Developing Next-Generation Smart Grids: Modeling and Simulation with MATLAB and Simulink

Valtteri Forsman
Application Engineer
MathWorks

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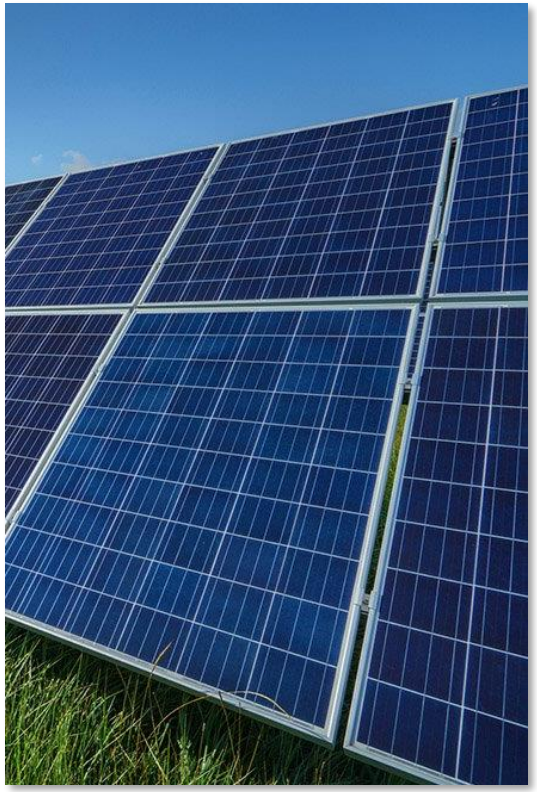
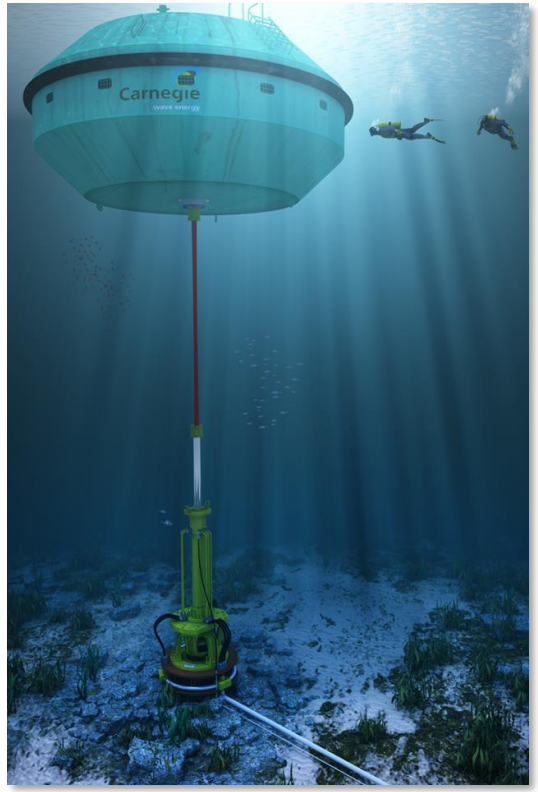
Electrification of Everything

The electrification of everything

Clean Electricity Production



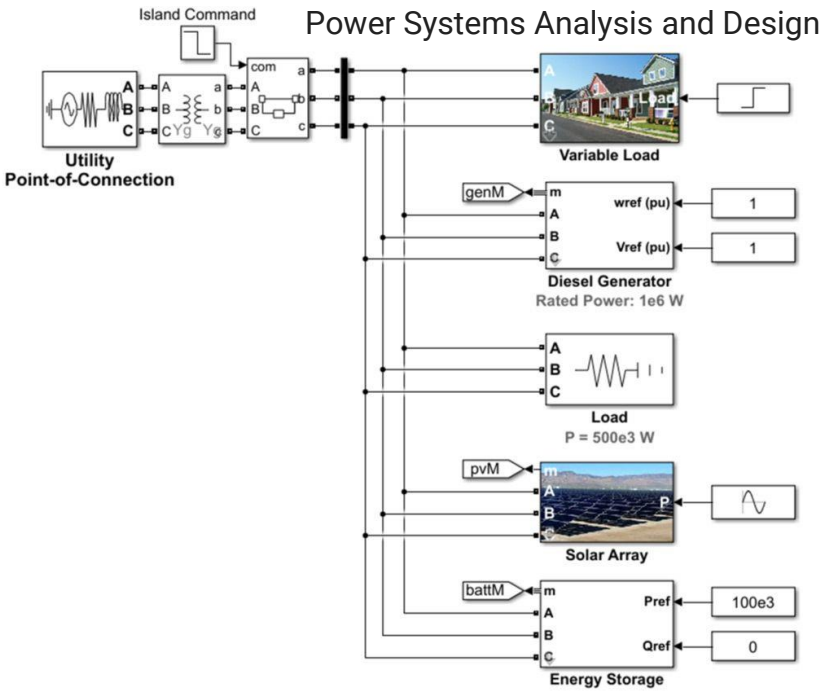


The electrification of everything

Electrified Transportation

Moving towards a clean, electrified future

How can modeling, simulation and analytics best support moving technology from early-stage feasibility through to proven in-service operation?

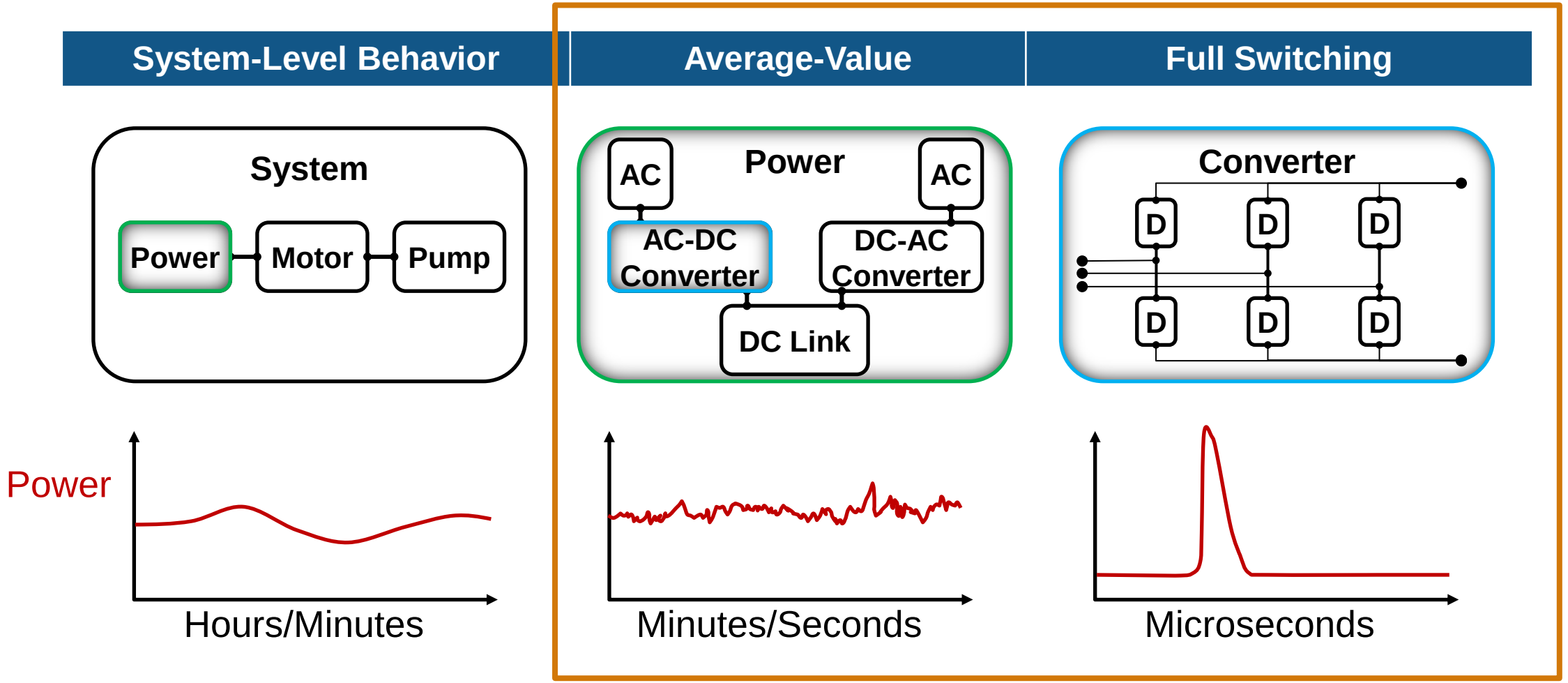


Agenda

- **Modeling and simulation of renewable energy systems**
- System-level and control system design for smart grids
- Deploying and testing control systems

