Advances in Modeling Bulk Power System Inverter Based Resources and Distributed Energy Resources in an Evolving Power System

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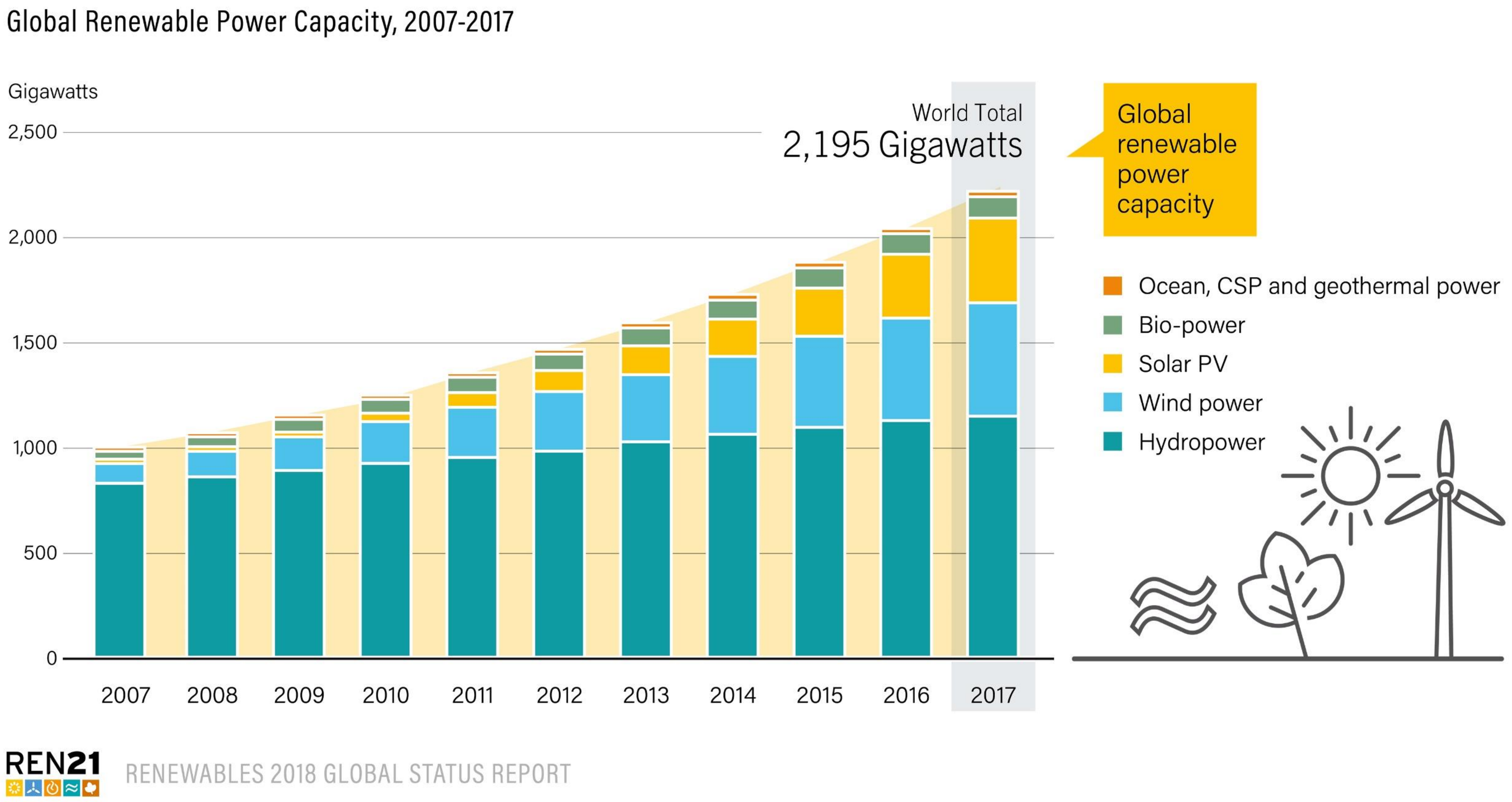
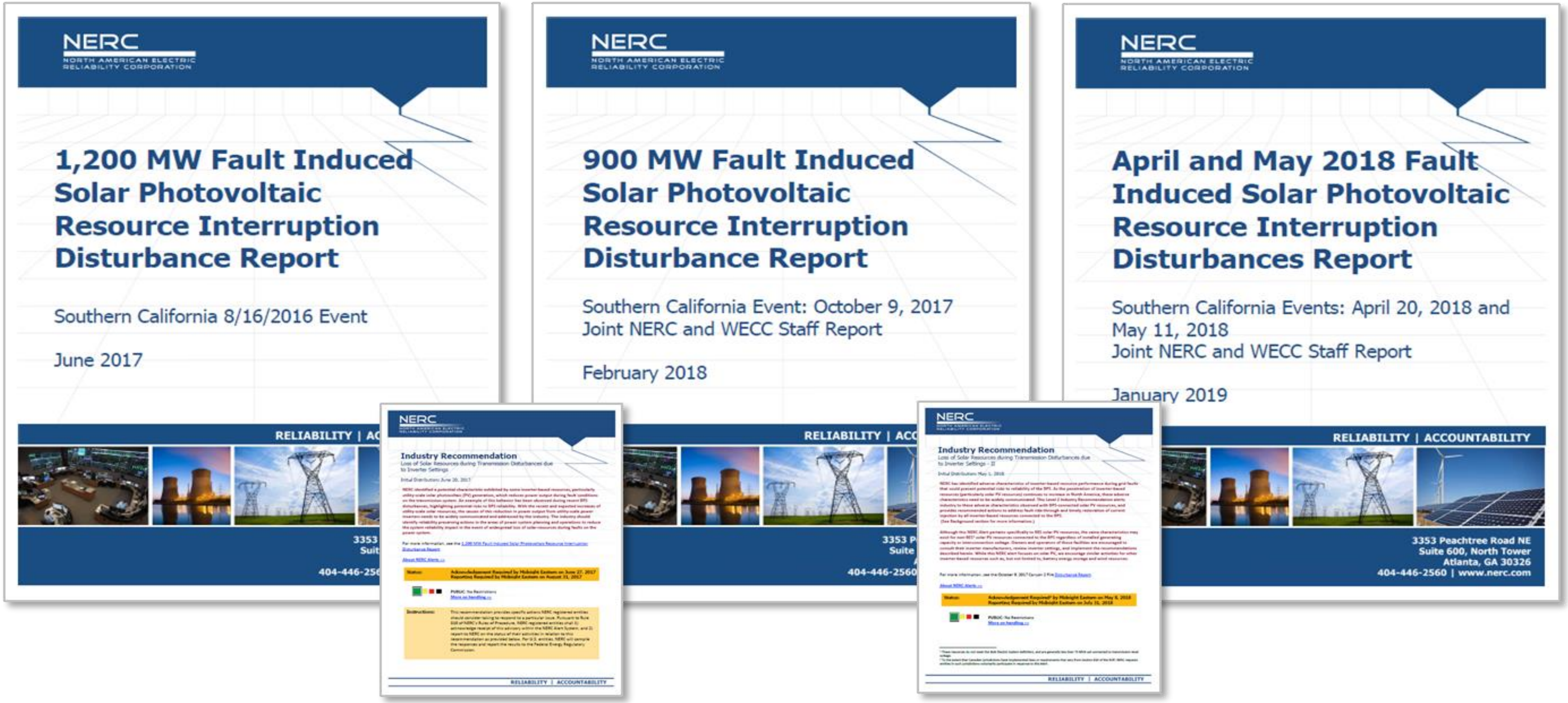
2nd IEEE Workshop on Representations of Power Electronics for Grid Dynamic (PEGD) Studies

London, United Kingdom
December 5 2019

Renewables are increasing…



Recent system events in North America highlight need for improved modeling…



Source: Ryan Quint, "Reliability Perspectives: Increasing Penetrations of Inverter-Based Resources," 2019 IEEE PES General Meeting, Atlanta

Bulk power system inverter based resource modeling

VALUES OF GENERIC MODELS

- **Validation:** Numerous validation cases demonstrated

- **Portability across software platforms:** Implemented and tested in major commercial tools, and consistent across the tools

