A Scalable Control Architecture for 100% PV Penetration with Grid Forming Inverters – 2022 Update

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Abstract

This presentation summarizes the work performed by EPRI in 2022 under the Department of Energy (DOE) funded project “A Scalable Control Architecture for 100% PV Penetration with Grid Forming Inverters”. The work included the development of a generic positive sequence dynamic model for grid forming (GFM) inverters, and of an aggregate distribution feeder model that represents a mix of grid following (GFL) and GFM inverters, suitable for transmission studies.

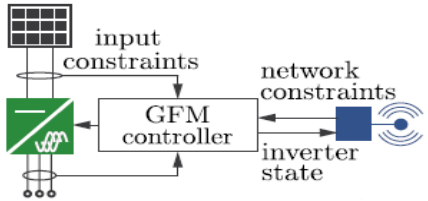
Keywords

- Droop Control
- Grid Forming Inverter
- Phase Locked Loop
- Virtual Oscillator
- Virtual Synchronous Machine

“A Scalable Control Architecture for 100% PV Penetration with Grid Forming Inverters”

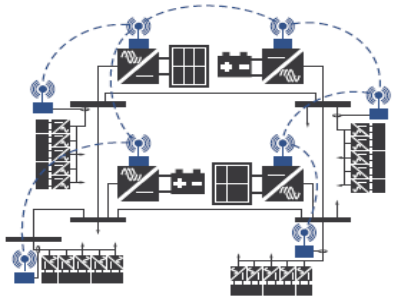
[R1] Decentralized Control Architecture for Regulation

- [R1-1] PV headroom estimation
- [R1-2] GFM controls for stabilization



[R2] Distributed Optimization Architecture for Restoration

- [R2-1] Estimating sensitivities for distributed algorithms
- [R2-2] Dispatch architecture for GFM inverters