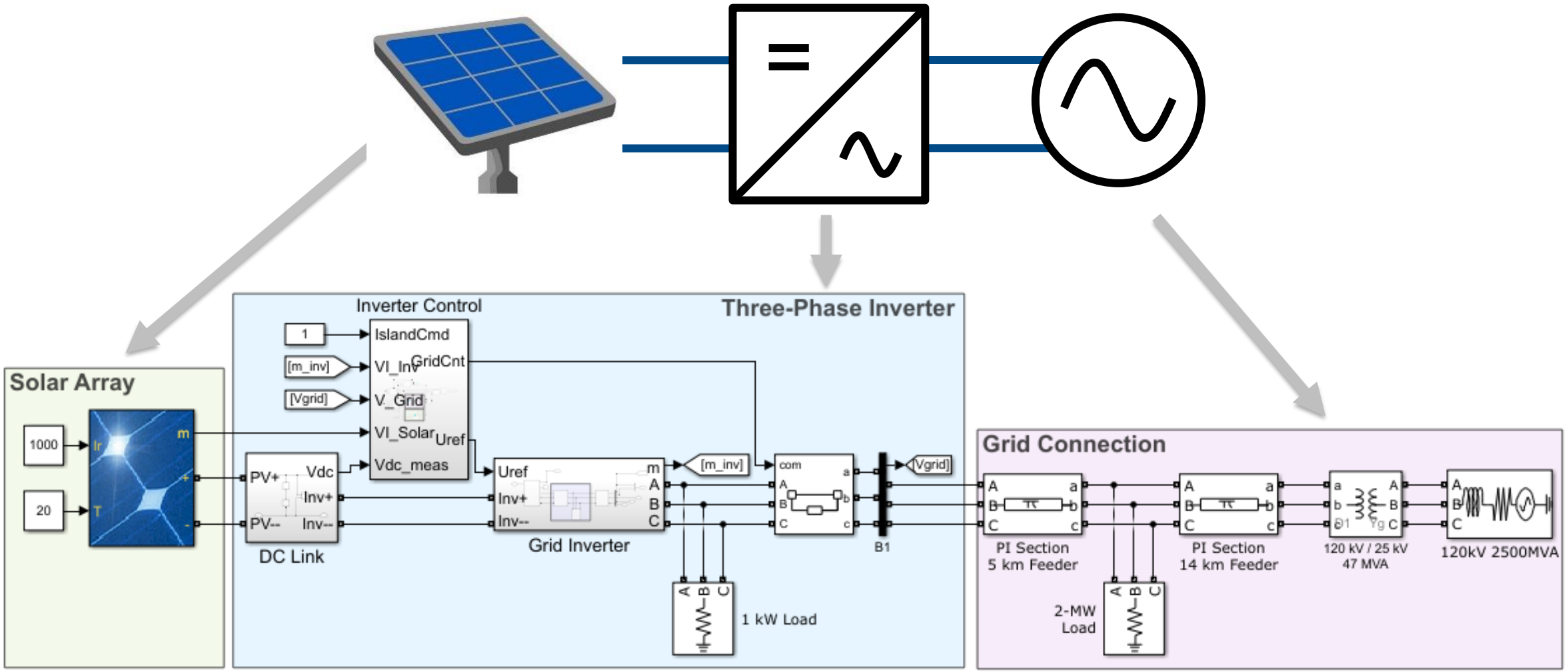
Simscape Electrical Simulation Modes

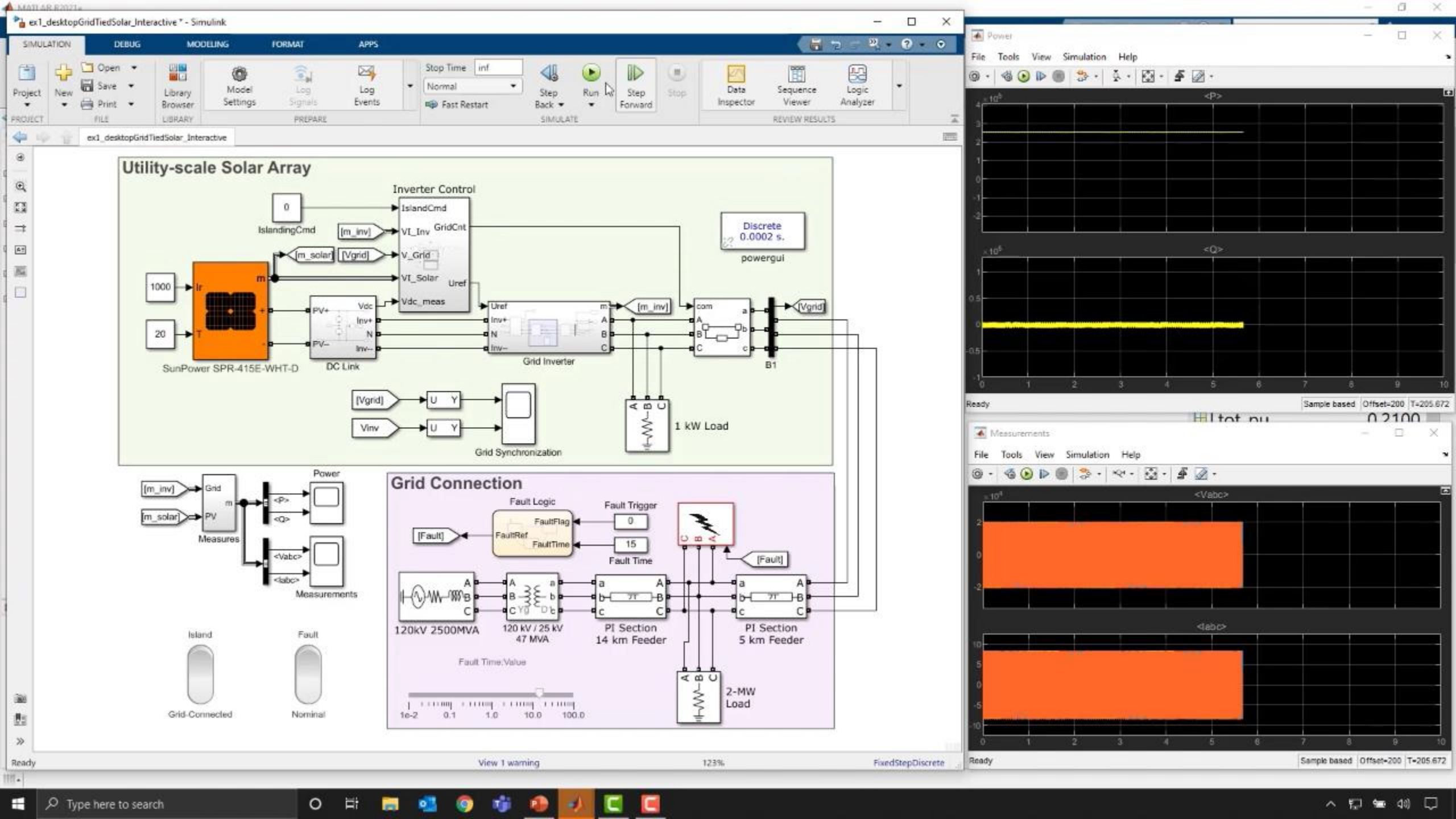
Different Fidelities for Different Tasks



Example Solar Inverter Simulation – For Equipment Design

Inverter Designers Leverage Proprietary Control




ex1_desktopGridTiedSolar_Interactive * - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Project
New
Open
Save
Print
Library Browser
Model Settings
Log Signals
Log Events
Stop Time
inf
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
Data Inspector
Sequence Viewer
Logic Analyzer
ex1_desktopGridTiedSolar_Interactive
Utility-scale Solar Array
Inverter Control
IslandCmd
VI_Inv
GridCnt
V_Grid
VI_Solar
Uref
Vdc_meas
[m_inv]
[m_solar]
[Vgrid]
Discrete
0.0002 s.
powergui
1000
20
SunPower SPR-415E-WHT-D
DC Link
Grid Inverter
B1
1 kW Load
Grid Synchronization
Vinv
Power
Measures
Measurements
Grid Connection
Fault Logic
Fault Trigger
FaultFlag
FaultRef
FaultTime
[Fault]
Fault Time
120kV 2500MVA
120 kV / 25 kV
47 MVA
PI Section
14 km Feeder
PI Section
5 km Feeder
2-MW
Load
Fault Time:Value
Island
Fault
Grid-Connected
Nominal
Ready
View 1 warning
123%
FixedStepDiscrete
Power
File
Tools
View
Simulation
Help
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<Q>
Ready
Sample based
Offset=200
T=205.672
Measurements
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<Iabc>
Ready
Sample based
Offset=200
T=205.672
Type here to search

