

INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

DER Flexible Interconnection Strategies and Approaches

Lessons learned from i2X Technical Assistance

8/14/2024

An initiative spearheaded by the Solar Energy Technologies Office and the Wind Energy Technologies Office

Meeting Recording Announcement

This call is being recorded and may be posted on DOE's website or used internally. If you do not wish to have your voice recorded, please do not speak during the call or disconnect now. If you do not wish to have your image recorded, please turn off your camera or participate only by phone. If you speak during the call or use a video connection, you are presumed to consent to recording and to the use of your voice or image.

AGENDA



1. Introduction (Dexter Hendricks)
2. i2X TA Projects (i2X Partner Labs)
3. Q&A

Interconnection Innovation e-Xchange (i2X)

Mission: To enable a **simpler**, **faster**, and **fairer** interconnection of clean energy resources while enhancing the **reliability**, **resiliency**, and **security** of our **distribution and bulk-power electric grids**

Stakeholder Engagement

Nation-wide engagement platform and collaborative working groups

Data & Analytics

Collect and analyze interconnection data to inform solutions development

Strategic Roadmap

Create roadmap to inform interconnection process improvements

Technical Assistance

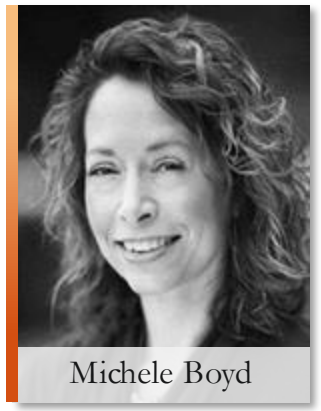
Leverage DOE laboratory expertise to support stakeholder roadmap implementation



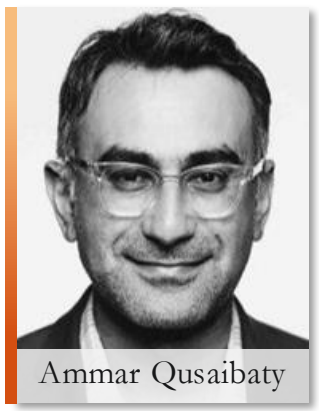
energy.gov/i2x

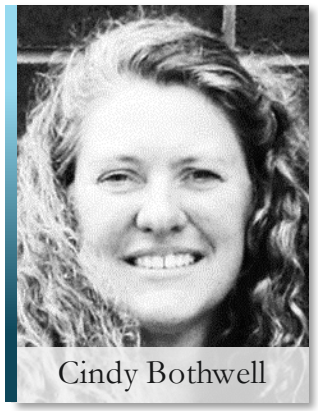
INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

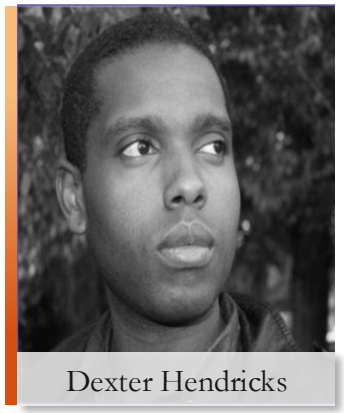
i2X is a collaboration among DOE offices and labs

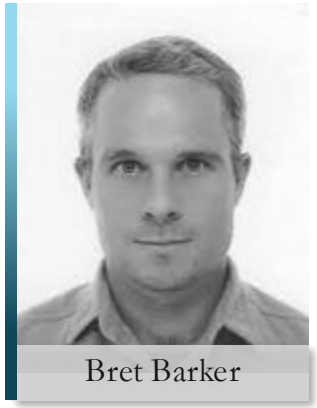

SETO
Michele Boyd


WETO
Jian Fu


SETO
Ammar Qusaibaty


WETO
Cindy Bothwell


SETO
Dexter Hendricks


WETO
Bret Barker

BERKELEY LAB

Pacific Northwest NATIONAL LABORATORY

Joint Office of Energy and Transportation

U.S. DEPARTMENT OF ENERGY
Office of Energy Justice and Equity

OTT Office of Technology Transitions

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
VEHICLE TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF ENERGY
Office of Cybersecurity, Energy Security, and Emergency Response

Sandia National Laboratories

NREL Transforming ENERGY

GDO GRID DEPLOYMENT OFFICE

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

i2X INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

energy.gov/i2x

i2X Activity Highlights

Stakeholder Engagement

- 900+ people at 530+ organizations partnered with i2X
- 25+ public events and engagements (e.g., RE+ 2023)
- 22 Solution e-Xchange meetings covering six topics
- EEJ Technical Advisory Committee
- 85+ Office-Hour Calls with stakeholders

