IBR Models and Modeling Needs

Deepak Ramasubramanian
(dramasubramanian@epri.com)
Technical Leader, EPRI

ESIG 2022 Fall Technical Workshop
Minneapolis, USA
October 25, 2022

Power system simulations

- An objective of a simulation:
  - Get visibility and insight regarding dynamic characteristic response of a system

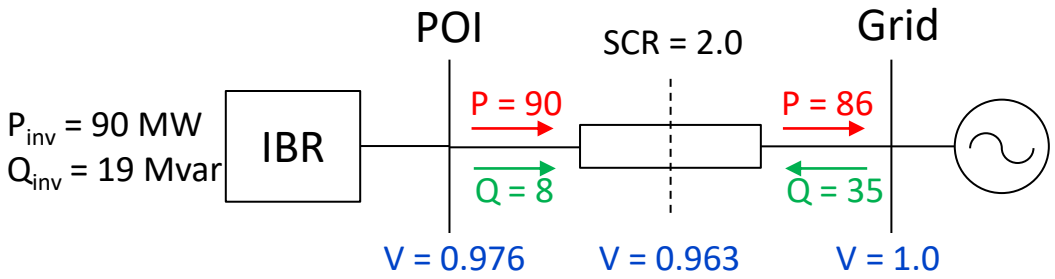
- How are dynamic characteristics represented?
  - Predominantly through use of differential equations that represent the rate at which quantities change.

- How is the above objective achieved?
  - Through integration of differential equations
  - Along with solution of algebraic equations (if present)

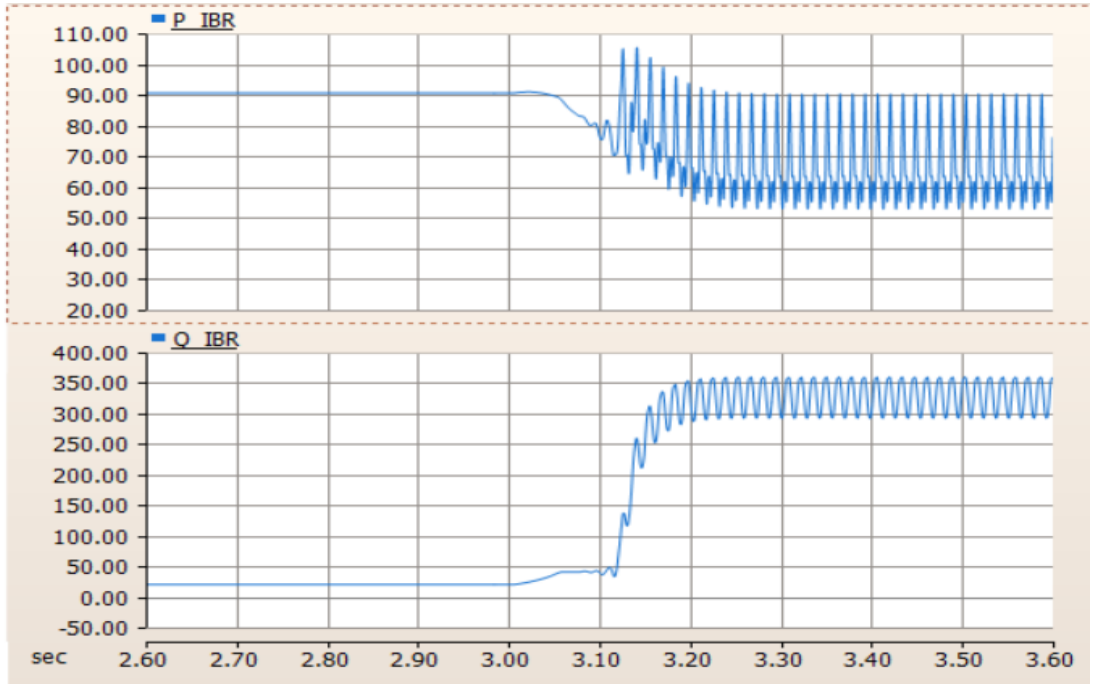
Objective of a model

- Provide a trend of response of dynamic behavior
- Not advisable to have too strict/tight a set of expectations from a model
  - A lot of uncertainty is present when carrying out a simulation study
- Models across simulation domains may have nuanced differences in implementation in order to provide similar time domain response

