Challenges for Distribution Planning, Operational and Real-time Planning Analytics
DOE SETO Workshop
May 16-17, 2019

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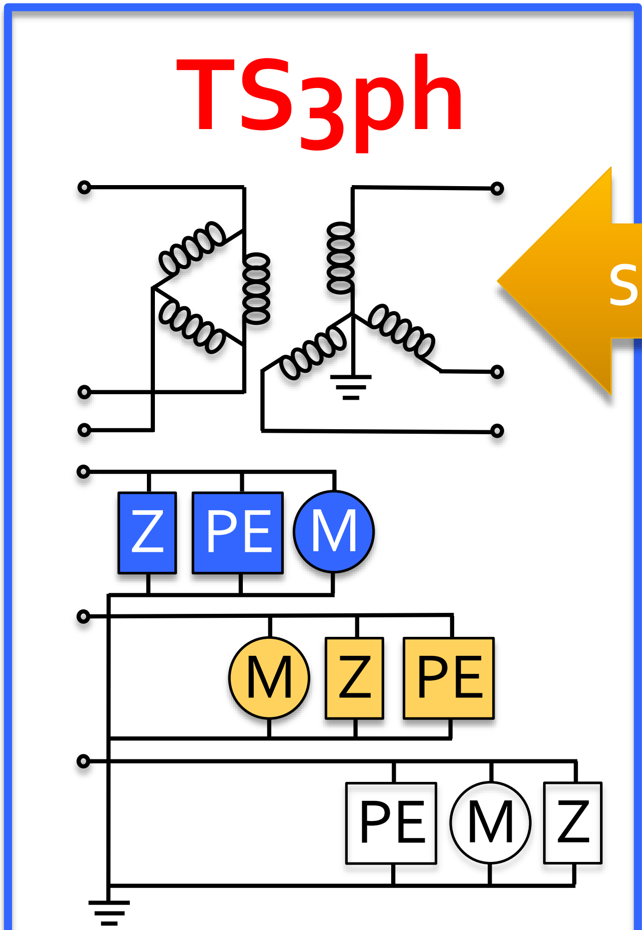
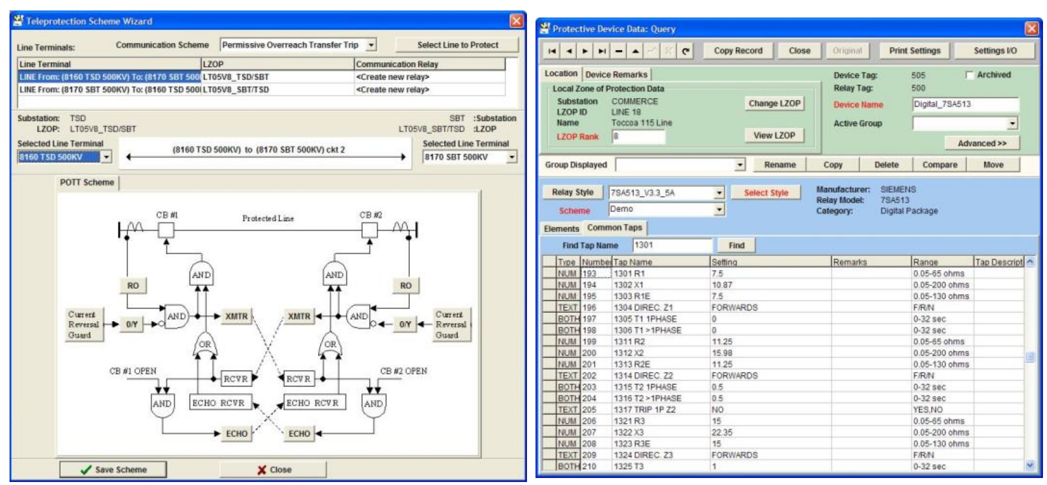
SuNLaMP Update: T&D Dynamics Analysis & Dynamic Modeling of Variable Generation Systems

TS3ph-CAPE Framework



electrocon international incorporated CAPE



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A Tool-Suite for Improving Reliability and Performance of Combined Transmission-Distribution Under High Solar Penetration

High Solar PV Penetration Participants (DOE plus…)

