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Reliability Barriers to Enhanced Solar PV Deployment: Selected Research Findings – State Outreach Policy Sessions

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Western Interstate Energy Board -State Outreach Policy Sessions
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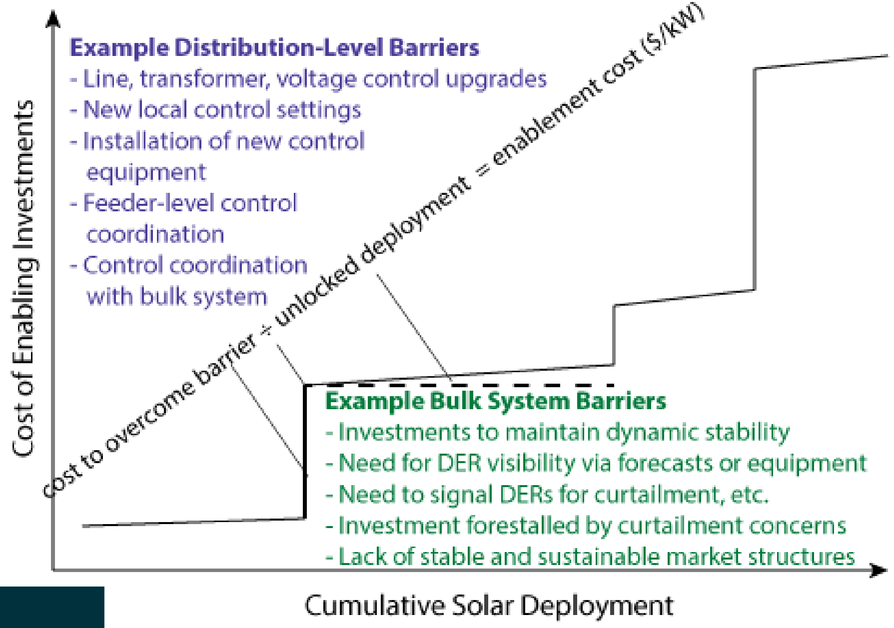
Enhanced Distributed Solar Photovoltaic Deployment via Barrier Mitigation or Removal in the Western Interconnection

WIEB-NREL-LBNL **Solar Energy Evolution and Diffusion Studies 2 – State Energy Strategies (SEEDS2-SES)** project in which we proposed to address three categories of barriers:

- Interconnection
- Net Metering
- **Reliability**



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Reliability Barriers Screening

Photo by Dennis Schroeder, NREL 45218

NREL Internal Experts Brainstorm → Perceived Reliability Barriers to PV Deployment → Internal & External[1] Screening → Research Plan

Research focused on reducing uncertainty

- Importance of perceived barrier
- Potential mitigation strategies
- Ability of state-of-the-art modeling tools to represent the issue

Photo by Jamie Keller, NREL 19697

[1]Technical Advisory Committee (TAC)

Studied high penetration PV through the lens of three Western Interconnection regions

Contents

High-level overviews of three selected reports:

- Power System Flexibility and Supply
- Resource Adequacy Considerations
- Simulating Distributed Energy Resource Responses to Transmission System-Level Faults Considering IEEE 1547 Performance Categories on Three Major WECC Transmission Paths

Additional reports and other information are available from the project website

Power System Flexibility Requirements and Supply

Assessment of net load ramping needs and what resources are available to provide ramping at different timescales