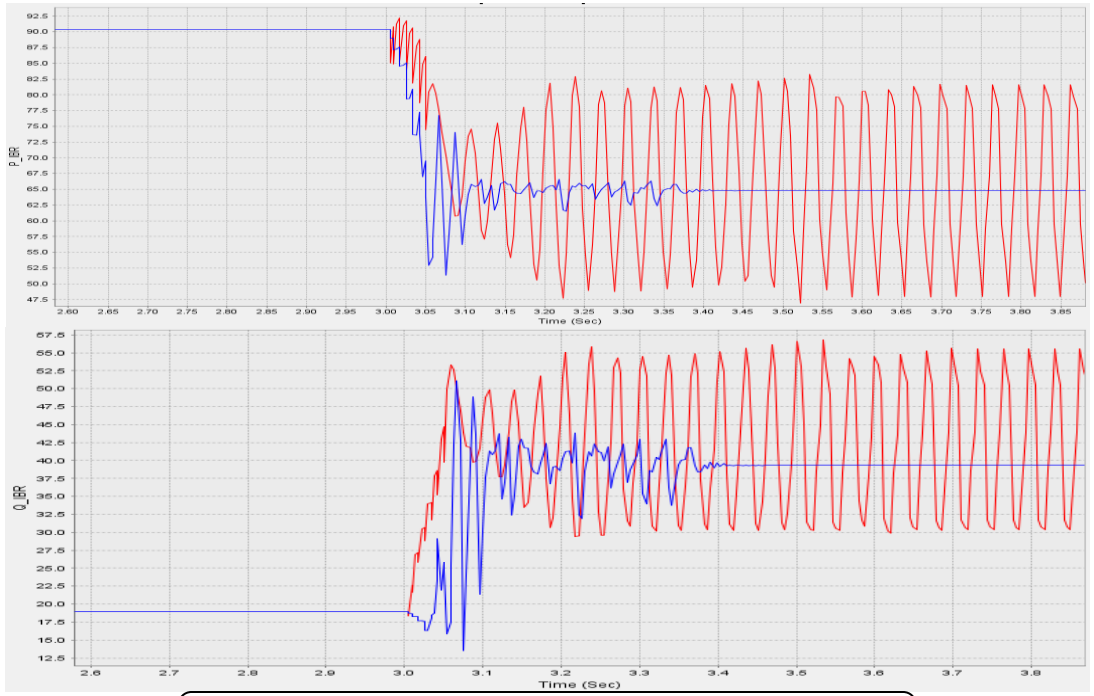
Consider an example of IBR and low short circuit scenario



