Modeling, parameterization, and impacts of DER on the bulk power system

An overview of DER research work at EPRI

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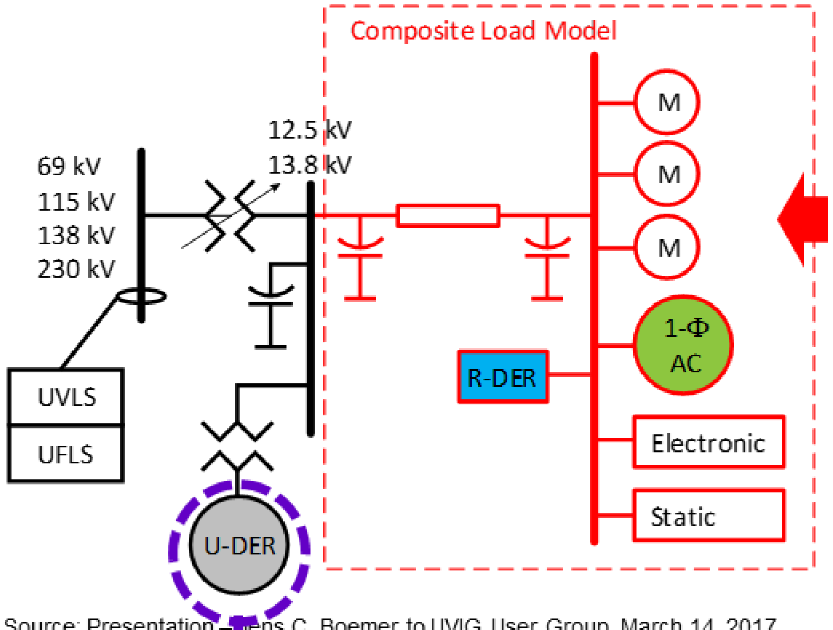
The Three Pillars of Accurate Modeling of DER for Transmission Planning Studies

I. Accurate Model Specification	II. Accurate Model Integration	III. Accurate Model Parameters
• Aggregate generator in power flow case • Generic or dynamic equivalent model in dynamic case	• Power flow case • Dynamic case	• Feeder aggregation/ equivalent impedances • Split of legacy/ modern DER • Partial Voltage Trip Parameters
➢ 2nd generation renewables models ➢ Aggregated DER (DER_A) model (3002015320) – *public!*	➢ Aggregated DER Model Integration (ADMI) Tool (3002014316)	➢ Feeder Aggregation Research (3002013500)

Research commenced in 2015 and continues over the next few years as joint project of programs P40.016 & P173A

How can DER be modeled for bulk power system planning studies?

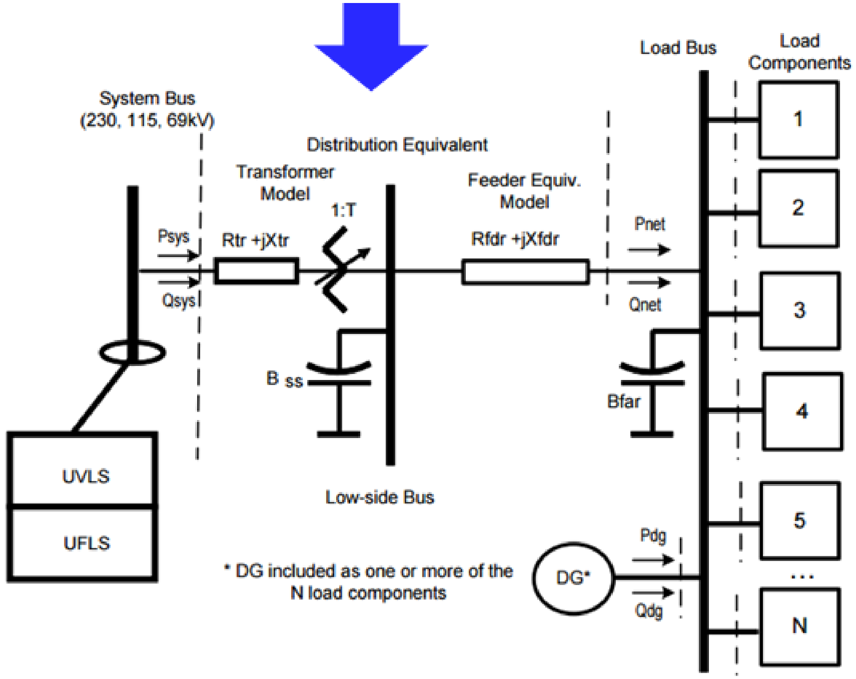


Source: Presentation – Jens C. Boemer to UVIG User Group, March 14, 2017, *Advanced DER Modeling for Transmission Planning Studies*

Model	R-DER Representation#
cmpldw, cmldblu1/2	Should be added as an additional source.
cmpldwg	Inherently negative load. Can alternatively be added as an additional source
cmpldw2	Modular structure with PVD1 or DER_A

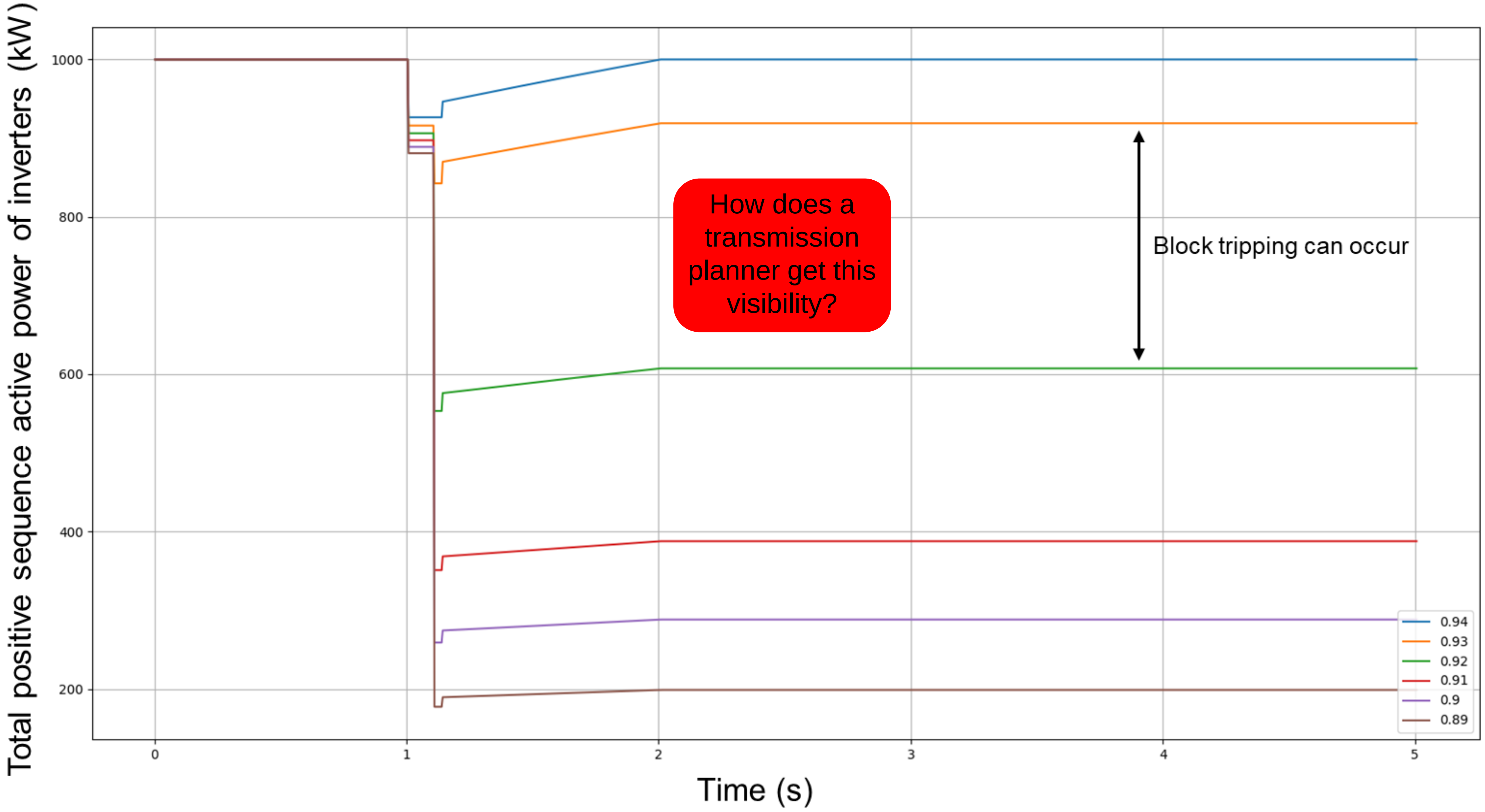
U-DER Representation	Model#
Detailed and specific	REGC_A REEC_A/REEC_B/REEC_C REPC_A
Simple and aggregate	PVD1 or DER_A

#Model names are with respect to GE PSLF™. DER assumed to be non-synchronous



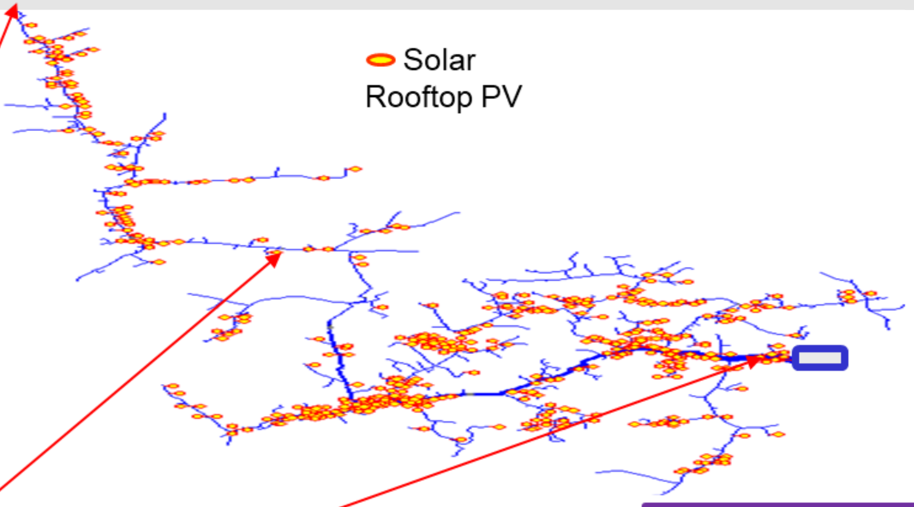
Source: Document – W. W. Price, May 18, 2016, *WECC Dynamic Composite Load Model (2nd Generation) Proposed Structure*