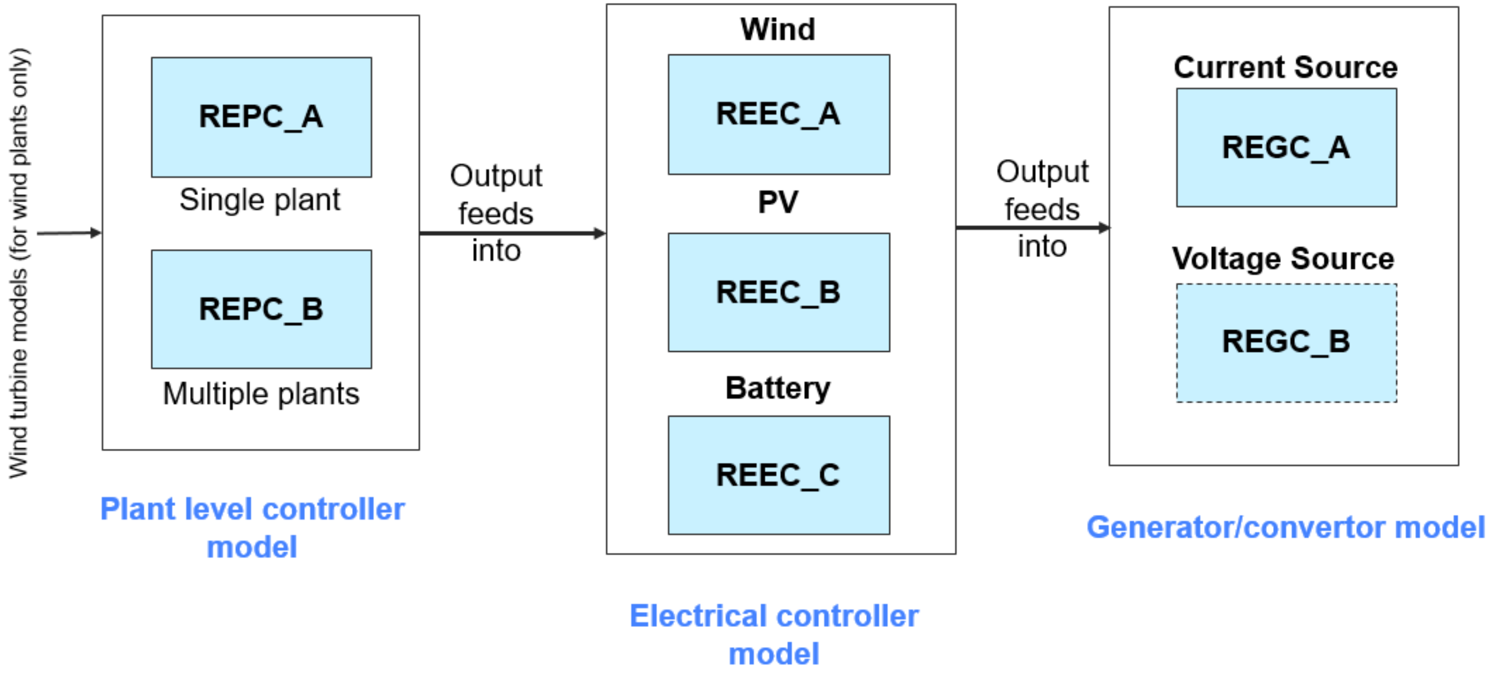
- **Transparency & Documentation:** Standard, generic, public and open with documentation/specifications that are available to all

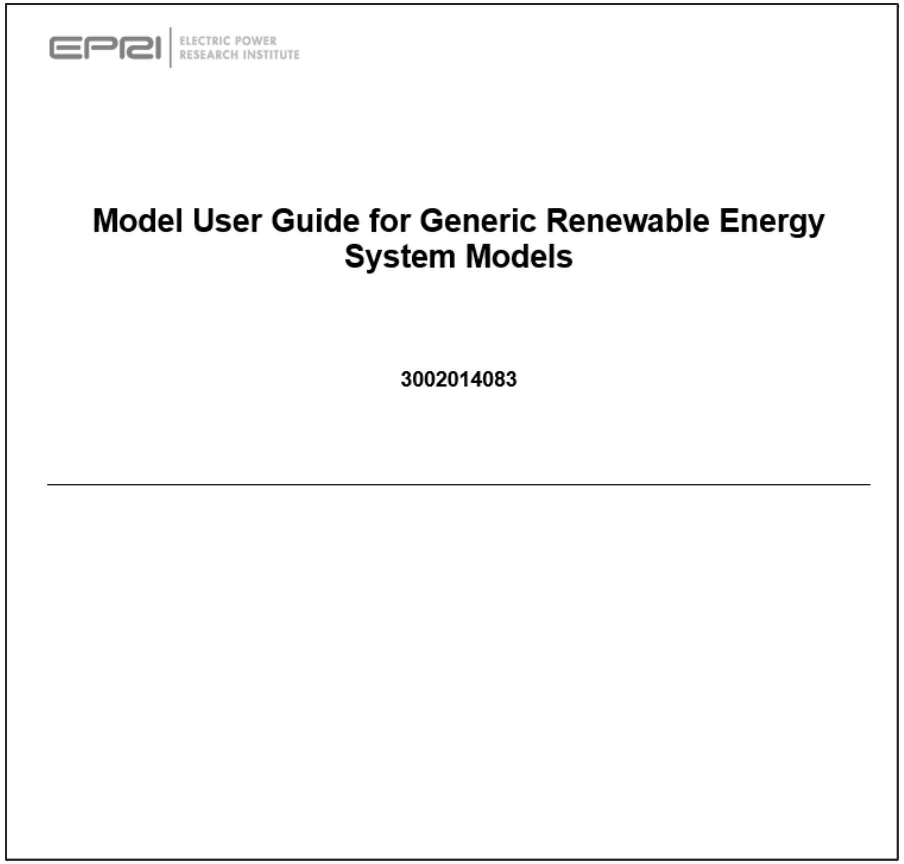
- **Publicly Available:** Avoid this issue of being able to share models.

- **Modeling the Future:** Generic models are useful for performing futuristic studies where the actual equipment to be used is not yet known

- **Trend of Response:** The models are accurate to represent the trend of response one can expect from inverter based resources

State of the art available generic models





Model User Guide for Generic Renewable Energy System Models

3002014083

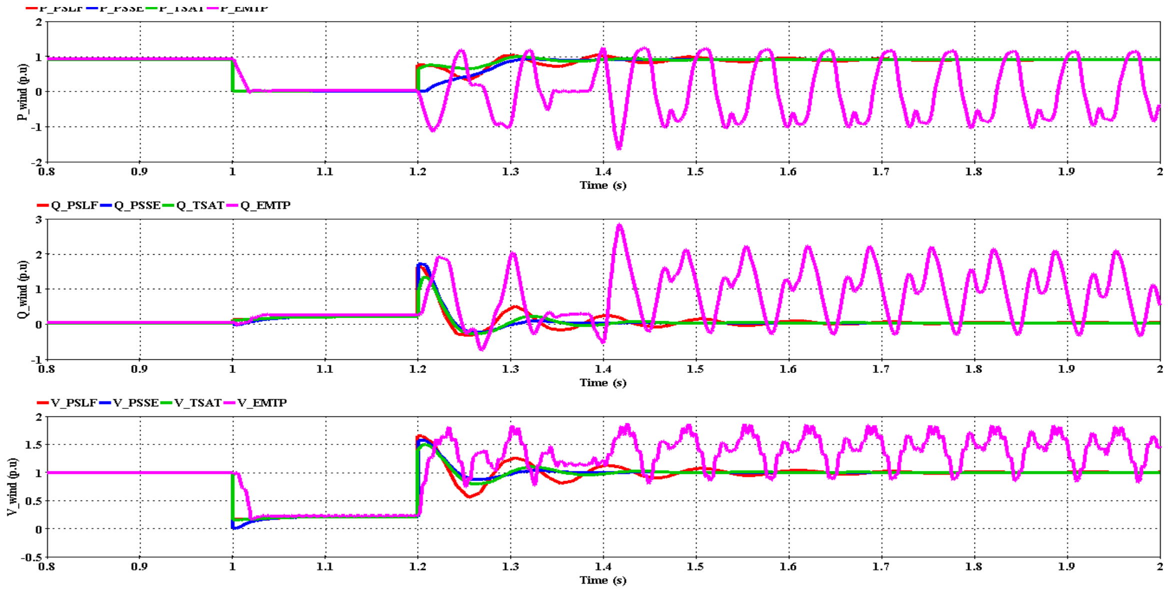
Latest renewable energy models available in commercial platforms for dynamic studies (positive sequence)

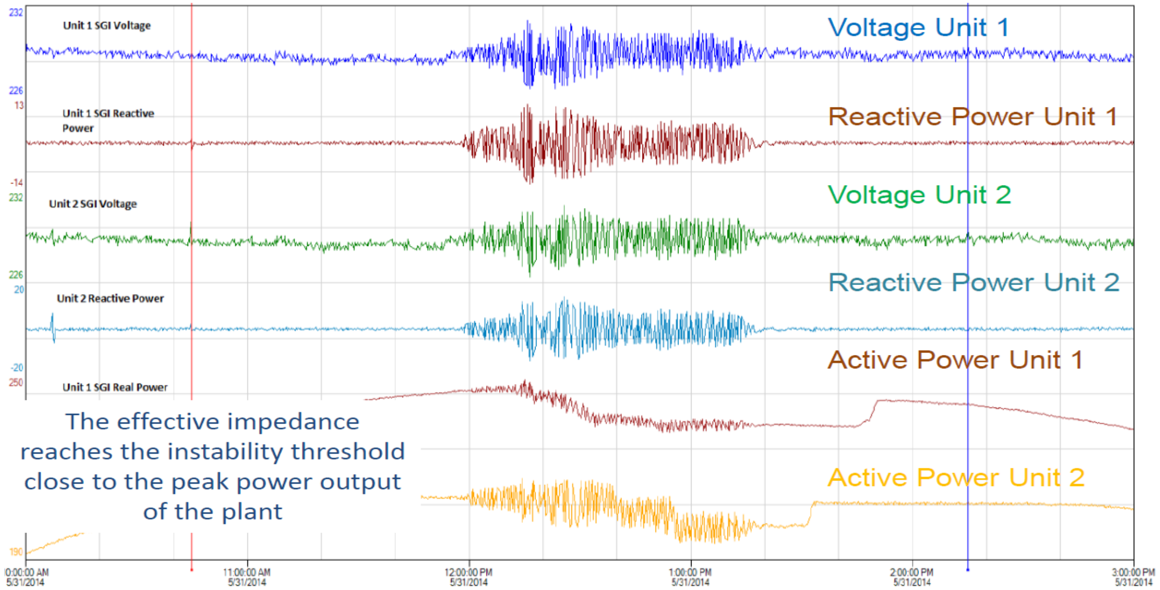
Public document:
https://www.epri.com/#/pages/product/000000003002014083/?lang=en-US