https://www.nrel.gov/docs/fy21osti/72471.pdf

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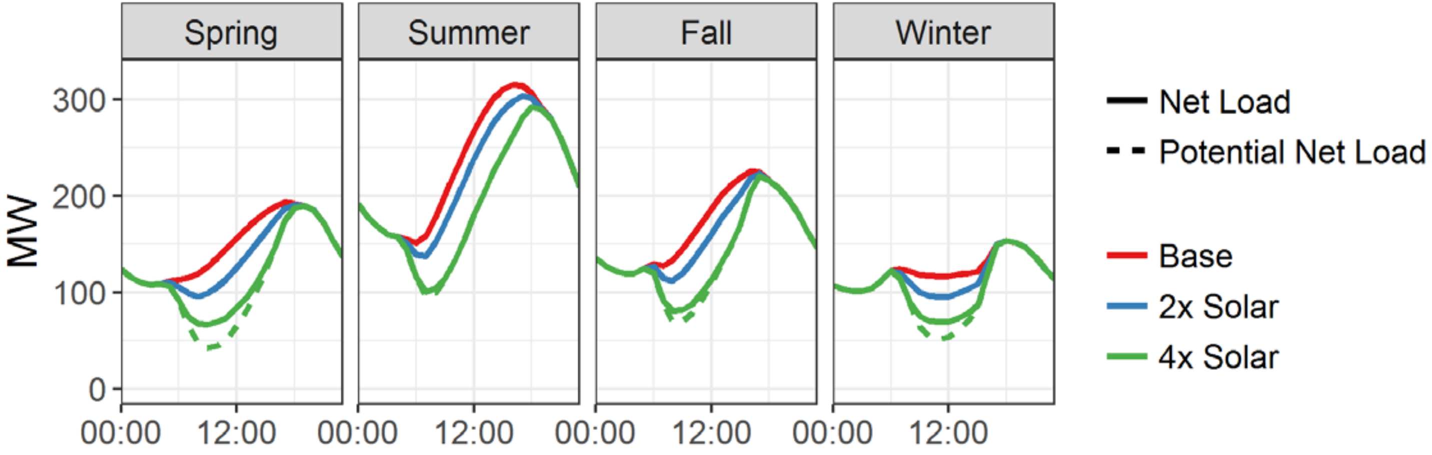
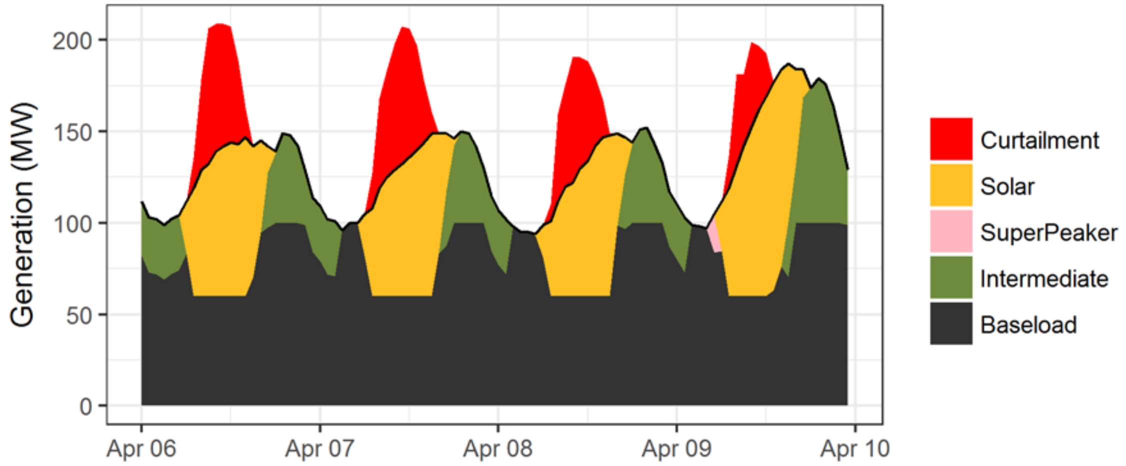
Power System Flexibility Demand

Example of net-load ramps increased in both *magnitude and frequency* because of solar generation



- Solar (and other variable) generation changes the shape of the net load curve
- How can the power system accommodate increased flexibility requirements?

