IBR Models and Modeling Needs

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

ESIG-NAGF-NERC-EPRI Generator Interconnection Workshop
August 10, 2022

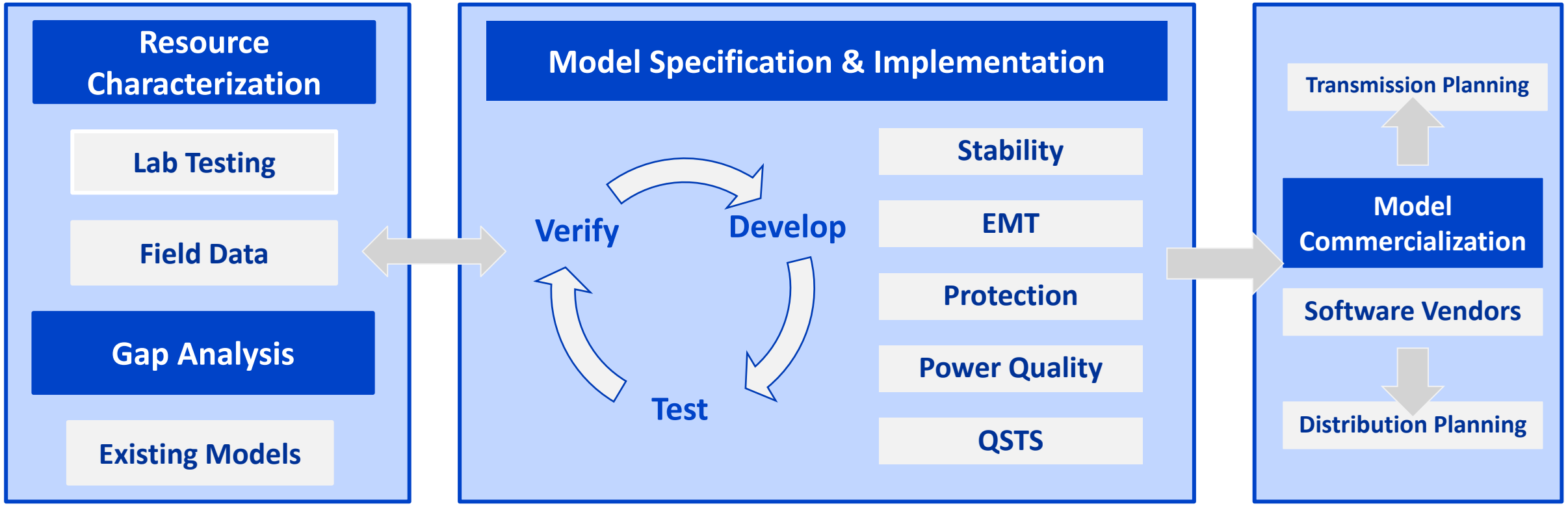
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

This work is, in part, supported by the U.S. Department of Energy, Solar Energy Technologies Office under Award Number DE-EE0009019
Adaptive Protection and Validated MODels to Enable Deployment of High Penetrations of Solar PV (PV-MOD). https://www.epri.com/pvmod

EPRI's Generic Model Development and Improvement

Objective

Validated; publicly available models for various types of studies, reports detailing the research, close collaboration with industry stakeholders (NERC, WECC, IEEE, etc.)