Layers of Control in Smart Grid Applications

IEEE1676 – Power Electronic Building Blocks

Control Transients

Hours

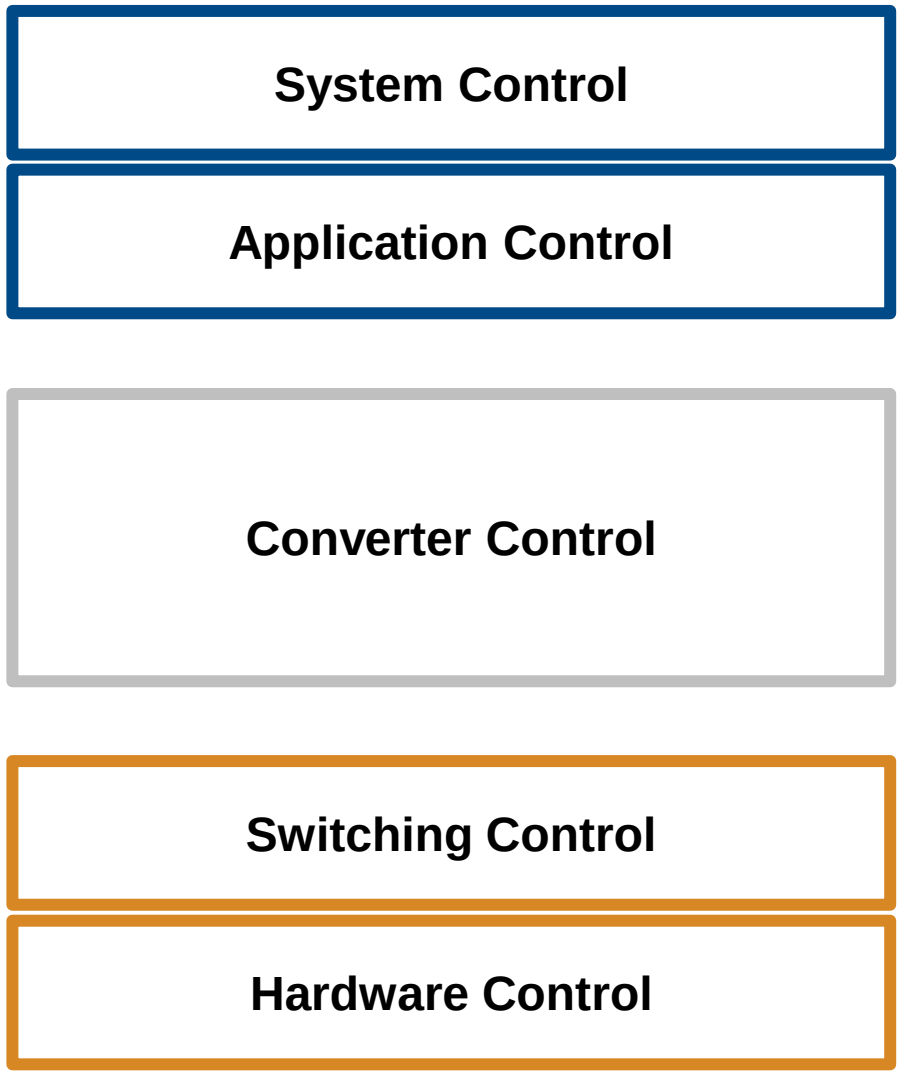
- Peak Shaving/Load Leveling
- Energy Markets
- Integration of Renewables
- Islanding Operation (No Grid)

Seconds

- Voltage/Frequency Regulation
- Transient Smoothing
- Reactive Power Control

m/µ-Seconds

- Switched-Mode Control
- Harmonic Analysis



Agenda

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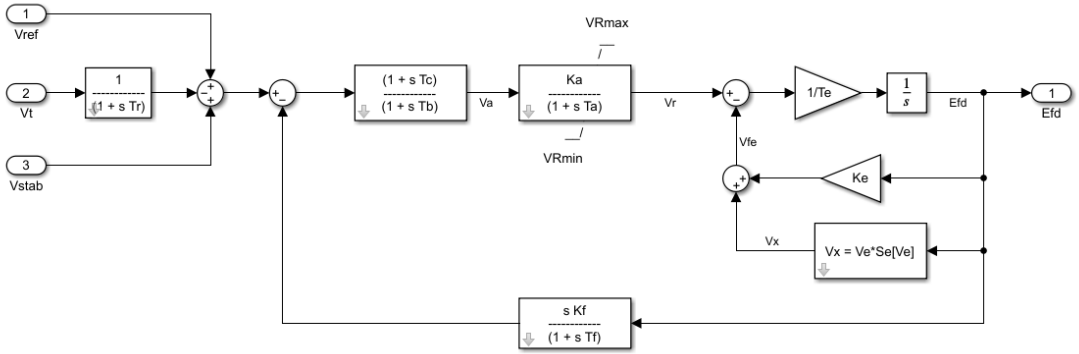
- **System-level and control system design for smart grids**
- Deploying and testing control systems

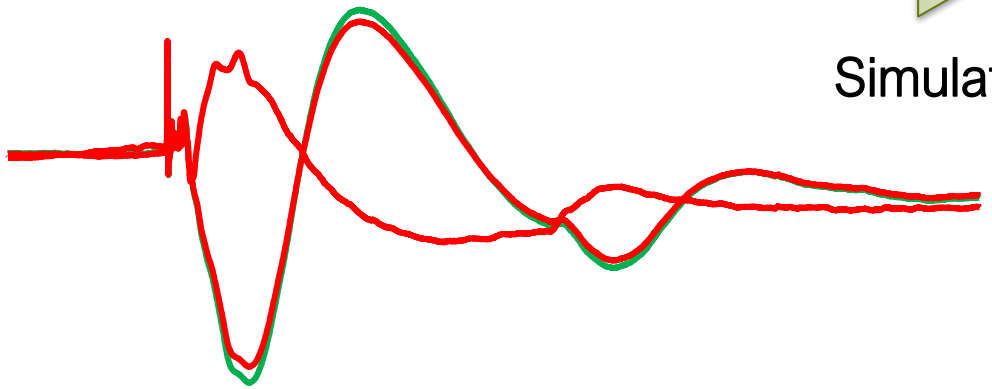
What is Model Validation?