Limitations of State of the Art Converter Positive Sequence Dynamic Models

Generic Positive Sequence Models Limitations

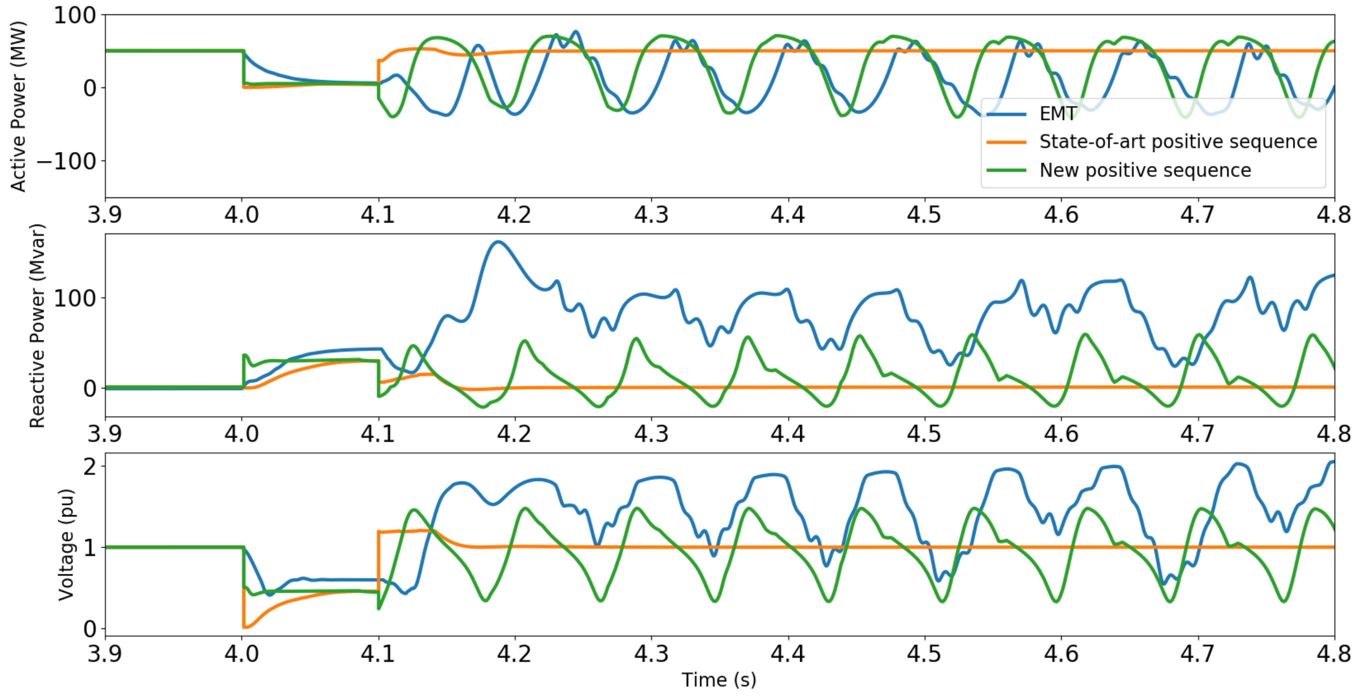
- **Models not suitable for capturing fast controller dynamics/interactions**
- **Models not accurate for studying unbalanced conditions near the converters**
- **Models not suitable for interconnection studies of a wind/solar power plant to a weak transmission system**
- **Models not suitable for detailed studies related to phenomena such as sub-synchronous resonance and ferro-resonance**





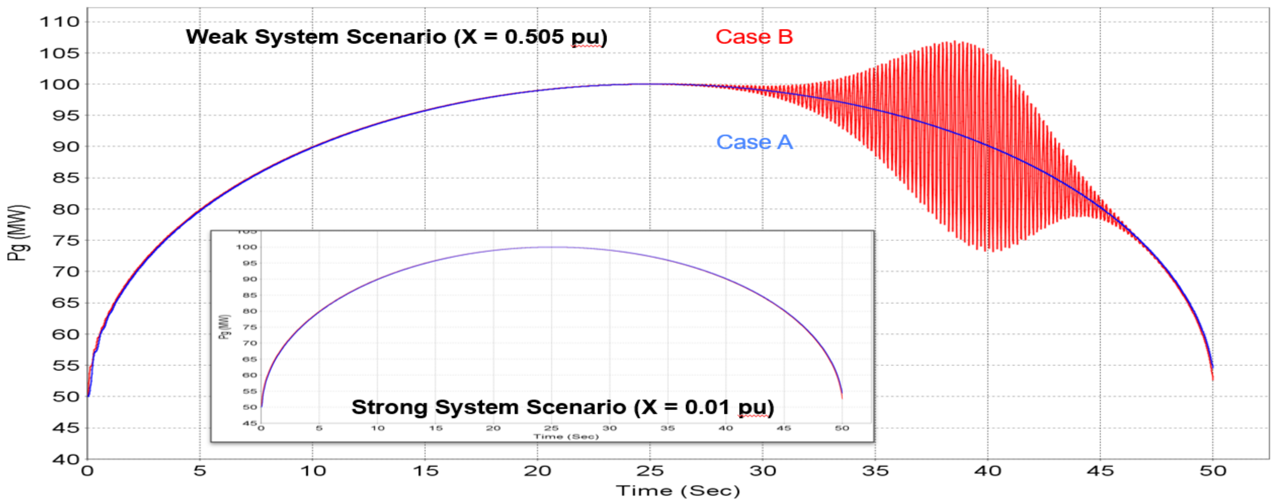
Source: "Deploying Utility-Scale PV Power Plants in Weak Grids", First Solar, 2017 PES General Meeting, Chicago, IL, July 2017

Proposed new positive sequence model for low short circuit systems



- Representation of PLL and inner current control loop
- Voltage source interface with the network
- Smaller timestep required (1ms)

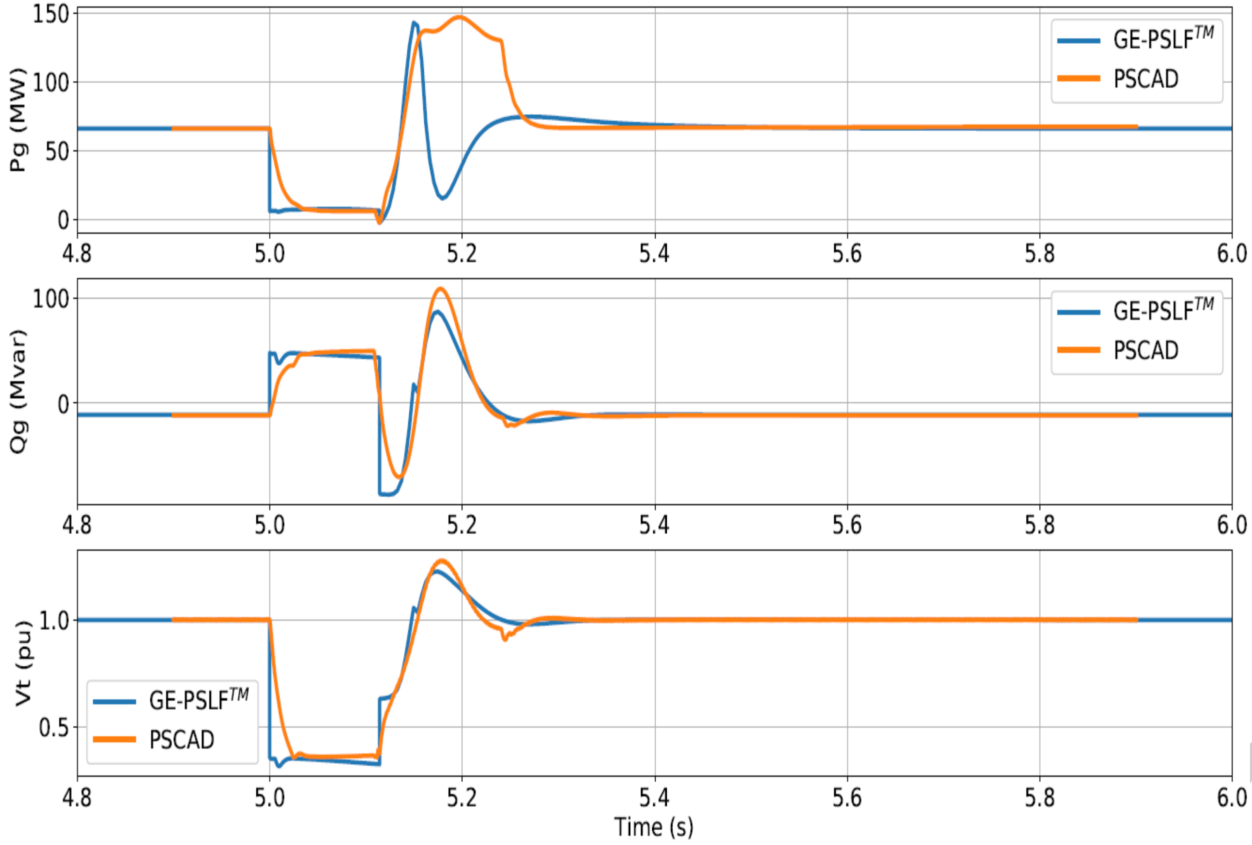
- **Improves numerical stability**
- **Suggested to be used for weak grid studies before conducting detailed three-phase EMT studies**