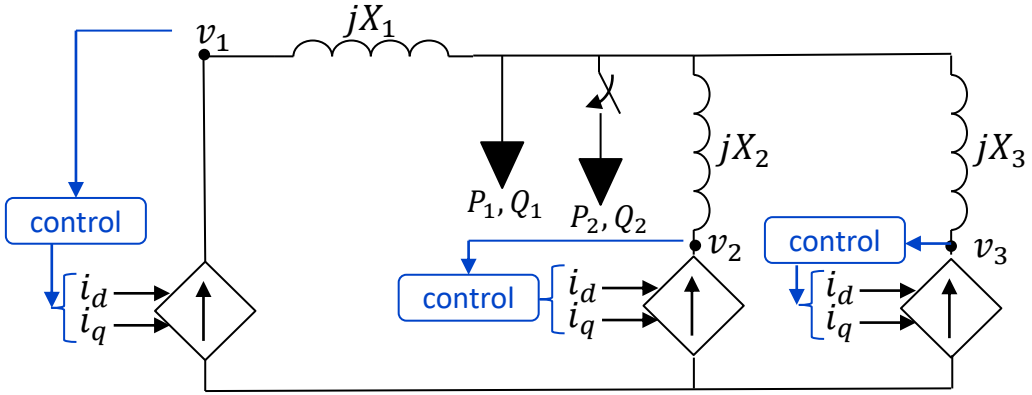
More info at https://www.epri.com/pvmod

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

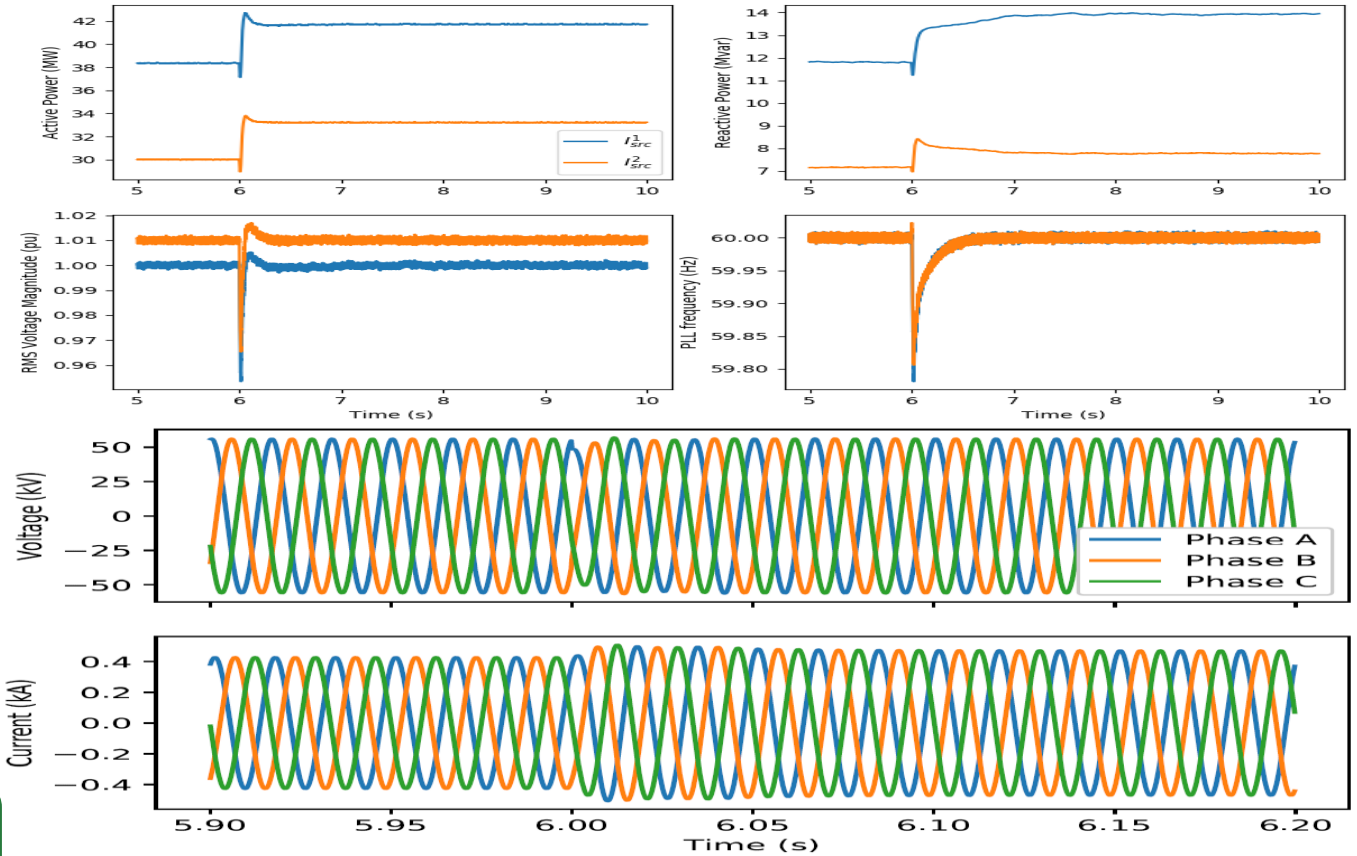
- All mathematical models have limitations
- When using mathematical models, few questions to be asked:
  - Is this the appropriate type of model for the study that is to be done?
  - Is the model being used in a correct manner?
  - Are all relevant components/control loops, that matter for the study,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