Here, if SCR reduces to 1.0, instability results



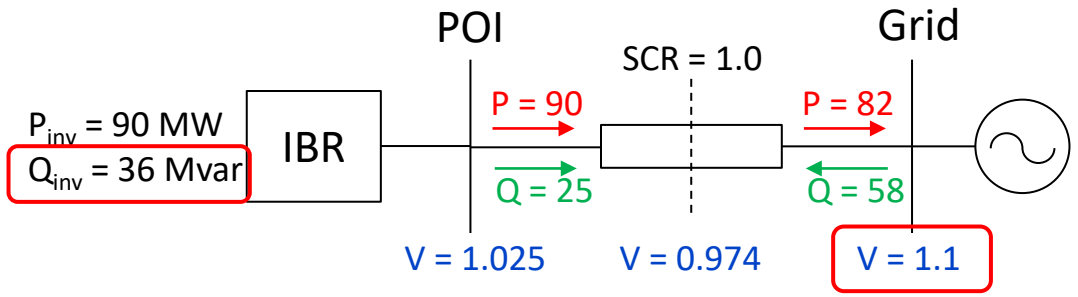
EMT domain



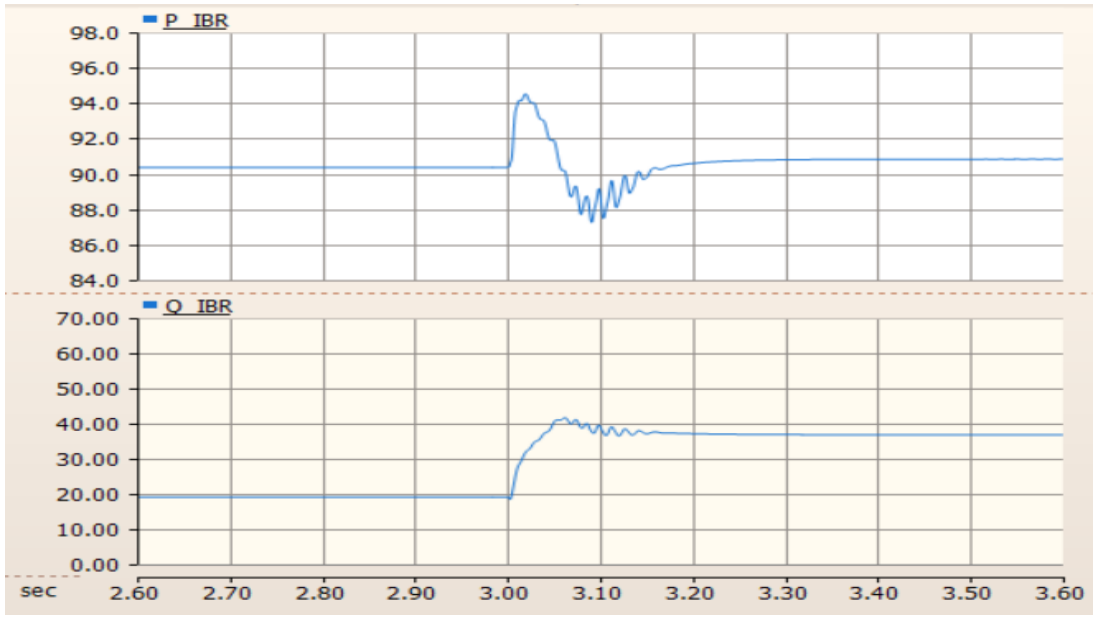
+SEQ domain (old vs new models)

Details regarding IBR models used

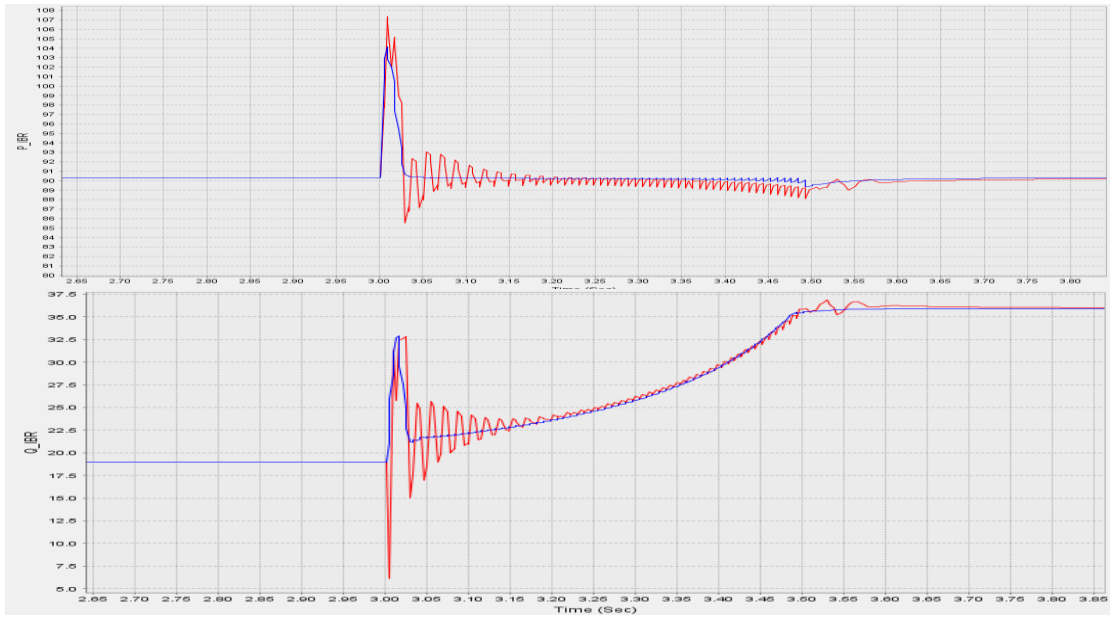
Consider an example of IBR and low short circuit scenario



Knowing the power flow solution, can help to obtain stability



EMT domain



+SEQ domain (old vs new models)

