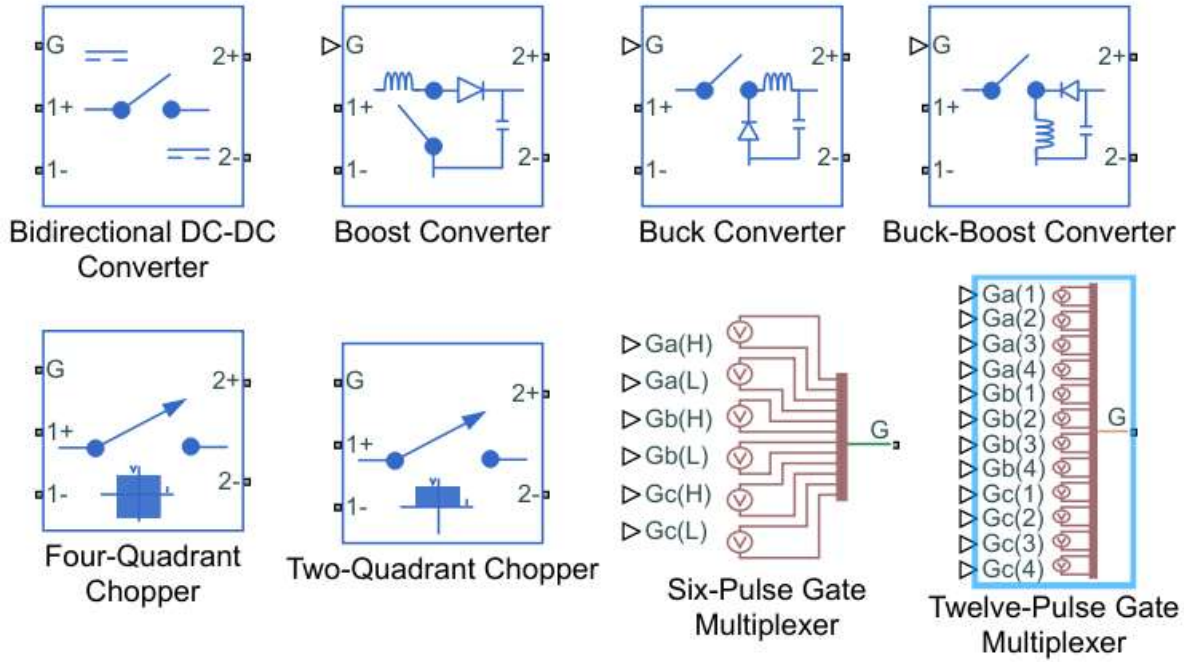

```
>> pe_ipmsm_torque_based_load_control
```

New feature in R2018a

Simscape Power Systems SC

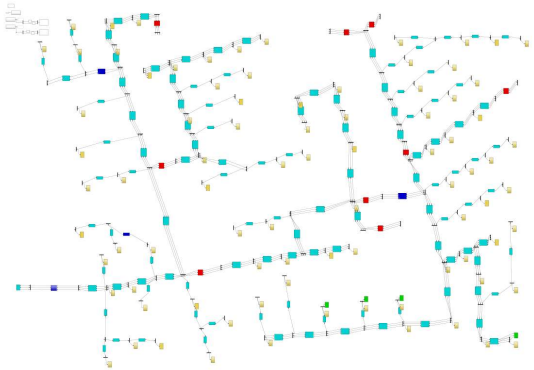
DC-DC Converters

- Bidirectional DC-DC Converter
- Boost Converter
- Buck Converter
- Buck-Boost Converter
- Four-Quadrant Chopper
- Two-Quadrant Chopper
- Four-Pulse Gate Multiplexer
- Two-Pulse Gate Multiplexer

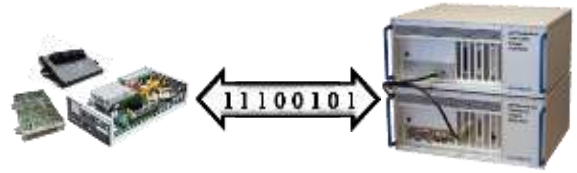



```
>> pe_boost_converter_control
```

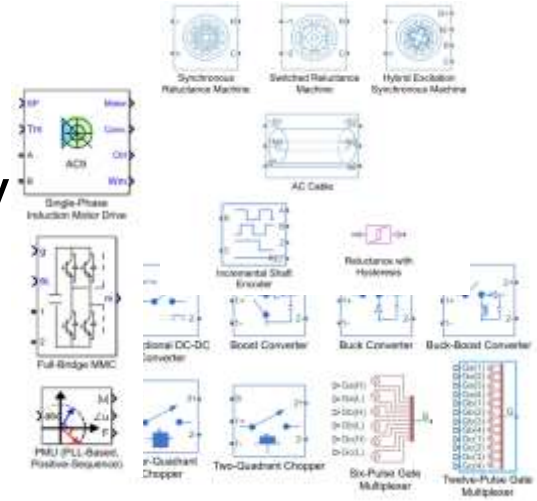
Summary



- Enable Physical Modeling of Large-Scale Grid Systems
  - Hybrid Phasor-EMT Simulation
  - Solvers optimized for fast simulation of high-speed switching electronics



- Build Concurrent Execution Using Simulink Real Time Easily
  - Model Reference for improved memory management and parallel build to facilitate the creation of ‘larger’ networks.



- Develop Libraries for Motor and Power Control Continuously
  - Single-Phase Induction Motor Drive, Full-Bridge MMC, PMU
  - DC-DC Converter, Motor and Power control libraries

Q&A