Kirchhoff's Laws still apply in a 100% current source network



- Voltage levels in network decided by current and impedance
- Network will collapse if i_d and i_q do not change when load changes
- But from circuit theory, this network has a stable/viable solution

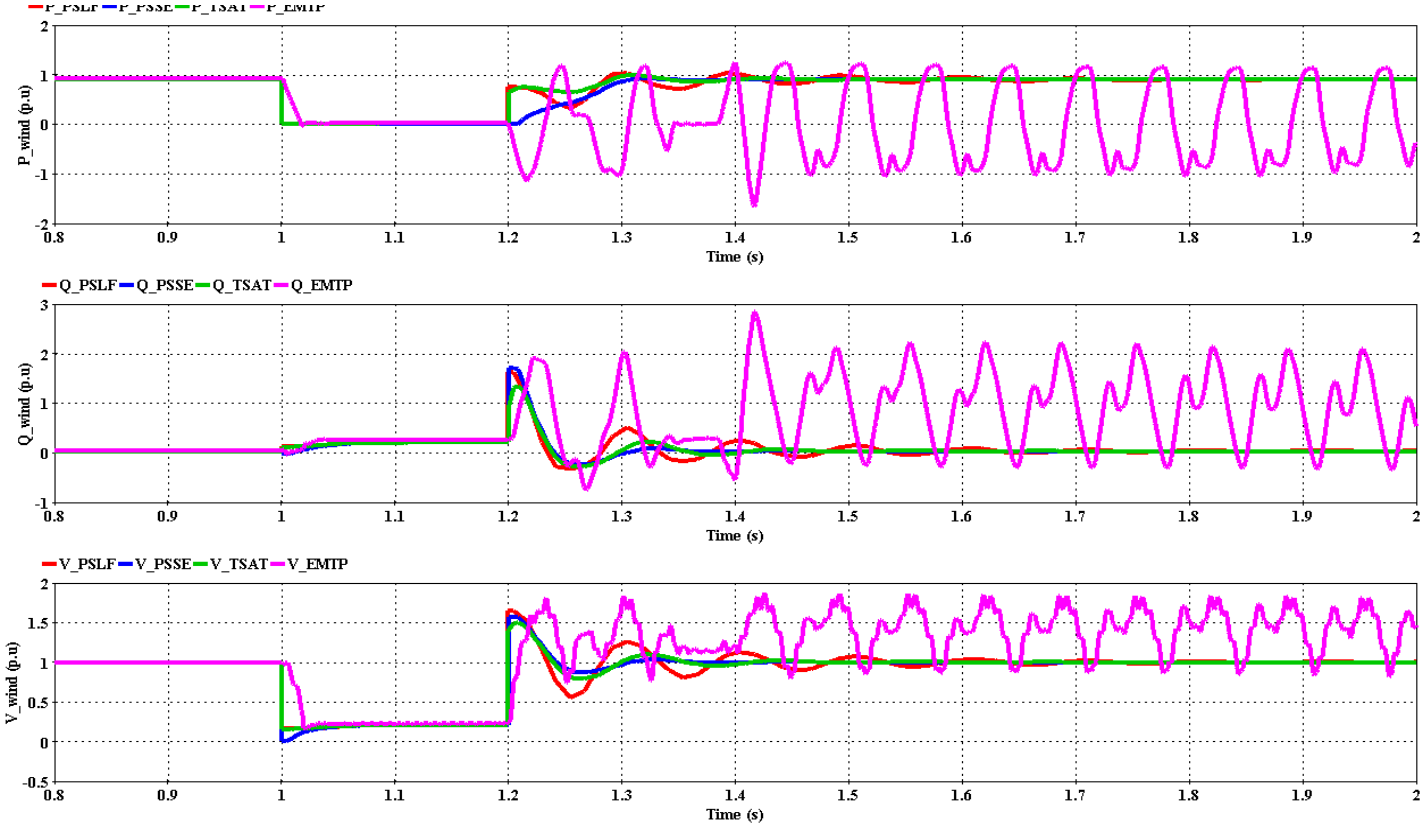
Values of injected current to be controlled in a timely manner for network to be stable



10% increase in constant power load

What does this have to do with IBR Models?