New models still have more room for improvement

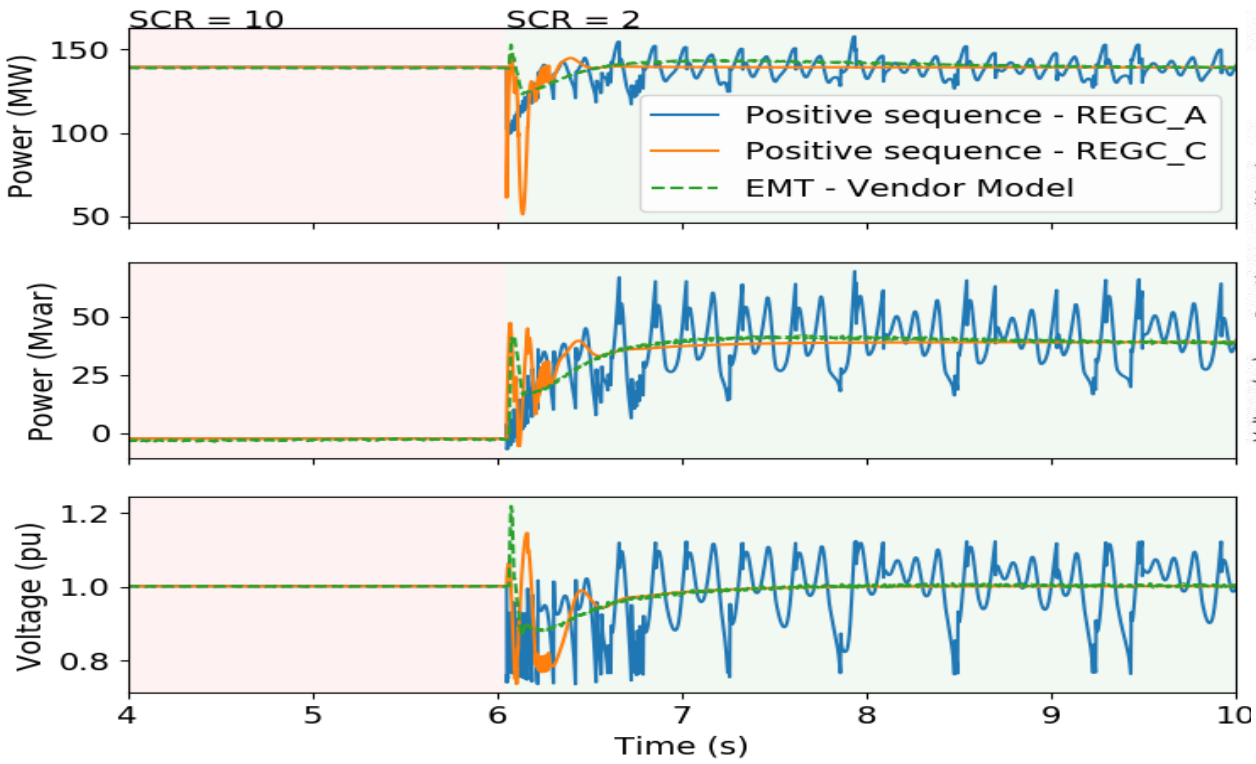
Representation of IBRs in simulation

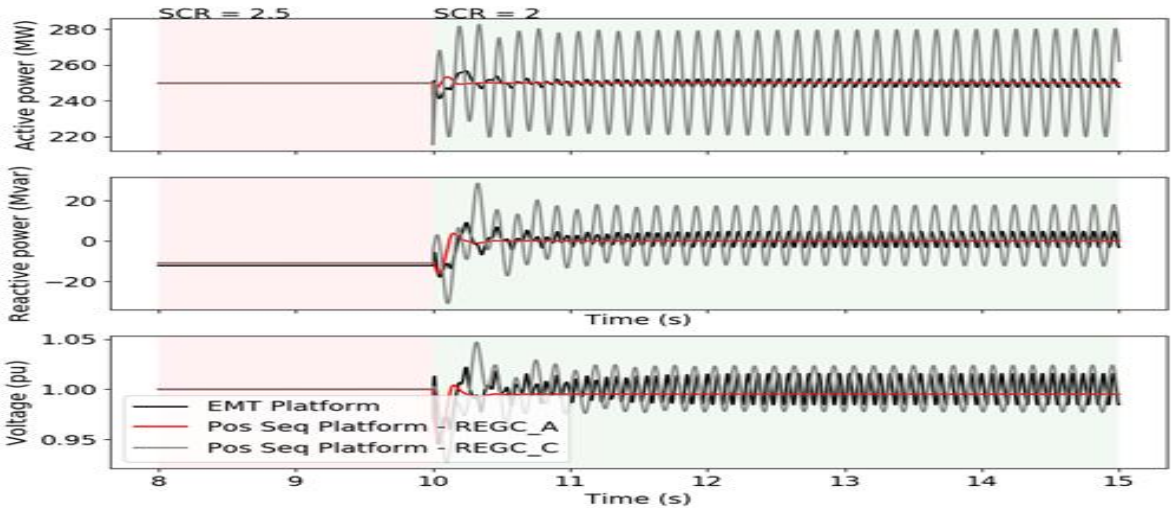
- Every inverter for power system operation is a voltage source inverter