Data & Analytics

- BPS interconnection cost reports for MISO, PJM, NYISO, SPP, and ISO-NE, plus a summary published (LBNL)
- Queued Up report on BPS interconnection timelines (LBNL)
  - 2022, 2023, 2024 Editions
  - https://emp.lbl.gov/queues

Technical Assistance

- 12 technical assistance projects covering flexible interconnection, utility data management, streamlining interconnection modeling, and alternatives to costly grid network upgrades
- Workforce upskilling with i2X/NERC bootcamps for BPS grid engineers on using Electromagnetic Transient (EMT) modeling methods and techniques

Strategic Roadmap

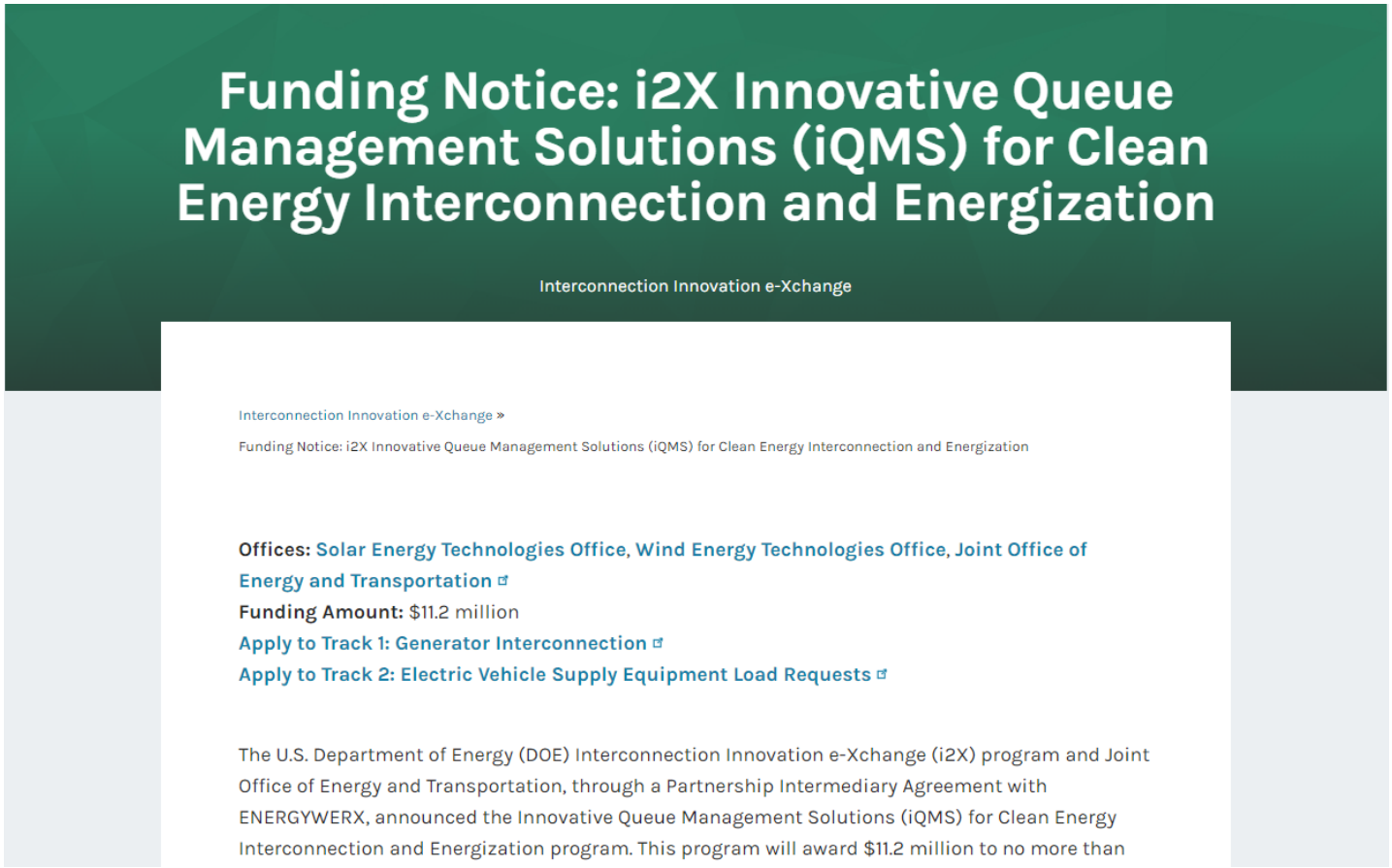
- Final Transmission Interconnection Roadmap released on April 17th, 2024.
- Distribution Interconnection Roadmap draft release via a request for information process (RFI) planned for Q3 FY 24.