Renewables Field Equipment

Standardized Models of Equipment

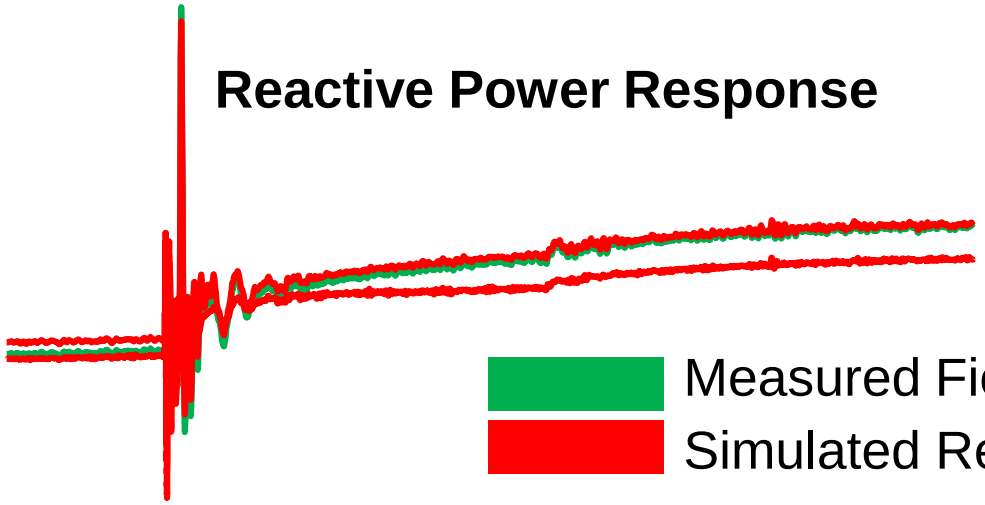


Active Power Response



Simulation

Reactive Power Response

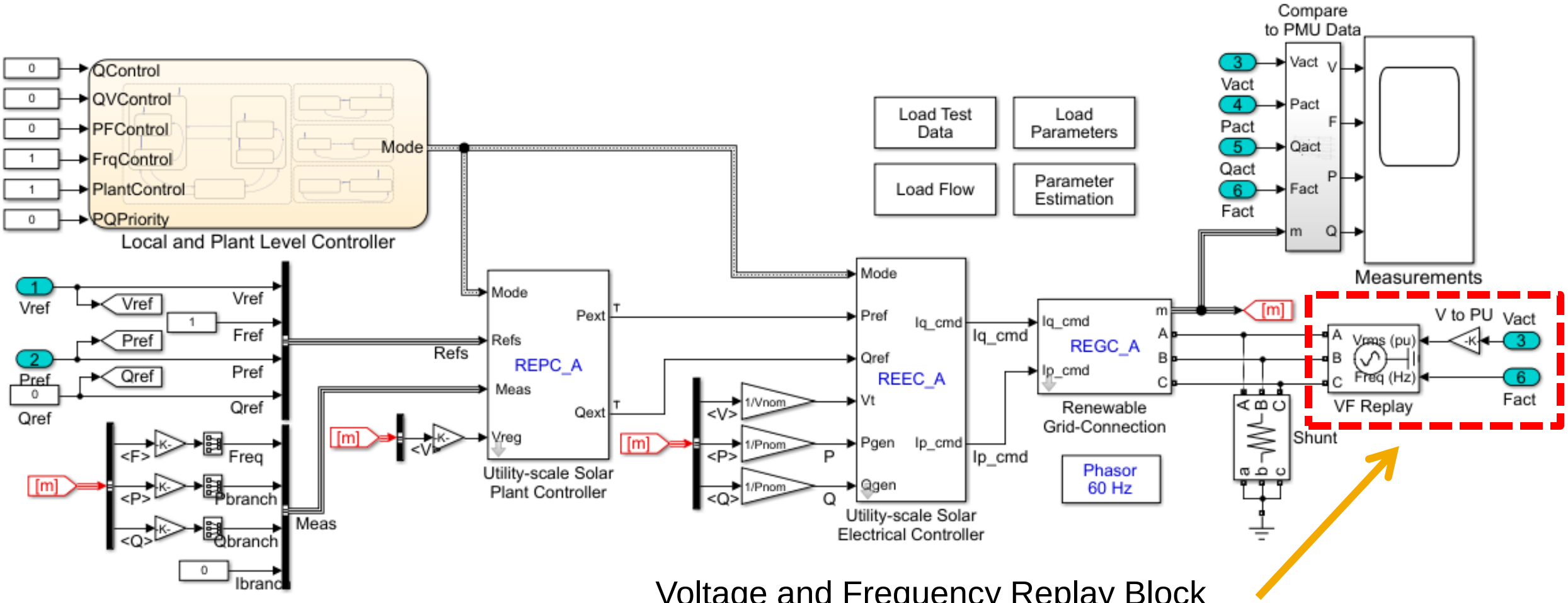


Measured Field Data

Simulated Response

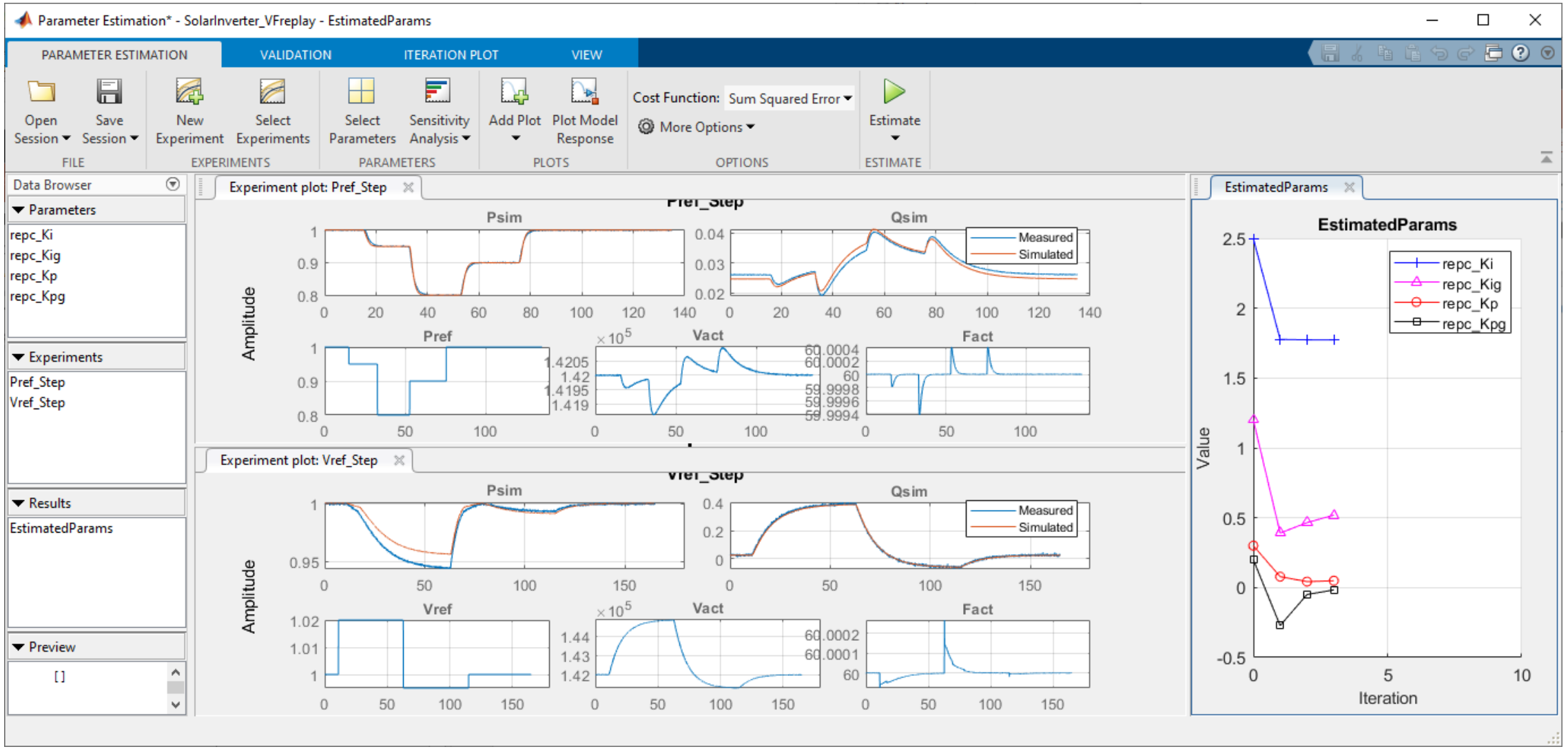
“Replay” Field Measurements to Compare Model to Data

Use Field Voltage/Frequency and Match Plant P/Q Response



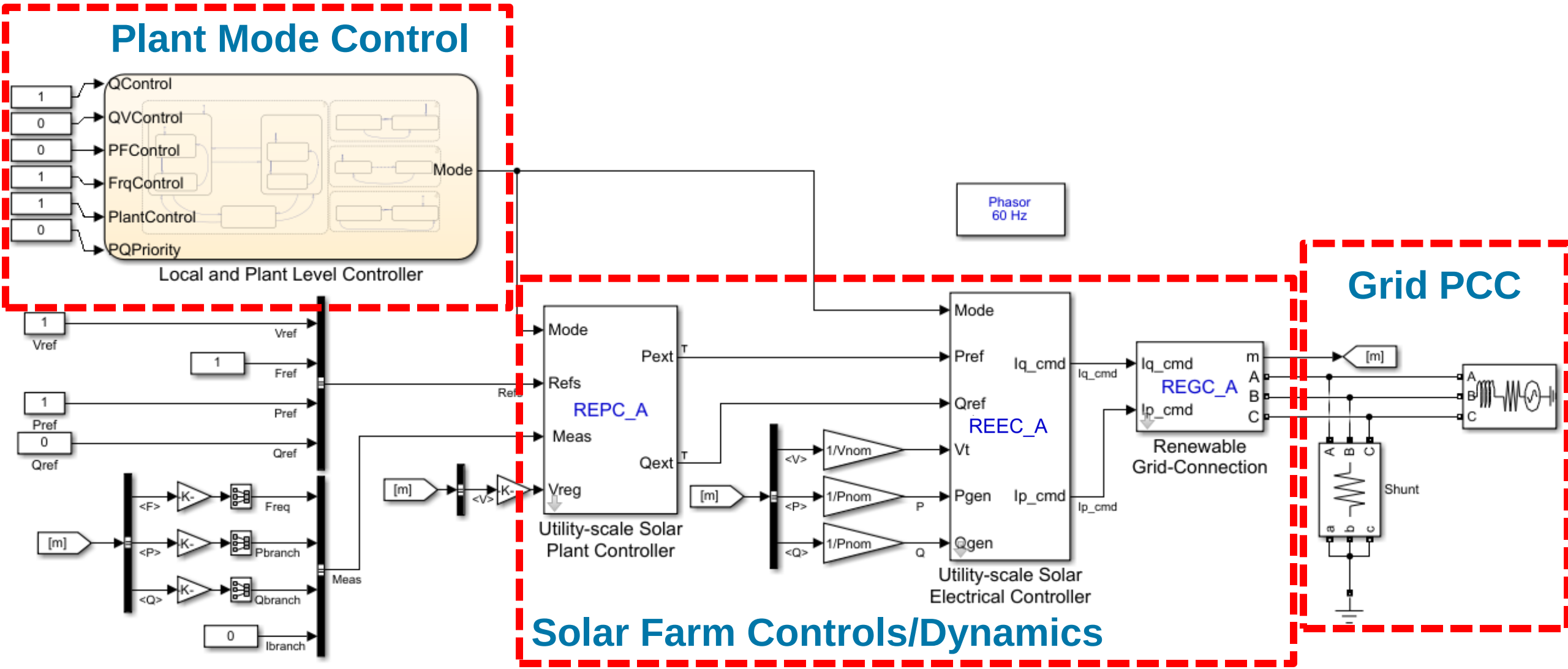
Voltage and Frequency Replay Block
Replaces “Simulated” Grid to Leverage Field Data