Power System Flexibility Supply



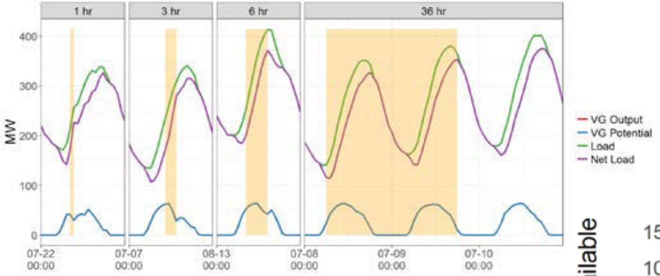
Flexibility Sources

- Commitment and dispatch of the generator fleet, including:
  - Thermal generators
  - Hydropower
  - Storage
  - Demand Response
- Imports and exports
- Renewable Curtailment (Waste of "free" energy →)
- Unserved Reserves (Not great →)
- Load shedding (**BAD** →)

Power System Flexibility Requirements and Supply

Step 1:

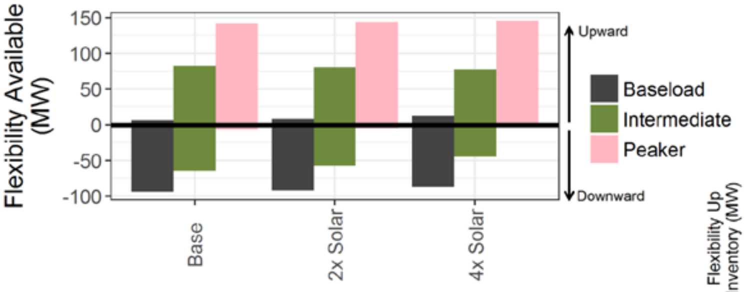
Quantify flexibility needs



Identify largest ramps over various timescales

Step 2:

Quantify flexibility supply

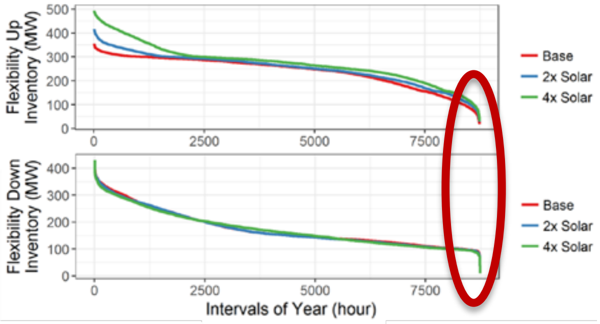


Identify sources of flexibility in aggregate and temporally

Step 3:

Identify potential shortages

Identify when flexibility is the most constrained



Power System Flexibility Results

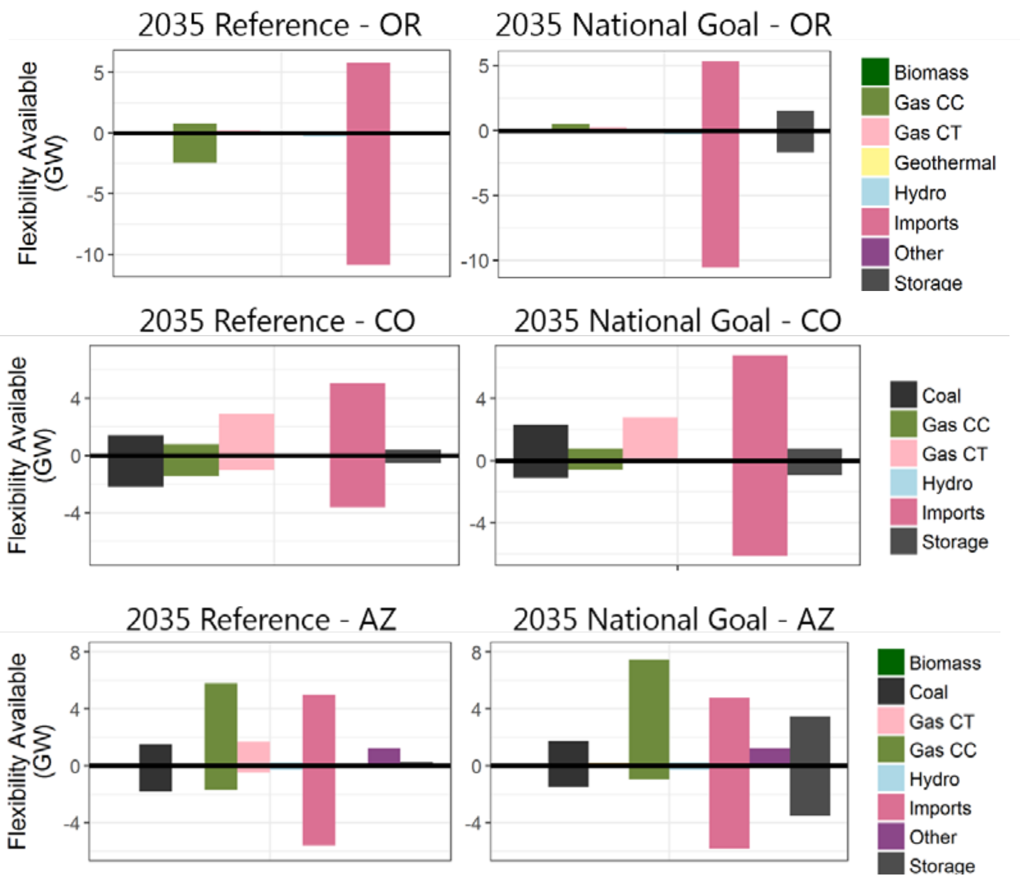
Themes

- No major flexibility shortages, even under high PV penetrations
- Each region has different sources of flexibility, but
- All regions use imports and exports as a large source of flexibility

Complications

- Regions are not likely to deploy PV in isolation, as we have modeled here
- Markets/utilities may not be able to exchange energy as modeled
- Increased PV deployment may result in economic generator retirement, which we do not fully capture

Average Hourly Flexibility per Region



Resource Adequacy and the Capacity Credit of Solar

Comparison of methods for assessing resource adequacy under high solar penetrations, including approaches to PV capacity credit estimation

https://www.nrel.gov/docs/fy21osti/72472.pdf

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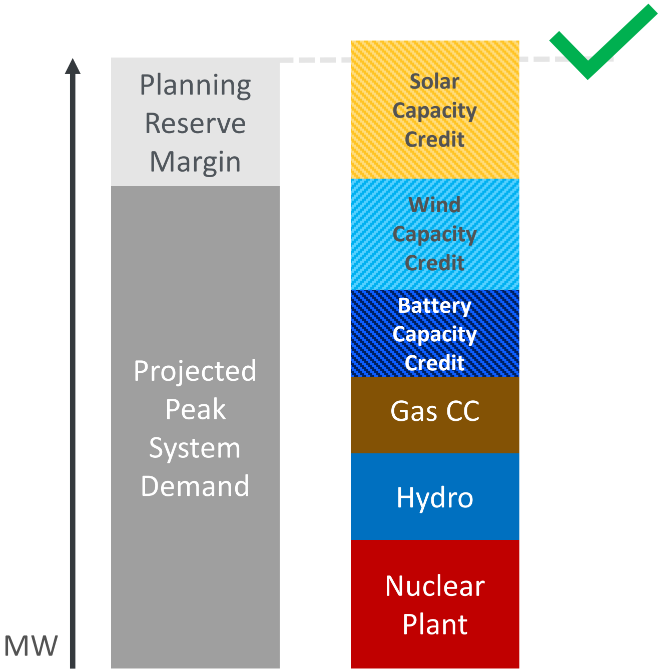
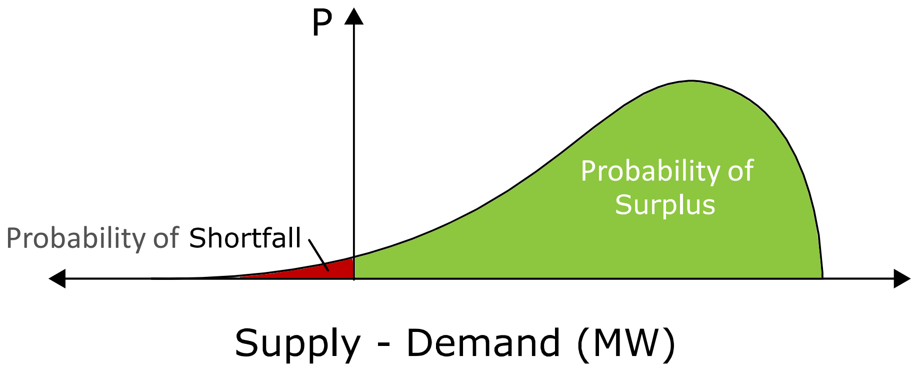
Methods for Assessing System Resource Adequacy