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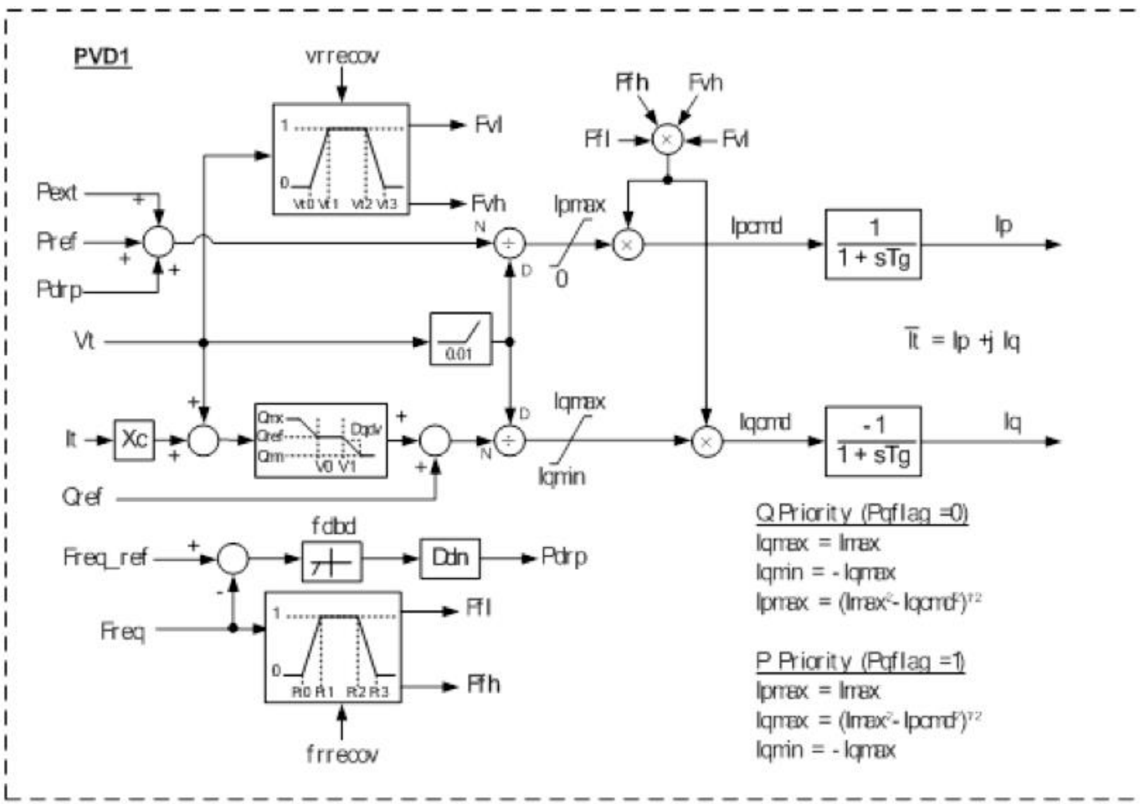
- Argonne National Laboratory – Computational methods, steady-state analysis
  - Shri Abhyankar (1st PI) , Karthik Balasubramaniam (2nd PI), Ning Kang
- National Renewable Laboratory – Quasi-static time series analysis
  - Bryan Palmintier, Ibrahim Krad, Himanshu Jain
- Illinois Institute of Technology – Simulator development (TS3ph)
  - Alex Flueck, Yagoob Alsharief, Sheng Lei, Bikiran Guha, Jianqiao Huang
- Electrocon – Relay protection simulation (CAPE)
  - Sandro Aquiles-Perez
- HECO – Utility (Hawaii)
  - Dean Arakawa, Ken Fong
- PG&E – Utility (San Francisco)
  - Vaibhav Donde (1st lead), Franz Stadtmueller (2nd lead)