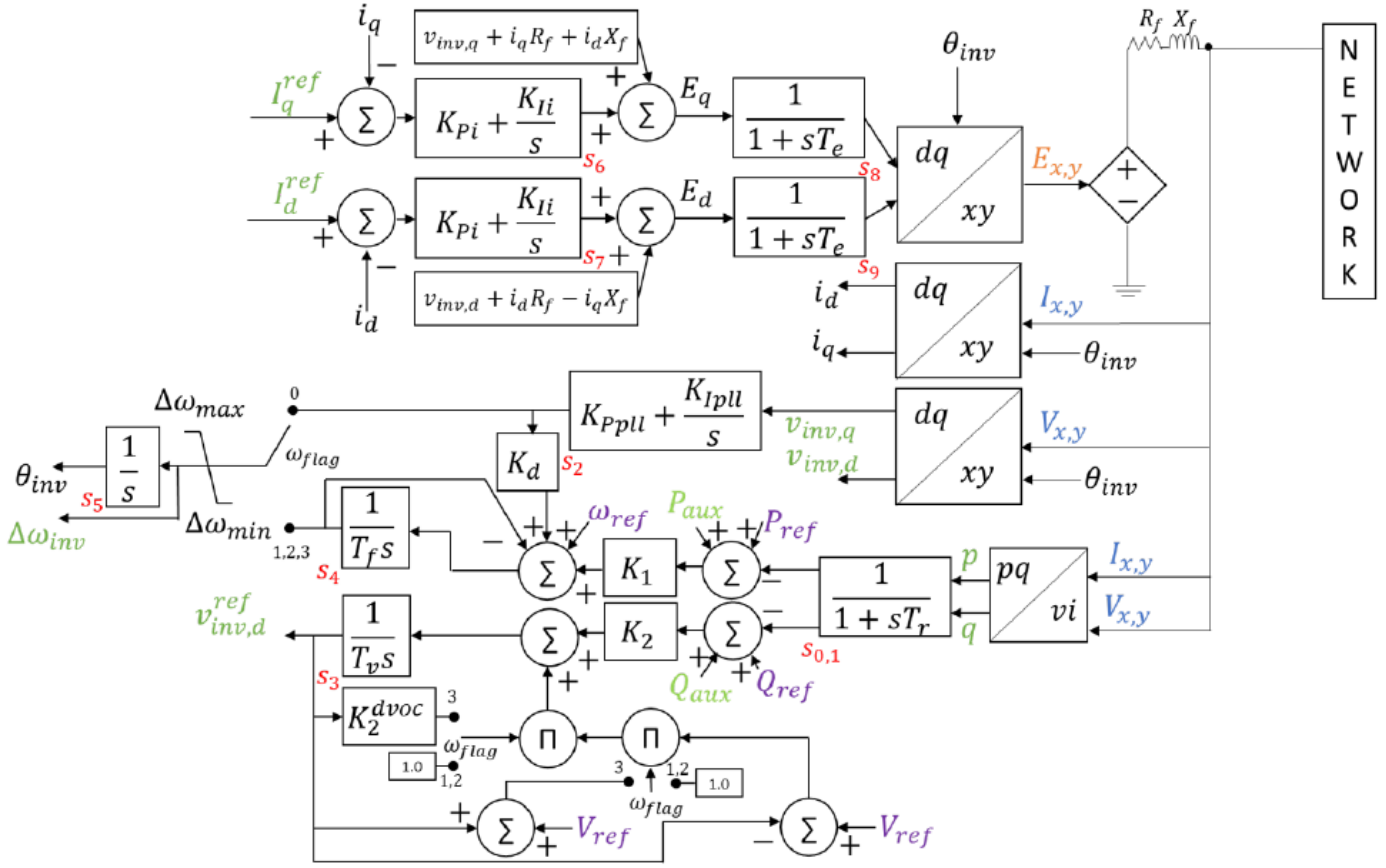


[V1] Simulation Platform for Networks with 1000+ GFM/GFL Inverters

[V2] Hardware Testbed with 100+ Inverters @ 100+ kW

Generic Positive Sequence GFM Inverter Dynamic Model

GFM Renewable Generator/Converter Model

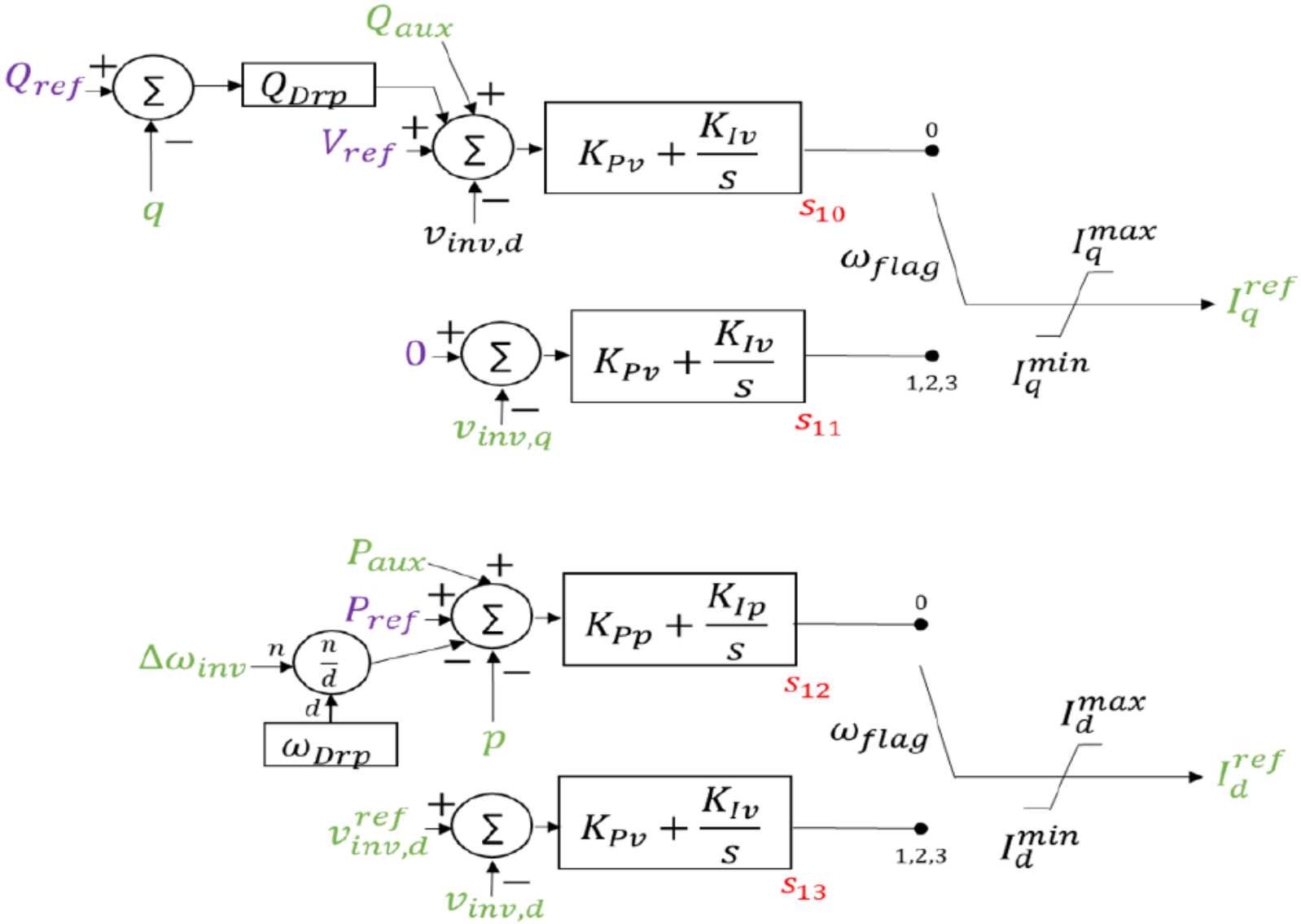


- proposed GFM REGC_* model
- choice of ω_{flag} switches between different GFM control types
- fault current limitation handled at network interface similar to existing REGC_B and REGC_C models

The model represents 4 types of GFM controls

1. Droop based GFM
2. Virtual Synchronous Machine (VSM) based GFM
3. Dispatchable Virtual Oscillator (dVOC) based GFM
4. Phase Locked Loop (PLL) based GFM