- State of the art interconnection wide simulations (generic and most UDM models available today) represent the inverter as a current source interface:
  - Assumes that current controller and PLL loops are fast

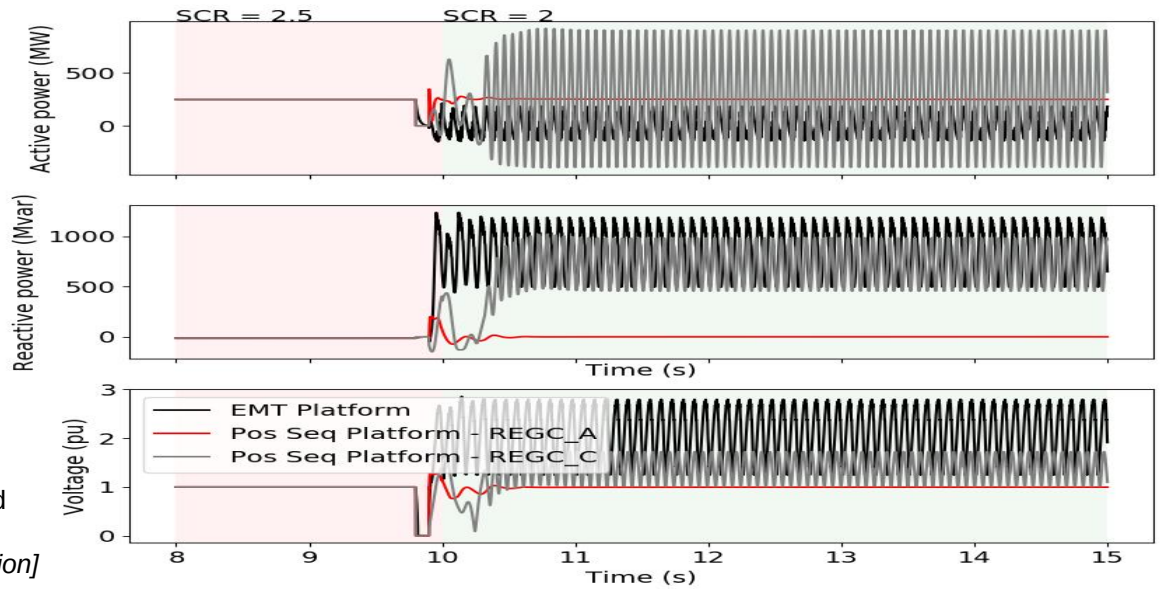
- Maybe we need all IBRs to be represented using a voltage source interface
  - Allows for greater accuracy and characterization of IBR dynamic behavior
  - Allows for representation of current controller and PLL loops