Reserve margin assessment:



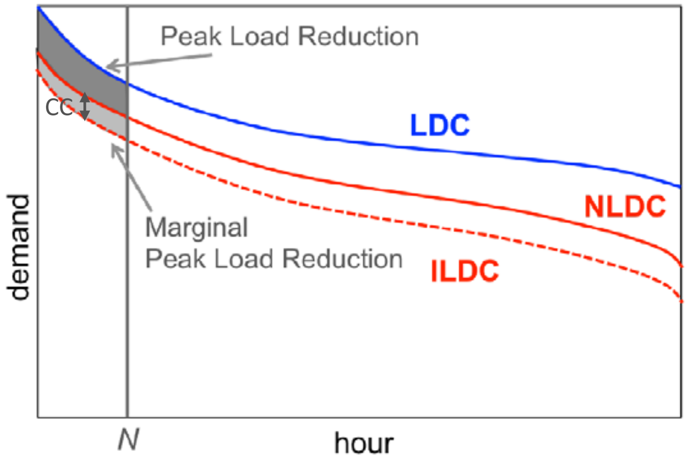
Probabilistic assessment (single-region, single-period):



Loss-of-Load Probability (LOLP): Probability of shortfall in one time period (red area)
Expected Unserved Energy (EUE): Probability-weighted average total shortfall magnitude
Loss-of-Load Expectation (LOLE): Average number of periods with shortfall

Methods for Estimating Solar Capacity Credit

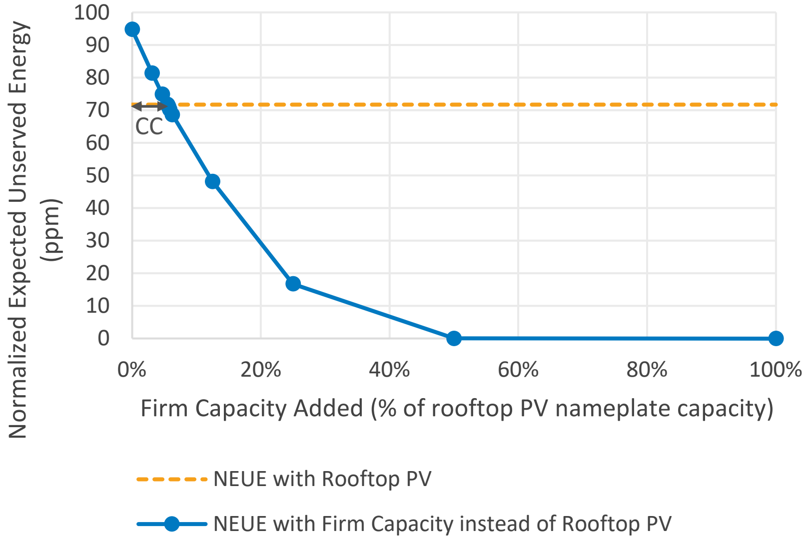
Incremental Net Load Duration Curve (INLDC) Method: Average decrease in net load over the top N peak net load hours, after adding the variable / energy-limited resource



LDC = load duration curve
NLDC = net load duration curve
ILDC = incremental load duration curve (with added resource)

Hale, Stoll, and Mai, 2016

Equivalent Firm Capacity (EFC) Method: Amount of 100%-available capacity that would provide the same incremental reliability benefit as the variable / energy-limited resource, per some probabilistic metric (e.g. LOLE, [N]EUE)



Resource Adequacy and the Capacity Credit of Solar: Two Key Takeaways

1

Larger planning reserve margins do not always correspond to improved probabilistic resource adequacy metrics (e.g. LOLE, EUE)

- Resource adequacy is more than the sum of reliability-derated generator capacities – interactions between resources through time matter
- The systems studied were well within resource adequacy thresholds.[1] Heuristic methods should be double-checked more frequently against their probabilistic counterparts as one approaches such thresholds.