Block tripping of DERs is a concern to improved resiliency



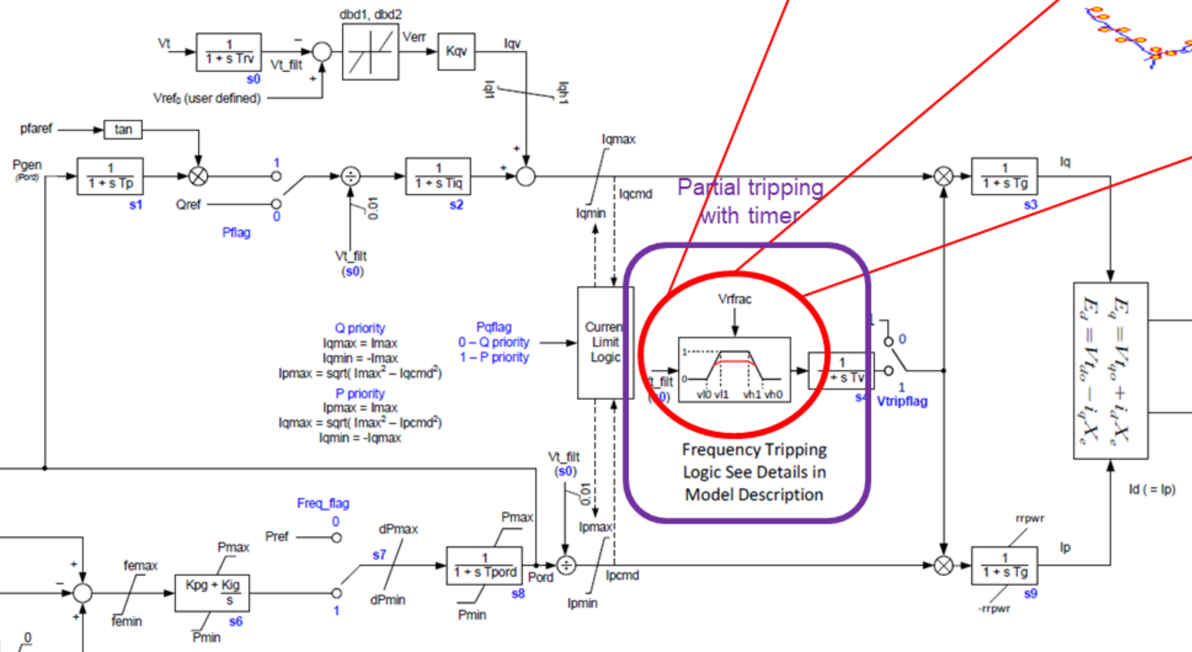
- Each indicated sag depth is multiplied by initial substation voltage for actual depth.
- Represents a simulation carried out with 100 DERs each of 10kW

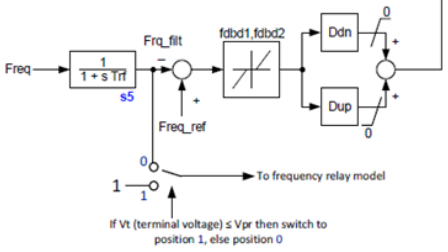
The DER_A Model

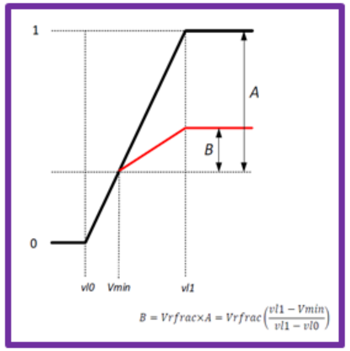


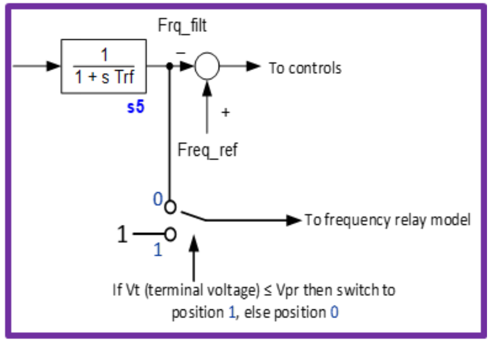
References:

- *EPRI (2019): 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.* (Online)
- P. Pourbeik, "*Proposal for der a model: memo issued to WECC REMTF, MVWG and EPRI P173.003*," (Online) 10/11/16 (REVISED 11/16/16; 3/6/17; 3/15/17; 3/28/17; 3/29/17; 3/31/17; 4/17/17; 10/5/17; 11/9/17; 2/9/18; 2/15/18; 3/9/18; 7/17/18; 8/29/18; 9/11/18) 2018.







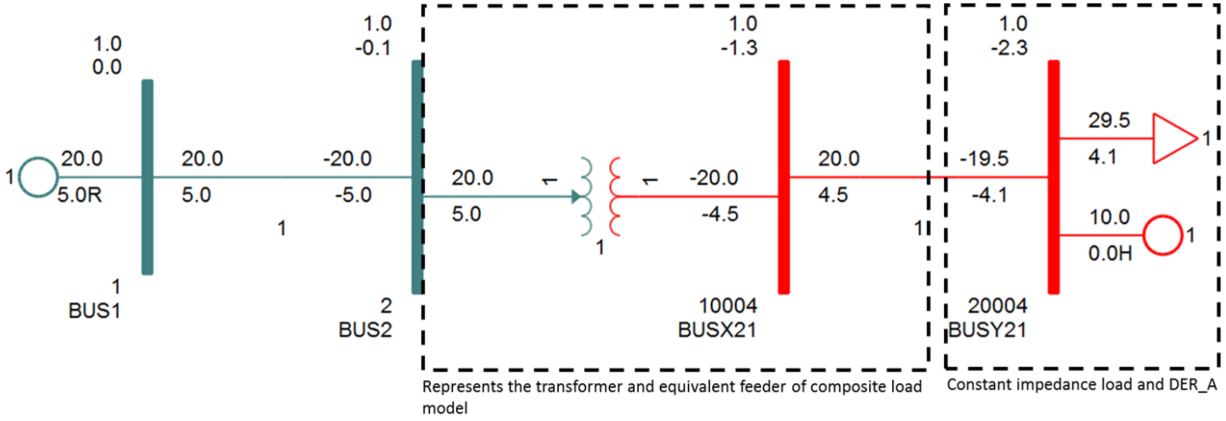


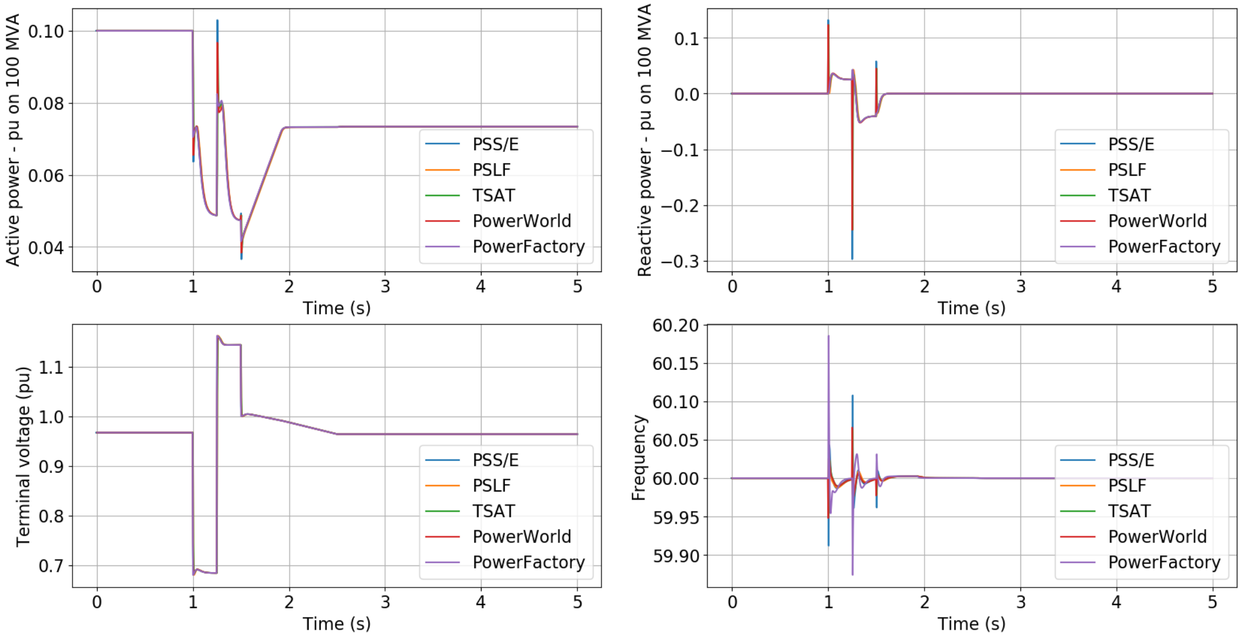
Partial voltage tripping:

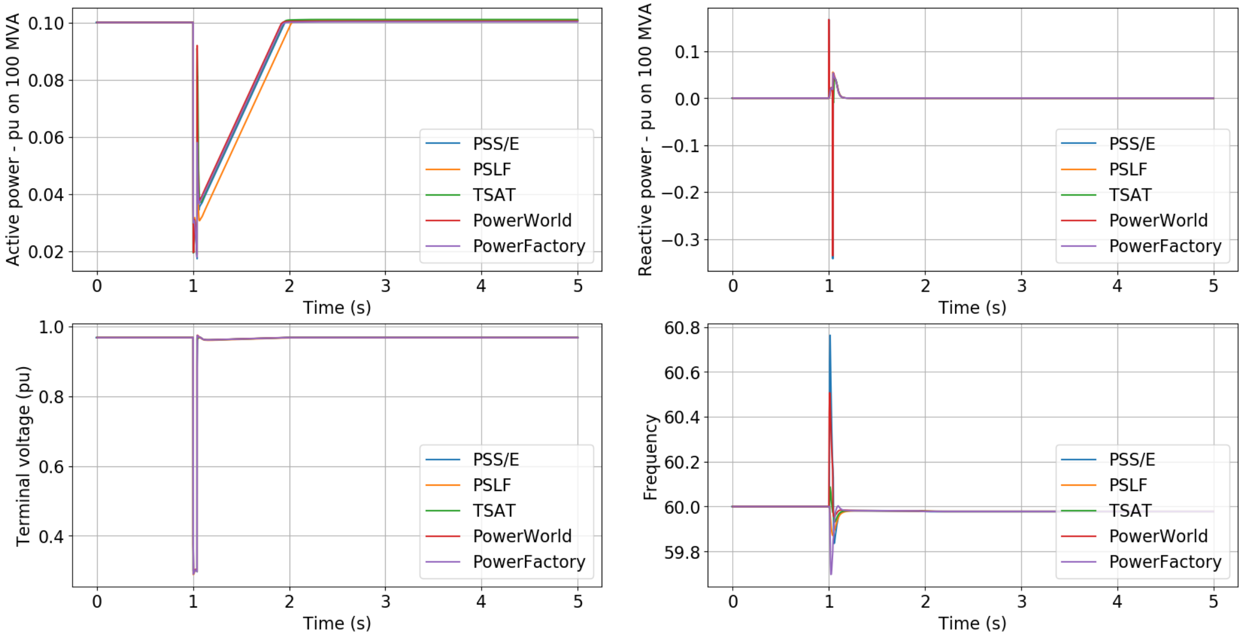
- Legacy ↔ modern DER (param. *Vrfrac*)
- Voltage drop over distribution feeder (*vl0, vl1, vh0, vh1*)
- Corresponding trip times (*tl0, tl1, th0, th1*)

How to find parameter values for the model? Present focus is on voltage thresholds.

Benchmarking of the DER_A model to ensure consistency of implementation…







- Representative results shown here for play-in voltage waveform (on the left) and fault and subsequent clearance (on top)

References:

- *EPRI (2019): 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.* (Online)

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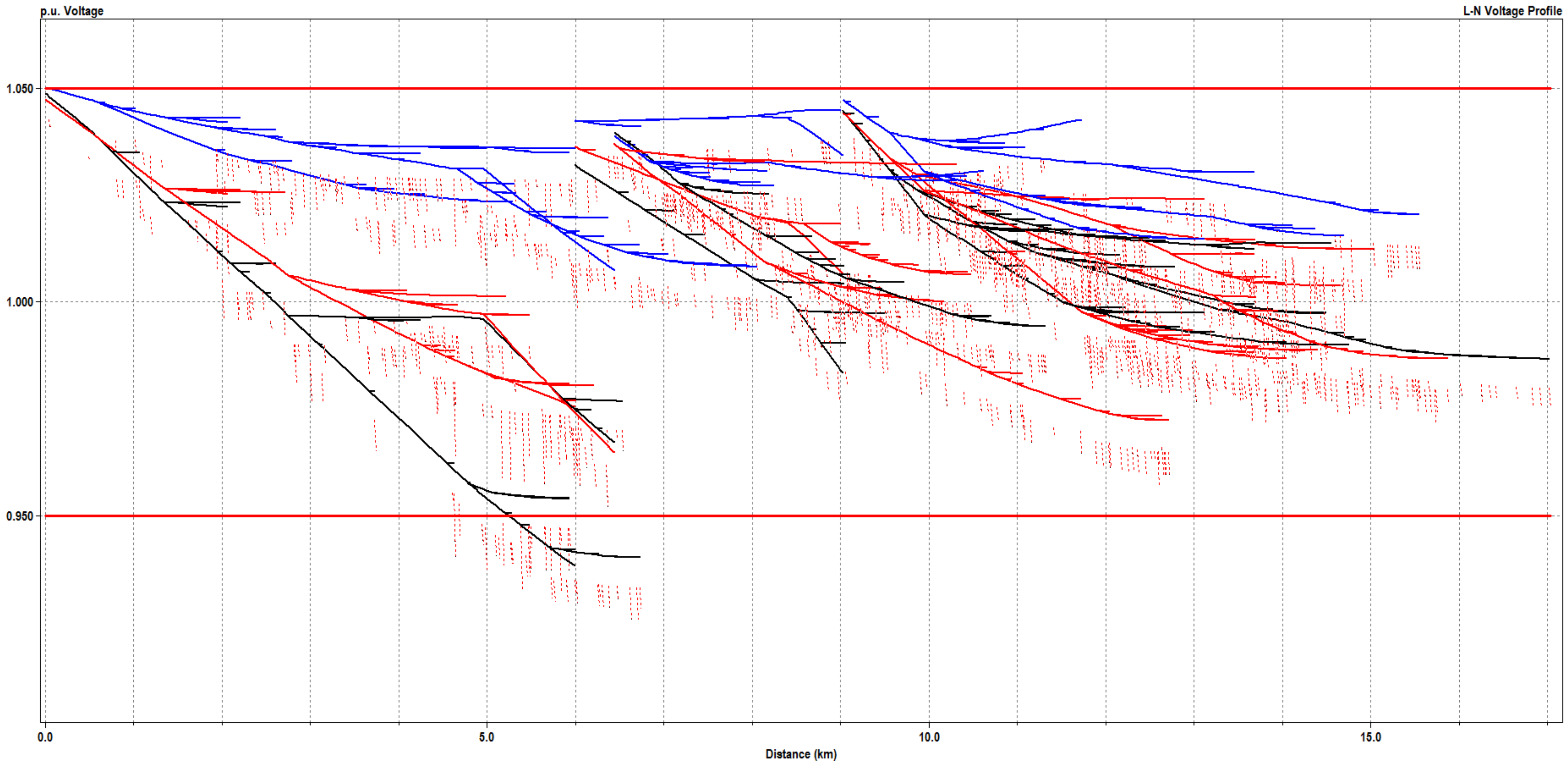
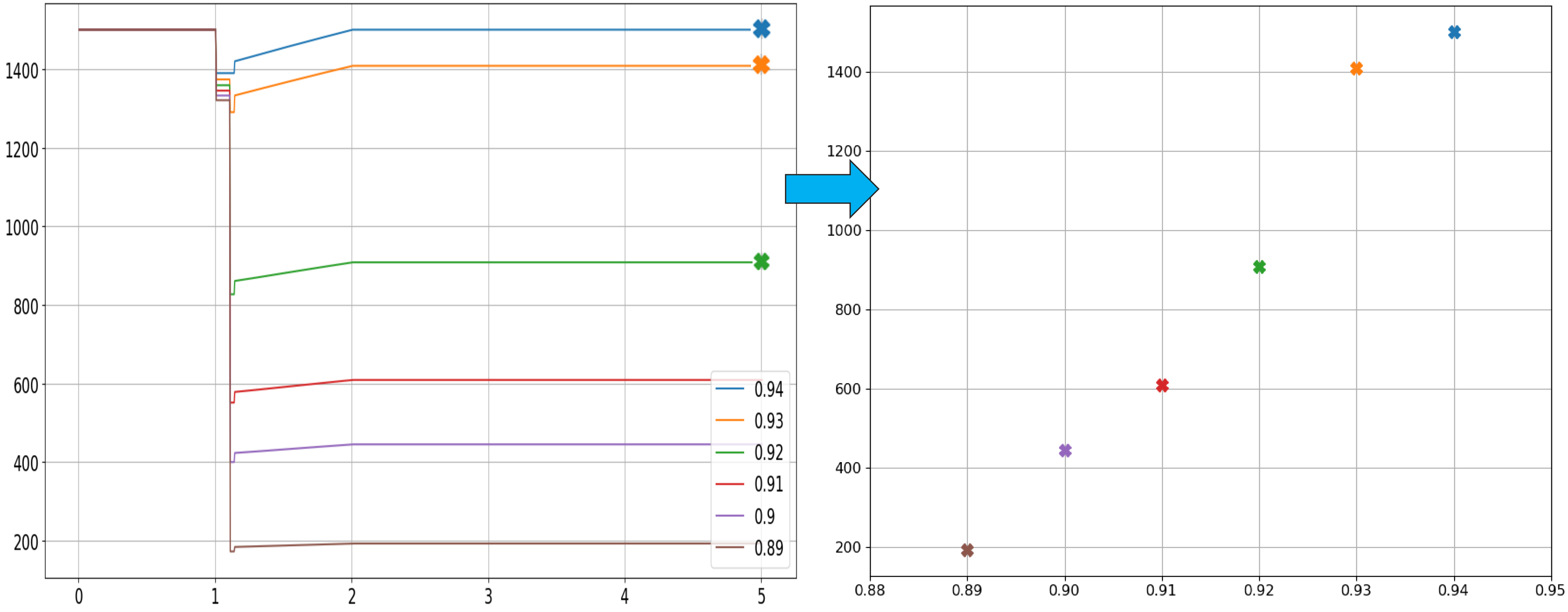
Line to neutral voltage profile of 8500 node feeder without any additional inverters and balanced loads



Individual Legacy Inverter Description

- Group A (residential R-DER)
  - P = 15kW
  - S = 15kVA
  - Under voltage trip = 0.88pu for 0.1s
- Group B (commercial R-DER)
  - P = 35kW
  - S = 35kVA
  - Under voltage trip = 0.5pu for 0.1s
- Both are 3-phase, roughly based on IEEE 1547-2003
  - **Only legacy inverters in the present analysis**