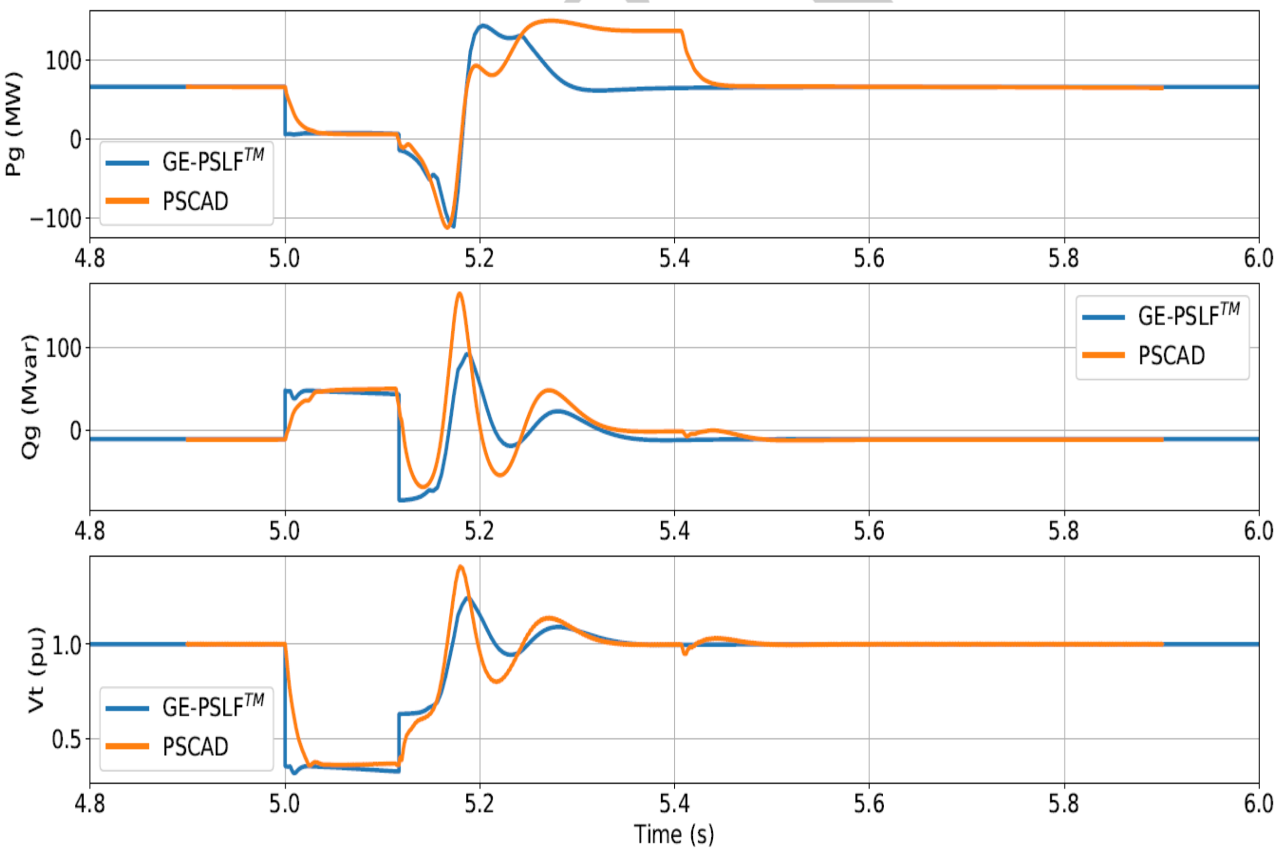


Reference: Deepak Ramasubramanian, Wenzong Wang, Pouyan Pourbeik, Evangelos Farantatos, Anish Gaikwad, Sachin Soni, and Vladimir Chadliev, "Positive Sequence Voltage Source Converter Mathematical Model for Use in Low Short Circuit Systems," IET Generation, Transmission & Distribution, [to appear]

Does it work in a large system..?

- A portion of a large utility's system
- While an exact match is not obtained (and is not expected), the trend of response is same





Summary…

- With increased IBR connected to low short circuit regions of the network, state of the art positive sequence models may not show certain instabilities.

- Improved positive sequence converter model can represent fast oscillatory dynamics from inverter controls
  - Requires values for additional parameters

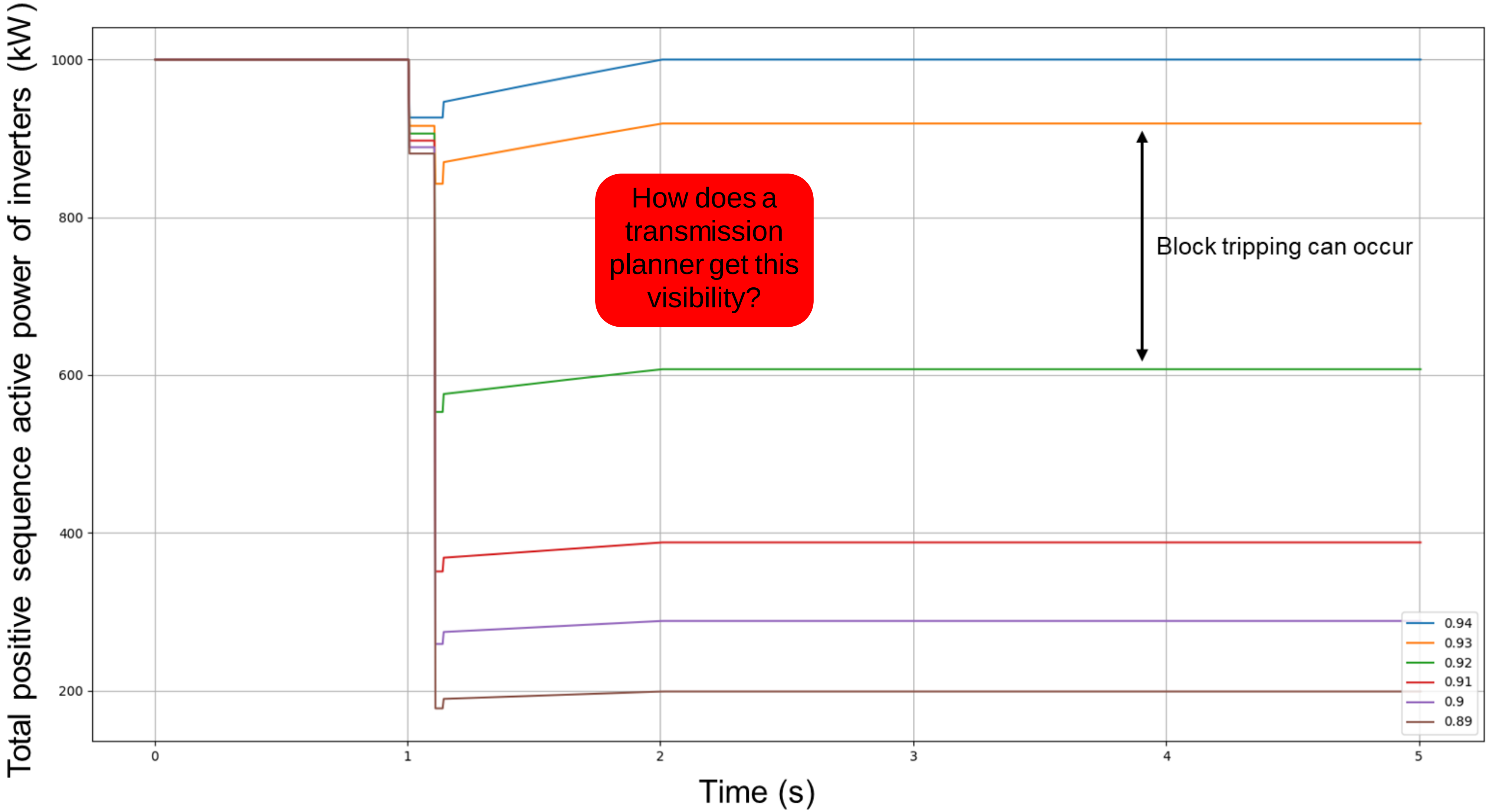
- It provides another dimension to a transmission planner in analyzing generator interconnection requests.

- It is however not intended to be a replacement for detailed EMT studies (where necessary)