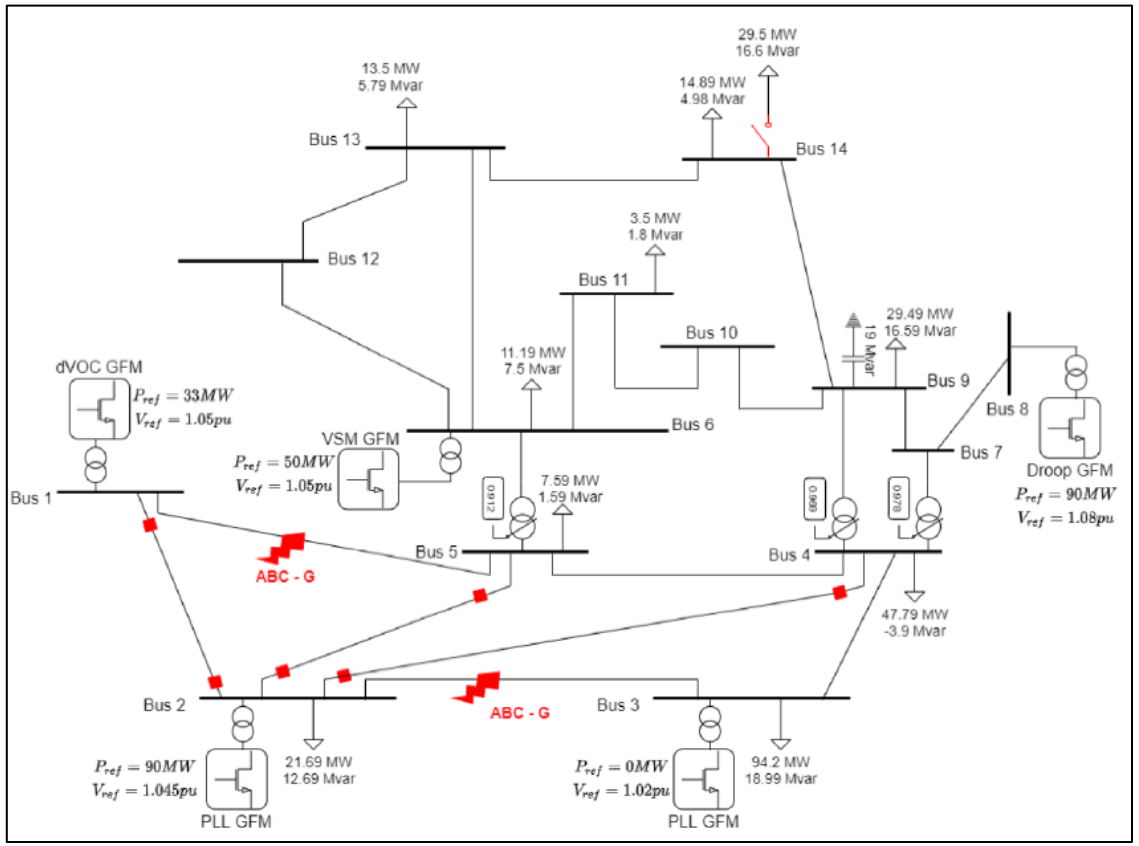
GFM Renewable Electrical Control Model



- proposed GFM REEC_* model
- choice of ω_{flag} switches between different GFM control types

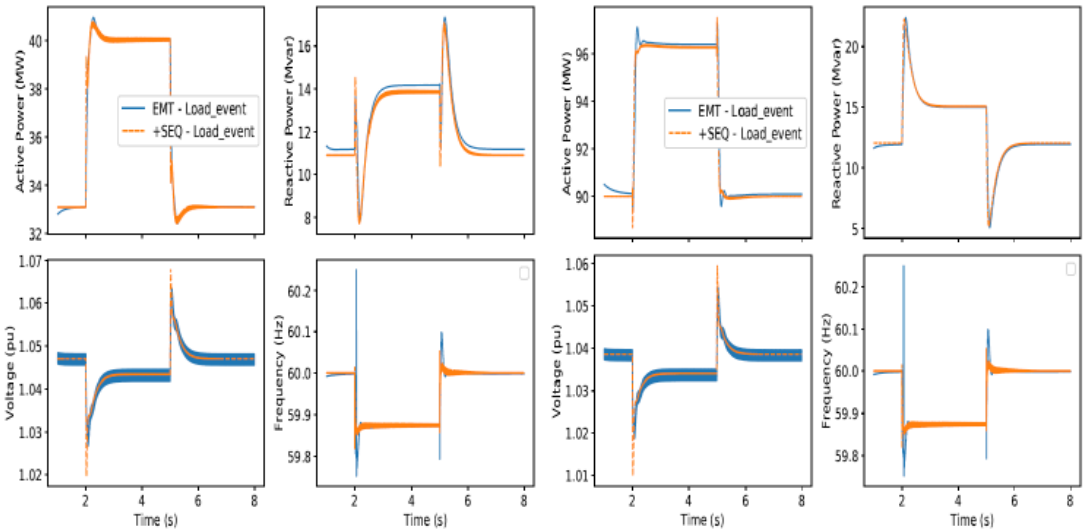
GFM Model Comparison - Positive Sequence vs EMT