Translation to an Under Voltage Trip Characteristic

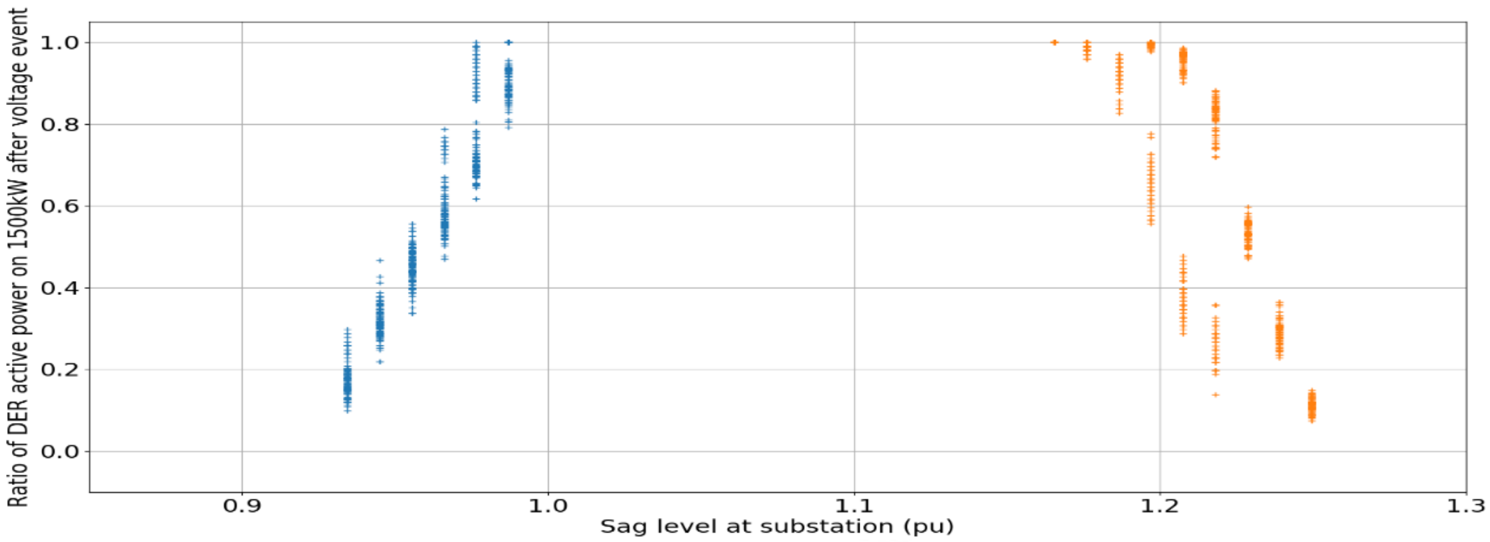


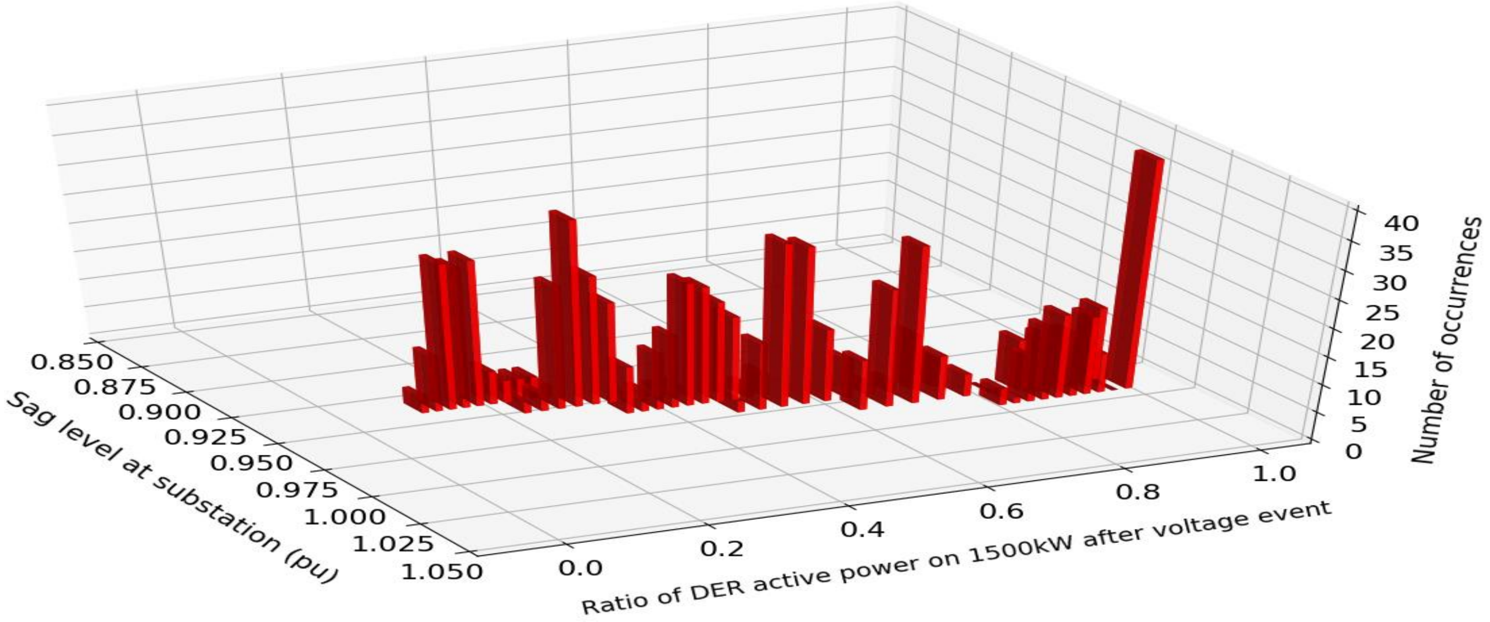
Fitting these trip results to the DER_A trip characteristic

But is this the only type of variation possible?

When considering combinations of 3 – φ DER, 1 – φ DER, balanced load, unbalanced load

- While the trend is the same for all combinations, the spread is different
  - Both vertical spread and horizontal
- But, there are some values of ride-through ratio that have a higher probability of occurrence than other values.
- These values must be used for the parameterization of the DER_A trip characteristic

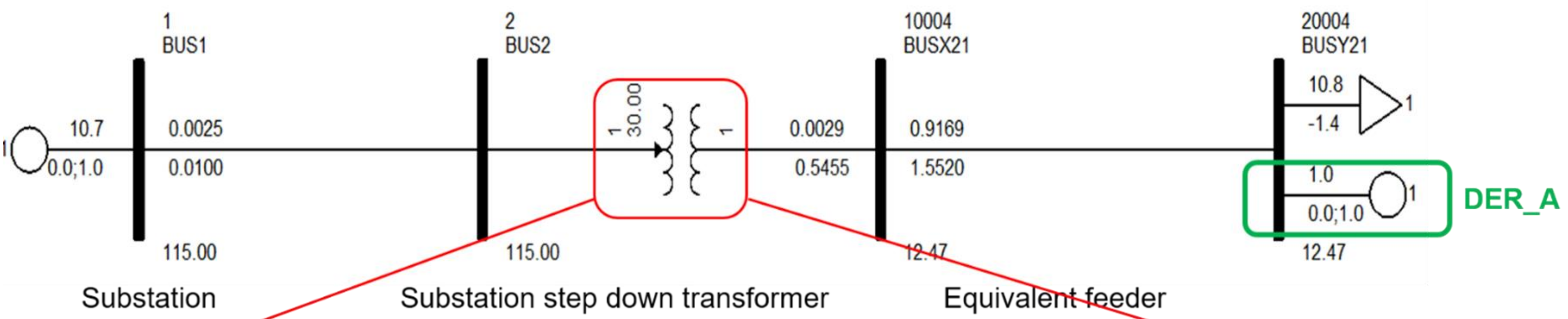




Reference:

Detailed Distribution Circuit Analysis and Parameterization of the Partial Voltage Trip Logic in WECC's DER Model (DER_A): Towards Regional Default Settings in the Absence of Detailed Distribution Circuit Data. EPRI, Palo Alto, CA: 2018. 3002013500 (Online)

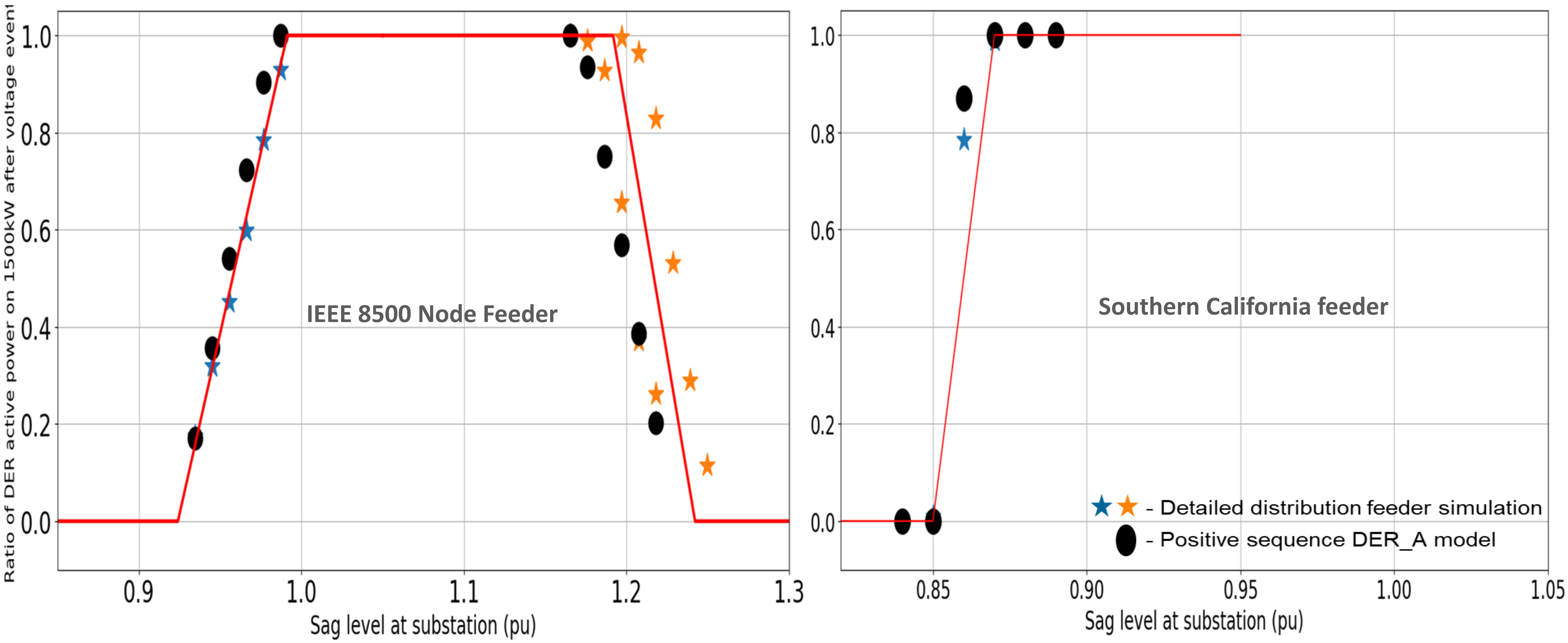
Would a transmission planner see the same behavior from the aggregate model?