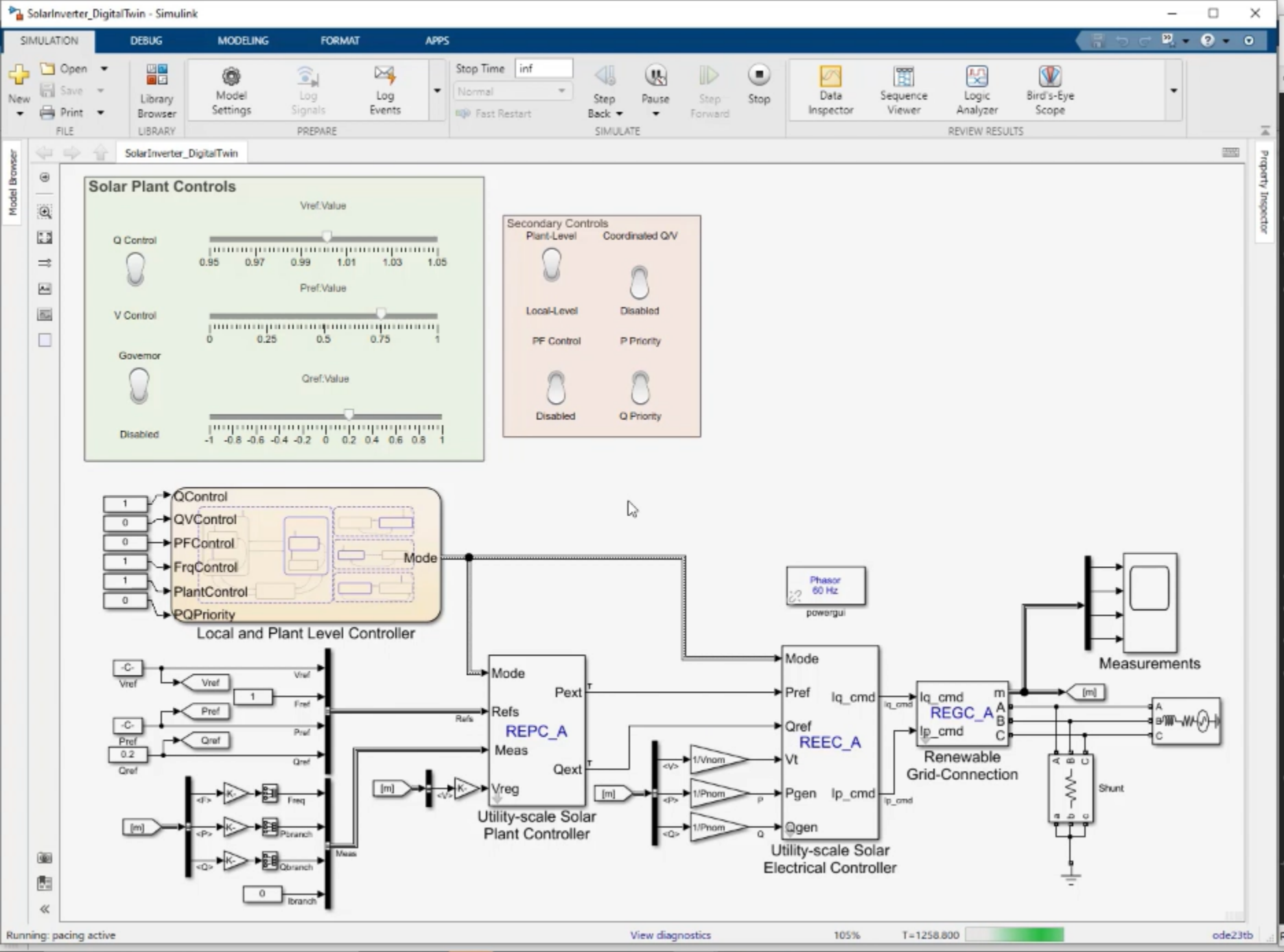
Parameter Estimation for Multiple Grid Tests



Central Station Solar Plant in Simscape Electrical

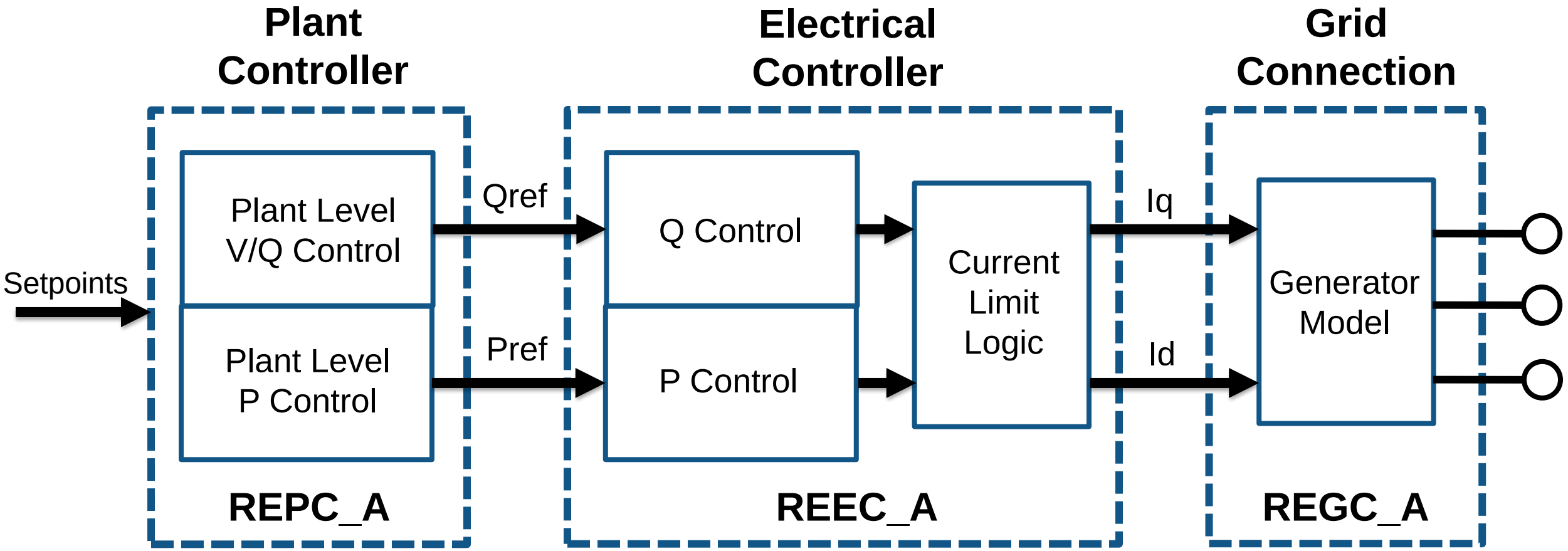
IEEE Standardized Controls for System-Studies and Validation




