Research & Development Perspectives Around Modeling of Grid Forming Inverters

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Few basics about various inverter mathematical models

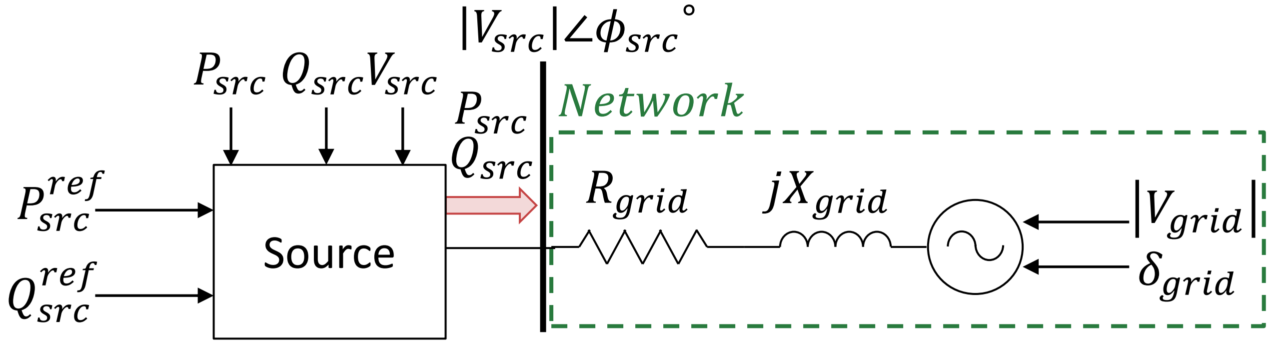
Generic model	Does not always imply	Bad model
User defined model from manufacturer	Does not always imply	Good model
RMS/Positive sequence model	Does not always imply	Bad model
Electromagnetic transient (EMT) model	Does not always imply	Good model

- All mathematical models have limitations
- When using mathematical models, few questions to be asked:
  - Is this the appropriate type of model for the study that is to be done?
  - Is the model being used in a correct manner?
  - Are all relevant components/control loops, that matter for the study, modeled?
  - Is the model appropriately parameterized?
  - Are sufficient validation results of model behavior available?
  - Nature of validation also important, e.g., field event data, or field test model.

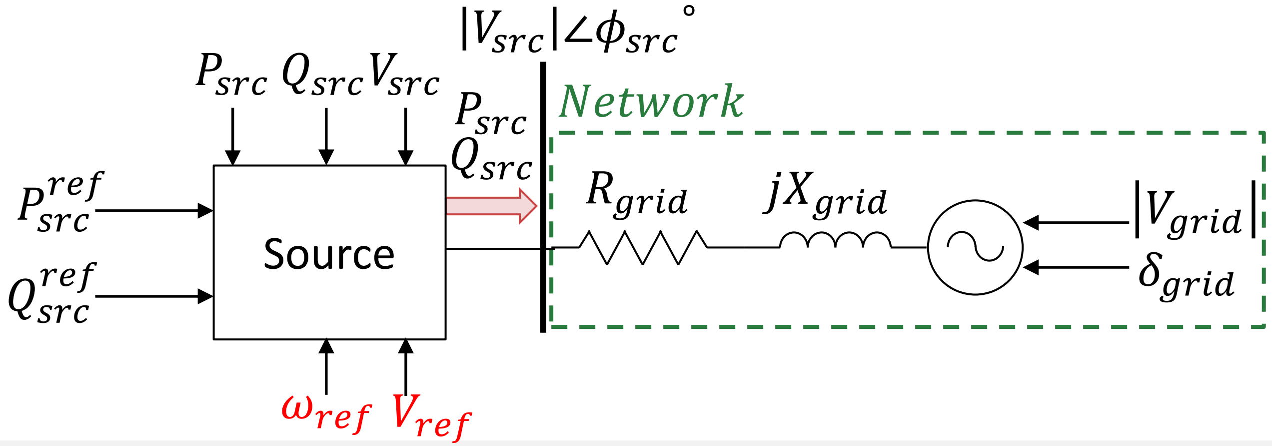
[REF] Deepak Ramasubramanian and Andrew Isaacs, “Bad Model,” NERC Inverter-Based Resource Performance Subcommittee (IRPS), Virtual Meeting, May 2022

What makes a source grid forming?

- Without looking internally inside the resource
  - Grid following – explicitly controls P and Q



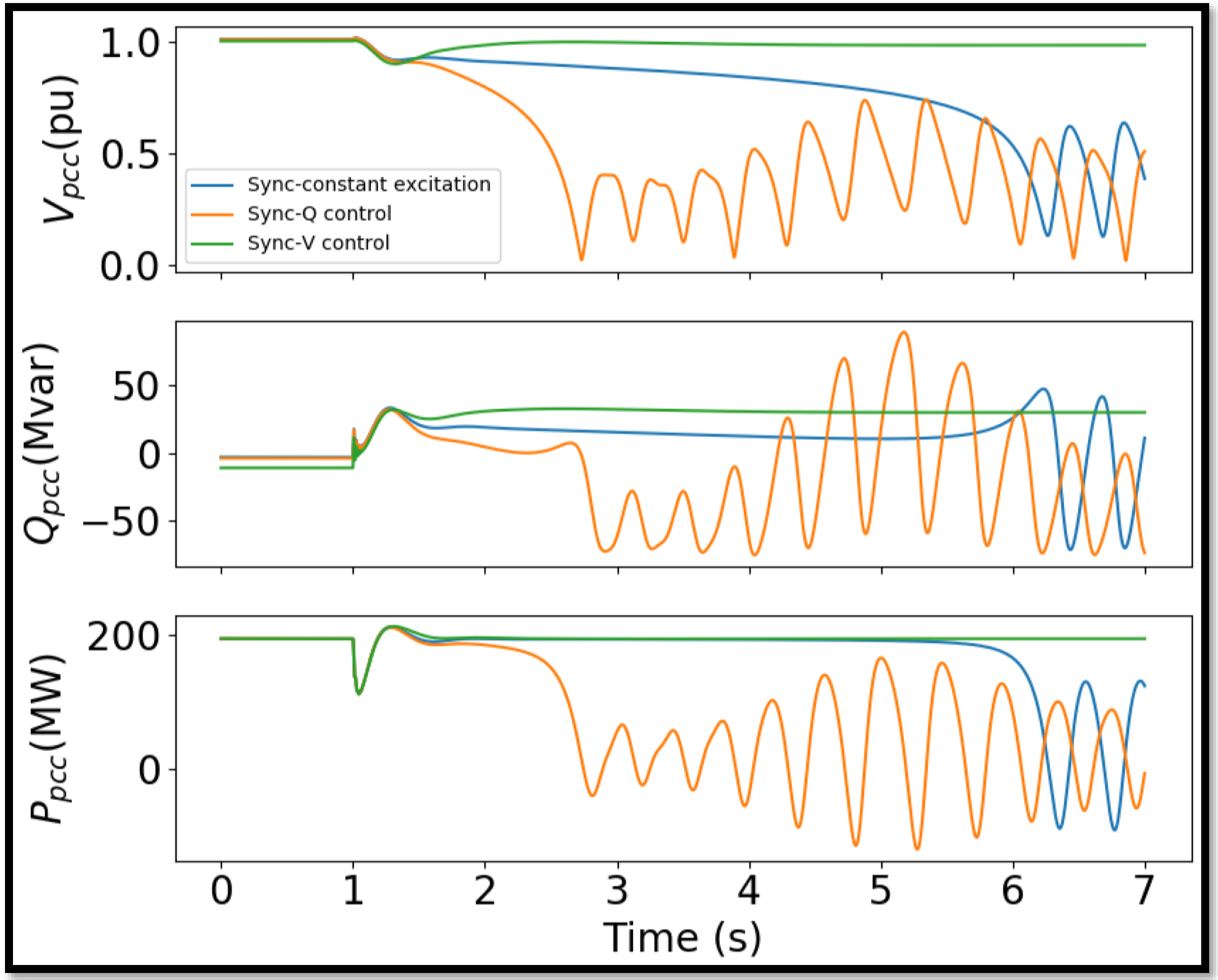
  - Grid forming – explicitly controls V and f and implicitly P and Q



Observing behavior in sub-transient time frame may be challenging

Behavior of voltage source behind impedance (a.k.a. synchronous machine) for low short circuit strength