Values of MVA, r, X & base kV from OpenDSS definition of the element

```
! HV/MV Substation connected Delta/grounded-wye
New Transformer.HVMV_Sub  phases=3  windings=2  buses=(HVMV_Sub_HSB, regxfmr_HVMV_Sub_LSB.1.2.3.0)
~ conns=(delta wye)
~ kvs=(115, 12.47)  kvas=(27500, 27500)
~ xhl=15.51  sub=y  subname=HVMV_Sub
~ wdg=1  %r=0.67202
~ wdg=2  %r=0.67202
```

Results from analysis of two separate feeders



Reference:

Detailed Distribution Circuit Analysis and Parameterization of the Partial Voltage Trip Logic in WECC's DER Model (DER_A): Towards Regional Default Settings in the Absence of Detailed Distribution Circuit Data. EPRI, Palo Alto, CA: 2018. 3002013500 (Online)

Concept behind generalization for widespread application

In a distribution feeder

- The first inverter to trip on the feeder is likely located towards the tail.
- The last inverter to trip is likely located towards the head.
- The first inverter would trip when the tail of the feeder has a voltage below the individual inverter trip threshold (0.88pu in our case)
- The last inverter would trip when the head of the feeder has a voltage below the individual inverter trip threshold. (0.88pu in our case)

In positive sequence

- Assuming DER_A bus represents the tail of the feeder (at present, this is a big assumption!).
- Assuming a net downward trend in voltage profile across the feeder (even with regulators and capacitor banks):
  - vl1 in DER_A = 0.89pu (Indicates the start of tripping of the first inverter at the tail)
  - vl0 in DER_A = 0.89 - $v_{feeder-drop}$ (indicates the end of tripping with the last inverter at the head)
  - $v_{feeder-drop}$ is usually between 0.02pu – 0.08pu

Options for trip settings

Parameter	IEEE 1547-2003 Default
vl0	0.89 - ($Vsub_0$ – $VtDER\_A_0$) OR 0.49
vl1	0.89 OR 0.50 + ($Vsub_0$ – $VtDER\_A_0$)
vh0	1.1 OR 1.2
vh1	1.1– ($Vsub_0$ – $VtDER\_A_0$) OR 1.2 – ($Vsub_0$ – $VtDER\_A_0$)
tvl0	(0.1-1.5) OR 0.16
tvl1	(0.1-1.5) OR 0.16
tvh0	(0.1-1.0) OR 0.16
tvh1	(0.1-1.0) OR 0.16
Vrfrac	0/(0-0.8)

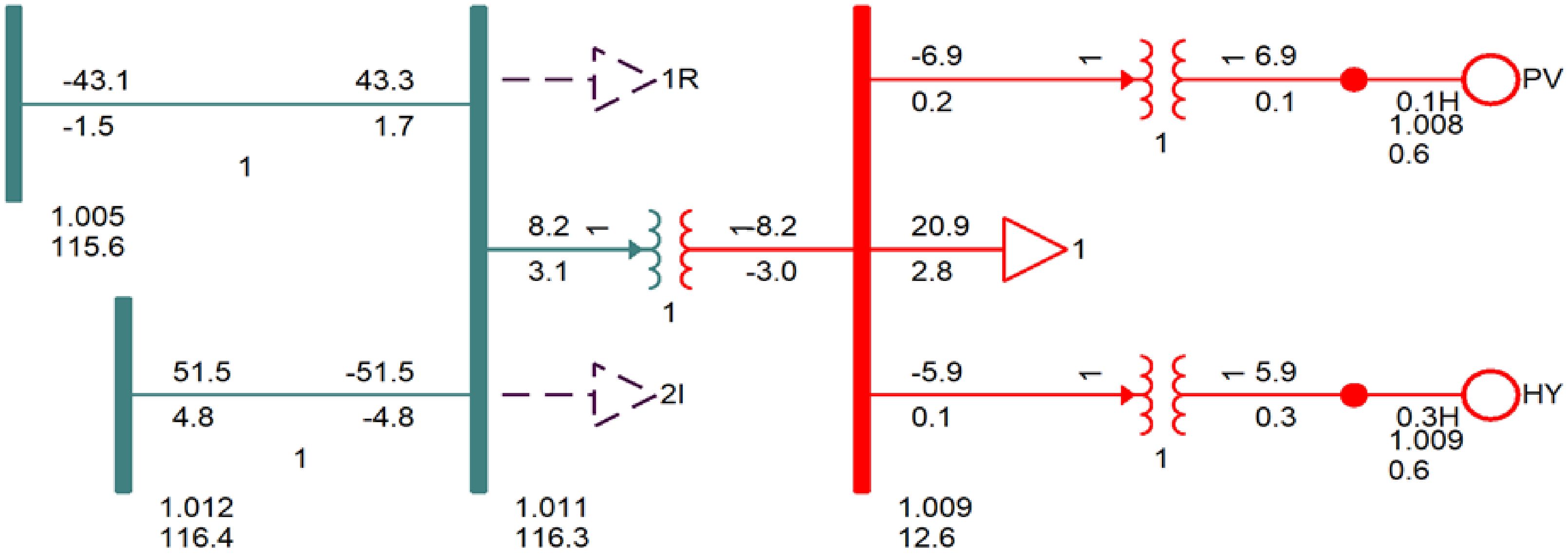
- $VtDER\_A_0$ = power flow solution voltage at the DER_A terminal
- If the load tap changer has a ratio other than 1.0, then V_{LTC} should be used instead of Vsub0

- Option 1:
  - If all the DERs on the feeder have a trip threshold as 0.88pu
  - vl1 = 0.89pu; vl0 = 0.89 - ($Vsub_0$ – $VtDER\_A_0$); tvl0 = tvl1 = between 0.1s and 1.5s.
- Option 2:
  - If all the DERs on the feeder have a trip threshold of 0.5pu.
  - vl1 = 0.50 + ($Vsub_0$ – $VtDER\_A_0$); vl0 = 0.49; tvl0 = tvl1 = 0.16s.
- Option 3:
  - If some DERs have a threshold of 0.88pu while others have a threshold of 0.5pu,
  - vl1 = 0.89; vl0 = 0.49pu; tvl0 = tvl1 = between (0.1s – 1.5s) and 0.16s respectively.
- Option 4 (invalid):
  - As vl1 should be greater than vl0.

There is a further complexity: If total amount of DER is around the feeder hosting capacity, then ($Vsub_0$ – $VtDER\_A_0$) can be halved – This is still a heuristic and does not yet have a solid analytical/mathematical basis

Can this be applied for bulk power system studies?

- In Duke Energy's system, 490 MW existing DER modeled (1300 MW capacity)
- EPRI's ADMI tool[1] modeled aggregated DERs as U-DER at 138 locations
- Scaled DER and recommitted generation to create 750, 1250, 1760, 3050, and 3650 MW cases
- Evaluated bus faults + clearing

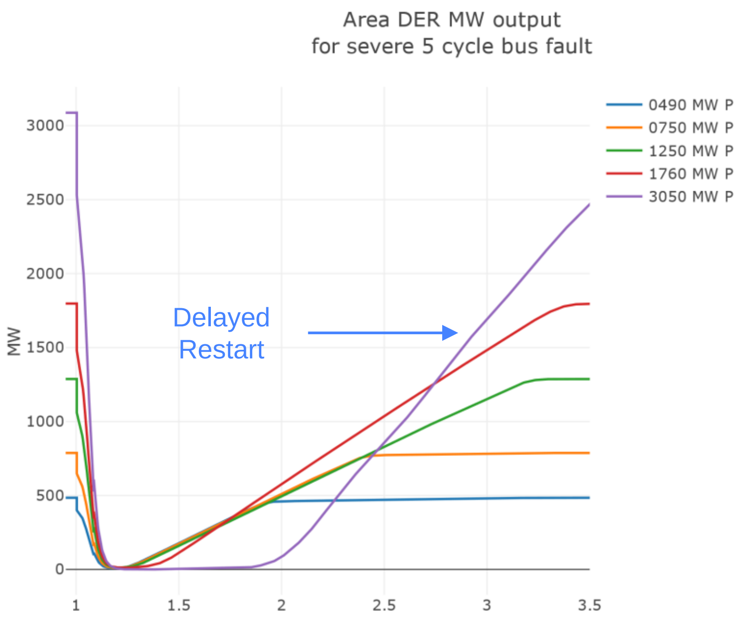


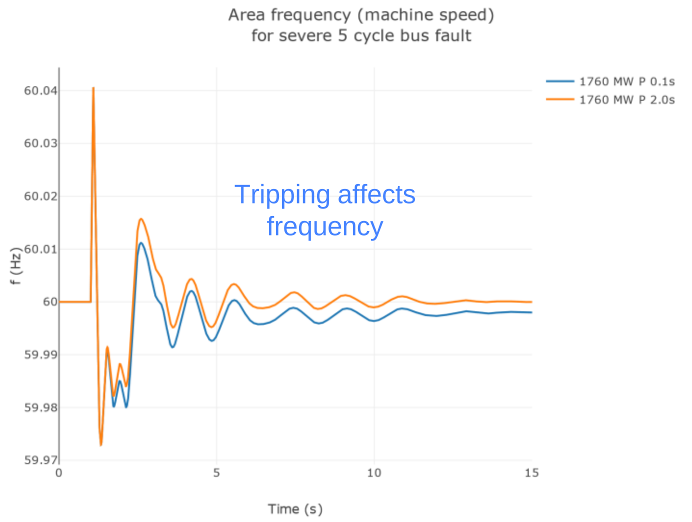
Thanks to Bill Quaintance and Anthony Williams from Duke Energy for tremendous support and guidance