Tool Suite - T&D Dynamics Developments

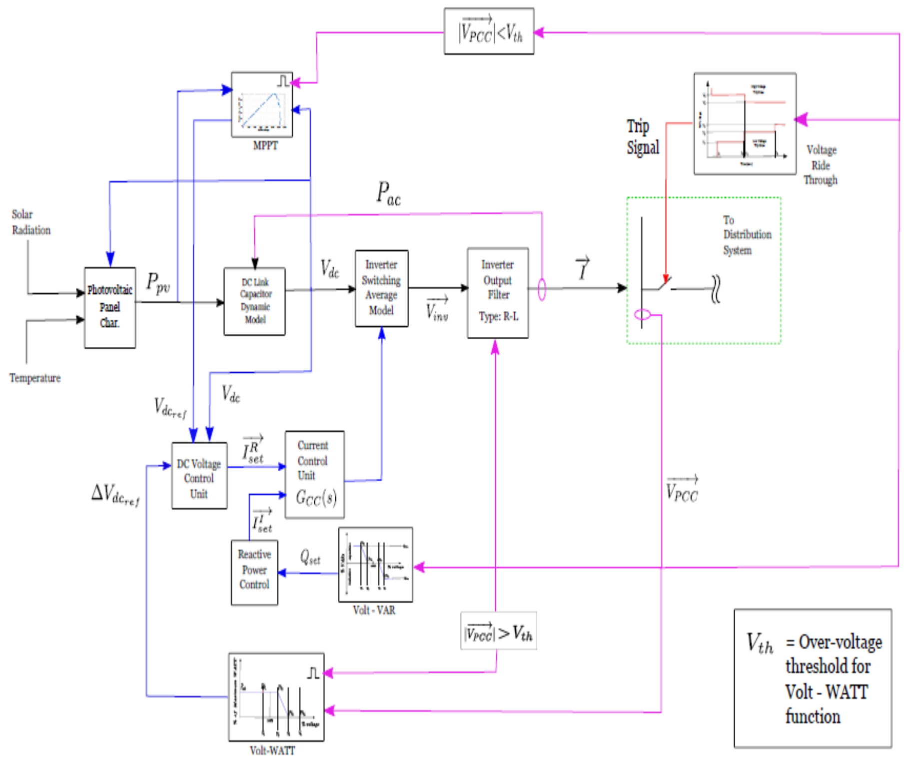
- Dynamics and protection
  - IIT TS3ph, Electrocon CAPE
  - Inputs:
    - Transmission model (3-phase unbalanced), including generator and network dynamics
    - Distribution model (3-phase unbalanced), including solar PV inverter dynamics and motor load dynamics
    - CAPE database
    - Time steps: fraction of a cycle (~5 ms)

WECC PVD1 Aggregated Model

- Modeling and Validation Working Group 2014
- Pos. seq. model at distribution substation