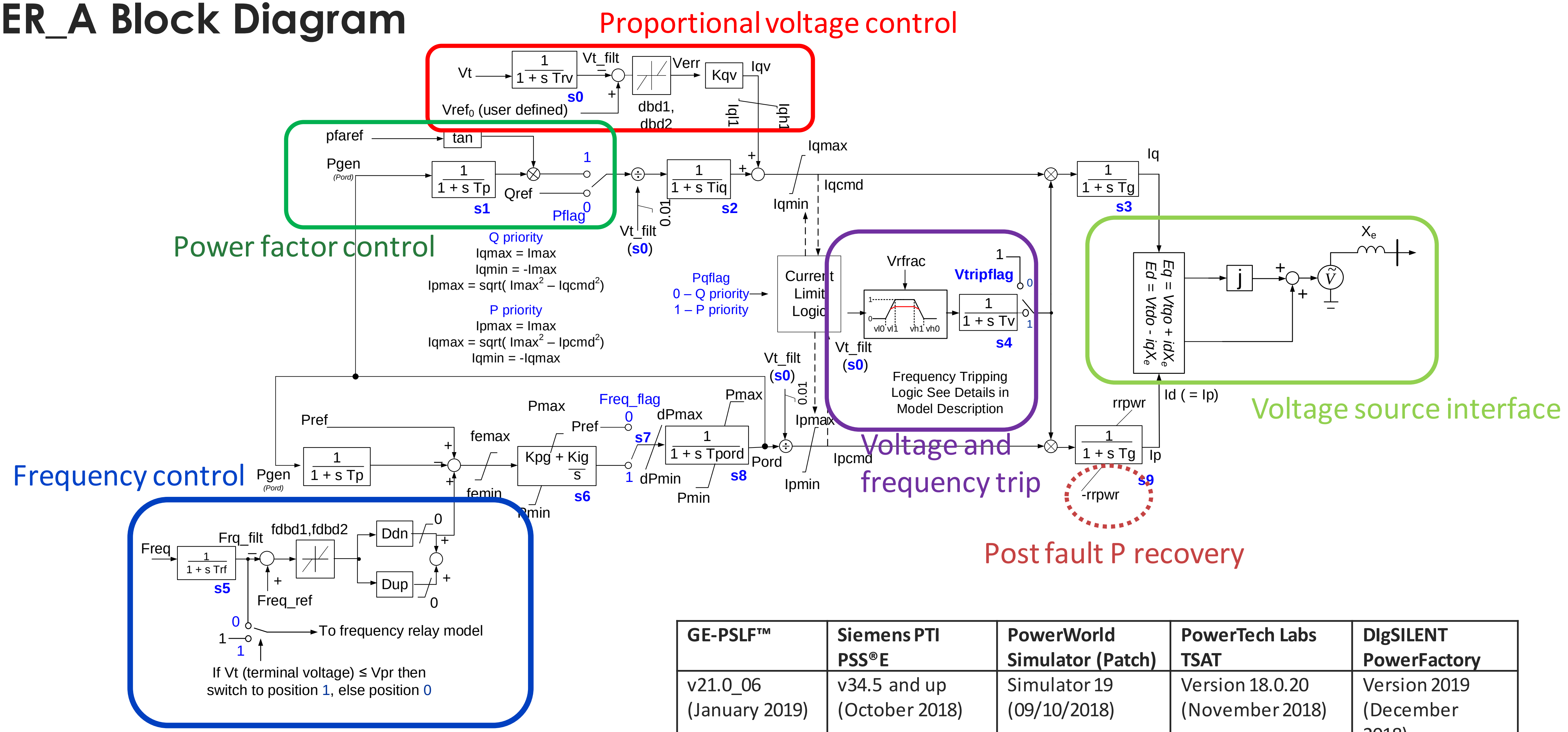
DER Modeling for Transmission Planning Studies

Why should DER be modeled explicitly…?

<u>Block tripping of DERs can be a concern to system stability</u>



DER_A Block Diagram

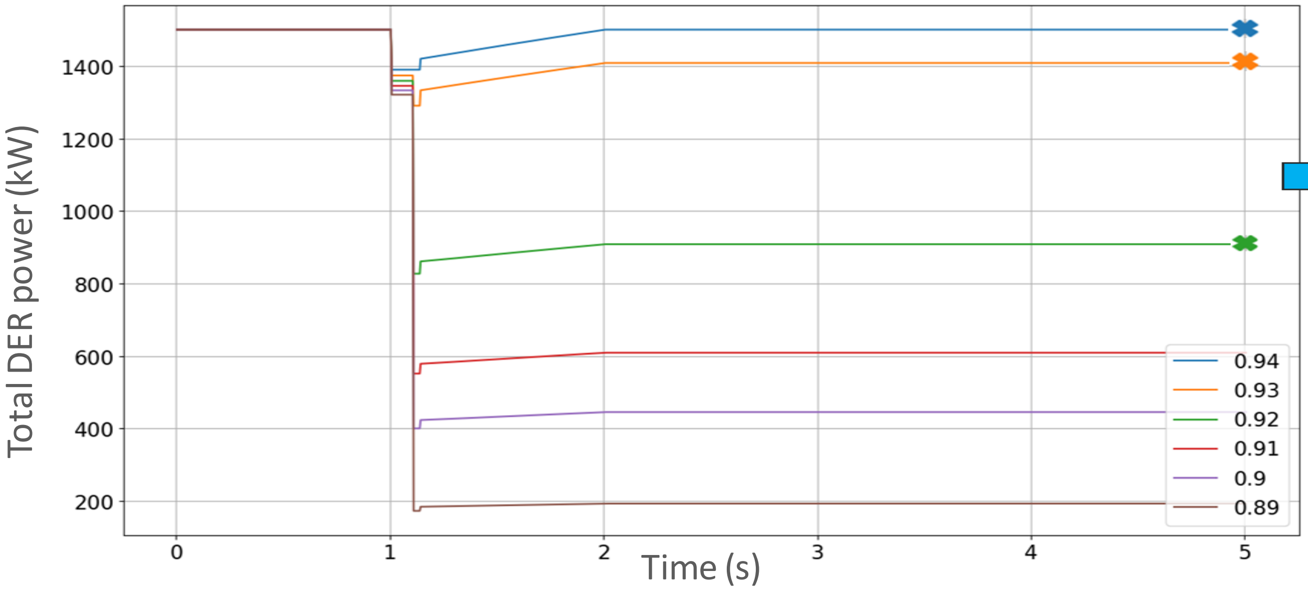


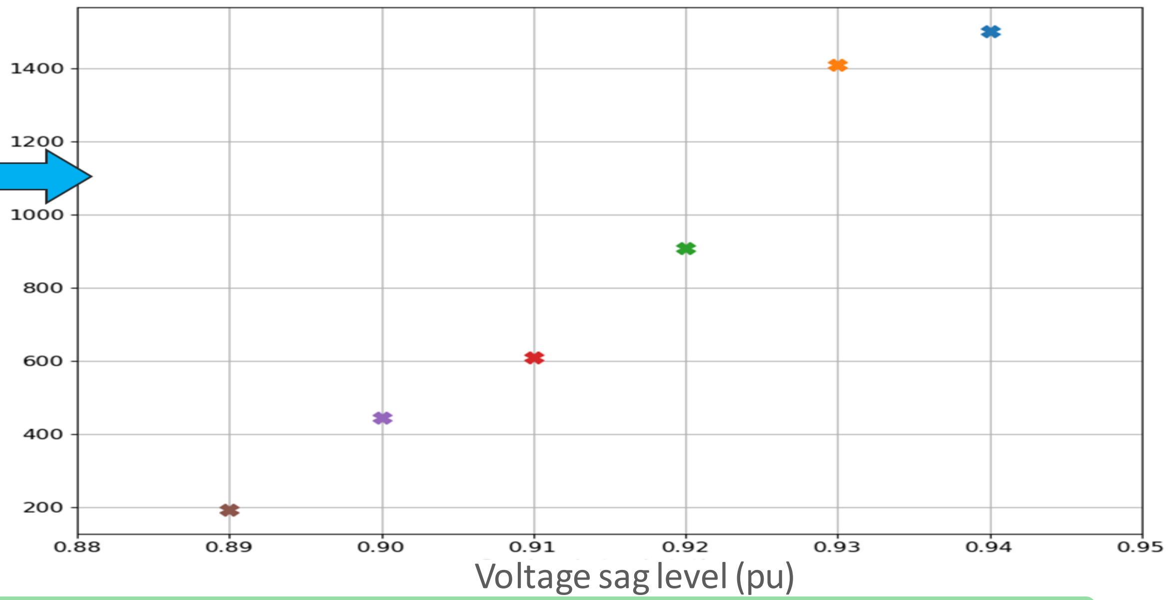
GE-PSLF™	Siemens PTI PSS®E	PowerWorld Simulator (Patch)	PowerTech Labs TSAT	DIgSILENT PowerFactory
v21.0_06 (January 2019)	v34.5 and up (October 2018)	Simulator 19 (09/10/2018) Simulator 20 (08/30/2018)	Version 18.0.20 (November 2018)	Version 2019 (December 2018)

The New Aggregated Distributed Energy Resources (der_a) Model for Transmission Planning Studies. 2019 Update. White Paper. 3002015320. Electric Power Research Institute (EPRI). Palo Alto, CA

Obtaining generic parameters of the voltage trip characteristics

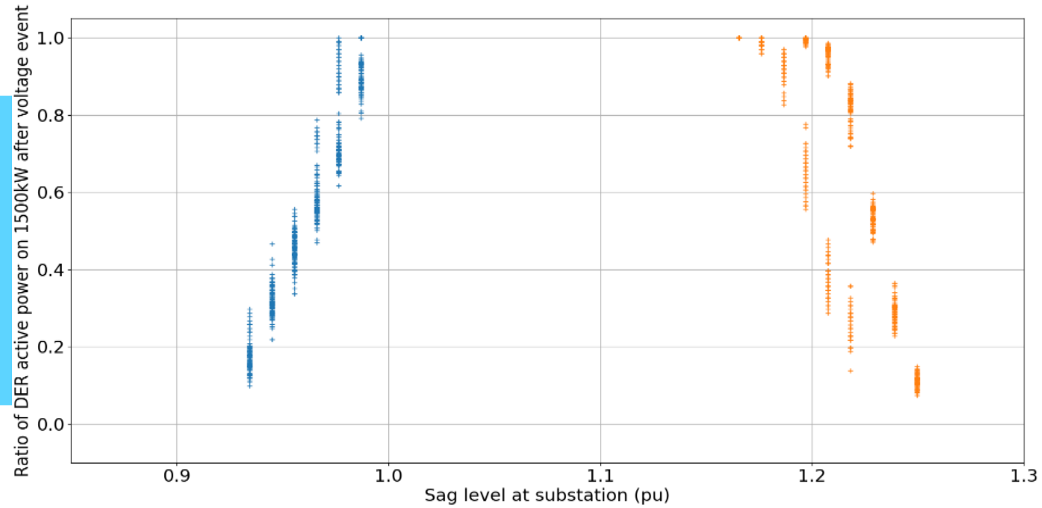
The model parameterization challenge…

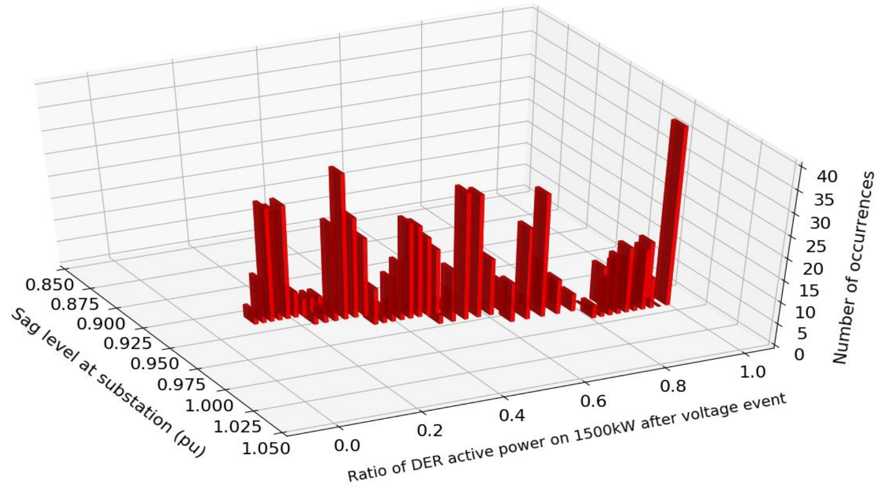




Total kW of DER that are able to ride through a voltage event has a nonlinear relationship with level of sag/swell