100% IBR IEEE 14 Bus System

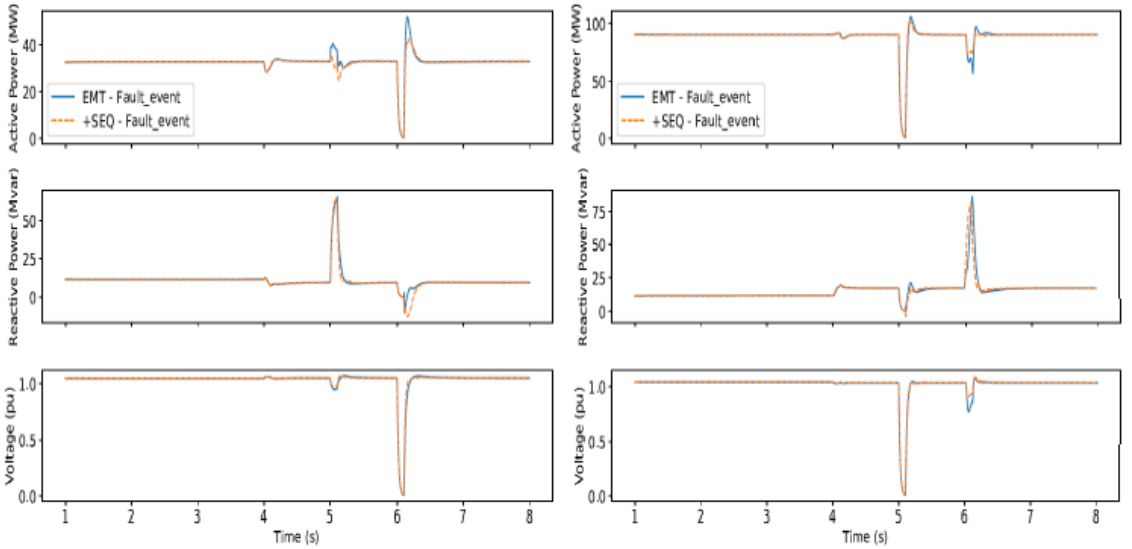


Good match between the generic +seq and EMT GFM inverter models

Load Events



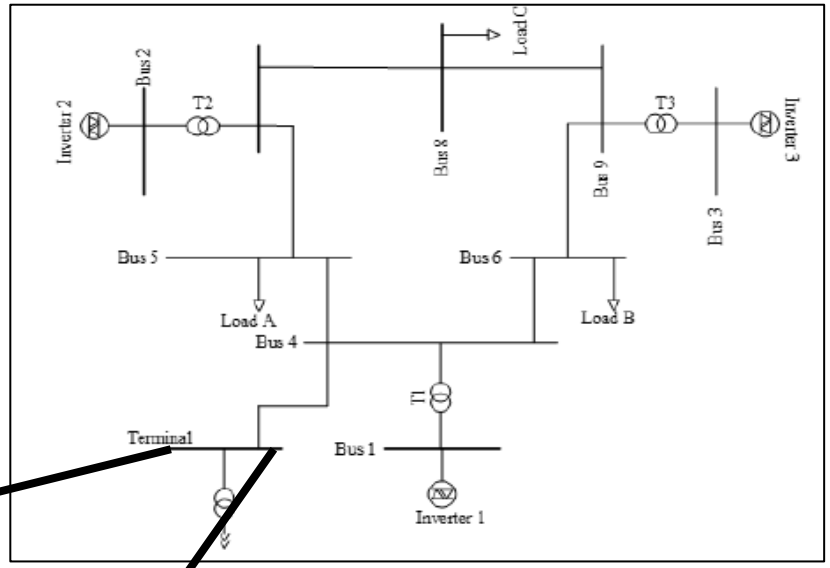
Line Trip and Fault Events

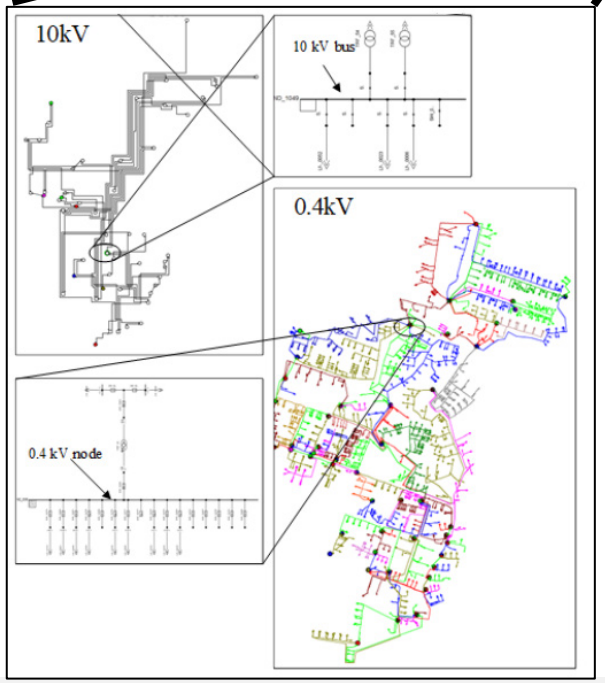


Aggregate Positive Sequence Distribution Feeder Dynamic Model with a Mix of GFL & GFM Inverters