SolarInverter_DigitalTwin - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Stop Time
inf
Step Back
Pause
Step Forward
Stop
Data Inspector
Sequence Viewer
Logic Analyzer
Bird's-Eye Scope
Solar Plant Controls
Vref:Value
Q Control
Pref:Value
V Control
Governor
Qref:Value
Disabled
Secondary Controls
Plant-Level
Coordinated Q/V
Local-Level
Disabled
PF Control
P Priority
Disabled
Q Priority
QControl
QVControl
PFControl
FrqControl
PlantControl
PQPriority
Mode
Local and Plant Level Controller
Phasor 60 Hz
powergui
Mode
Pext
Refs
REPC_A
Meas
Qext
Vreg
Utility-scale Solar Plant Controller
Mode
Pref
Iq_cmd
Qref
REEC_A
Vt
Pgen
Ip_cmd
Qgen
Utility-scale Solar Electrical Controller
Iq_cmd
Ip_cmd
REGC_A
Renewable Grid-Connection
Measurements
Shunt
Measurements
File
Tools
View
Simulation
Help
Voltage
Measured
Reference
Frequency (Hz)
Active Power
Reactive Power
Running: pacing active
View diagnostics
105%
T=1258.800
ode23tb
Running
Sample based
Offset=1200
T=1258.600

Central Station Solar Plant One-line Diagram and Controls

IEEE Standardized Controls for System-Studies and Validation



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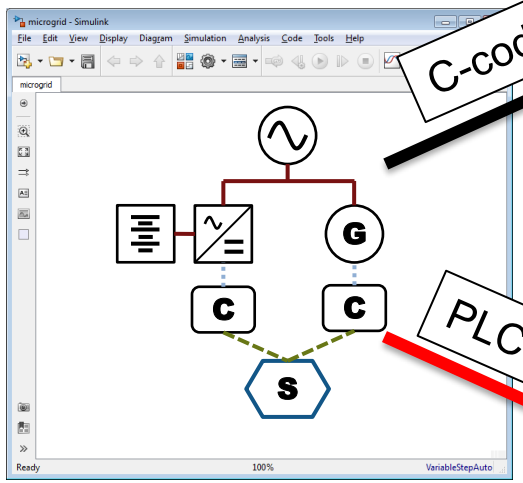
- **Deploying and testing control systems**

Design

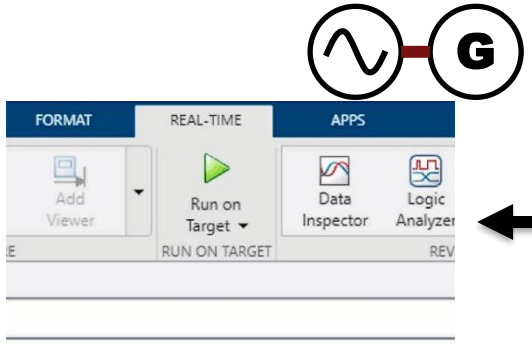


Desktop Simulation

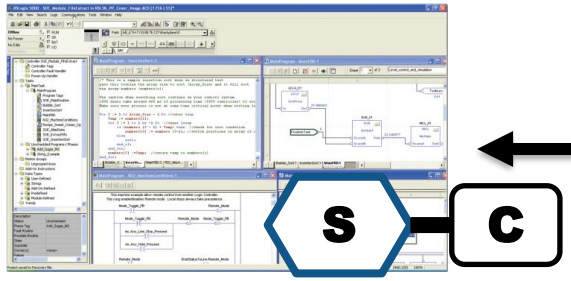
C-code Generation

PLC Code Generation

Implement

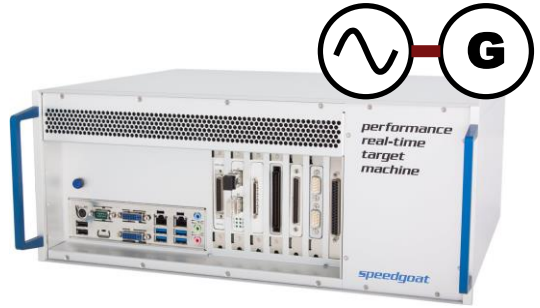


Real-time Interface



PLC Development Environment

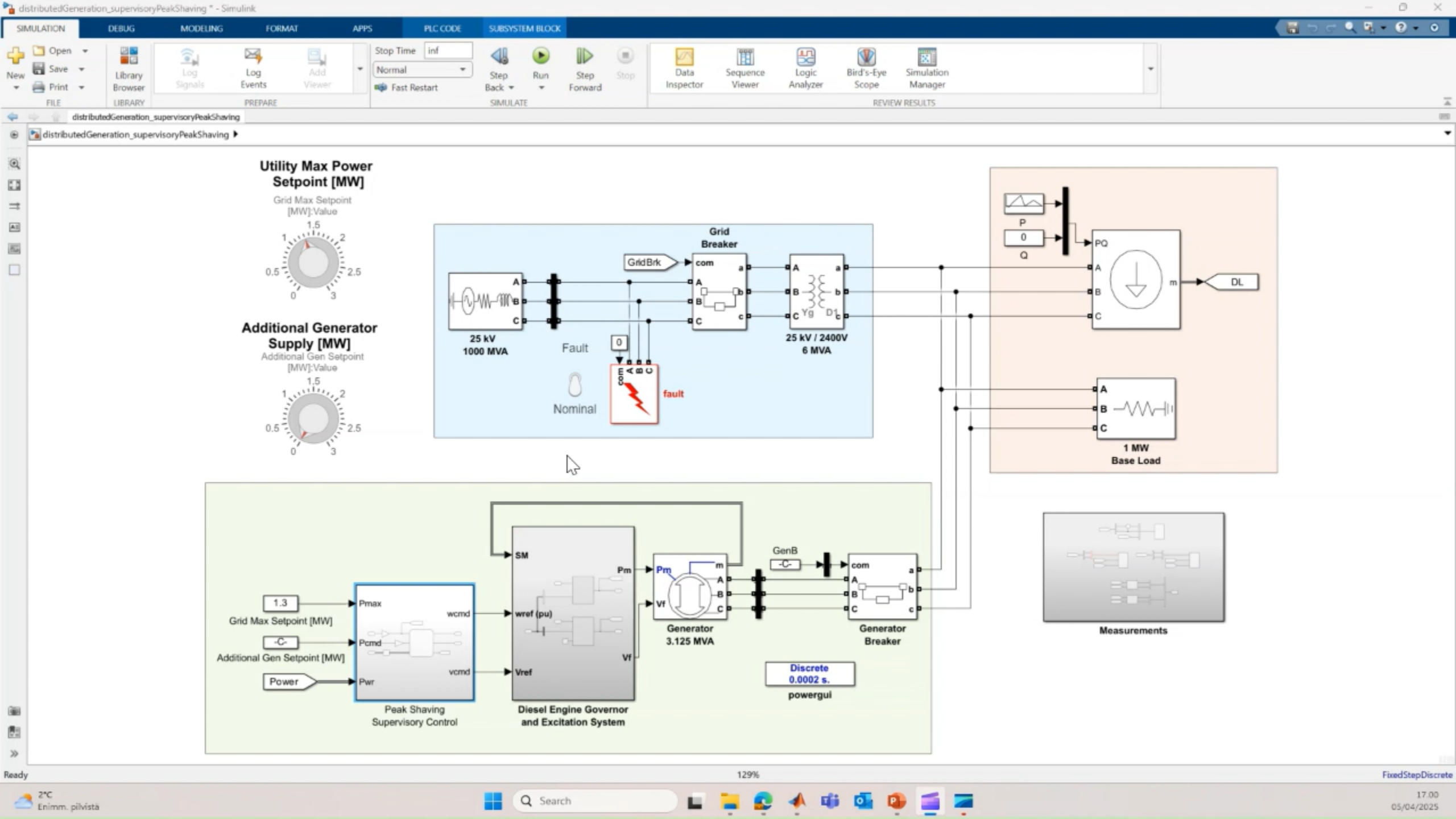
Test



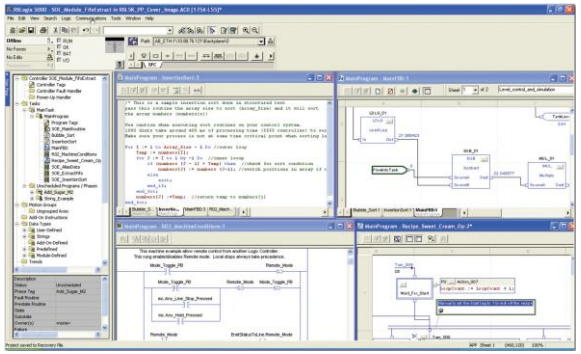
Equipment Simulation

Bus

Industrial Controller


distributedGeneration_supervisoryPeakShaving * - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
PLC CODE
SUBSYSTEM BLOCK
Open
Save
Print
New
Library Browser
Log Signals
Log Events
Add Viewer
Stop Time
inf
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
Data Inspector
Sequence Viewer
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
FILE
LIBRARY
PREPARE
SIMULATE
REVIEW RESULTS
distributedGeneration_supervisoryPeakShaving
Utility Max Power Setpoint [MW]
Grid Max Setpoint [MW]:Value
Additional Generator Supply [MW]
Additional Gen Setpoint [MW]:Value
Grid Breaker
GridBrk
25 kV 1000 MVA
Fault
Nominal
fault
25 kV / 2400V 6 MVA
P
Q
PQ
DL
1 MW Base Load
Measurements
1.3
Grid Max Setpoint [MW]
-C-
Additional Gen Setpoint [MW]
Power
Pmax
Pcmd
Pwr
wcmd
vcmd
Peak Shaving Supervisory Control
SM
wref (pu)
Vref
Pm
Vf
Diesel Engine Governor and Excitation System
Generator 3.125 MVA
GenB
Generator Breaker
Discrete 0.0002 s.
powergui
Ready
129%
FixedStepDiscrete
2°C
Enimm. pilvistä
Search
17.00
05/04/2025