Beware false positive and false negative results from inaccurate models



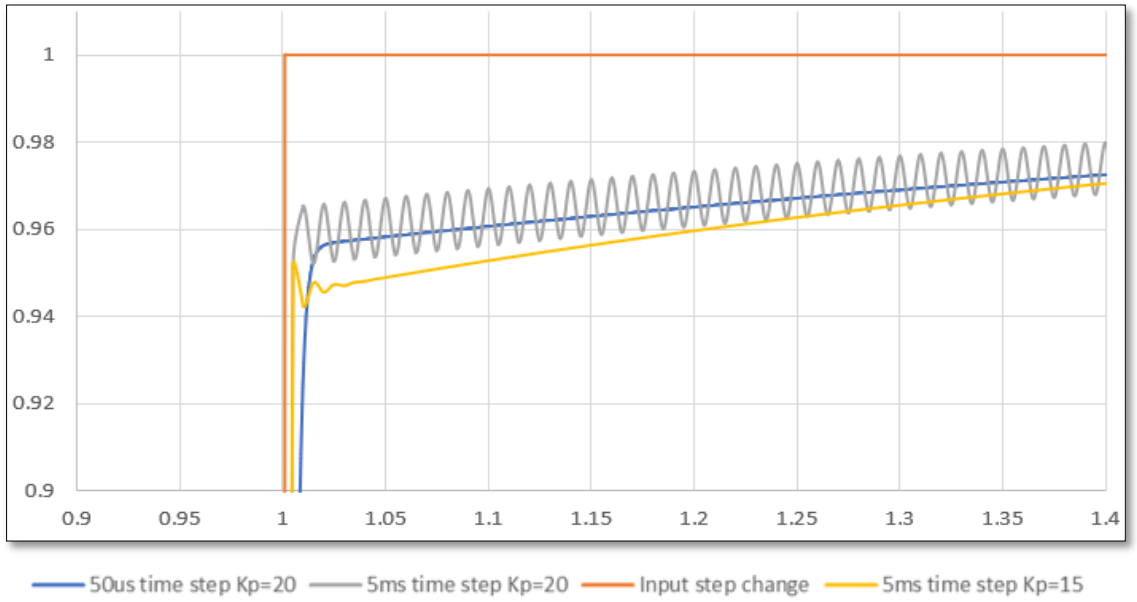


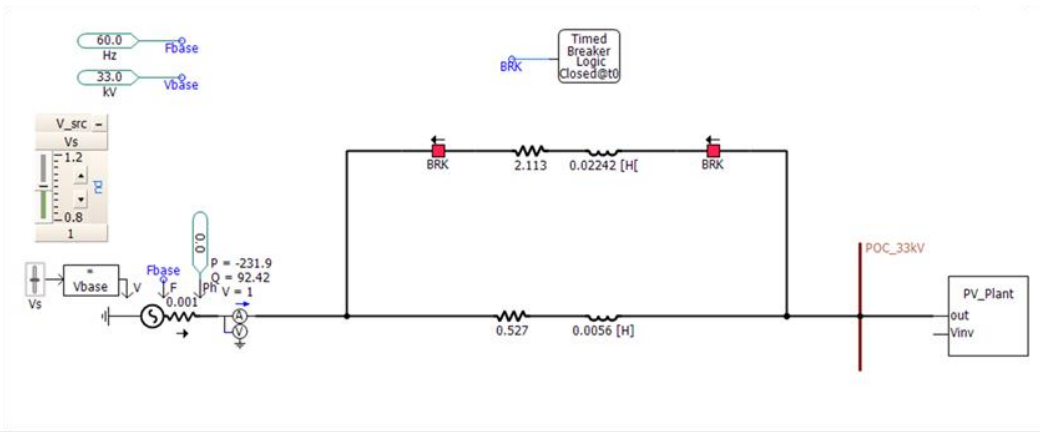
User defined positive sequence model from OEM was unable to show the oscillations

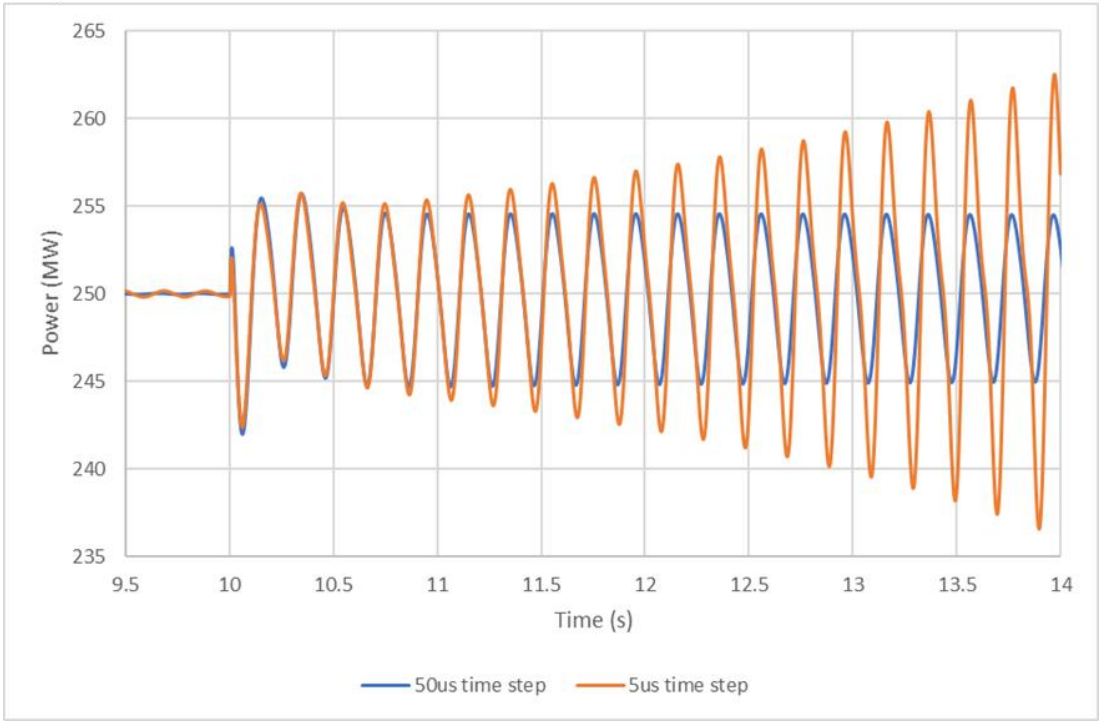


Deepak Ramasubramanian, Xiaoyu Wang, Sachin Goyal, Manjula Dewadasa, Yin Li, Robert J. O'Keefe, and Peter F. Mayer, "Parameterization of Generic Positive Sequence Models to Represent Behavior of Inverter Based Resources in Low Short Circuit Scenarios," *Electric Power Systems Research*, *[accepted for publication]*