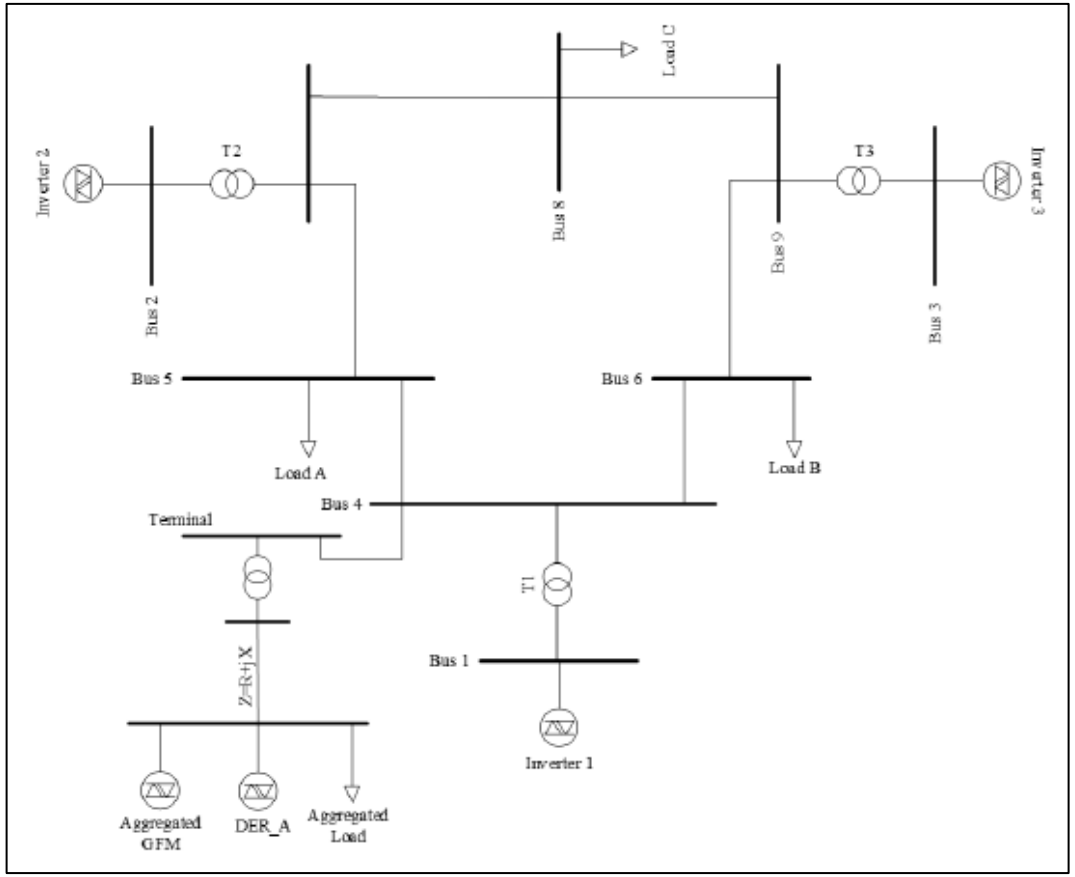
Test System

Transmission network with all three sources being inverters





Distribution network with voltage levels: 0.4 kV, 10kV, 30 kV. Includes 365 DERs, mix of grid following (GFL) and grid forming (GFM) inverters



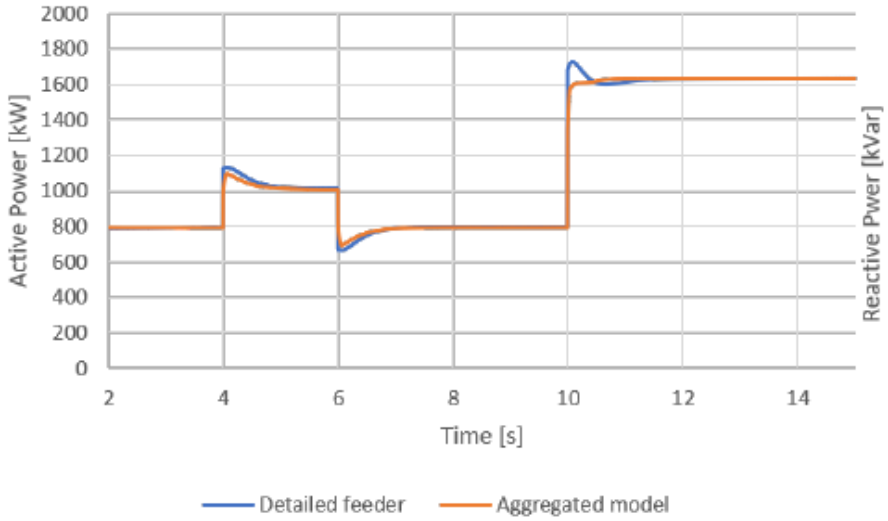
Detailed distribution feeder at bus 4 replaced with aggregate models

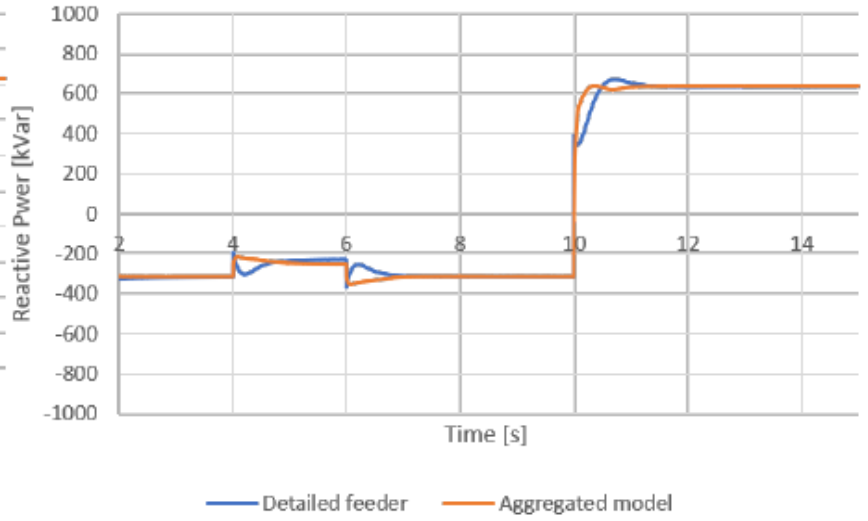
1. An equivalent feeder and transformer
2. An aggregate load model
3. Two aggregate DER models
   a) GFL DER using DER_A model
   b) GFM DER