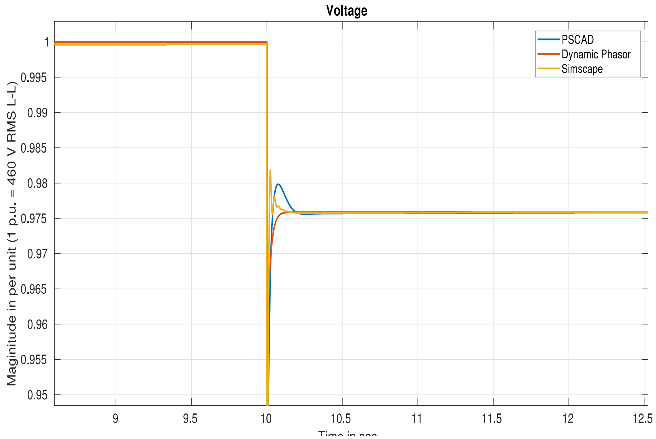


ANL phasor model of solar PV system

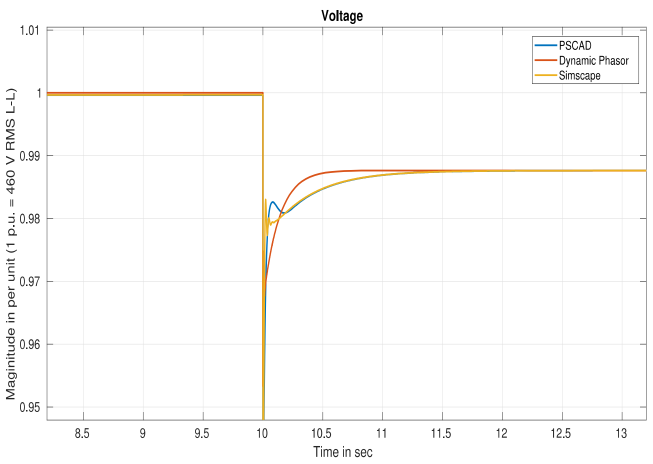


Block Diagram

Without Volt-VAR



With Volt-VAR



Simultaneous T&D Transient Stability – Phasor vs. EMT

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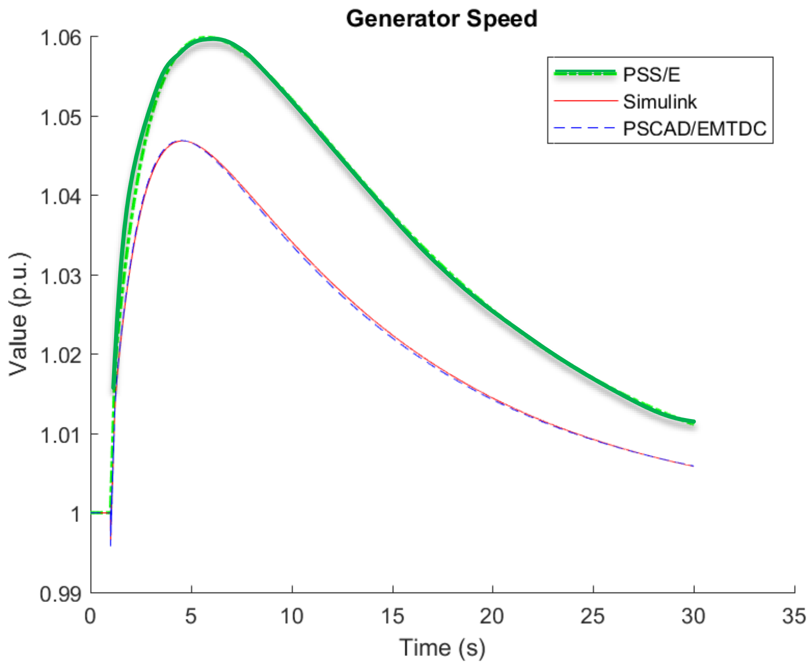
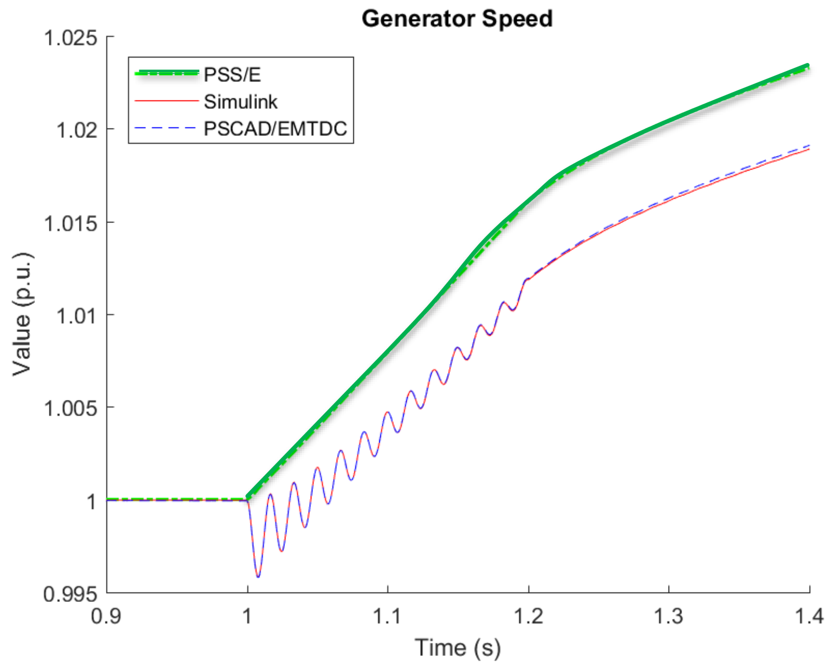
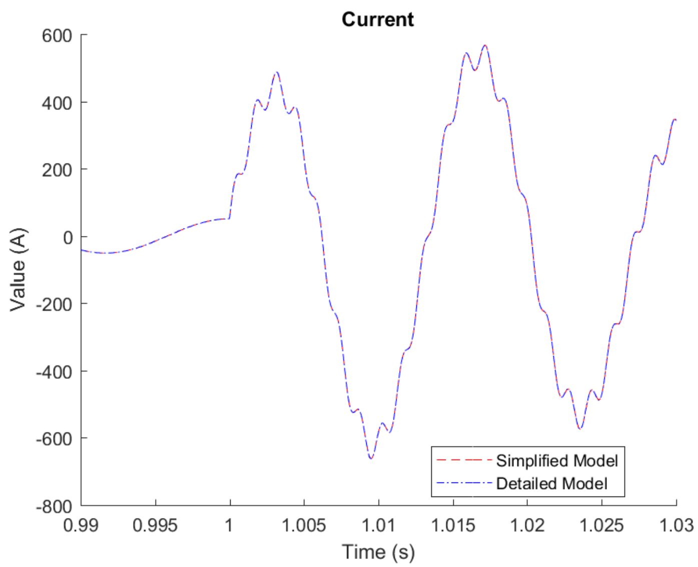
- Detailed generator model response to 3ph fault
- PSSE speed (pu) does not match electromagnetic transient (EMT) model; no torque ripple