Total kW of DER ride through has a wide variation with type of DER and location of DER on the feeder





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The Parameterization Challenge (cont'd)…

- Factors that affect the ride through of DER on a feeder:
  - Type of DER (3-phase or 1-phase)
  - Location of individual DER on the feeder
  - Balance of load across three phases
  - Presence of capacitor banks or voltage regulators
  - Voltage magnitude threshold of DER trip
  - Type of voltage event
    - Sag or swell, along with balanced or unbalanced

Transmission planner has minimal to zero information

Transmission planner has information

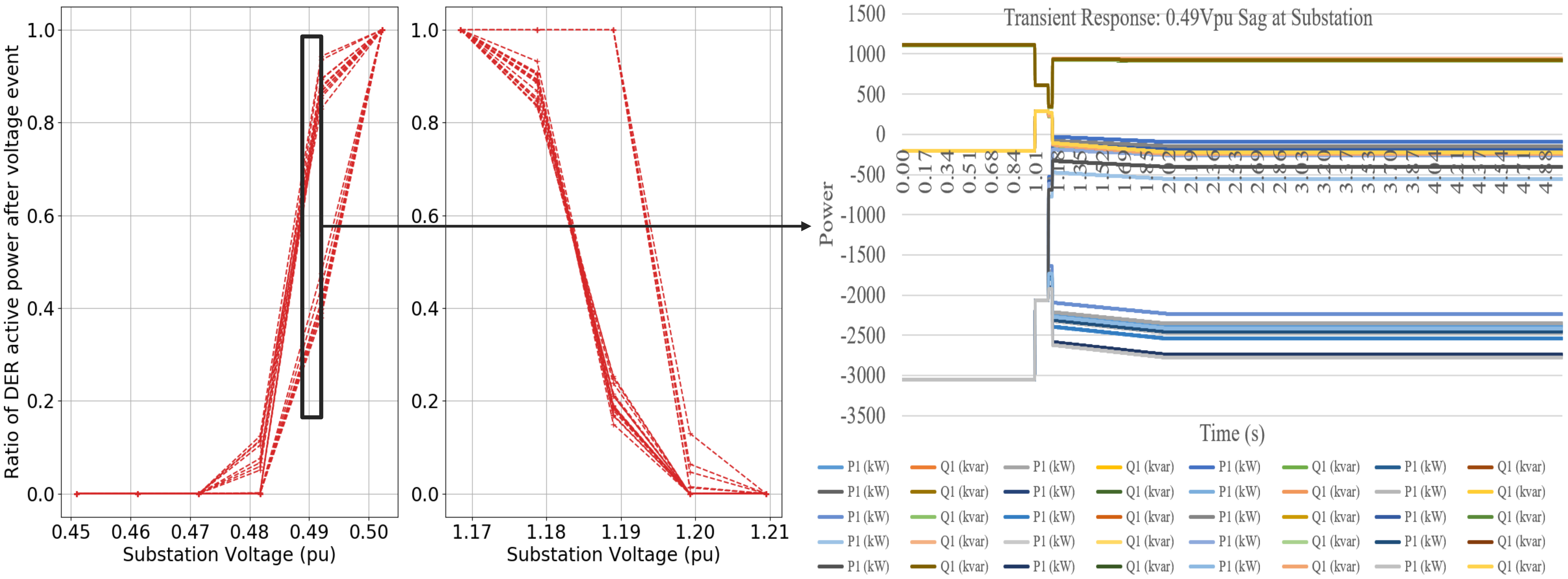
This behavior is essentially within a black box, and development of generic parameters for a wide variety of feeders and geographical areas is of interest

Feeders in Arizona…

- Feeder 1:
  - Purely residential
  - Peak load of 9.69 MW, minimum load of 1.71 MW
  - Only single phase DERs were studied, with total DER of 4.8 MW and 7.2 MW
- Feeder 2:
  - Urban with mixed customer class of 25 % commercial and 75 % residential
  - Peak load of 9.69 MW, minimum load of 2.45 MW
  - Only single phase DERs were studied, with total DER of 2.42 MW and 7.27 MW
- Feeder 3:
  - Rural with mixed customer class of 60% commercial and 40% residential
  - Peak load of 5.27 MW, minimum load of 2.05 MW
  - Both three phase and single phase DERs were studied, with total DER of 2.63 MW and 3.95 MW