Parameterization, integration method, and time step

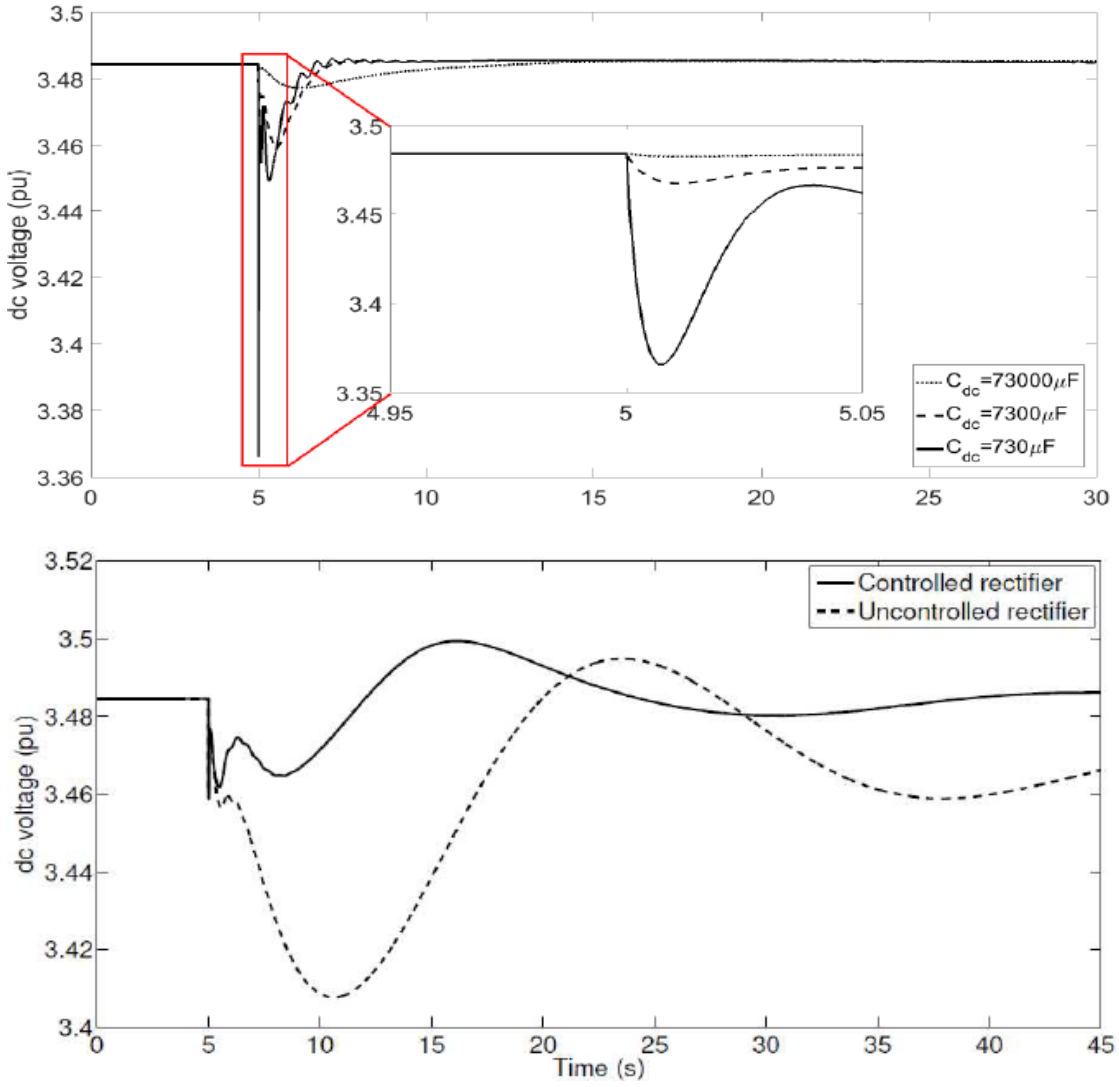






- Value of time step of numerical integration can impact time domain dynamic response
- Method of numerical integration method can have an impact

Should we represent IBR dc side dynamics?