- Constant voltage phasor behind impedance doesn't automatically imply/guarantee grid forming stability
- Fast closed loop voltage control (e.g., fast excitation control of synchronous machines) plays a dominating role in maintaining stability in low short circuit environments

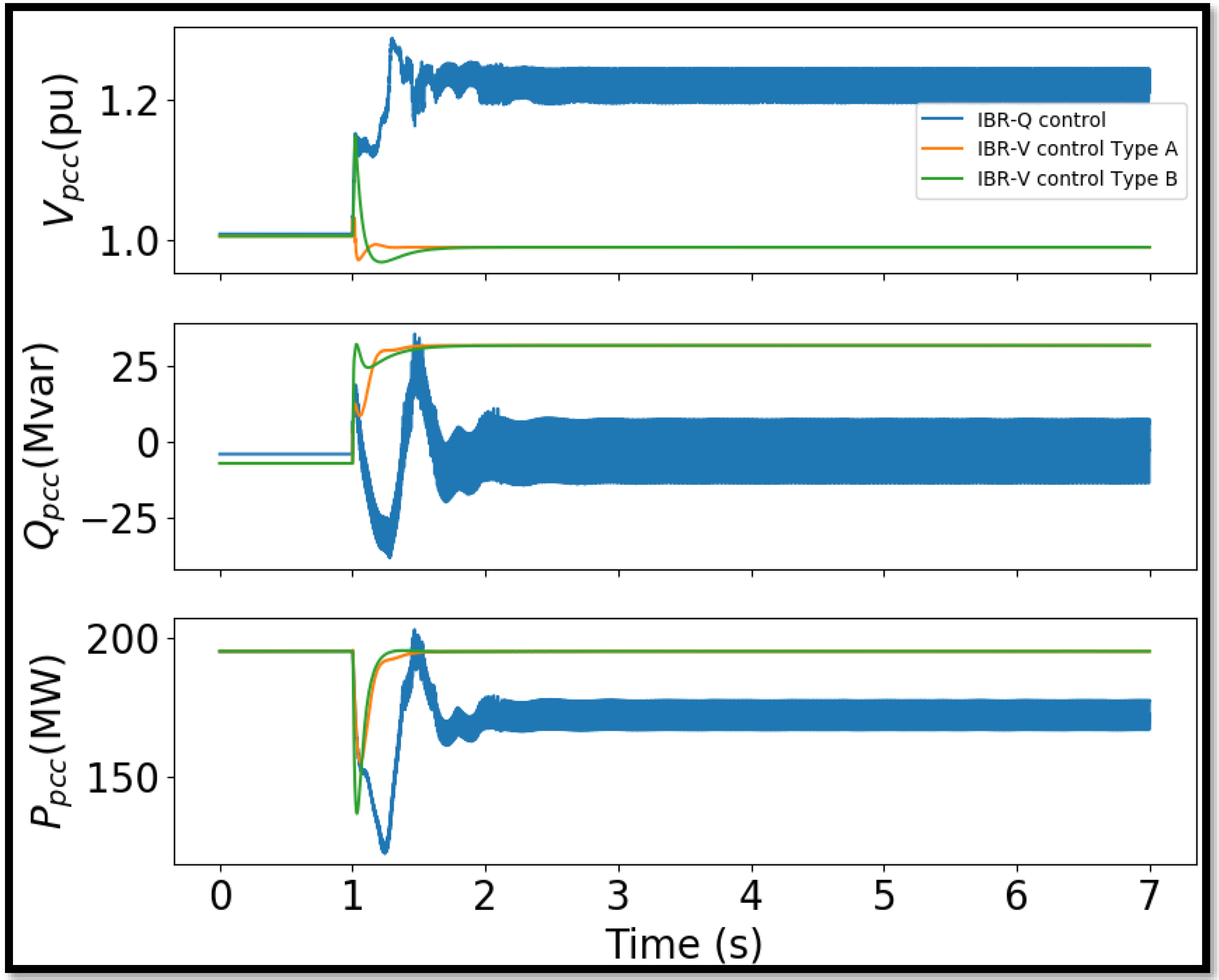


SCR reduces from 5.0 to 1.5 at t = 1.0s

Behavior of inverter-based resource for low short circuit strength

- Fast closed loop voltage control can maintain stability in low short circuit environments

- Closed loop voltage control can be explicit or implicit depending on type of IBR control

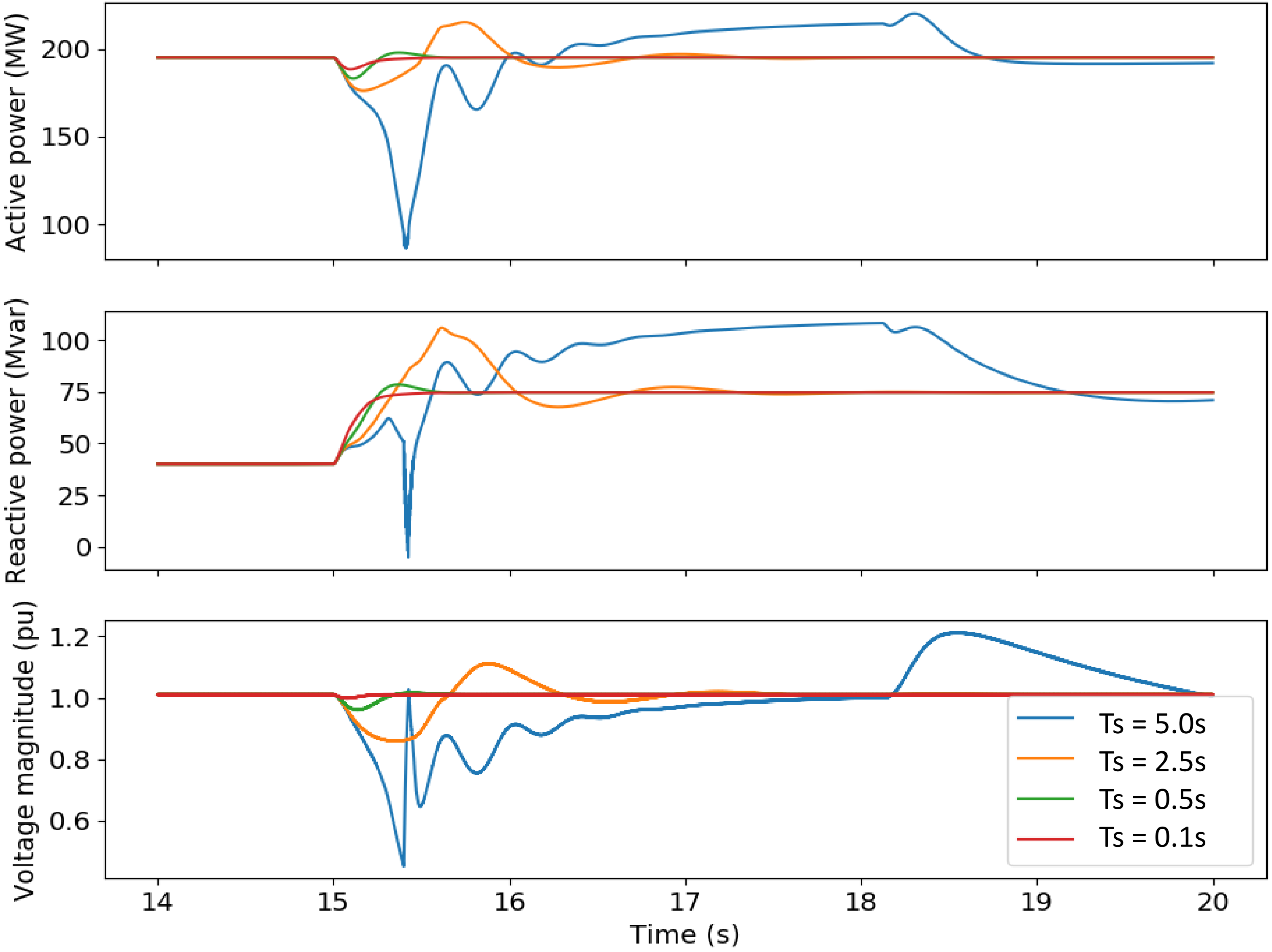


What is the importance with respect to modeling?