[1]Aggregate Distributed Energy Resource (DER) Model Integration (ADMI): Version 2.1 - Beta, EPRI, Palo Alto, CA: 2018, 3002014316 (Online)

Observations

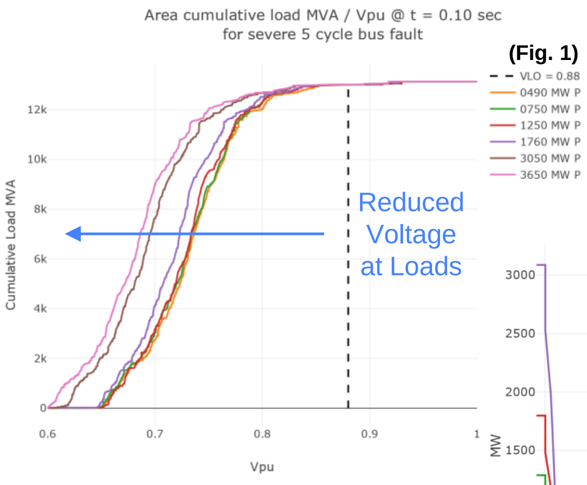
- Increasing DER penetration tended to delay recovery of pre-disturbance output
  - Indicates slower voltage recovery
- Undervoltage trip setting selection impacts steady-state frequency deviations
  - Determines number of DERs which trip during disturbances
  - No frequency problems observed, even with pessimistic assumptions (0.88pu trip within 0.1 seconds)
- Slight benefit from using dynamic voltage support functions
  - Doesn't take into account chance of DER going into momentary cessation
- Slight benefit from using Q priority
- Network upgrades need to be considered with high DER penetrations

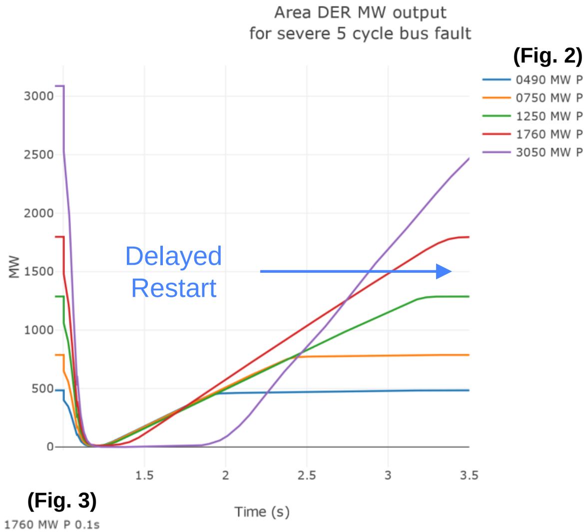


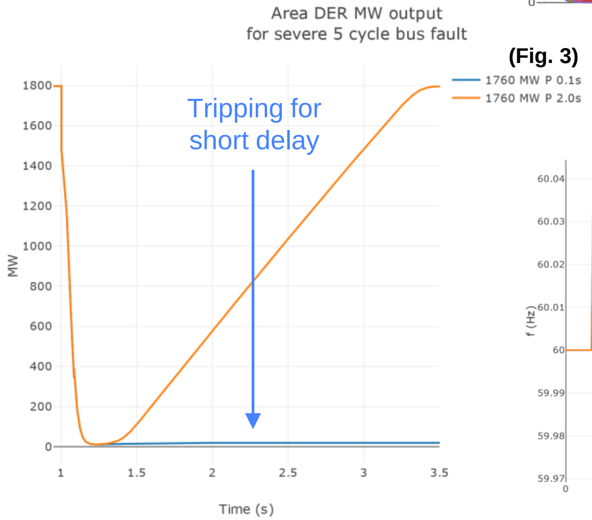


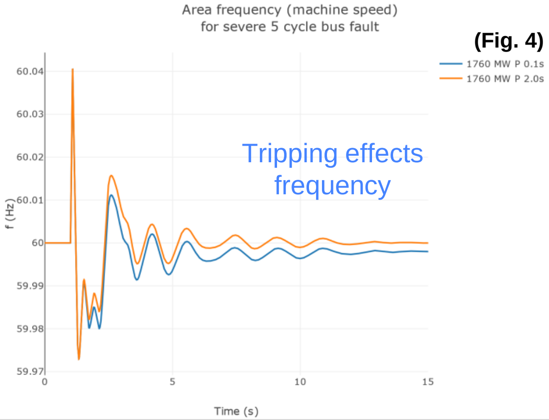
Observations (cont'd)

- Sensitivity to DER penetration
  - Tendency for decreased voltage at loads after fault clears (Fig. 1)
  - Decreased voltage delays resumption of pre-fault output (Fig. 2) (assuming long UV trip delay)
- Sensitivity to UV trip delay
  - Longer UV trip delay reduced likelihood of UV tripping (Fig. 3)
  - Indirectly affects system frequency deviation (Fig. 4)









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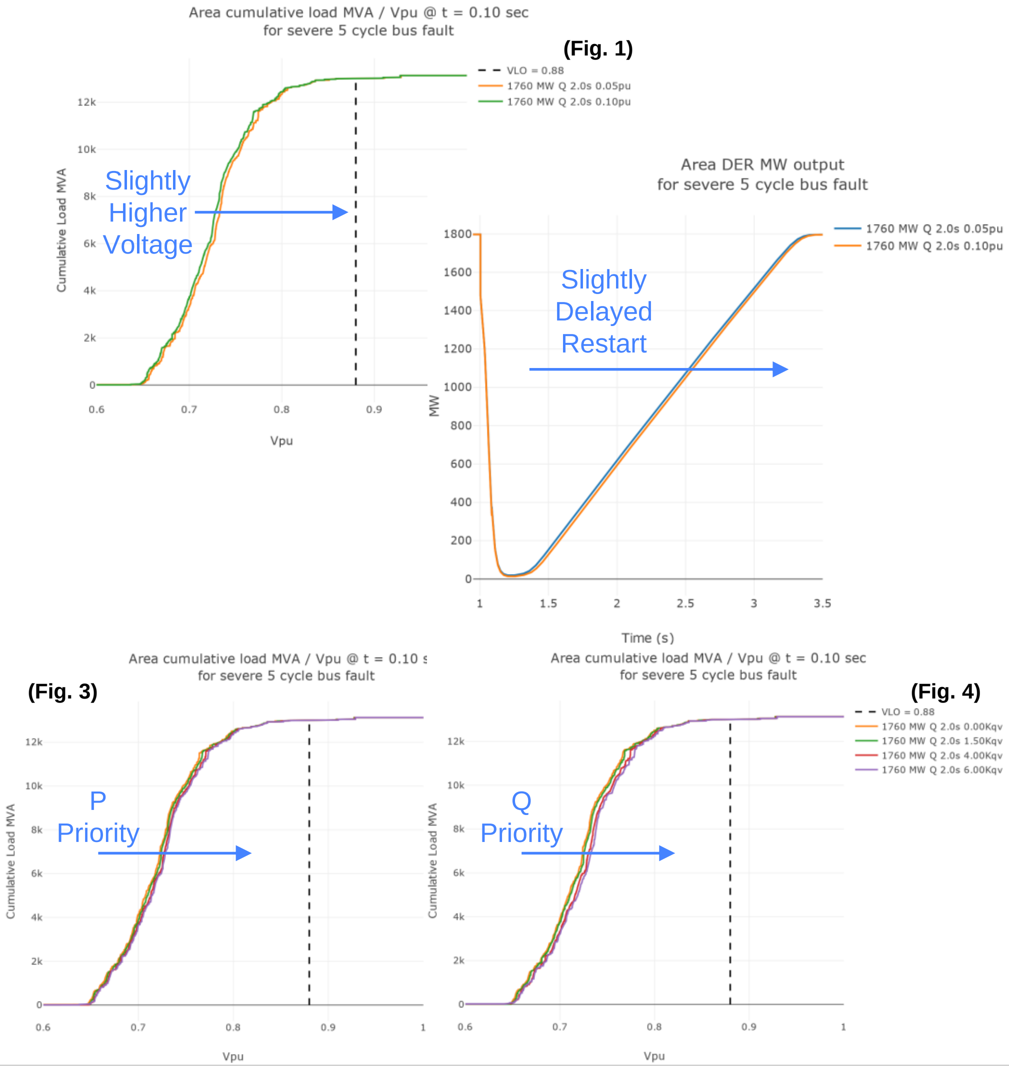
Observations (cont'd)

- Sensitivity to voltage support deadband
  - Slight improvement in load voltages for smaller deadband settings (Fig. 1)
  - Slightly quicker resumption of pre-fault output for smaller deadband settings (Fig. 2)
- Sensitivity to voltage support gain
  - Slight improvement in load voltages for higher gain settings (Fig. 3)
  - Increasing gain setting more effective in Q priority (Fig. 4)