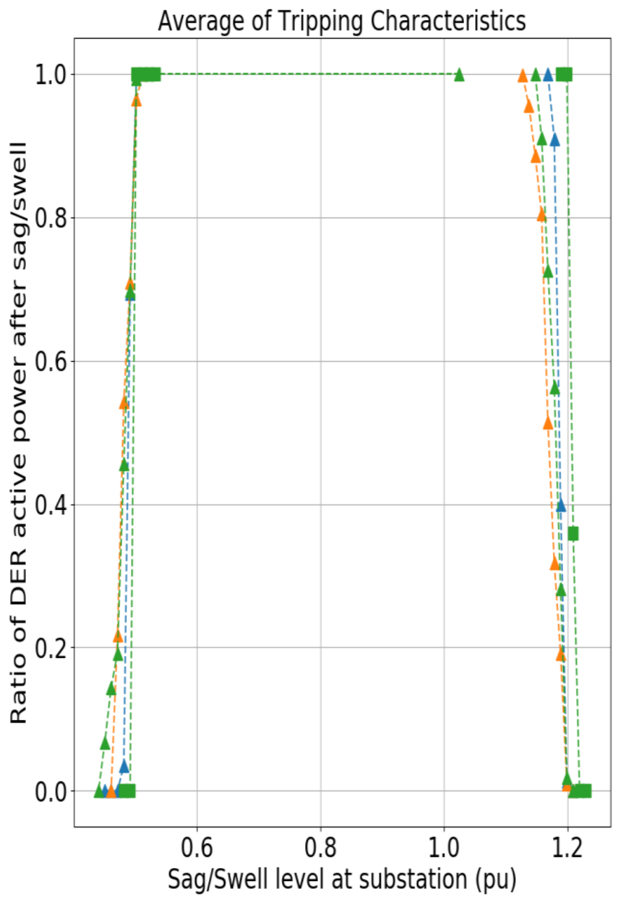
A result from feeder 1…

- Wide variation in DER kW that ride through depending on location on feeder

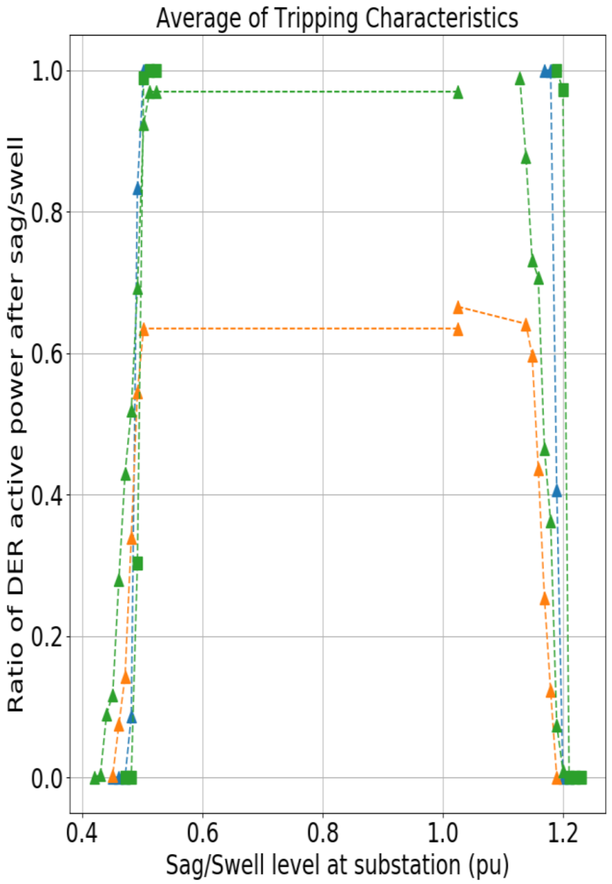


Summary of Arizona feeder results…

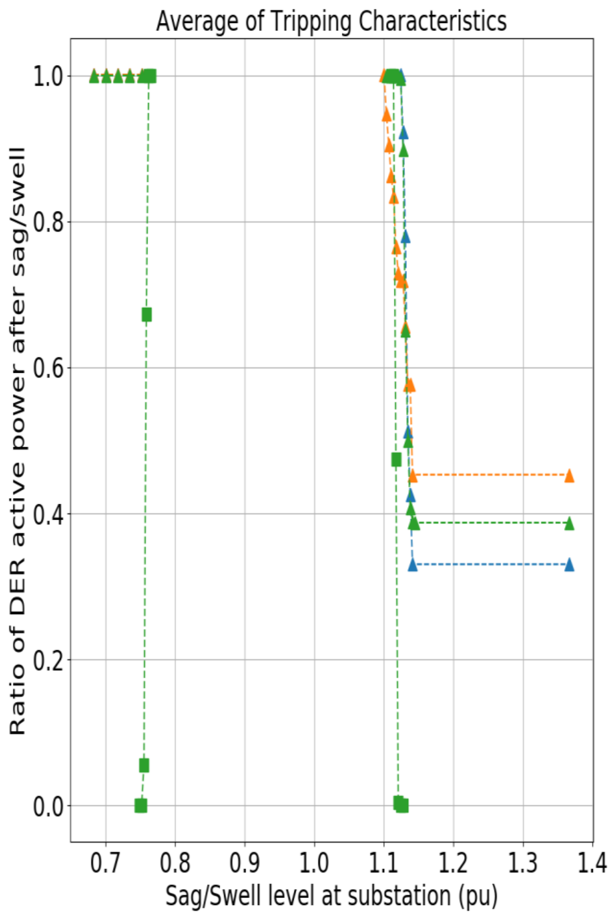
- Tripping profile split by %age of DER presence, for balanced/unbalanced event



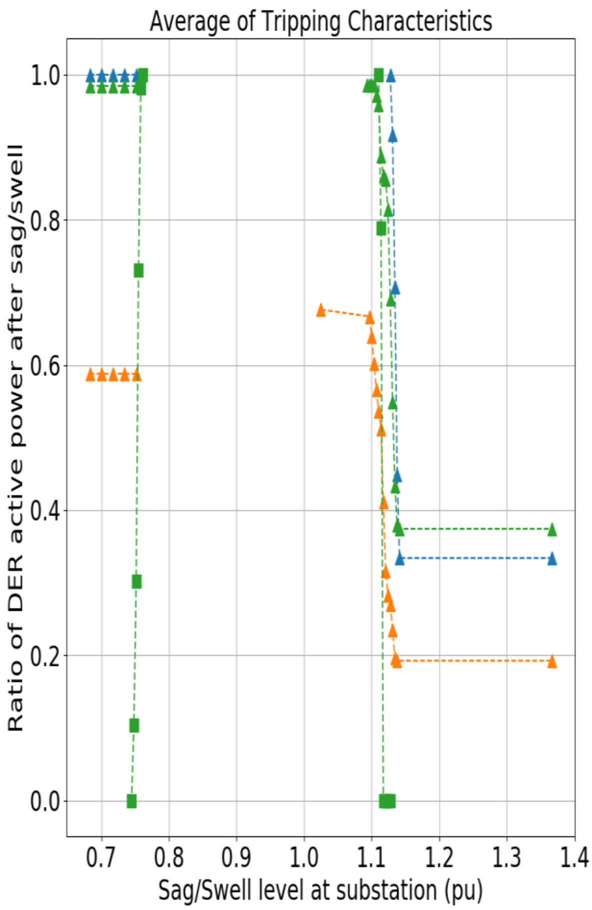
50% DER with balanced event



75% DER with balanced event



50% DER with unbalanced event



75% DER with unbalanced event

Generally, 0.52pu – 0.48pu for under voltage and 1.17pu – 1.23pu for over voltage, with Vrfrac = 0.0

Generally, 0.78pu – 0.75pu for under voltage and 1.1pu – 1.15pu for over voltage, with Vrfrac = 0.5

The Importance of DER_A Parameterization

The system challenge…

- In the transmission system, single phase faults and trips are more common than three phase faults.

- Based on the transformer winding connection, a single phase fault on the primary side can impact two phases on the secondary side.

- DER connected on both affected phases may trip.

- Can a positive sequence model (which assumes balanced phases and models all phases equally) capture this trip behavior?

How does this impact DER tripping…?

Ignoring transient impact of other elements on the feeders

When the transformer is Y-Y connected

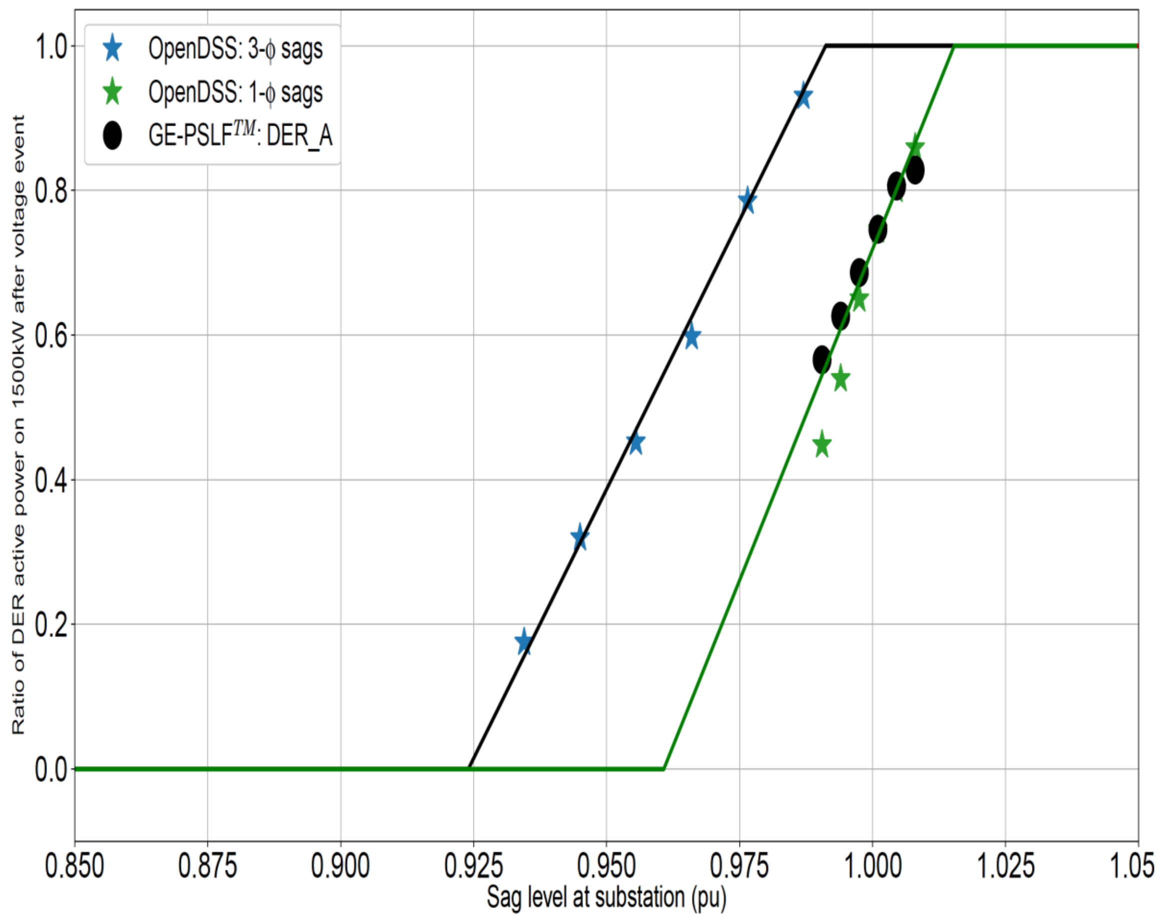
- Assuming all DER on the feeder have a voltage trip threshold of 0.5pu
  - Any three phase DER can trip because voltage of phase A goes below 0.5pu
  - Any single phase DER on phase A can trip as phase A voltage is below 0.5pu
  - Chances of cascade impacting neighboring phases is minimal