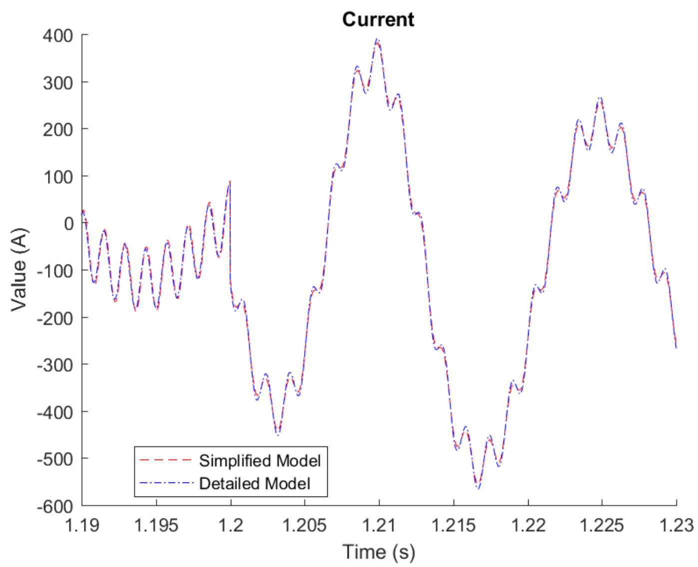




T&D Dynamics – EMT PV Models

- Electromagnetic transients: 1ph PV PWM switch & filter vs. 1ph PV averaged model
- PV and infinite bus; fault from 1.0s to 1.2s





Bridge the gap between 3ph EMT and pos-seq RMS phasor

TS3ph: Transient Stability simulator with "three-phase everywhere" model

TS3ph Dynamic PVD1D Model

- PVD1D (TS3ph's single-phase/three-phase version of PSSE & PowerWorld PVD1) model comparison
  - PowerWorld uses PVD1 aggregated at transmission bus
  - TS3ph uses individual PVD1D models distributed on feeder
- Assume same inverter protection characteristic for aggregated PVD1 and distributed PVD1D
  - |V| >= 0.7 pu, no inverter tripping
  - 0.5 < |V| < 0.7 pu, linear sliding scale for inverter output
  - |V| <= 0.5 pu, complete inverter tripping

Combined T&D Test System

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- Combined T&D system with 321 buses
  - Transmission model: 9-bus system
  - Distribution model: 24 copies of the IEEE 13-Node Test Feeder representing roughly 24% of the total transmission load
    - 10 copies at transmission bus 5
    - 8 copies at transmission bus 6
    - 6 copies at transmission bus 8

Distribution Feeder and Inverter Protection

- Each IEEE 13-Node Test Feeder contains two PVD1D PV inverter models
  - Three-phase PVD1D with 1000 kW output to represent utility-scale solar PV installation
    - Trip if any phase drops below limit
    - NOT based on positive sequence voltage
    - Need all three phases (ABC), especially transformer configurations
    - NERC Inverter-Based Resource Performance Task Force (IRPTF)
  - Aggregated single-phase PVD1D with 500 kW output to represent 100 rooftop single-phase inverters of 5 kW each