SCR reduces from 5.0 to 1.5 at t = 1.0s

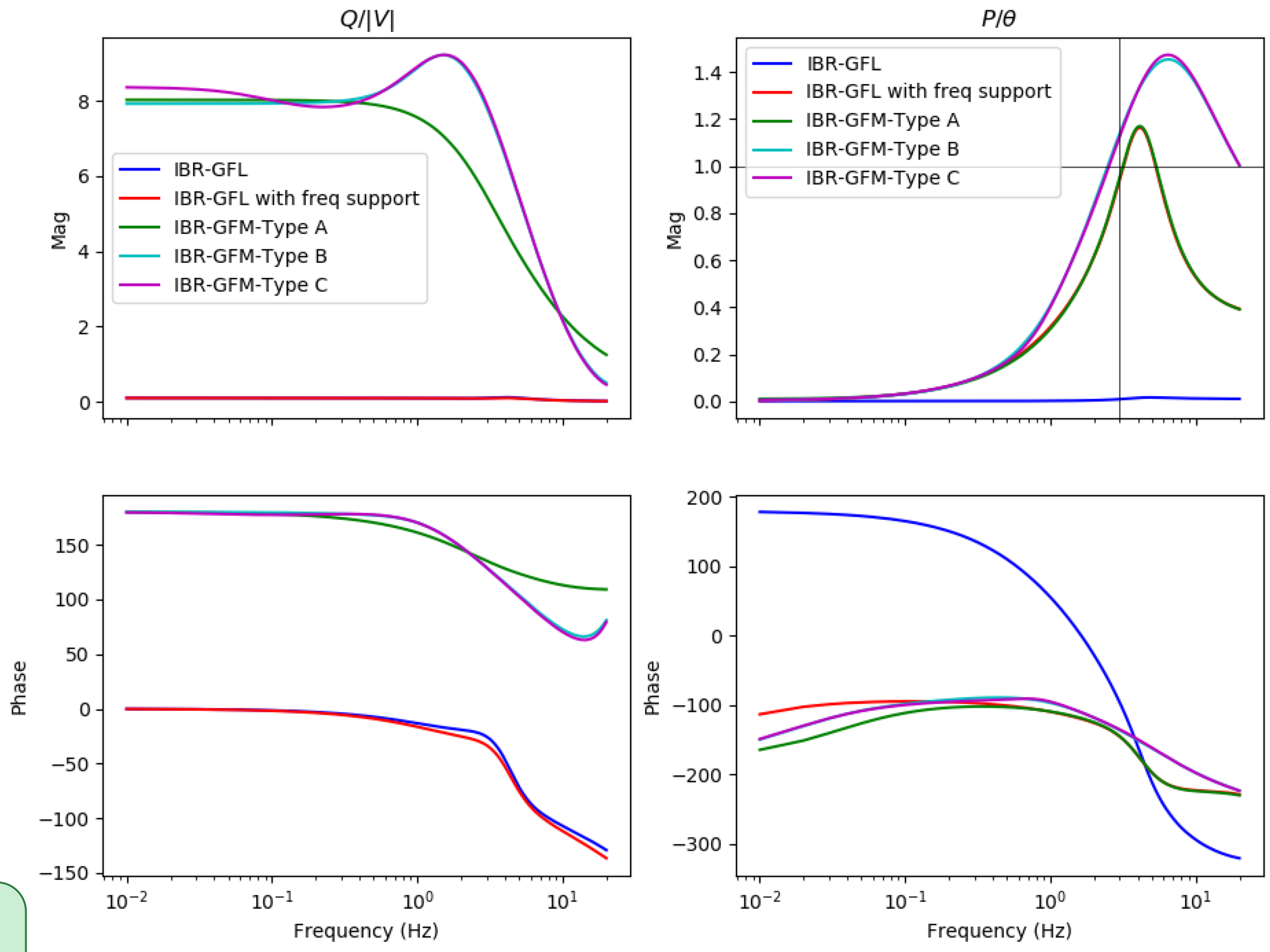
Specification of fast closed loop voltage control

- Lowest value of maximum step response time from IEEE 2800 is 1.0s
- Results on the right shown with SCR of 1.0, and a step reduction in grid voltage of 0.1pu
- To achieve grid forming behavior, potentially a faster voltage control loop may be required at the inverter level
  - With maximum step response time of less than 1.0s



Various types of grid forming resources exhibit similar characteristics in frequency domain

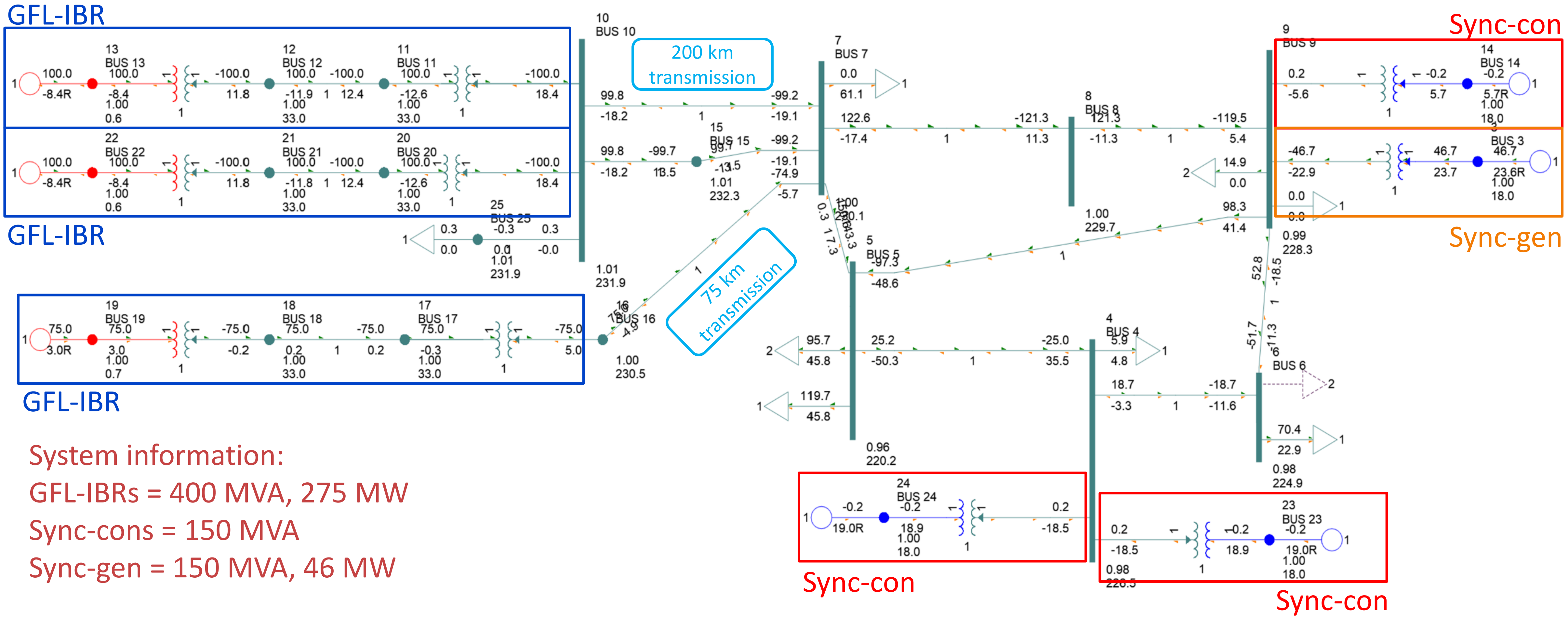
- If an IBR provides no voltage control and no frequency control, magnitude ≈ 0.0
- To be GFM, both voltage and frequency control is to be provided
- GFM of different control topologies exhibit similar frequency domain characteristics



The similarity in response allows for development of generic models of GFM that can subsequently be used in planning studies

Typical 5% droop frequency control

Locating and sizing of grid forming resources using generic models



System information:

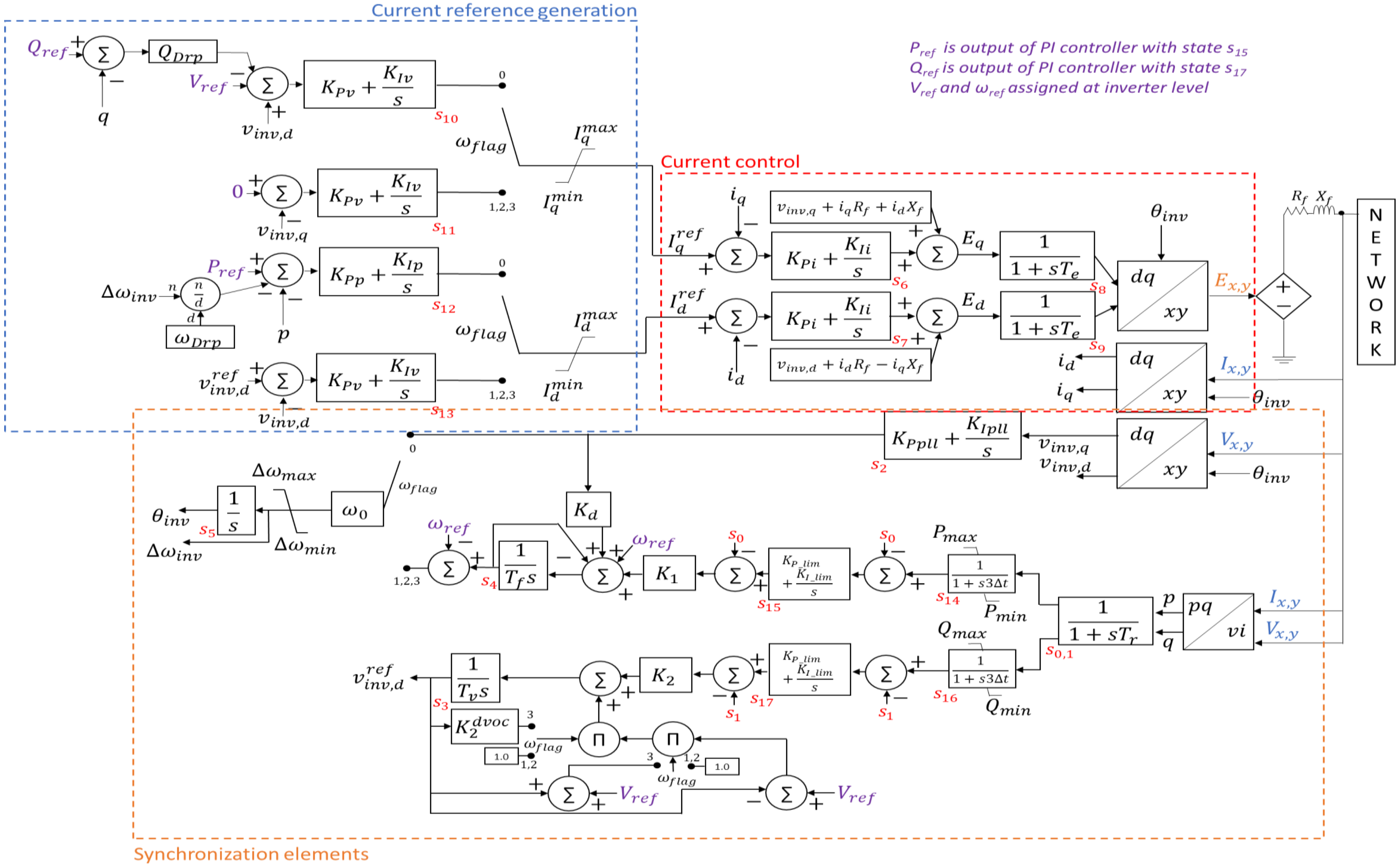
GFL-IBRs = 400 MVA, 275 MW

Sync-cons = 150 MVA

Sync-gen = 150 MVA, 46 MW

- Study objective: To allow retirement of synchronous condensers and generator from the load centers, where to place a GFM device and what should be its rating?

Structure of generic GFM model used in this study



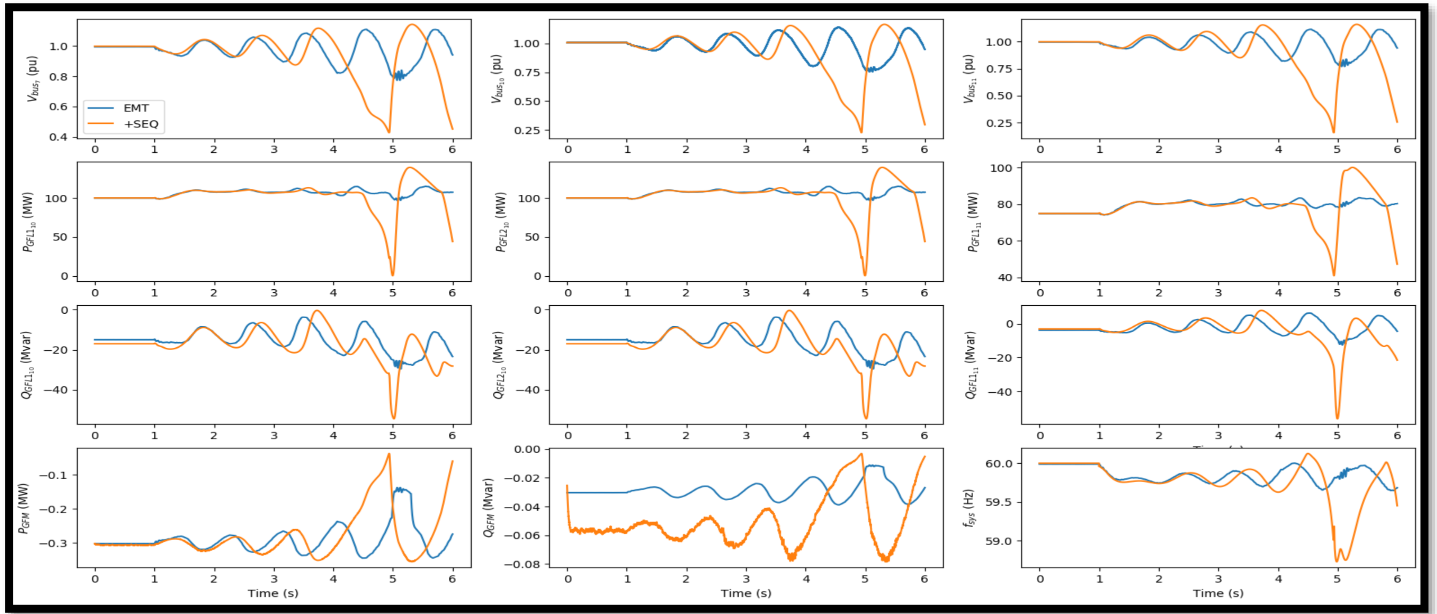
- Choice of type of GFM model decided by value of ω_{flag}
  - 0 – Type B droop
  - 1 – Type A droop
  - 2 – VSM
  - 3 – dVOC
- Fault current limiting handled at network interface
- User only has to toggle flag to switch from one GFM type to another

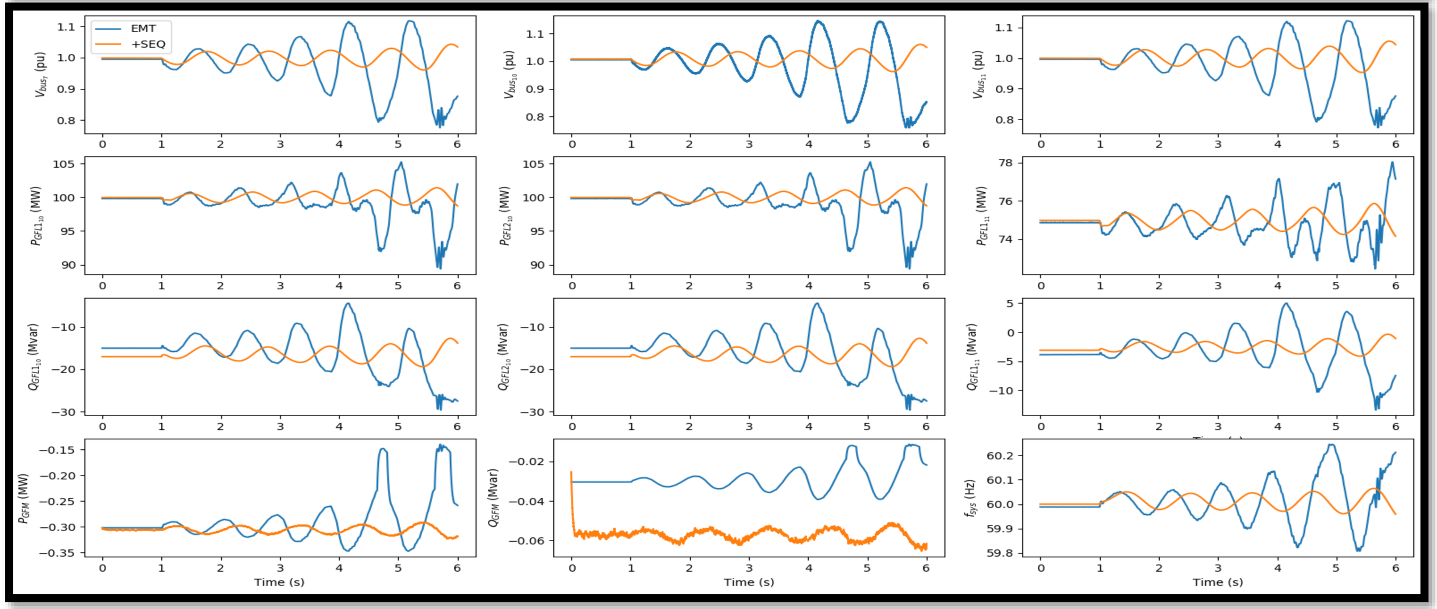
B. Johnson, T. Roberts, O. Ajala, A. D. Dominguez-Garcia, S. Dhople, D. Ramasubramanian, A. Tuohy, D. Divan, and B. Kroposki, “A Generic Primary-control Model for Grid-forming Inverters: Towards Interoperable Operation & Control,” *2022 55th Hawaii International Conference on System Sciences (HICSS)*, Maui, HI, USA, 2022 [Link]