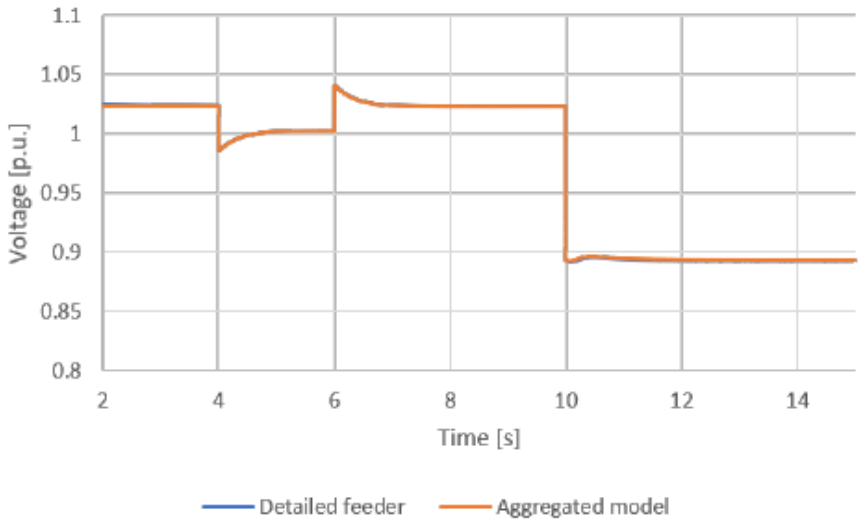
Test Scenarios

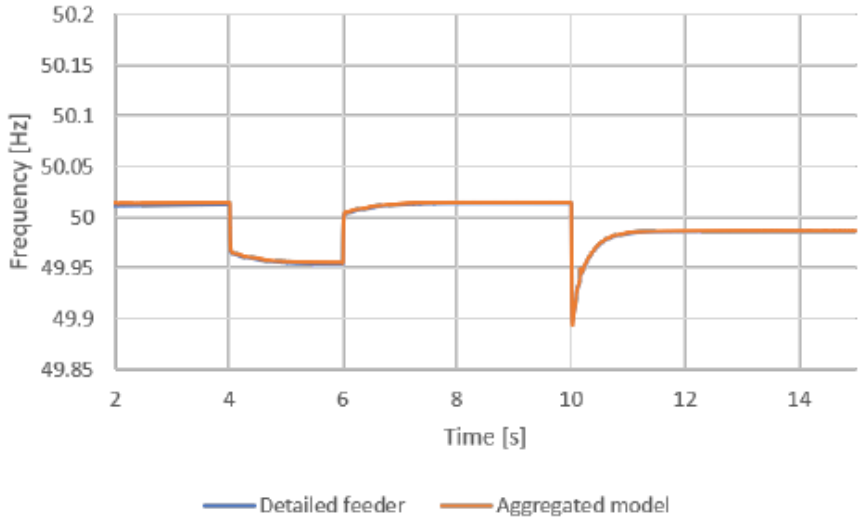
Transmission network				Distribution network		
Scenario	Inverter 1	Inverter 2	Inverter 3	Simulation	GFM (%)	GFL (%)
1	GFL	GFL	GFM	1	10	90
				2	50	50
				3	90	10
2	GFL	GFM	GFM	1	10	90
				2	50	50
				3	90	10
3	GFM	GFM	GFM	1	10	90
				2	50	50
				3	90	10