- It is possible to capture IBR dc dynamics in a positive sequence model
- Whether it is required to be captured in the model will be known only after detailed studies
  - Keeping in mind that most studies (including EMT) represent controls of one inverter/turbine, and scale appropriately

D. Ramasubramanian and V. Vittal, "Positive sequence model for converter-interfaced synchronous generation with finite dc capacitance," *IEEE Transactions on Power Systems*, vol. 33, no. 3, pp. 3172–3180, 2018

Model limitation versus simulation domain limitation

- Present models in planning base cases (both positive sequence and EMT) have been unable to capture causes of inverter tripping
- Limitation of a model should not be confused with limitation of the simulation domain itself
- Models (such as REGC_C and other future models) can help bring about added capability that can be leveraged

Cause of observed behavior	Simulation domain limitation	Most of today's model incorrectly parameterized	Most of today's model do not represent	
Unbalanced conditions	✓			
Sub-cycle ac over voltage	✓			
Sub-cycle ac over current	✓			
Momentary cessation		✓		Future model can represent as capability exists in simulation domain
Error in frequency measurement		✓		
PLL loss of synchronism		✓		
Collector network level under frequency		✓		
Phase jump			✓	
dc reverse current			✓	
dc low voltage			✓	
Plant controller interactions			✓	

(a) Positive sequence simulation domain

Cause of observed behavior	Simulation domain limitation	Most of today's model incorrectly parameterized	Most of today's model do not represent	
Unbalanced conditions		✓		
Sub-cycle ac over voltage		✓		
Sub-cycle ac over current		✓		
Momentary cessation		✓		
Error in frequency measurement		✓		Future model can represent as capability exists in simulation domain
PLL loss of synchronism		✓		
Collector network level under frequency		✓		
Phase jump			✓	
dc reverse current			✓	
dc low voltage			✓	
Plant controller interactions			✓	

(b) EMT simulation domain

Differentiating between Applicability of Simulation Domains and Inverter Mathematical Models in these Domains. EPRI. Palo Alto, CA: 2022.3002025063. [Online] https://www.epri.com/research/products/000000003002025063

Draft questions for positive sequence model quality check to characterize sufficiency of obtained model

To be discussed with industry and various stakeholders

		Yes/No	Comments
RMS/Positive sequence model[1]			
1a	Is the model real code and is the same code used in the EMT model?		List out any assumptions/modifications made between EMT real code and positive sequence real code (including by-passing of control elements)
1b	Model should be represented using a voltage source interface, even for conventional grid following inverters[2]		
1c	Model should have a representation of dynam… inner current control loop, if such a control … is represented in the EMT model of the inverte…		
1d	Model should have a representation of dynamic… of phase locked loop, if such a control loop is represented in the EMT model of inverter [3]		
1e	If current output goes above max…m current limit, the model should be capa… the current to the limit at every time …p, wi… losing convergence with network s… tion		
1f	Document any change in values of p…meters between EMT and RMS/positive sequ… e m…els, with explanation		
1g	Document any cha… ntrol struct… (including by-pa… g any c… rol path) be… en EMT and RMS … itive sequ… ce models, w… explanation a… lidation		
1h	For three phase … an… ke … current should not be prese… more than 2 – … time steps		
1i	Mod… capable … erating in time st… between … – 10ms[4]		
1j	…es the model r… sent the d…amics of the …ource behind the i… ter and/or dynamics of the … bus?		

[1] Applicable only for use… RMS/positive sequence models and not for generic library models
[2] Voltage source interface … s that the model is not injecting current directly into the network solution of the simulation solver, but is instead creating either a Thevenin voltage or a Norton current (with low Norton impedance, typically 0.1 – 0.2pu representing the filter impedance)
[3] Exclusion of this feature can be acceptable only if validation report is provided comparing response with EMT model at SCR levels between 1.0 – 2.5 for small signal and large signal events. Additionally, if representation of dynamics are included, they have to be more than a single first order time constant.
[4] Use of higher values of time steps will depend on value of smallest time constant

Challenges for new modeling practices

- OEMs may require new techniques to write/construct models in simulation software
- Model validation techniques/guidelines may need more rigor
- Application of engineering judgement is extremely important when using models for simulation studies.

Together...Shaping the Future of Energy®