D. Ramasubramanian, “Differentiating between plant level and inverter level voltage control to bring about operation of 100% inverter-based resource grids,” *Electric Power Systems Research*, vol. 205, no. 107739, Apr 2022 [Link]

Deepak Ramasubramanian, Wes Baker, Julia Matevosyan, Siddharth Pant, and Sebastian Achilles, “Asking for Fast Terminal Voltage Control in Grid Following Plants Could Provide Benefits of Grid Forming Behavior,” *IET Generation, Transmission & Distribution,* early access [Link]

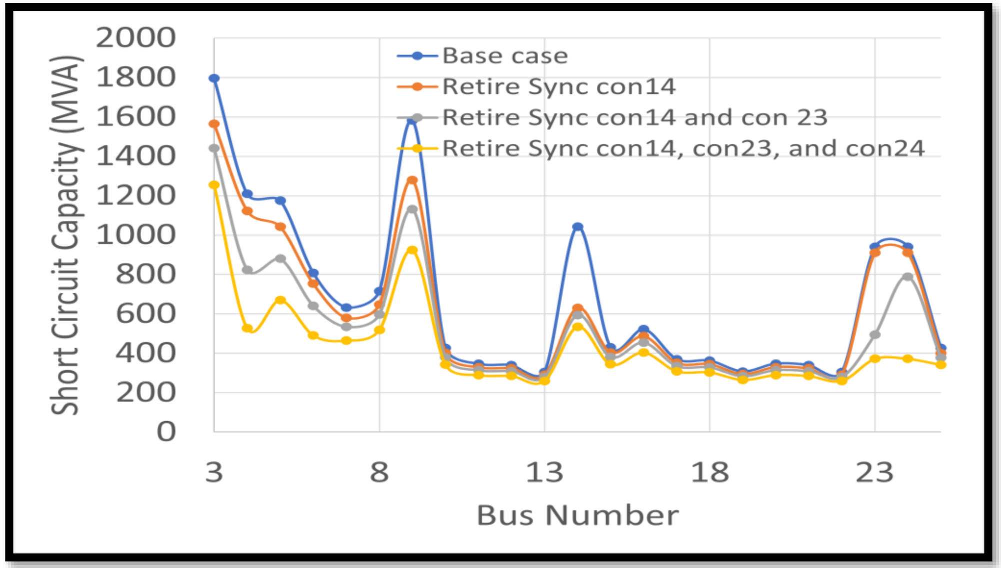
Locating and sizing of grid forming resources