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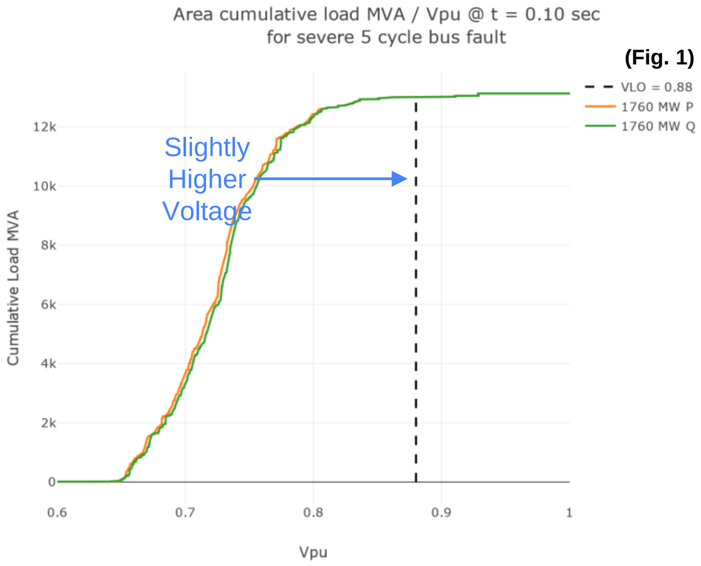
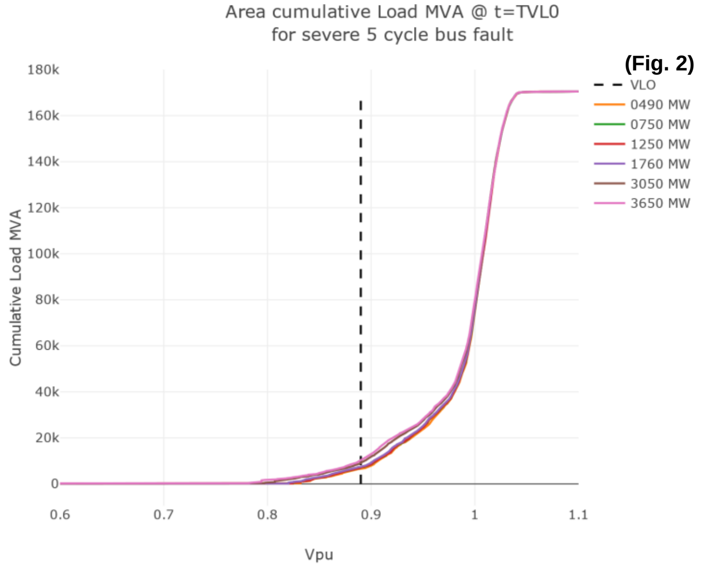
Observations (cont'd)

- Sensitivity to current priority
  - Slight improvement in load voltages for Q priority (Fig. 1)
  - DER penetration, distribution system connection, constant PF control mode all make Q priority less effective
- Impact on neighboring systems
  - Voltage depression observed in neighboring systems as well
  - Assuming DER penetration suggests how many MW of DER may be at risk of tripping in neighboring areas (Fig. 2)



(Fig. 1)



(Fig. 2)

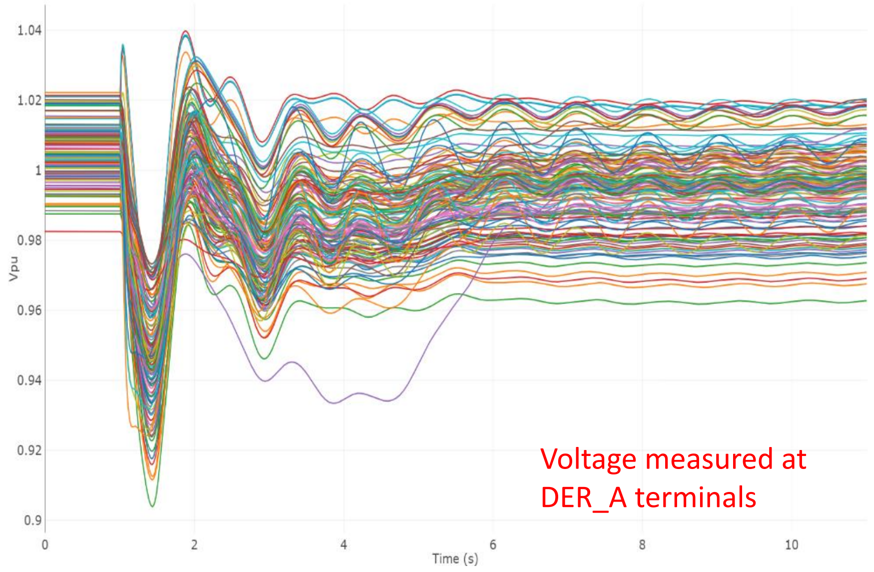
Sensitivity to islanding of bulk system region…

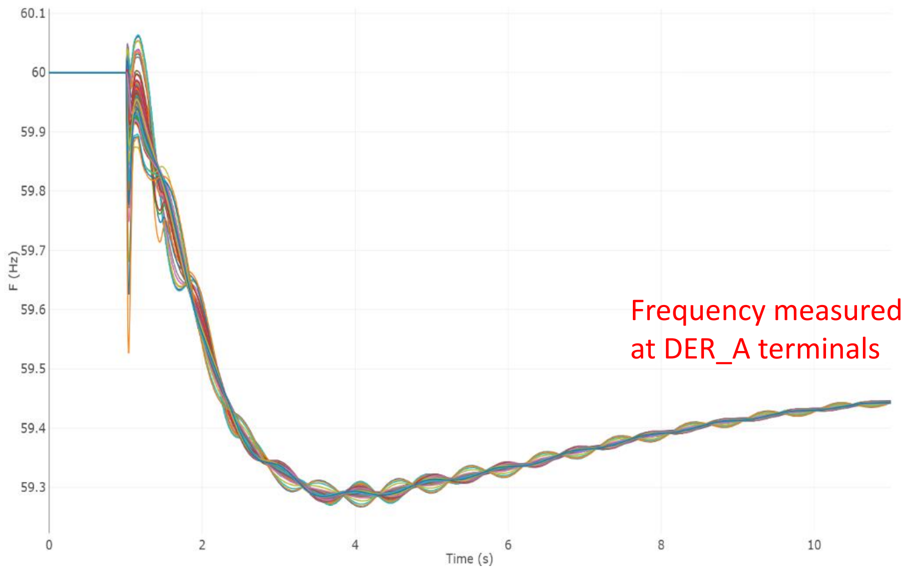
- Generic representation of system split
- All load at DER buses modeled with composite load model.
- All DER modeled as U-DER with an equivalent load step down transformer and individual U-DER transformer.
- All U-DER are in a single area and modeled with DER_A
  - Total Pgen of DER_A = 3087.45 MW
  - Total Pmax of DER_A = 3087.45 MW
- Non DER in the same area
  - Total Pgen = 8837.47 MW
  - Total Pmax = 9544.30 MW
  - Theoretical headroom = 706.83 MW
- Load in the area = 12691.94 MW/2872.52 Mvar
- Interchange of the area = 938 MW import.

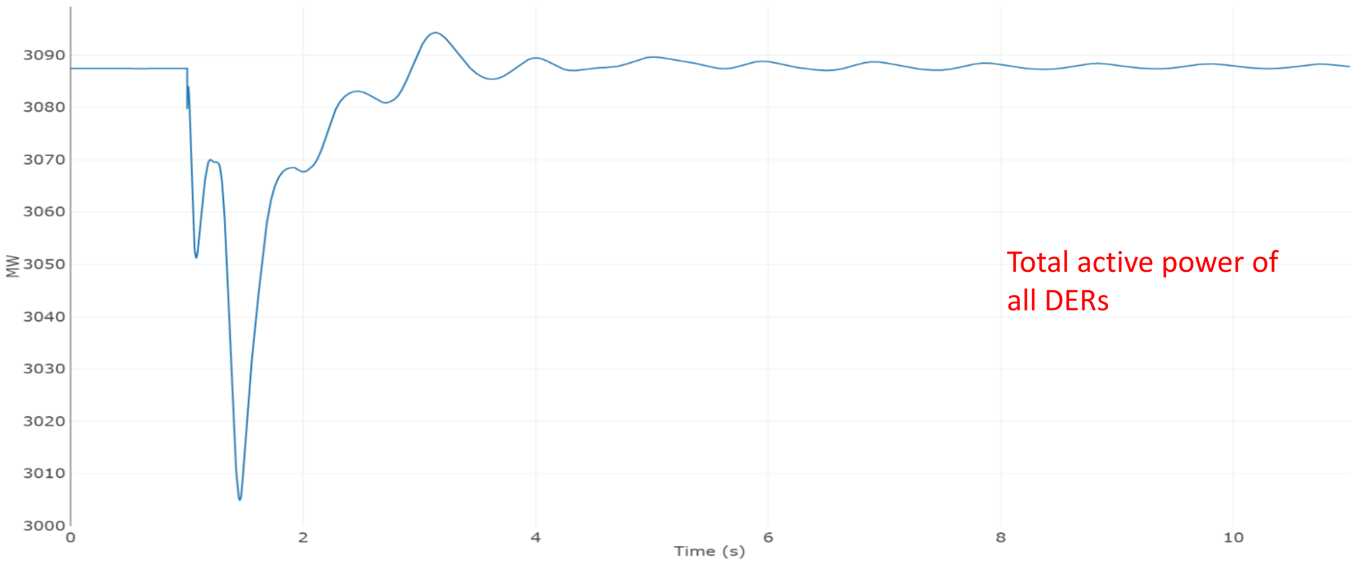
Premise of the simulations…

- DER_A main parameters:
  - v_{l1} = 0.93pu ; v_{l0} = 0.89pu
  - tv_{l1} = 2.0s ; tv_{l0} = 2.0s
  - v_{h1} = 1.05pu ; v_{h0} = 1.20pu
  - tv_{h1} = 2.0s ; tv_{h0} = 2.0s
  - f_{ltrp} = 59.0 Hz ; f_{htrp} = 61.0 Hz
  - tf_l = 7.1s ; tf_h = 7.1s
  - Vrfrac = 0.0
- All tie lines connecting the area with the rest of the system are disconnected during the simulation.
  - Results in a net deficit of 938 MW within the area as the imports are lost.