Fault Scenarios

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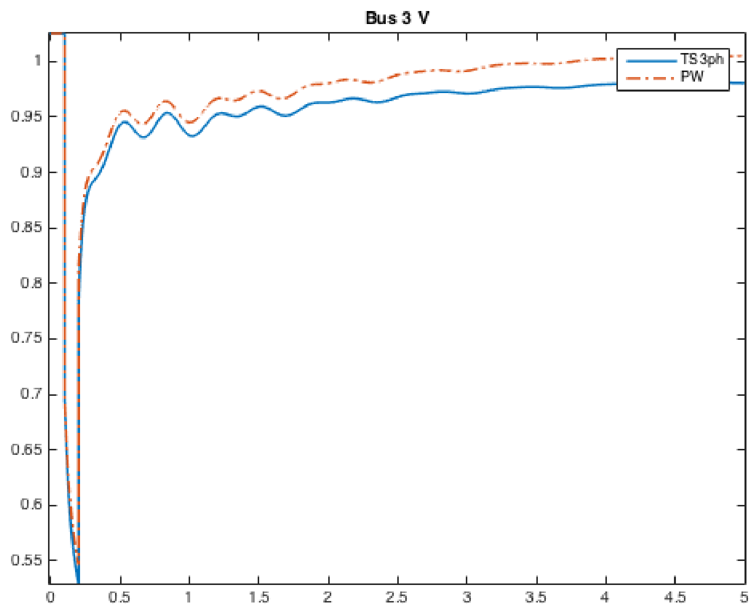
- Three different transmission fault scenarios
  - Three-phase fault at generator bus 3
  - Fault-on at 0.1 s, fault-off at 0.2s
    - Low fault resistance of 0.0084 per unit causes complete inverter tripping
    - Medium fault resistance of 0.1 per unit causes partial inverter tripping
    - High fault resistance of 0.3 per unit does not cause any inverter tripping

Medium fault R, partial tripping: Bus 3



Voltage magnitude at faulted bus (Solid: TS3ph, Dash-Dot: PowerWorld)

Medium fault R, partial tripping: Bus 5

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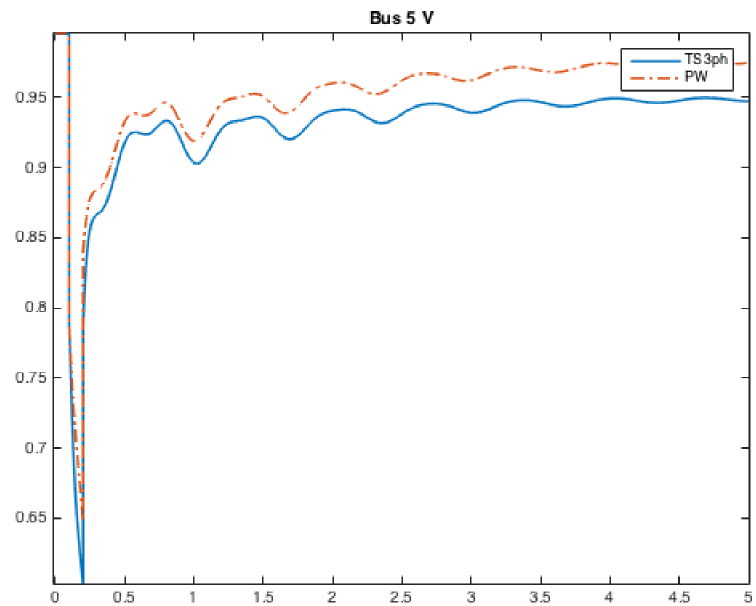

Voltage magnitude at load bus 5 (Solid: TS3ph, Dash-Dot: PowerWorld)

PVD1 vs. PVD1D summary

- PV behavior due to medium three-phase fault appears to be poorly captured by aggregated PVD1 model
  - Inverter protection played a significant role in the dynamic response
- Unbalanced disturbances are even harder to capture with aggregated positive-sequence models!

Conclusion 1

- More realistic PV inverter models, e.g., REGC_A and REEC_B combination, will be more challenging to represent in an aggregated PVD1 or DER_A model
  - Feeder voltage profiles depend on many things:
    - PV inverters (and other DERs): location and output
    - Voltage regulators
    - Voltage support capacitors
    - Loads (e.g., voltage-current relationships, induction motors)

Conclusion 2

- Engineering challenge:
  - Can you create an aggregated representation of all volt/VAR equipment for all operating conditions of interest?
- <u>Simultaneous</u> "3ph everywhere" transmission and detailed distribution feeder dynamics modeling is possible and promising!

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Thanks!

Any questions?

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