Test Results







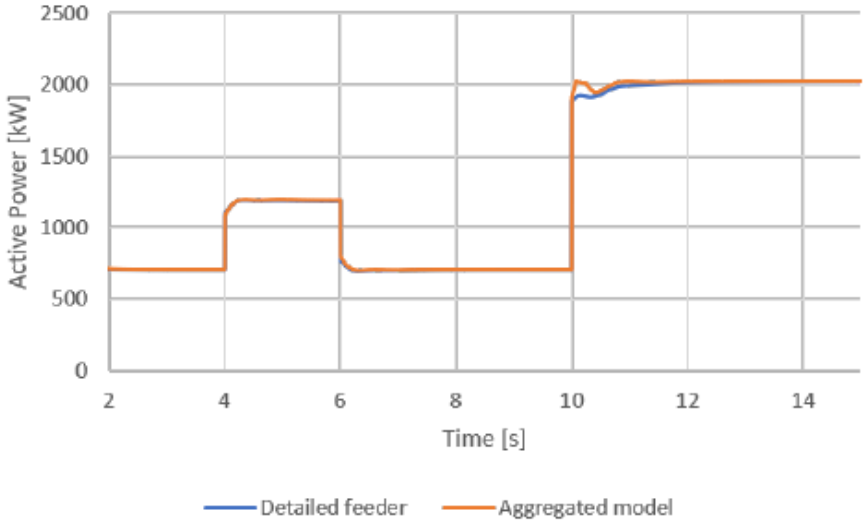


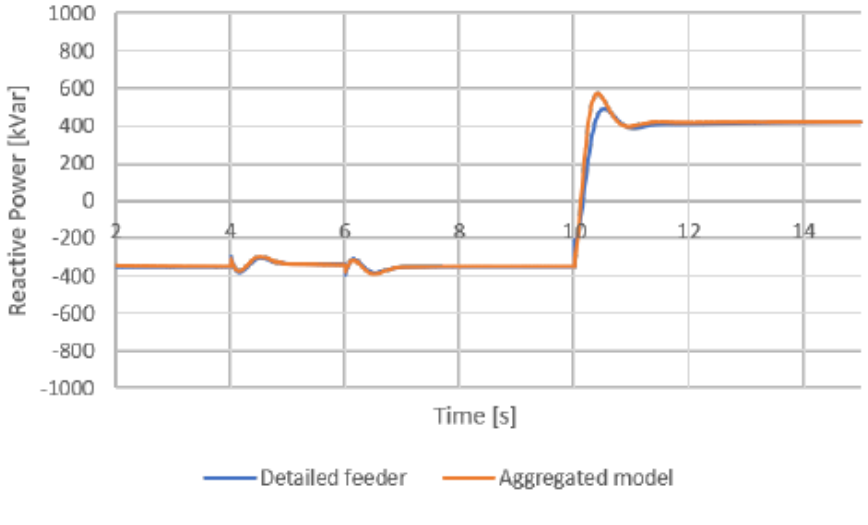
10% GFM and 90% GFL represented at distribution level (Scenario 2 / Simulation 1)

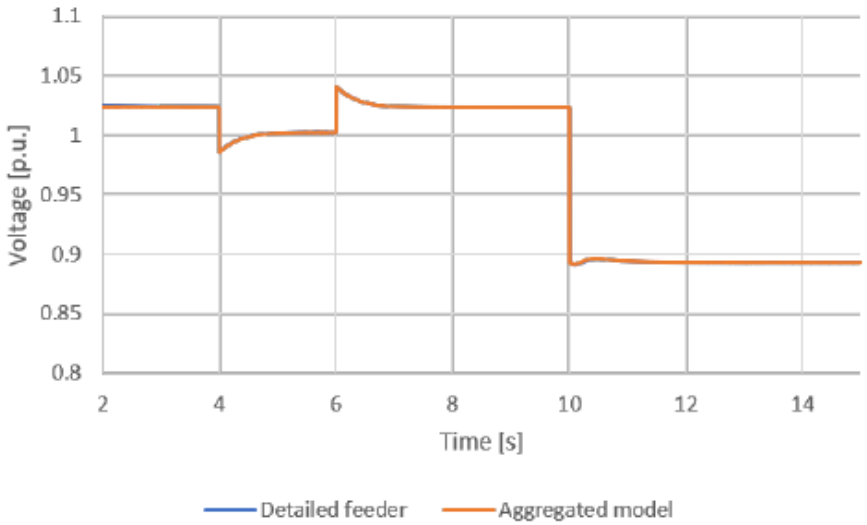
- Events:
  - 10% load increase at t = 4s
  - 10% load decrease at t = 6s
  - Radial system creation at t = 10s

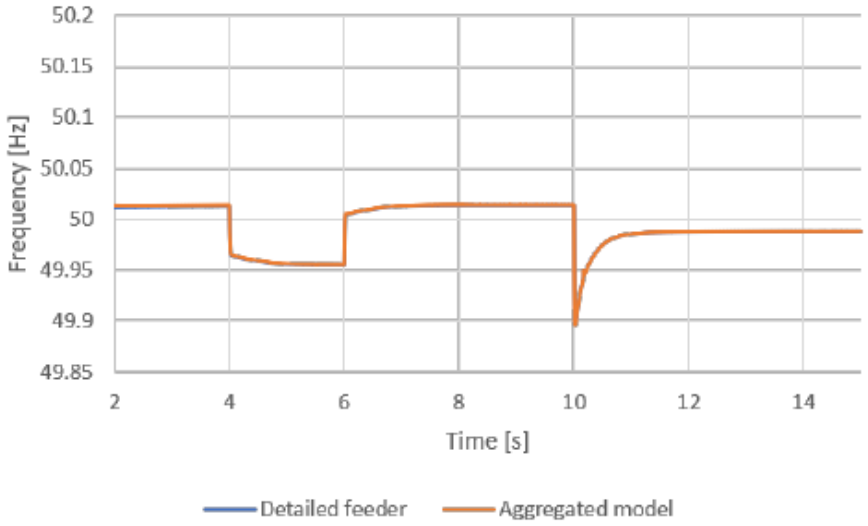
The aggregate model response matches well with the detailed model response