Results…



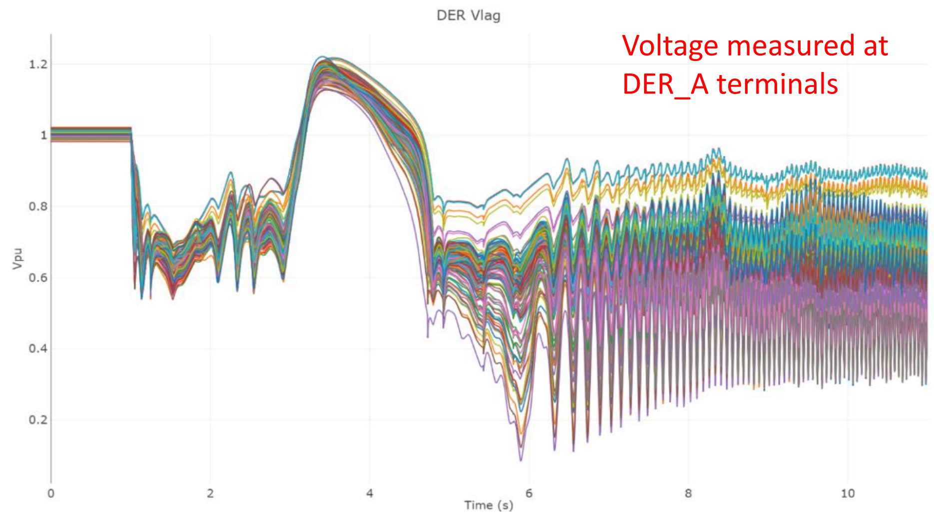


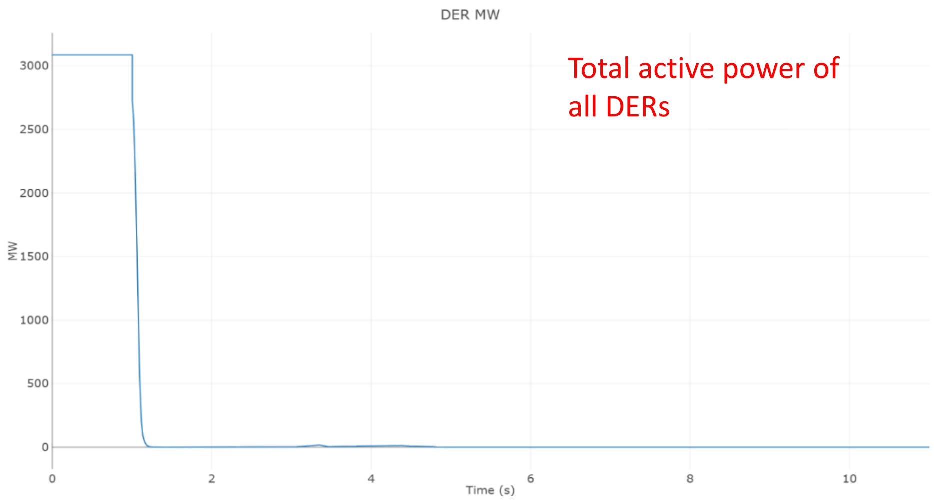


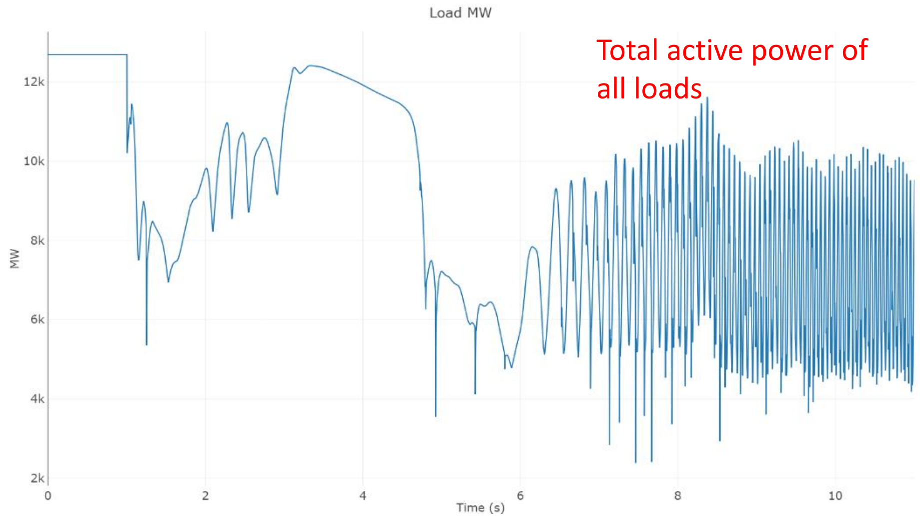
- The DER_A model is robust even for low frequency events.
- No DER trips for this scenario as both voltage and frequency stay within the trip regions

Results (cont'd)…

- Heavily loaded tie line is first faulted, and then area is islanded.



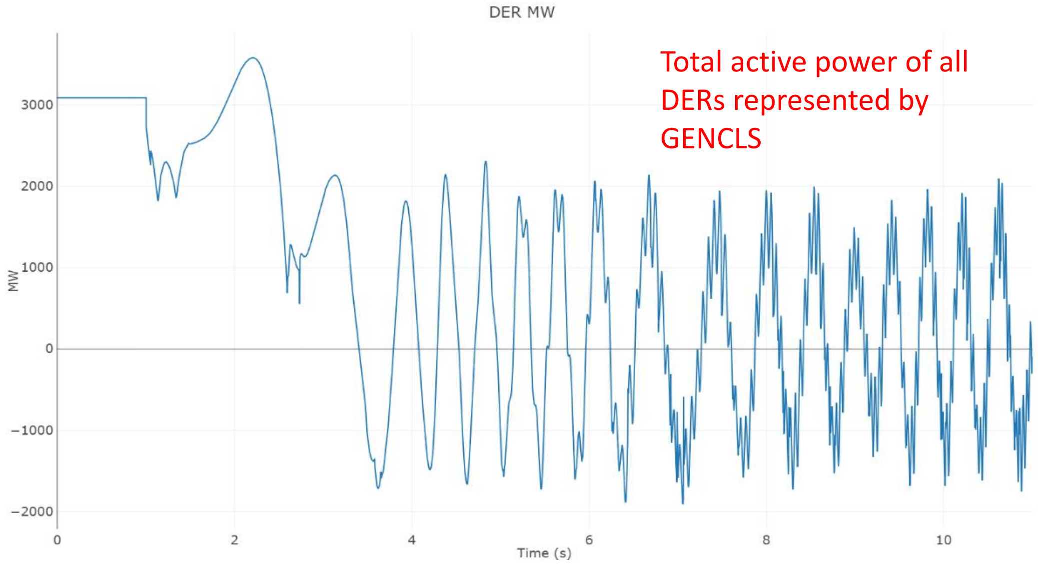


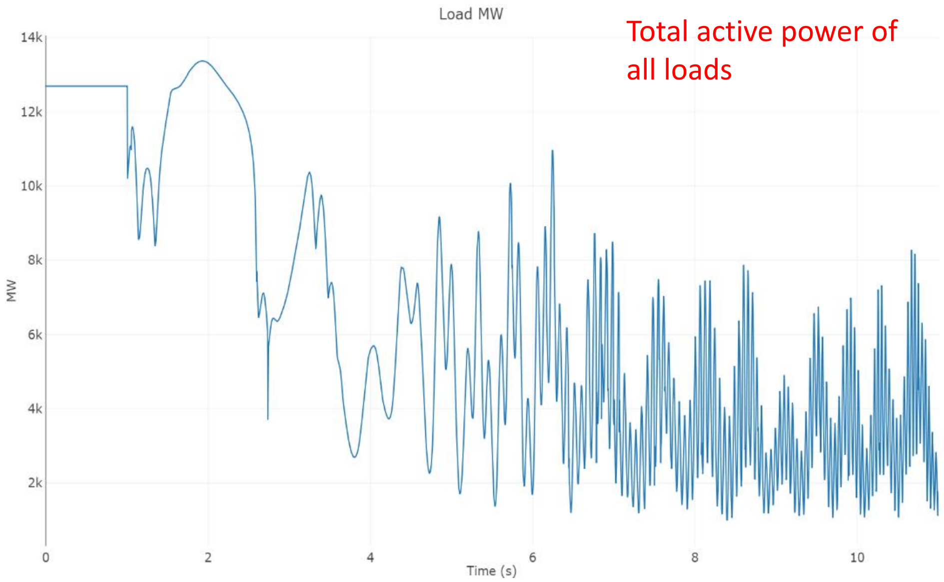


- System is unstable, but numerically robust!
- Instability is due to trip of all DERs following the fault resulting in 3000MW of deficit in generation within the area
- Is this due to the presence of DER_A model, or violation of voltage stability limits?

Results (cont'd)…

- All DERs represented by GENCLS rather than DER_A
  - Large value of inertia, high damping factor, and X" = 1.5pu
  - UV/OV protection set at 0.88pu/1.05pu with 2 second delay





- The system is again unstable because some of the DERs trip and from there, it cascades.

Conclusions…

- Implementation of DER_A across all positive sequence simulation programs is consistent.
- It is possible to parameterize the DER_A model using detailed simulations
  - The response in positive sequence matches well
  - Parameters may be adjusted to model momentary cessation versus tripping
- Use of multiple instances of DER_A in a large system is numerically robust.
- Sensitivity studies have been carried out to observe the impact of various parameters of the model on the performance of a large system
- System instability can be observed if an area with large amounts of DER islands from the main system
  - This instability is not necessarily due to the DER_A model, but more likely due to the generation load balance within the islanded area, and the parameterization of the DER_A model.
  - Or, if DER is actually parameterized to go into momentary cessation at voltage thresholds such as 0.88pu

Together…Shaping the Future of Electricity