Protection/ Control Implementation

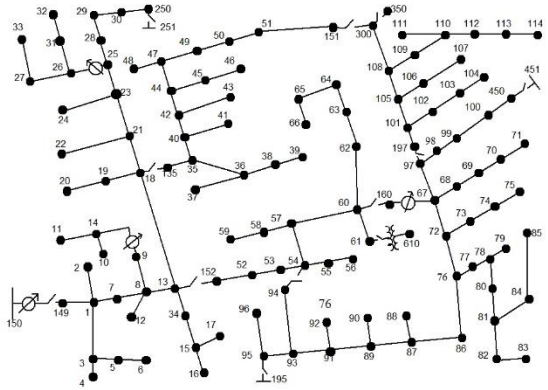


PLC Development Environment

Hardware Implementation

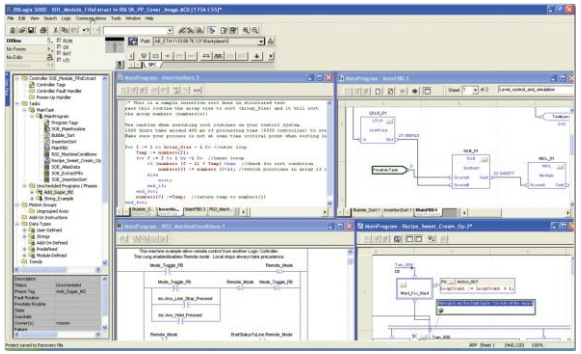
Industrial Controller

Grid Code Compliance Checks



Prototype/ Actual System

Protection/ Control Implementation



PLC Development Environment

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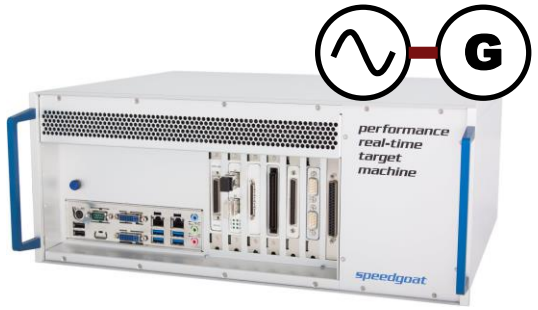
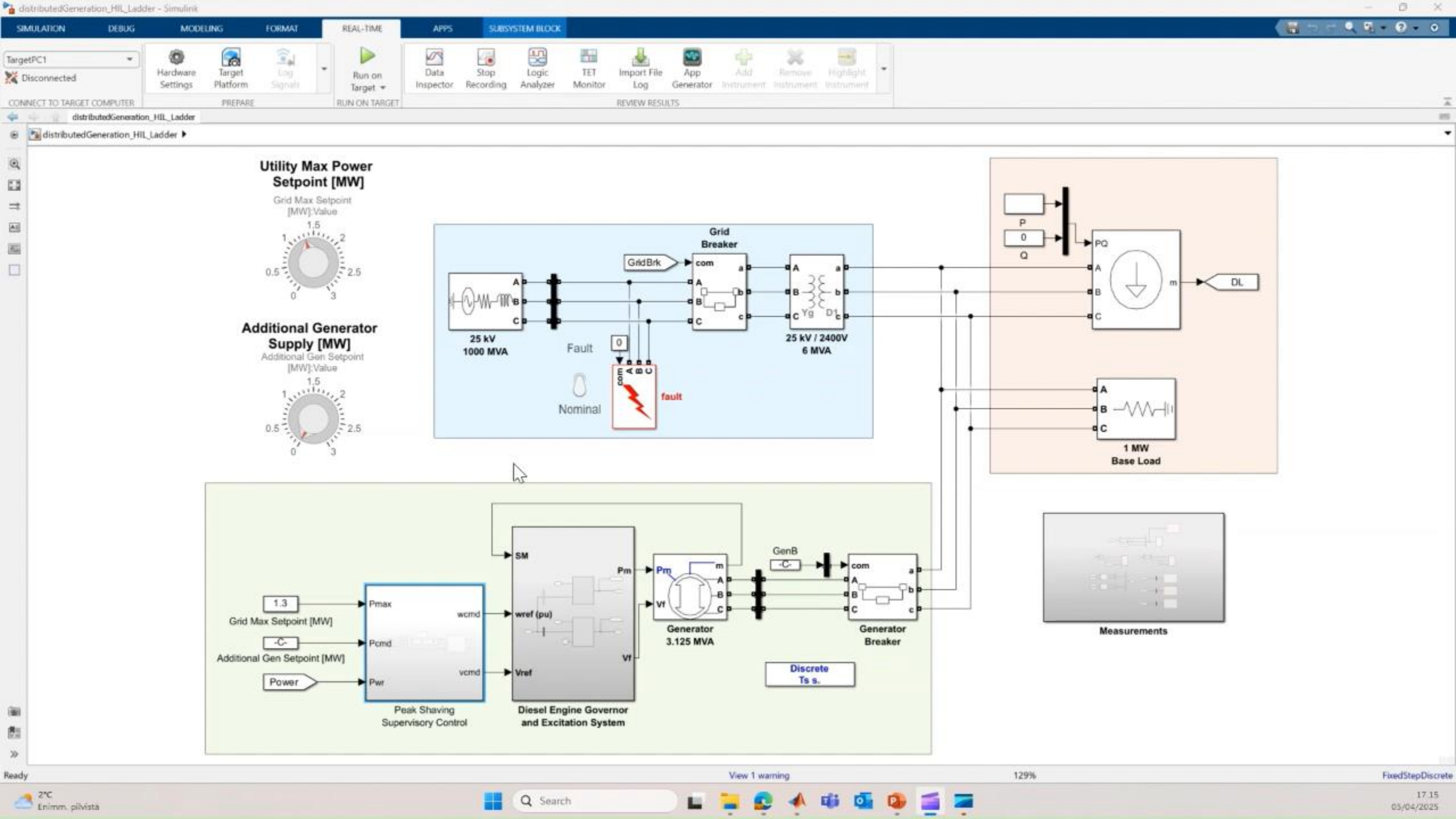
Grid Code Compliance Checks