Challenges faced by existing positive sequence IBR models in low short circuit conditions



- **Fast controller dynamics/interactions may not be modeled**
- **Advanced control features may not be modeled**
- **Numerical robustness issues may arise**

This doesn't automatically imply that EMT studies are the only solution available

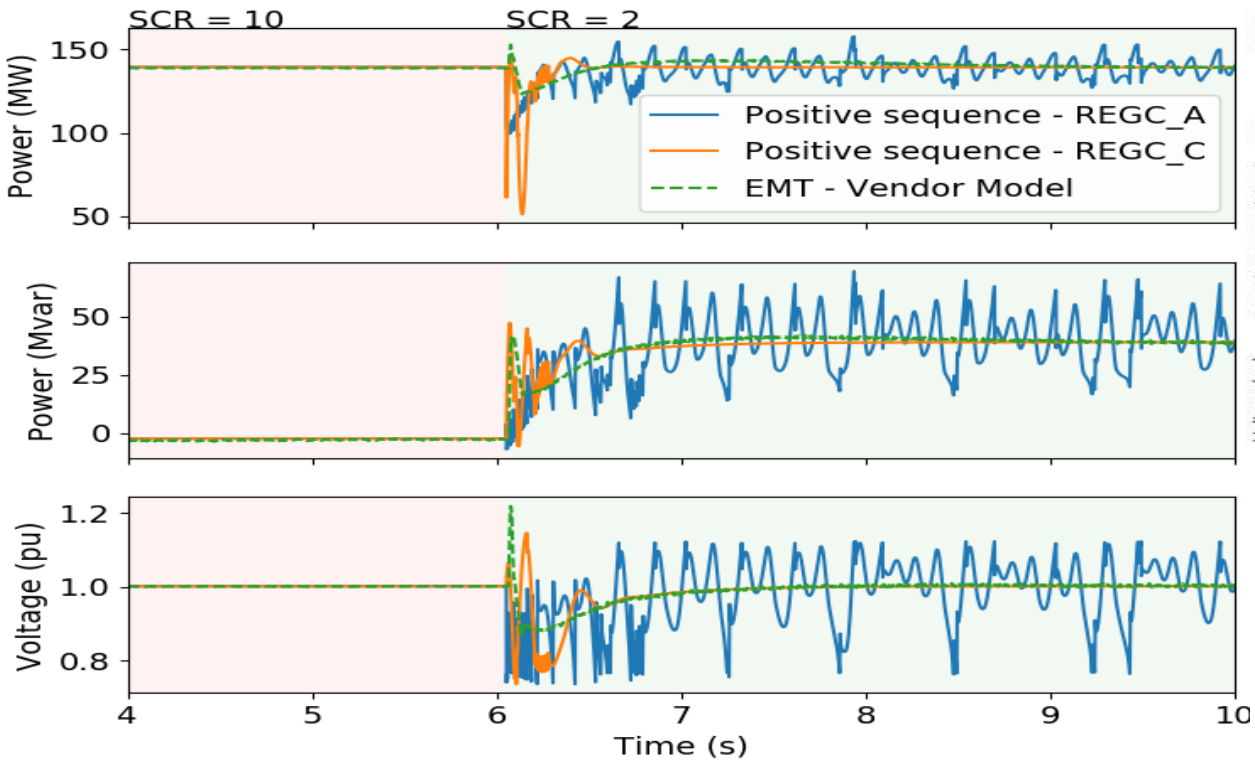
Representation of IBRs in simulation