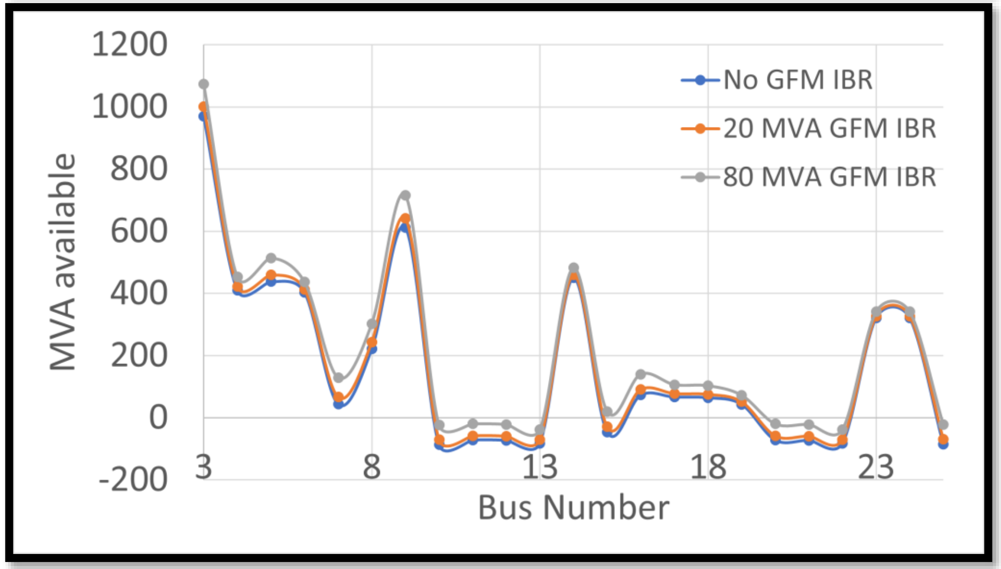


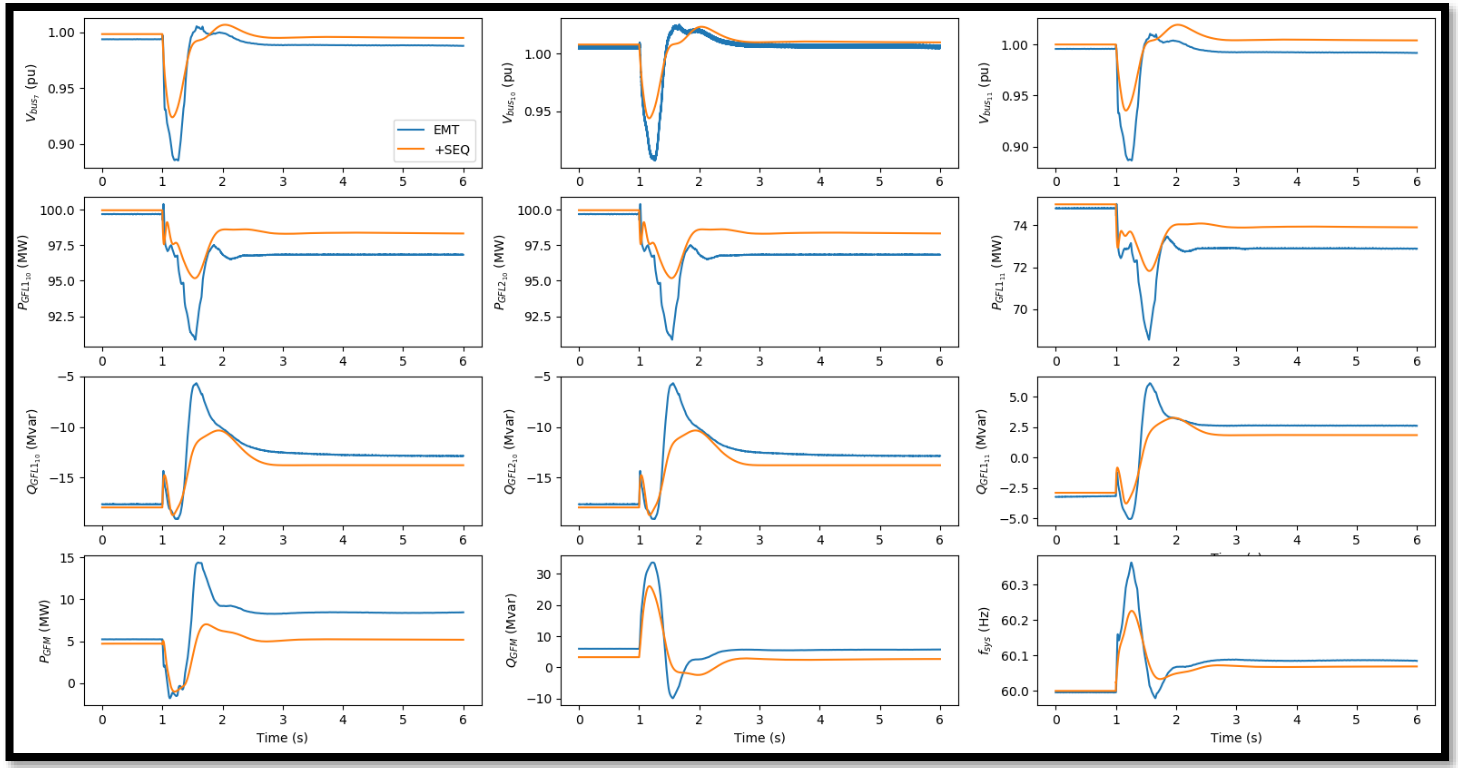


- Events shown:
  - Top: Load increase 10%
  - Bottom: Trip of one sync-con
- Even with synchronous resources (without power system stabilizers) system is on verge of instability
  - diligently parameterized models across both simulation domains

Locating and sizing of grid forming resources







- Determined size and location of GFM using steady metrics of short circuit strength and remaining MVA available
- Trip of all 150 MVA of sync-con could be stabilized with 80 MVA of GFM

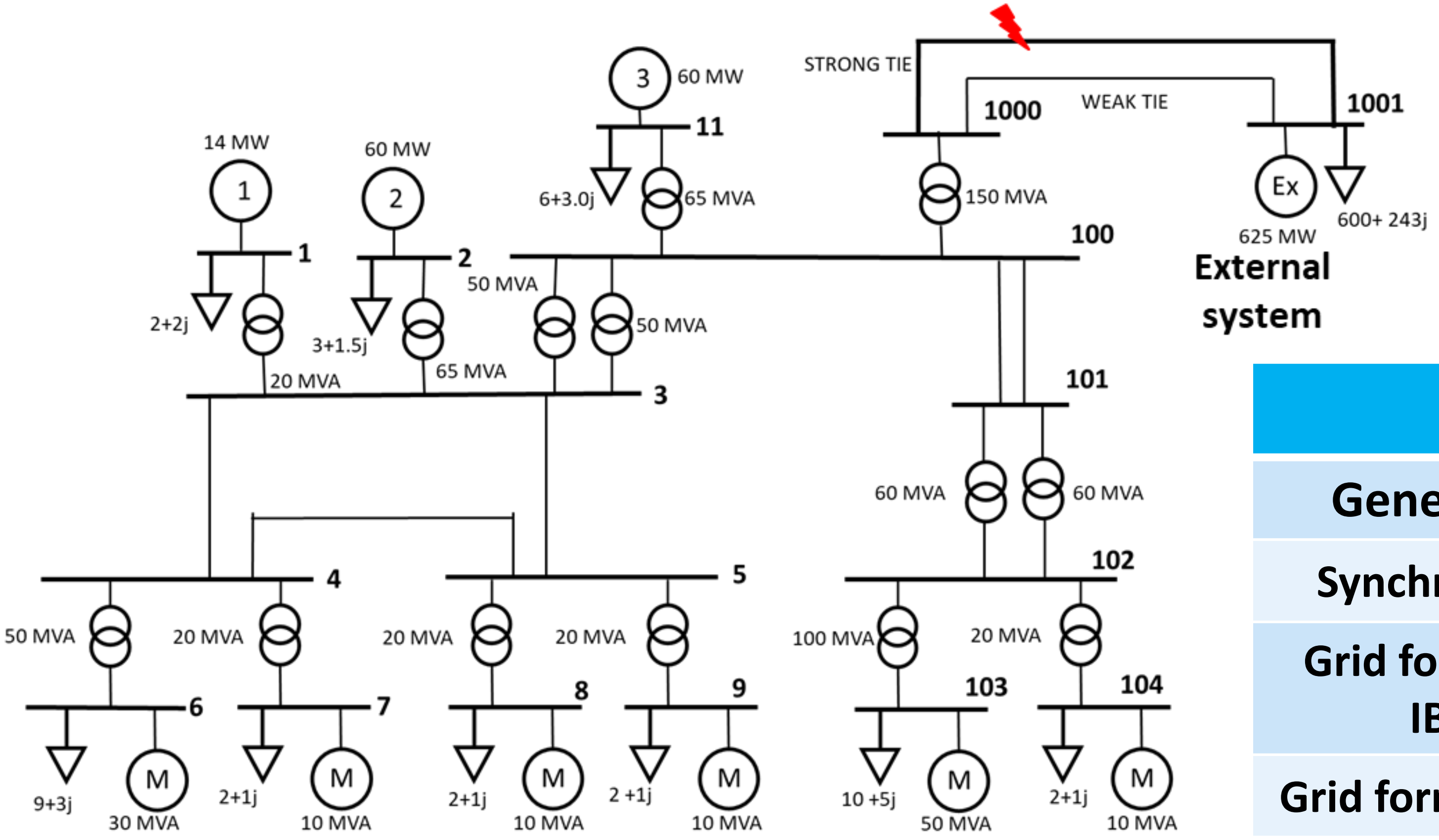
[REF] Deepak Ramasubramanian, "Location and Sizing of Grid Forming Devices in Islanded Networks," *[under review]*

Importance of Load Modeling with Grid Forming

- System loads have a significant impact on system dynamic response
- As we move from synchronous machines to more IBRs, their responses in the presence of different load types need to be examined
- Especially important as specifications and requirements are being prescribed for new resources

Important to account for loads while studying generator dynamics

System description and study matrix



Large Industrial Facility 147 MVA load

Study Matrix				
Generator	**Load type**			
Synchronous	**ZIP**	**3ϕ IM**	**1ϕ IM**	**Variable speed drive**
Grid following IBR				
Grid forming IBR				

Different types of proposed grid forming options as well as grid following models (e.g REGC_x) will be studied. Maximum current limit of 1.2pu has been assumed

Types of IBR control techniques studied

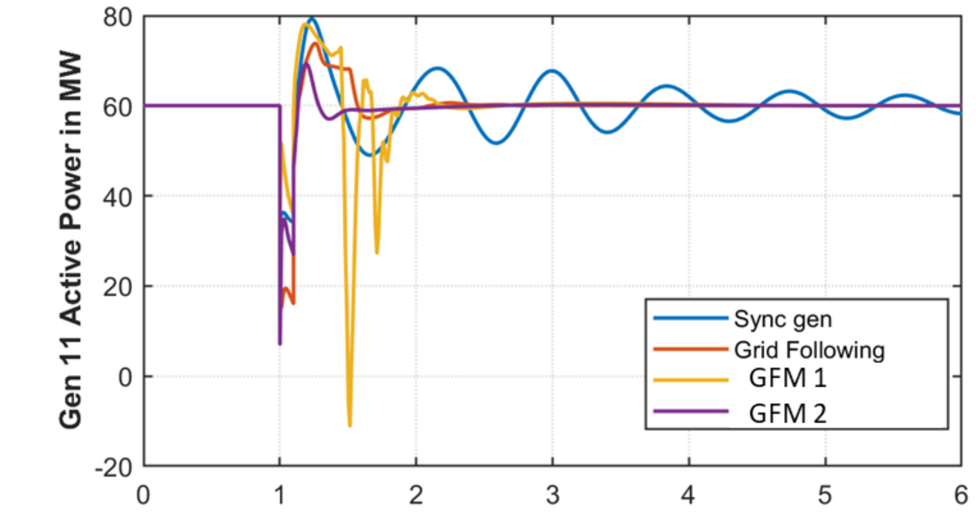
Grid Forming				Grid Following	
Droop based	PLL based	Virtual Synchronous Machine	Virtual Oscillator	PLL not modeled	PLL modeled
Textbook Beta Models ❑ Active power controls frequency ❑ Voltage control achieved through control of direct axis current				2nd generation RE models	