Test Results







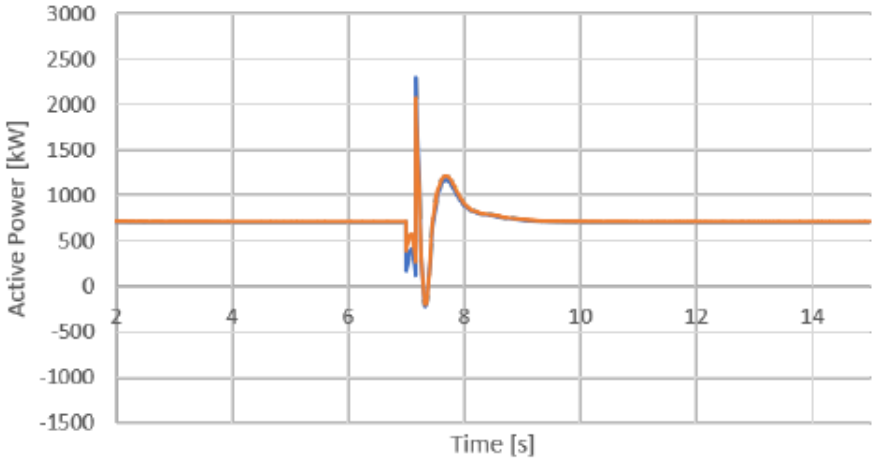


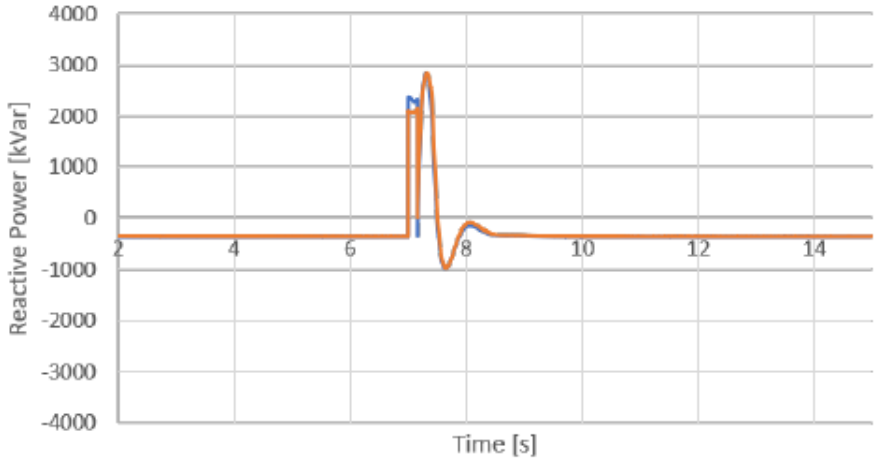
90% GFM and 10% GFL represented at distribution level (Scenario 2 / Simulation 3)

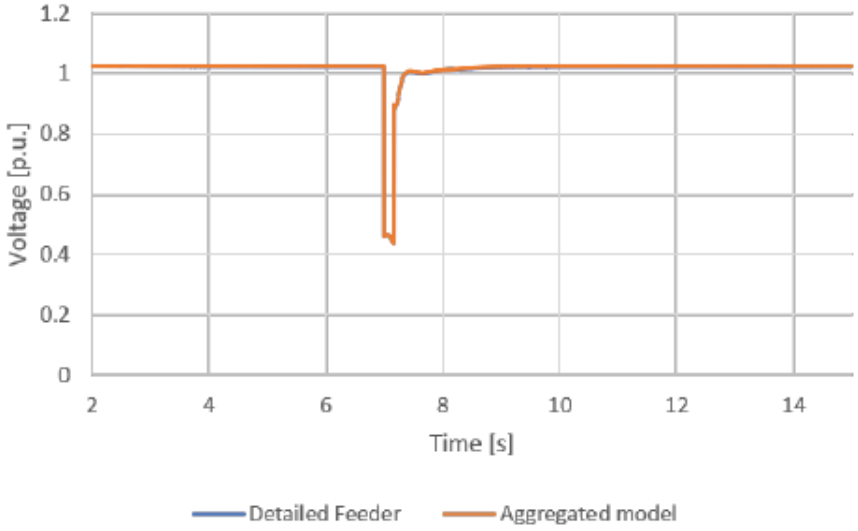
- Events:
  - 10% load increase at t = 4s
  - 10% load decrease at t = 6s
  - Radial system creation at t = 10s

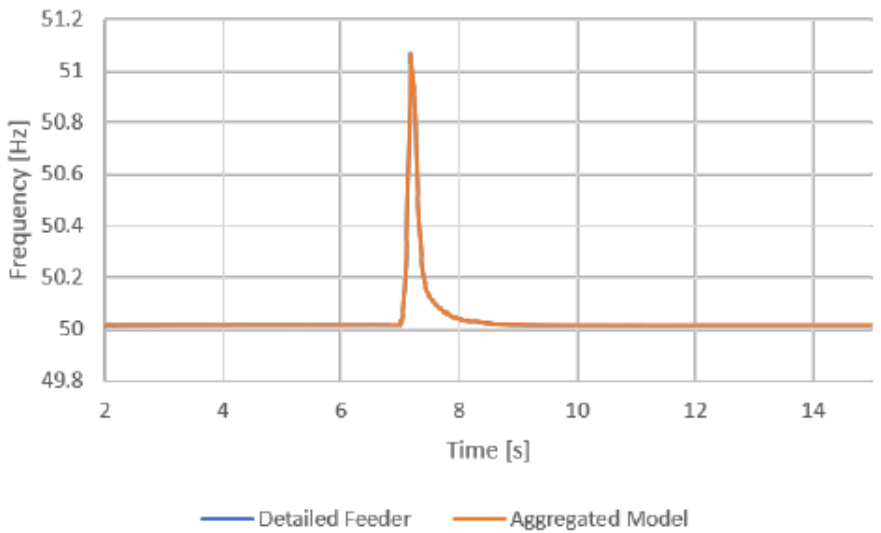
The aggregate model response matches well with the detailed model response

Test Results









90% GFM and 10% GFL represented at distribution level (Scenario 2 / Simulation 3)

- Events:
  - Three-phase fault at t = 7s

The aggregate model response matches well with the detailed model response

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