When the transformer is Δ-Y connected

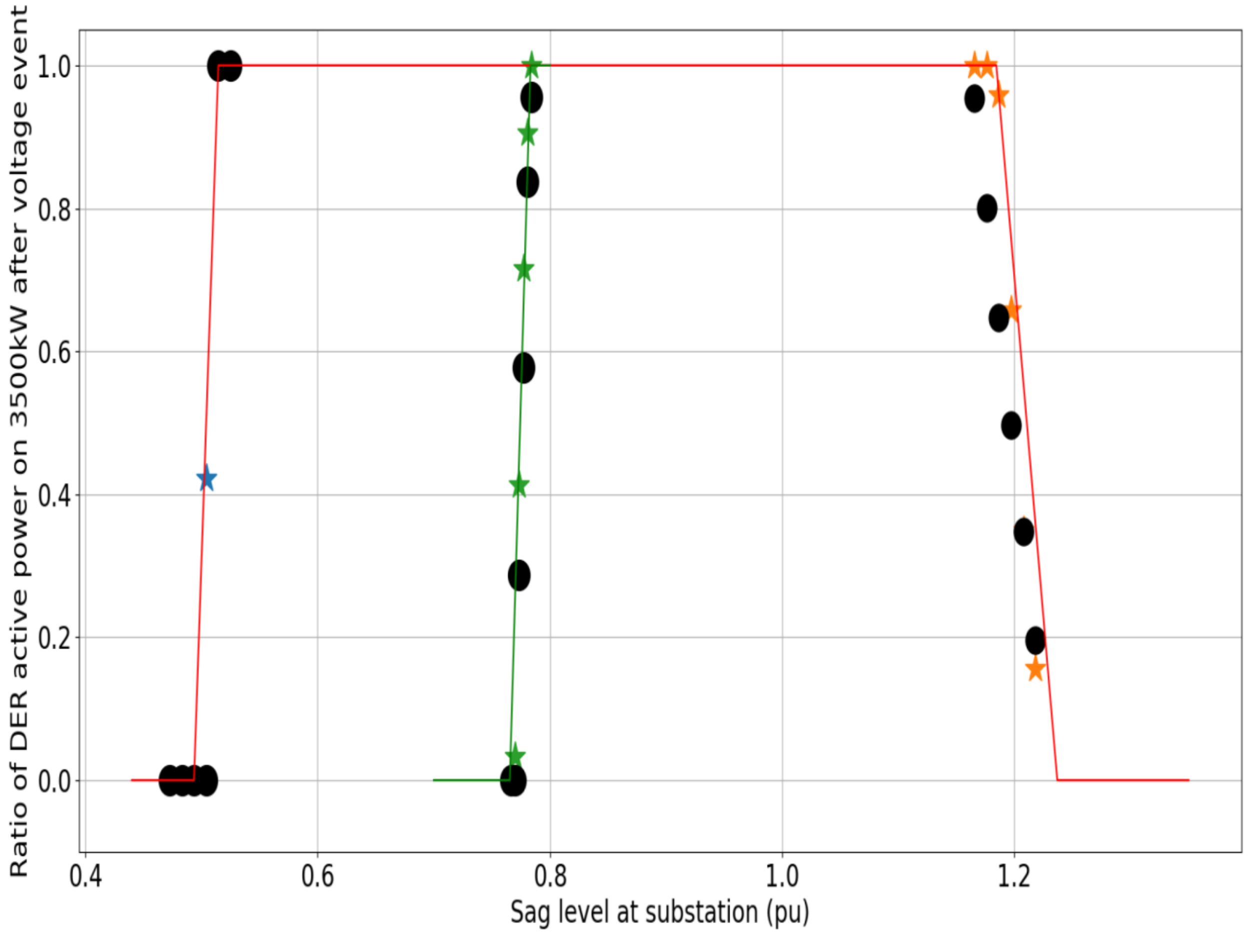
- Assuming all DER on the feeder have a voltage trip threshold of 0.5pu
  - Any three phase DER located towards the tail end of the feeder (which has minimal voltage support) may trip as phase A and C voltage are close to 0.5pu
  - Any single phase DER on phases A or C may trip as voltage is close to 0.5pu
  - Chances of cascade tripping are higher as voltages of two phases are close to trip threshold

1. In both scenarios, the trip of DER starts at a positive sequence voltage value greater than the 0.5pu trip threshold
2. For a largely balanced feeder, a Δ – Y transformer connection can result in larger DER trip

A possible solution using DER_A – construct a 'parallel' characteristic during the fault



Individual DER Vtrip = 0.88pu

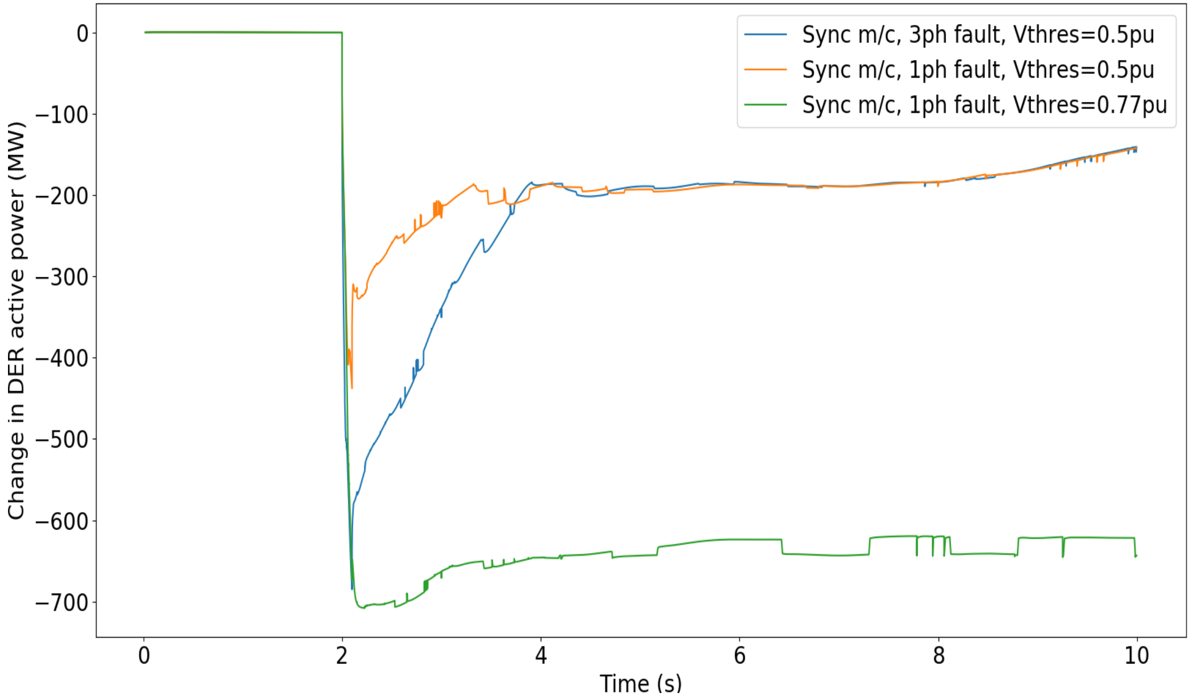


Individual DER Vtrip = 0.5pu

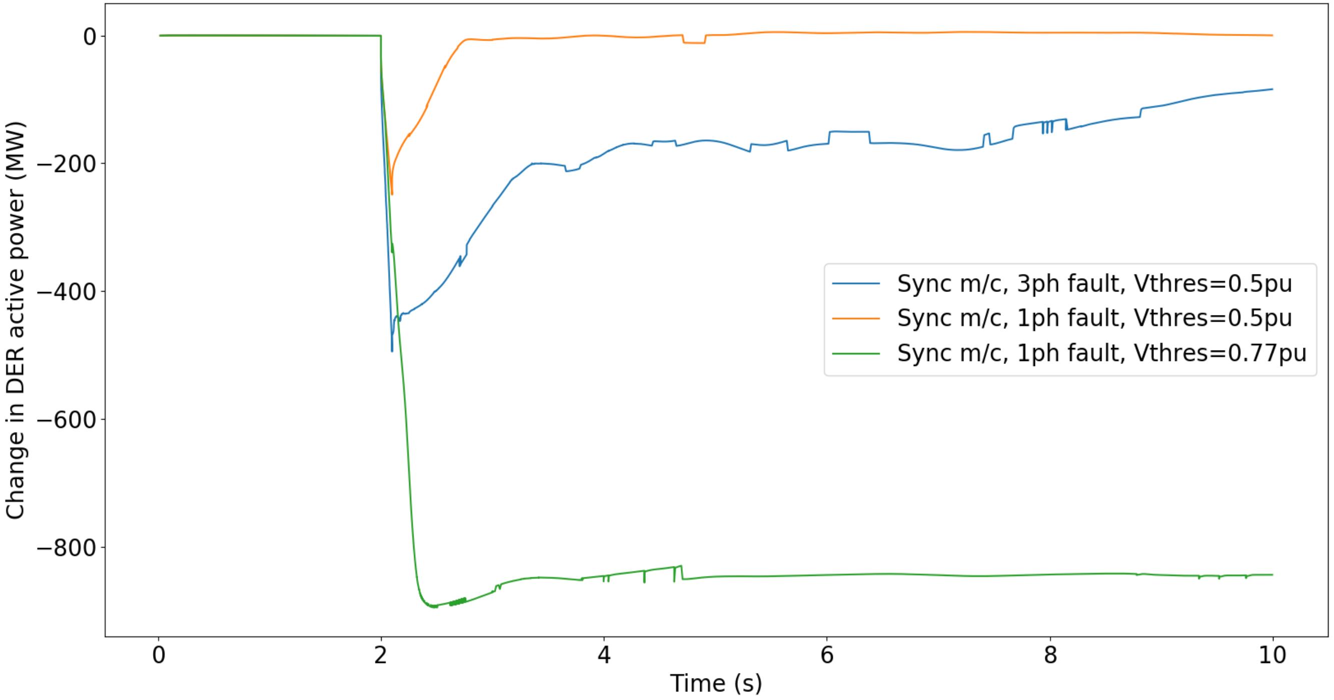
Reference: Deepak Ramasubramanian, Inalvis Alvarez-Fernandez, Parag Mitra, Anish Gaikwad and Jens C. Boemer, "Ability of Positive Sequence Aggregated Distributed Energy Resource Model to Represent Unbalanced Tripping of Distribution Inverters," 2019 IEEE Power & Energy Society General Meeting (PES), Atlanta, GA, 2019

Impact on bulk power system...

- Simulation premise
  - System generation is 69 GW, gross load is 81 GW, DER is 14 GW
  - Fault applied in the middle of transmission line, and subsequently line is cleared in 6 cycles
  - Load dynamics are considered along with DER dynamics



Transmission line A



Transmission line B

Without the parallel trip characteristic, there could be a huge misrepresentation of amount of DER that ride through a single phase fault

Summary…

- There is both a modeling and parameterization challenge to represent aggregate impact of distributed energy resources
  - Transmission planner has visibility only of one ride-through impacting factor out of six factors
  - Parameterization of an essential black box model
    - DER_A has shown promising preliminary results
    - Should however go hand-in-hand with load modeling

- It is possible that unexpected results might arise due to block tripping of DER represented by model
  - However, it is not uncommon for DER to trip in blocks as the tripping is based upon pure logic embedded in the controllers.

Thank you
Questions?

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