Equipment Simulation


distributedGeneration_HIL_Ladder - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
REAL-TIME
APPS
SUBSYSTEM BLOCK
TargetPC1
Disconnected
Hardware Settings
Target Platform
Log Signals
Run on Target
Data Inspector
Stop Recording
Logic Analyzer
TET Monitor
Import File Log
App Generator
Add Instrument
Remove Instrument
Highlight Instrument
CONNECT TO TARGET COMPUTER
PREPARE
RUN ON TARGET
REVIEW RESULTS
distributedGeneration_HIL_Ladder
Utility Max Power Setpoint [MW]
Grid Max Setpoint [MW]:Value
Additional Generator Supply [MW]
Additional Gen Setpoint [MW]:Value
Grid Breaker
GridBrk
25 kV 1000 MVA
Fault
Nominal
fault
25 kV / 2400V 6 MVA
P
Q
PQ
DL
1 MW Base Load
Measurements
1.3
Grid Max Setpoint [MW]
Additional Gen Setpoint [MW]
Power
Pmax
Pcmd
Pwr
wcmd
vcmd
Peak Shaving Supervisory Control
SM
wref (pu)
Vref
Pm
Vf
Diesel Engine Governor and Excitation System
Generator 3.125 MVA
GenB
Generator Breaker
Discrete Ts s.
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View 1 warning
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FixedStepDiscrete
2°C
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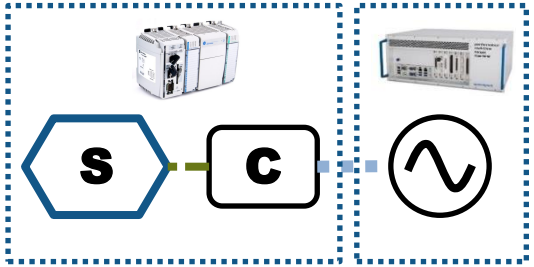
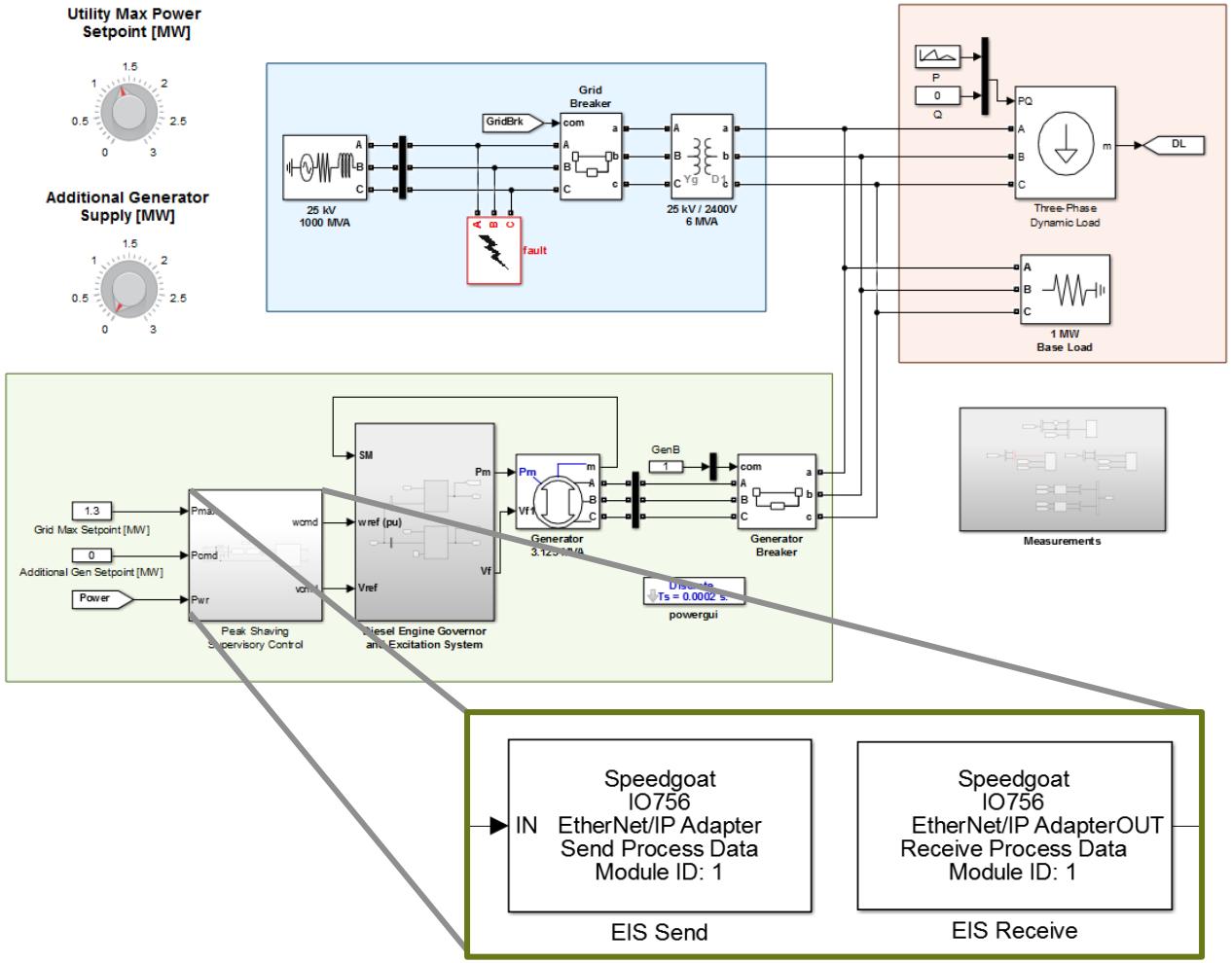
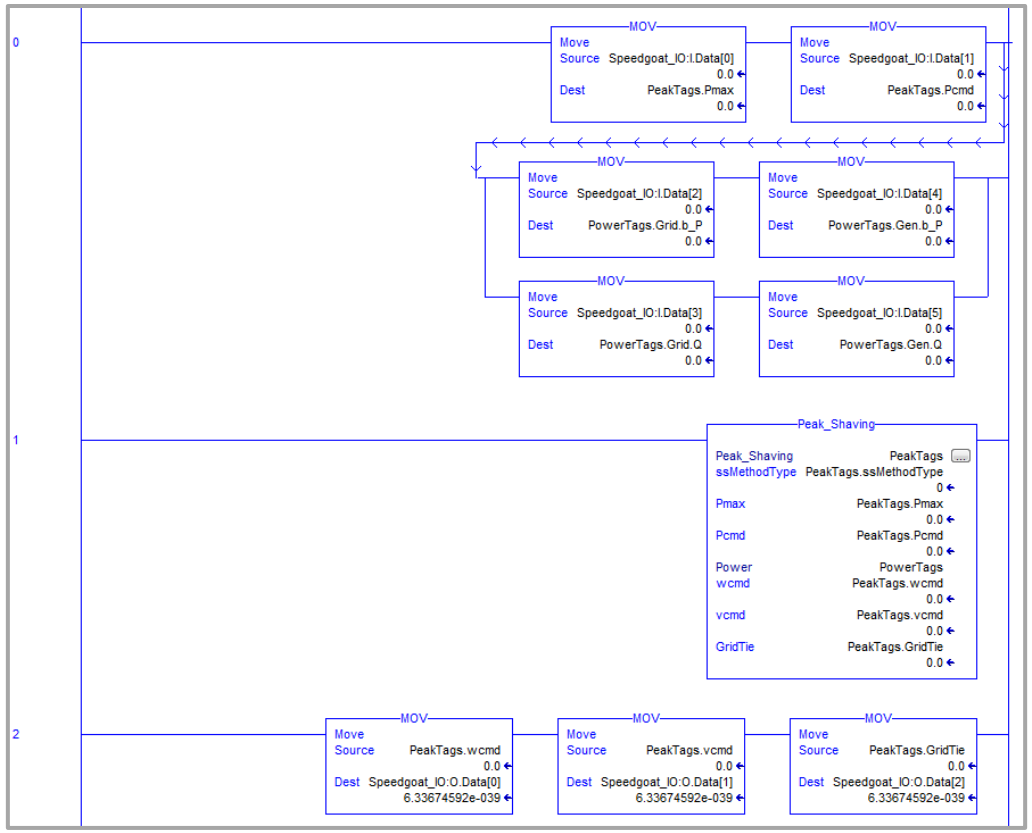
Search
17.15
05/04/2025

Testing Grid Controls with Hardware-in-the-Loop







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Renewable Energy Integration Design with Simscape

Version 24.1.2.1 (357 MB) by MathWorks Simscape Team STAFF

The repository provides design solutions that aid the operation of power systems with high penetration of renewable energy sources.
https://github.com/simscape/Renewable-Energy-Integration-Simscape

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Overview | Functions | Models | Examples | Version History | Reviews (7) | Discussions (6)

Renewable Energy Integration Design with Simscape

This repository provides engineering solutions for the operation of power systems with high penetration of renewable energy sources. The developed models comply with current IEEE/IEC and national grid standards.

File Exchange | Open in MATLAB Online

This Repository Includes the Following Engineering Solutions

1. Evaluate Performance of MTHVDC System with GFM Control for Offshore Wind Integration.
2. Evaluate Performance of Grid Forming Controls for Type 4 Wind Generators in Wind Farm.
3. Assess the Stability of Inverter-Based Resources using Admittance Scan Technique.
4. Performance Evaluation of Grid Forming Battery Energy Storage Systems in Solar PV Plants.

Overview

Performance Evaluation of Grid Forming Battery Energy Storage Systems in Solar PV Plants

Requires
MATLAB
Simulink
Control System Toolbox
MATLAB Test
Simscape
Simscape Electrical
System Identification Toolbox

MATLAB Release Compatibility
Created with R2024a
Compatible with R2022b to R2024a

Platform Compatibility
Windows macOS Linux

Others Also Downloaded
Power Converter Circuit and Control Design with Simscape
2.5K Downloads