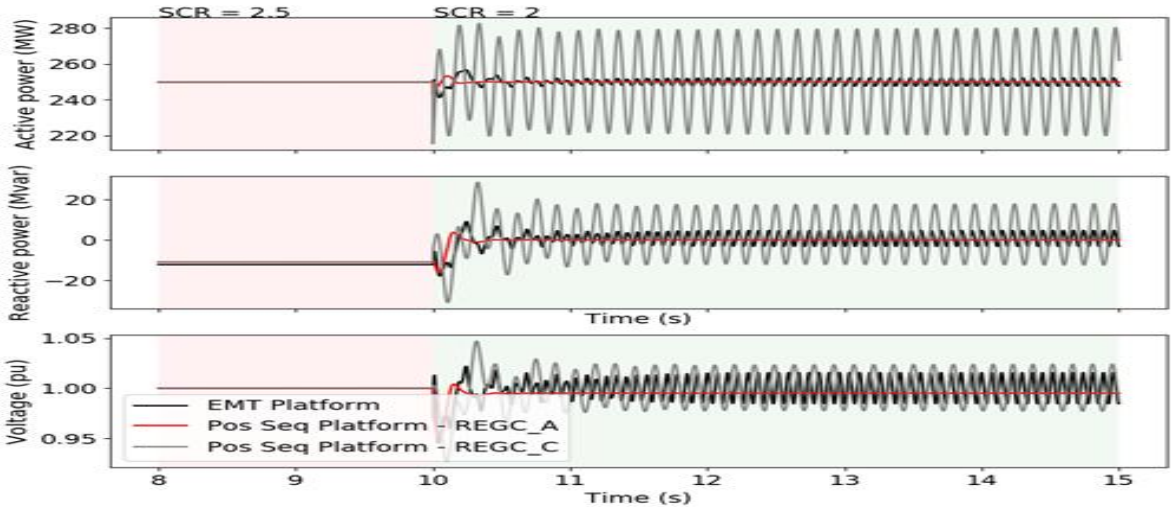
- Every inverter for power system operation is a voltage source inverter

- 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

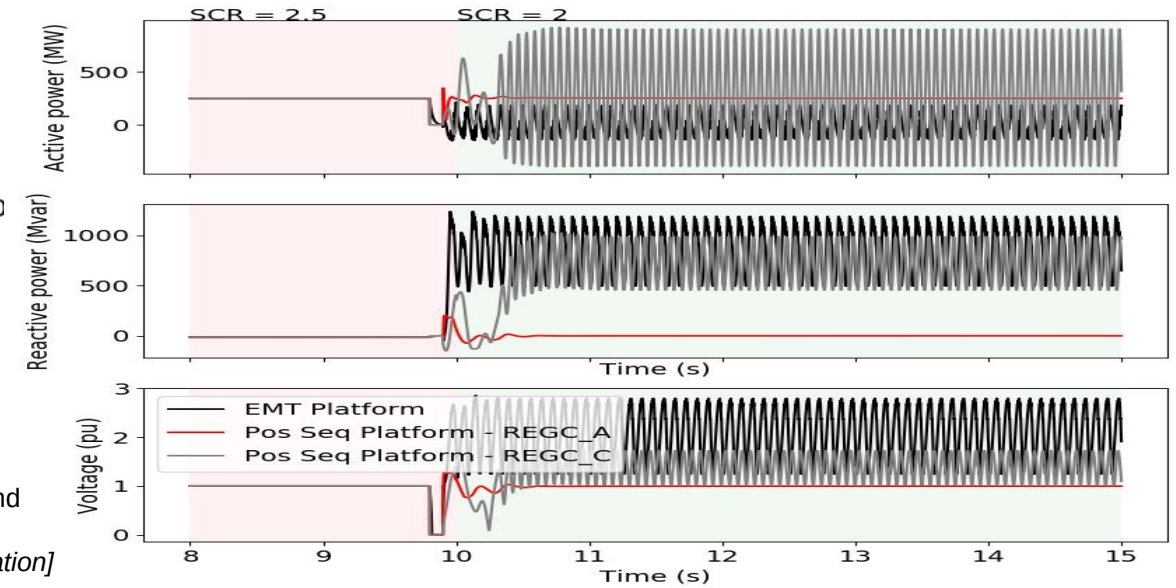
- IBRs should be represented using a voltage source interface
  - Allows for greater accuracy and characterization of IBR dynamic behavior
  - Allows for representation of current controller and PLL loops