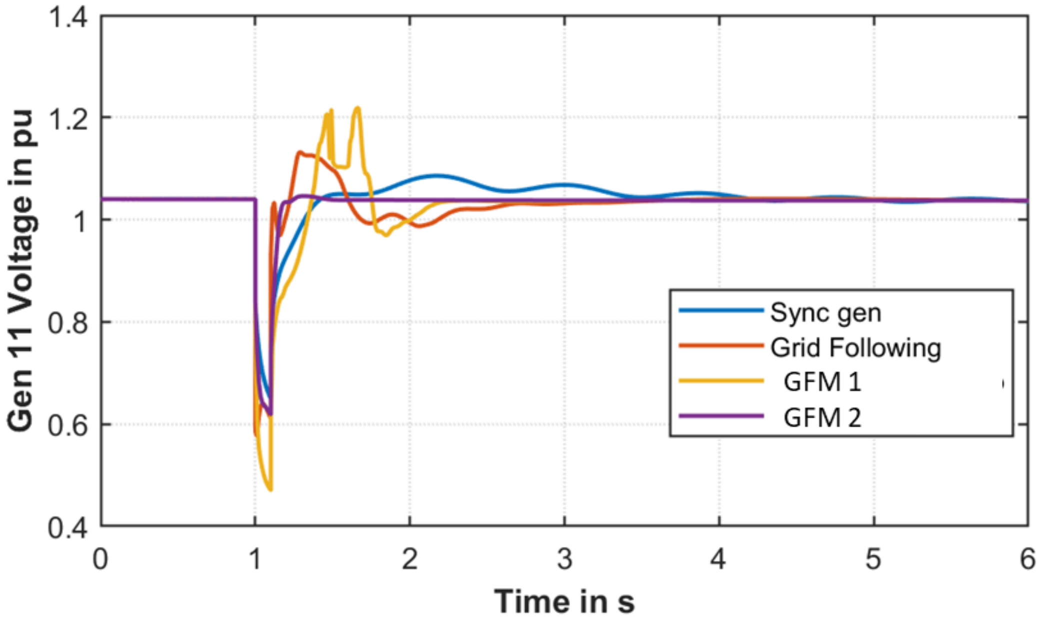
Caveat!!

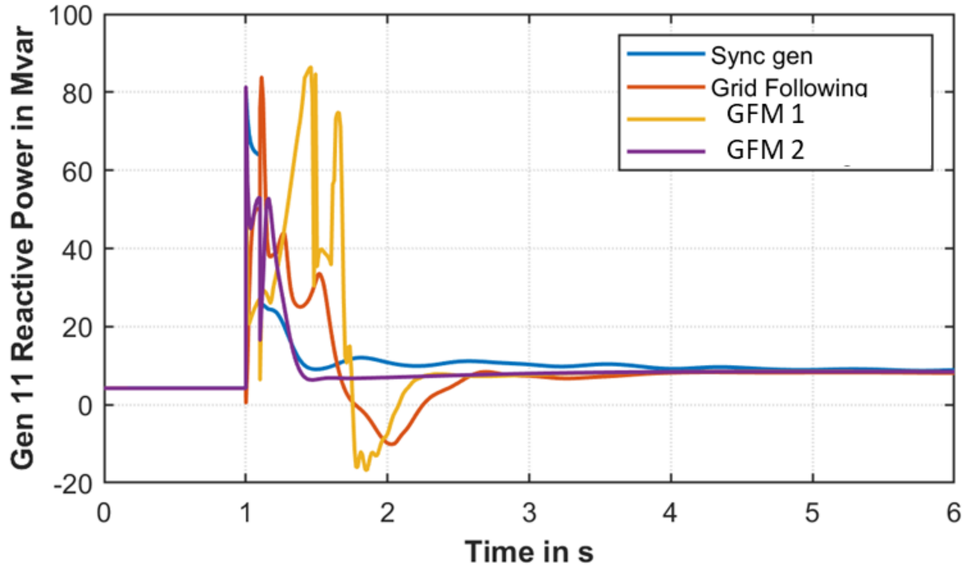
- **The controls are just one of many control strategies vendors may have.**
- **Simulation results are not intended to show one type of control is better than others. We cannot draw those from what is presented here.**
- **The presentations show why load modeling should be a part of such analysis since load behavior can drive significant dynamics**

EPRI

Loads are 3 phase Induction motors (Large Inertia)





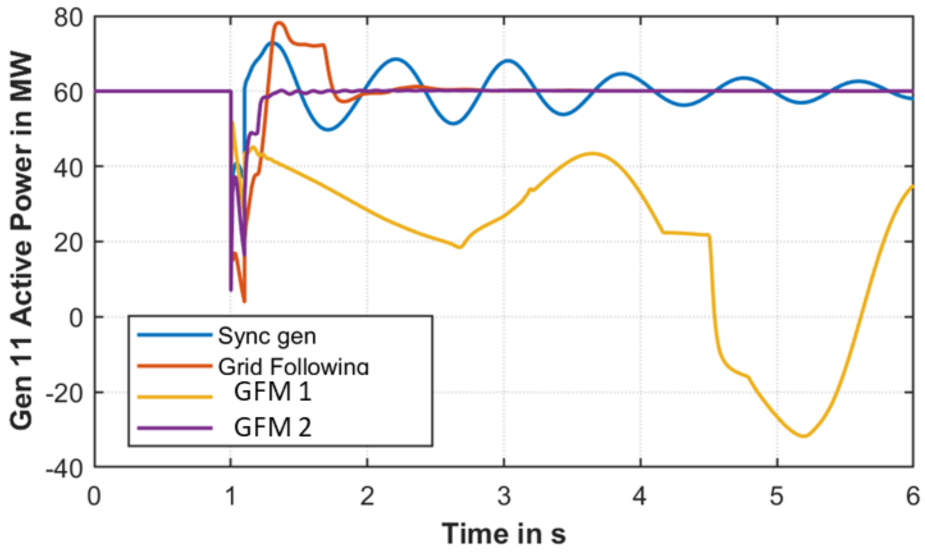


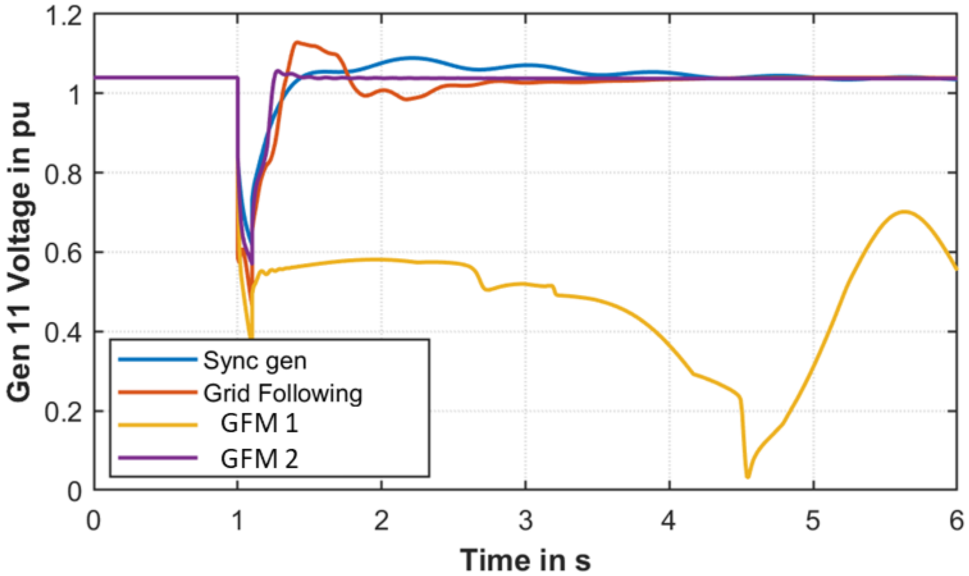
Key Observations

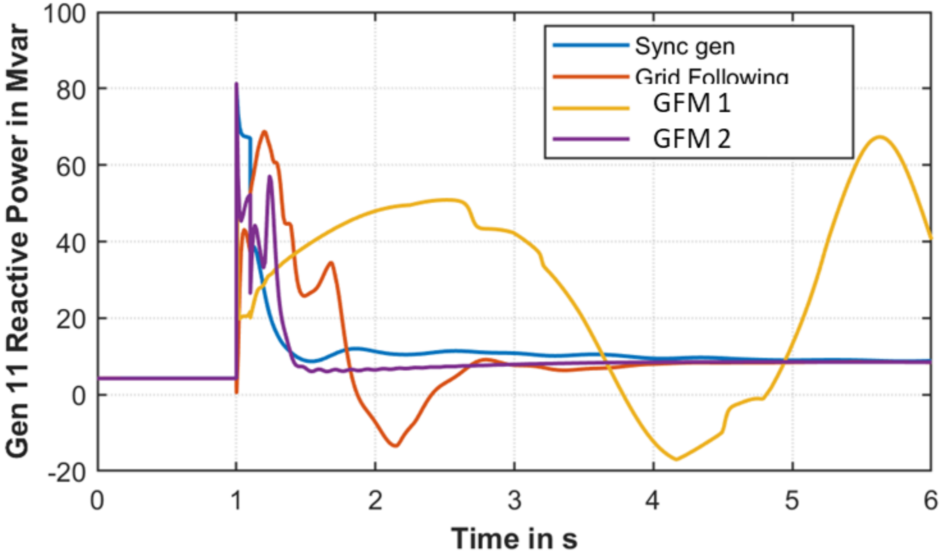
- Response is stable, but new overshoots have appeared
- Motor loads draw higher current during reacceleration
- Electromechanical mode was driven by the synchronous machine disappears even with motors.