2

The choice of capacity credit calculation method influences assigned resource contributions

- EFC and INLDC methods provide comparable results at moderate solar penetrations, but may begin to diverge at higher levels
- No one choice of INLDC peak hour parameter consistently tracks the more rigorous EFC method

[1]As best as the team could determine with the methods available at the time. Known shortcomings include a single year of wind and solar data, assumed full capacity credit for storage resources, and an incomplete assessment of retirements that could occur during the study period.

Simulating Distributed Energy Resource Responses to Transmission System-Level Faults Considering IEEE 1547 Performance Categories on Three Major WECC Transmission Paths

Richard 'Wallace' Kenyon, Barry Mather

https://www.nrel.gov/docs/fy20osti/73071.pdf

Study Impetus

With ever growing quantities of distributed energy resources (DERs) on the Western Interconnect (nearly 10 GW of capacity today), and varying connection standards regarding abnormal condition ride-through (IEEE 1547: 2003 (legacy), 2018; Category I, Category II, Category III), how can we best understand the impact that these DERs have on the bulk electric system using our current simulation capabilities?

Ride-through: indicates if, and for how long, the DER maintains its pre-disturbance power supply through a disturbance (frequency/voltage deviations). Not necessarilly indicative of any grid-support functionality.
distributed generation (DG): a subset of DERs, assumed to be Solar PV (I.e. DPV) for this study.

IEEE 1547 Low Voltage Ride Through

<table>
<tr><th>Voltage</th><th>IEEE 1547 2003 Pessimistic</th><th>IEEE 1547 2018 Category I</th><th>IEEE 1547 2018 Category II</th><th>IEEE 1547 2018 Category III</th></tr>
<tr><td>$V < 0.3$</td><td rowspan="5">Immediate trip</td><td rowspan="2">Immediate trip</td><td>Immediate trip</td><td rowspan="2">Momentary cessation; trip after 1.0 s</td></tr>
<tr><td>$0.3 \leq V < 0.5$</td><td rowspan="2">Momentary cessation; trip after 0.32 s</td></tr>
<tr><td>$0.5 \leq V < 0.65$</td><td rowspan="2">Momentary cessation; trip after 0.16 s</td><td rowspan="2">Continuous operation; trip after 10.0 s</td></tr>
<tr><td>$0.65 \leq V < 0.7$</td><td rowspan="2">Trip after 3 s + (8.7 s/p.u.) × (V – 0.65 p.u.)</td></tr>
<tr><td>$0.7 \leq V < 0.88$</td><td>Trip after 0.7 s + (4 s/p.u.) × (V – 0.7 p.u.)</td><td>Continuous operation; trip after 20.0 s</td></tr>
<tr><td>$0.88 < V$</td><td>Continuous operation</td><td>Continuous operation</td><td>Continuous operation</td><td>Continuous operation</td></tr>
</table>

In general, greater ride through participation; lower voltage, longer time

Driving Questions

For a bulk-system event triggered DER event (cascade), what matters and how do we study/plan for these events?

It depends on **DER shares**, fault/DER **location** and the ***ride through* settings** as dictated by the IEEE 1547 standard, which vary based on the type of grid event:

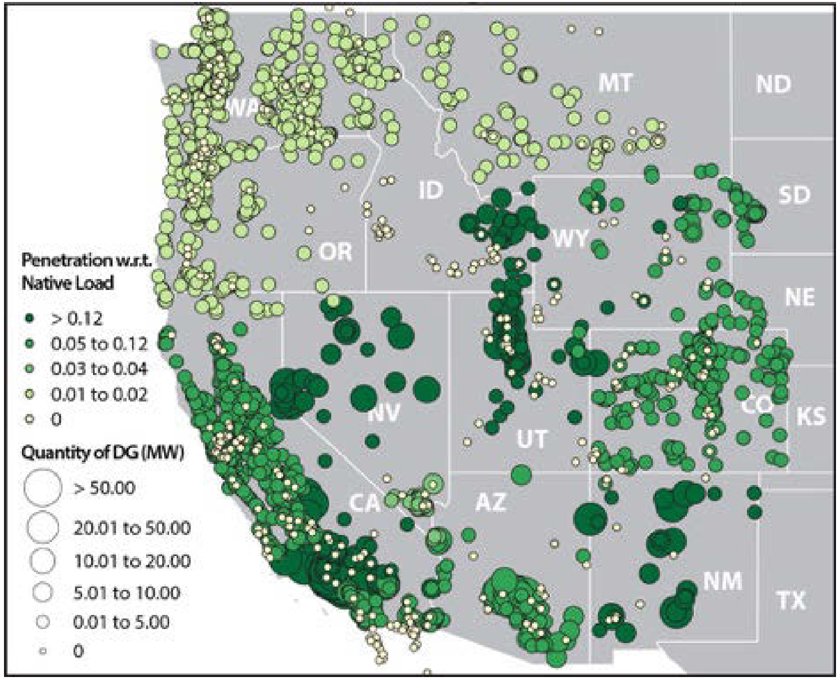
- Over frequency
- Under frequency
- Over Voltage
- Under Voltage (generally a result of faults) – biggest compromise

Our Simulation Solution:

Iteratively couple transmission and distribution-level modeling to assess the impacts of these various standards

Simulations of the Western Interconnection (WI)

- GE Positive Sequence Load Flow
- Heavy Summer 2023 planning case with high levels of utility scale (~17%) and distributed (~5%) renewable sources.
- Composite load model with generation
- Three phase fault scenario on all WI Paths to identify the most severe reactions.
    - Fault cleared after six cycles; 0.1 s
    - Severity with respect to distributed generation assessed with the introduced Volt-Sec, Volt-Sec-DG metric [2]



[2]: R. W. Kenyon and B. Mather, ‘‘Quantifying transmission fault voltage influence and its potential impact on distributed energy resources,’’ in Proc. IEEE Electron. Power Grid (eGrid), Nov. 2018, pp. 1–6.

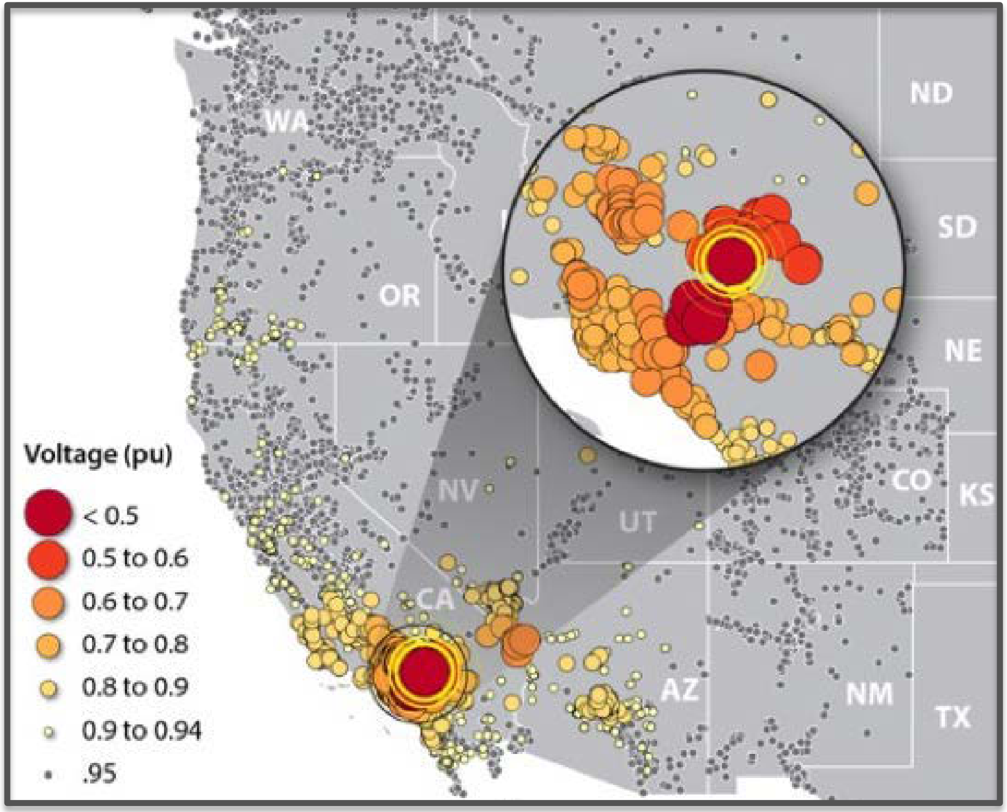
Significantly Low Voltages Following Transmission Fault