Beware false positive and false negative results from inaccurate models



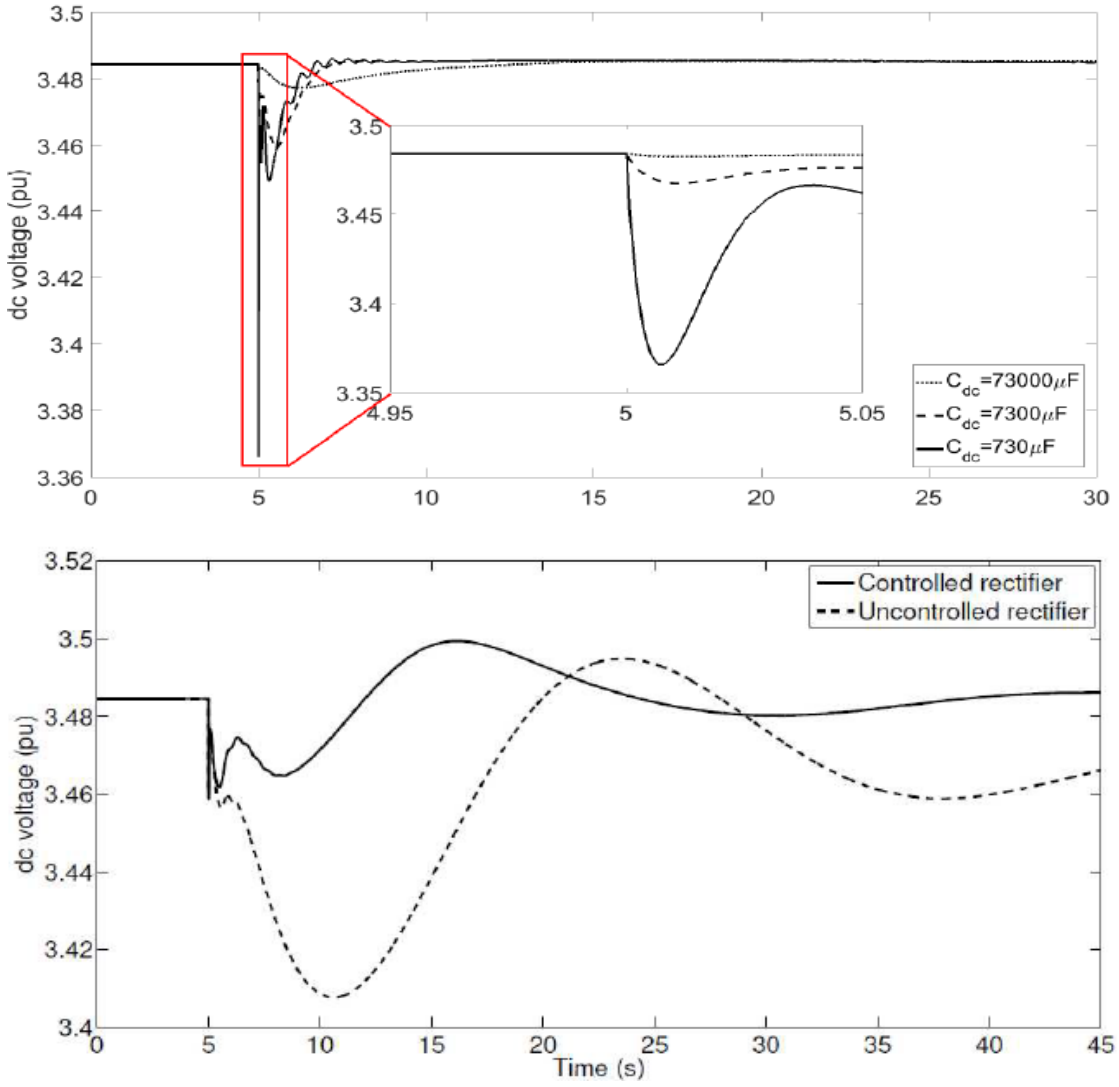


User defined positive sequence model from OEM was unable to show the oscillations



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]*

Representation of 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		✓		Future model can represent as capability exists in simulation domain
Sub-cycle ac over voltage		✓		
Sub-cycle ac over current		✓		
Momentary cessation		✓		
Error in frequency measurement		✓		
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

Summary

- In order to conduct sufficiently accurate studies, availability of adequate simulation models in software is important.
  - Both user defined models and generic models play role depending on the type of study
- Newer positive sequence models have been developed that can improve the state of art of representing IBR behavior
  - Not to be construed as replacement of EMT domain. Rather, meant to complement EMT domain studies
  - It is important to start collecting EMT models so that it is easier to run studies when needed
- With IBR newer control methods such as grid forming behavior, state of the art of positive sequence models continue to improve.
- Model validation is required for any types of model i.e., generic, user-defined, positive sequence, and EMT
- **Diligent parameterization of a suitable model is extremely crucial.**
  - **Critical for both EMT and positive sequence models**

Together...Shaping the Future of Energy®