EPRI

Loads are 3 phase Induction motors (low Inertia)



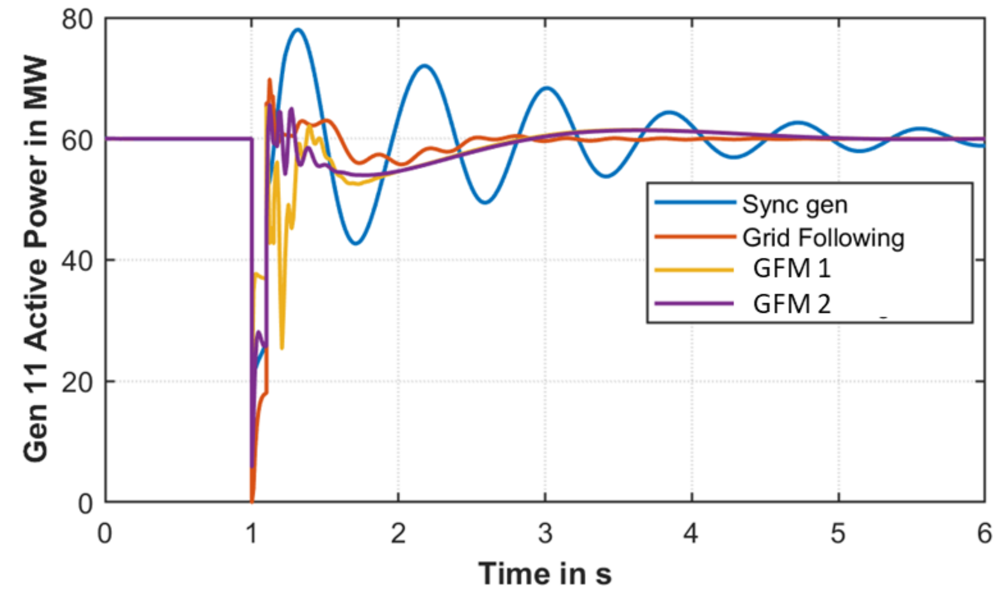


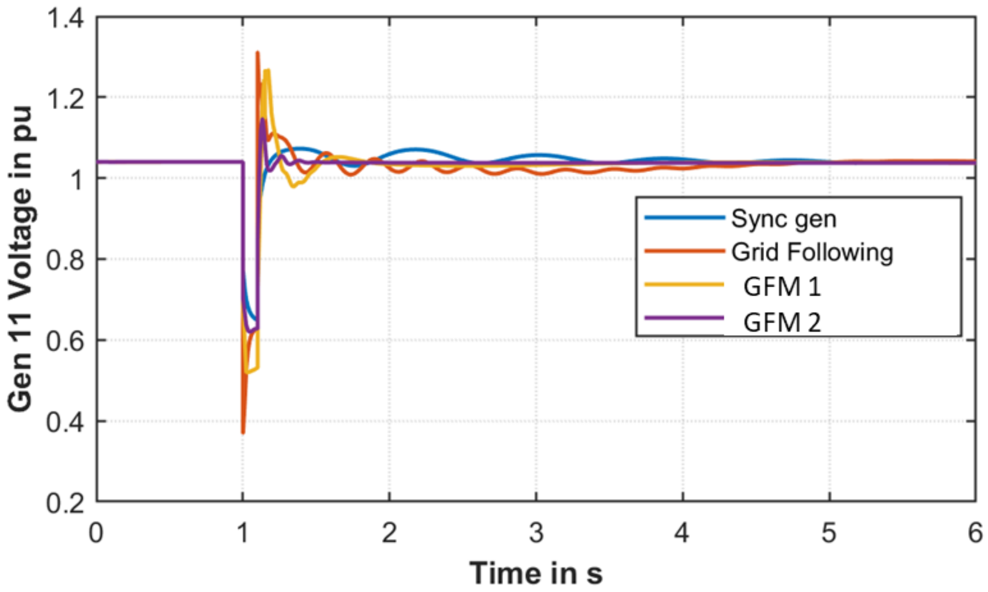


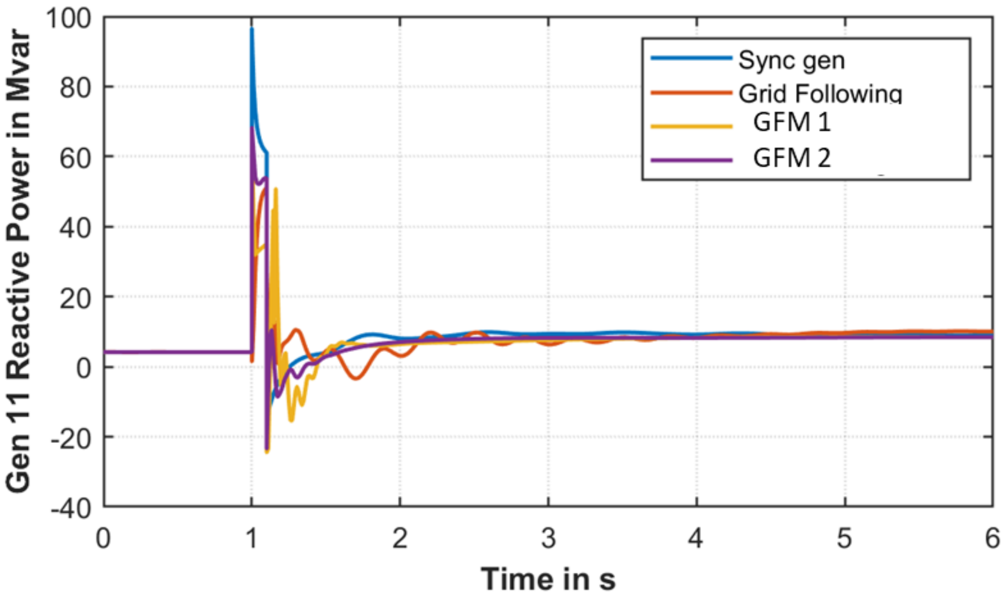
Key Observations

- One of the grid forming modes became unstable.
- Low inertia motors tend to slow down and draw excess current
- Absolutely value of maximum current and delivery of current at limit will affect stability significantly.

Loads modeled as variable speed drives (VSDs)







Key Observations

- All the different control modes produce stable responses
- Variable speed drives control the inrush and takes some of the burden of current control off inverters
- Some oscillations can be seen in the grid following control mode but these are not electro mech.

What does all this mean?

- Using appropriate load models will be critical in assessing the newer technologies that are being presented.
- It is important to understand the issues that may go away and issues that may start to appear
  - Electromechanical oscillations (goes away), limited current (new issue)
- Control parameters and options need to be tested depending on the loads that the IBRs will serve.

With the changing generation landscape understanding load behavior and load technology evolution will be critical

Summary

- Fast voltage control is a dominant factor to introduce stability.
- Different GFM control types have similar input-output characteristics
- Metrics such as available MVA could be used to locate and size GFM.
- Using appropriate load models will be critical in assessing the newer technologies that are being presented.
- It is important to understand the issues that may go away and issues that may start to appear
  - Electromechanical oscillations (goes away), limited current (new issue)
- Control parameters and options need to be tested depending on the loads that the IBRs will serve.

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