WECC 2023:
- Heavy Summer
- High Renewable Mix

Fault Induced Delayed Voltage Recovery
- Persistent low voltages (5-15s)
- Can timeout even 2018 Categories

Model distribution feeders with the time series voltage profiles to determine inverter operation

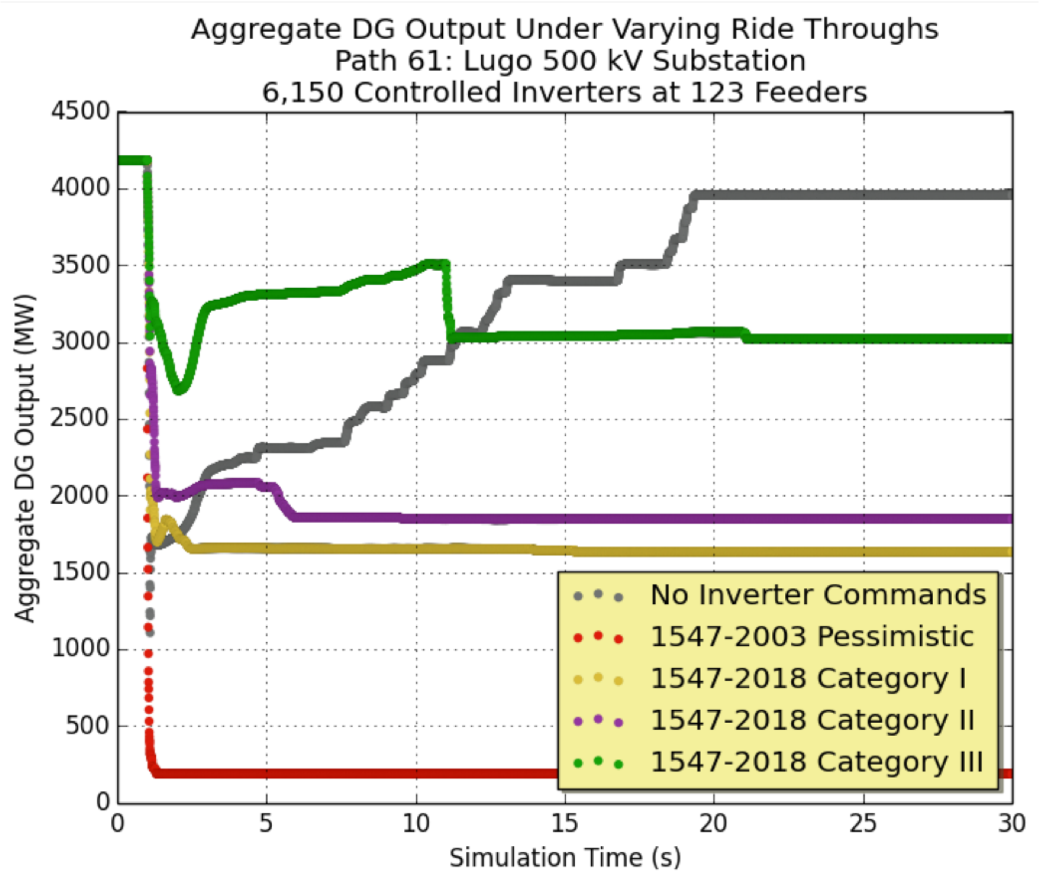
Three phase fault at Lugo 500 kV Bus with WWSIS Composite Load Model



Connection standards matter during abnormal events

- IEEE 1547-2018 Category III keeps the greatest amount of distributed generation online during this Fault Induced Delayed Voltage Recovery event

- The impact is only seen if we directly model the feedbacks between distribution and bulk power



Thank you

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