Program Purpose

Provide funding to distribution utilities experiencing large **interconnection queues** or **electric vehicle interconnection and energization queues** or **both** to **test and pilot** new and innovative solutions

Total Funding

$11,200,000



Joint Office of Energy and Transportation

INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

Upcoming i2X Webinars and Events

- **August 20, 2024, 11-1:30 p.m. ET |** I2X FORUM FOR THE IMPLEMENTATION OF RELIABILITY STANDARDS FOR TRANSMISSION (FIRST)
- **September 9, 2024, 8 a.m.-12 p.m. PT |** Deep Dive on Solutions in DOE's i2X Roadmap for Interconnection Innovation and Standards for Reliability Standards Improvement **Anaheim, CA during** RE+ 2024
- **September 19, 2024 | 2-4 p.m. ET | i2X Solution e-Xchange** Promoting Economic Efficiency in Interconnection
- **September 24, 2024 11-1:30 p.m. ET |** I2X FORUM FOR THE IMPLEMENTATION OF RELIABILITY STANDARDS FOR TRANSMISSION (FIRST)
- **October 24, 2024 | 2-4 p.m. ET |i2X Solution e-Xchange** Enhancing Interconnection Processes



Mutual Respect . Collaboration . Openness



INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

Pacific Northwest National Laboratory Technical Assistance Public Webinar

An initiative spearheaded by the Solar Energy Technologies Office and the Wind Energy Technologies Office

INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

Xcel Energy and ComEd

Flexible Interconnection

Karyn Boenker

TA Project Details

PNNL is assisting two utilities in exploring the complexity of implementing a flexible interconnection (FI) application processing option to increase DER penetration in saturated areas of their networks.

- The project specifically focused on residential and community solar + storage applications.
- PNNL worked to help our utility partners understand considerations and best practices for an end-to-end FI process framed by stages.
- The goal is to produce a set of considerations that will help decision makers (like regulators) and operational leaders (like utilities) define FI options for potential participants, while also informing the agreements, policy considerations, requirements, and processes needed to design and administer FI programs.

Results: Overarching Questions for Exploring FI

- Length of contracts
  - Are FI a permanent solution and/or a bridge until a more permanent upgrade happens?
  - What happens if more capacity is added later? Does FI remain the default?
  - Should FI become a default interconnection approach?
- Terms and Conditions
  - What new considerations and contracted principles are necessary for an FI agreement?
  - Is DER paired with storage treated differently than DER without storage?
  - How do these projects cascade or compliment a state's current interconnection processes?
  - Can FI projects shift to CI, but not the other way around?
- Level of sophistication
  - What is the right approach, given utility readiness, state policies and current technology?
  - FI programs may be simpler initially, given current state of technology and policy
  - Trade offs between level of complexity and risk
- Flexibility
  - Significant step-change to move to allow DER to connect without equipment upgrades
  - Are these prioritized over grid services, how are NERC load-shedding feeders handled?
- Developer perspectives
  - Do developers need to know the level of curtailment before project is initiated, or are more complex studies needed?
- Technical
  - What is the current state of technology for utilities and how does this affect critical design aspects? How does this influence the FI strategy?
  - What is desired to test and demonstrate before a broader/full-scale deployment?

Results: Overarching Possibilities for FI

FI is early in its deployment and there is *currently* no one-size-fits-all FI solution that can resolve all DER interconnection challenges.

- FI agreements could be less permanent than conventional interconnection agreements.
  - Should there be a renewal options if grid constraints or curtailment expectations change?
    - Important to contract whether or not the applicant wants to move to CI in the future.
  - Curtailment is going to be automated, even if there is a regulated capacity cap.
    - What could be the mediation process for violations of the contracted terms? What violations could occur?
- FI agreements may have additional paperwork to cover *contracted and agreed principles of available capacity and reliability*.
  - Additional paperwork may cover FI-specific; terms and conditions, communication requirements, curtailment expectations, interactions with other FI participants, mediation processes, interactions with incentive programs within and outside of the utility, contract re-negotiation options, technical standards and implementation profiles for those standards, system size allowances, and/or specific business and policy requirements.
- FI projects can shift to CI, but not the other way around, assuming the corresponding system constraint has been resolved for FI to shift to CI.
- FI programs can grow more sophisticated overtime and may not necessarily require DERMs to get started with simple approaches.
- If a project is operating under FI, those terms must take precedence over any grid service agreements (i.e., demand response or virtual power plants) that might be stacked on top.

Pacific Northwest
NATIONAL LABORATORY

Defining Flexible Interconnection (FI)



Conventional vs Flexible Interconnection

Solar applicants apply for **Conventional Interconnection (CI)** on a circuit by requesting permission to install and operate a specific system size with specific components.

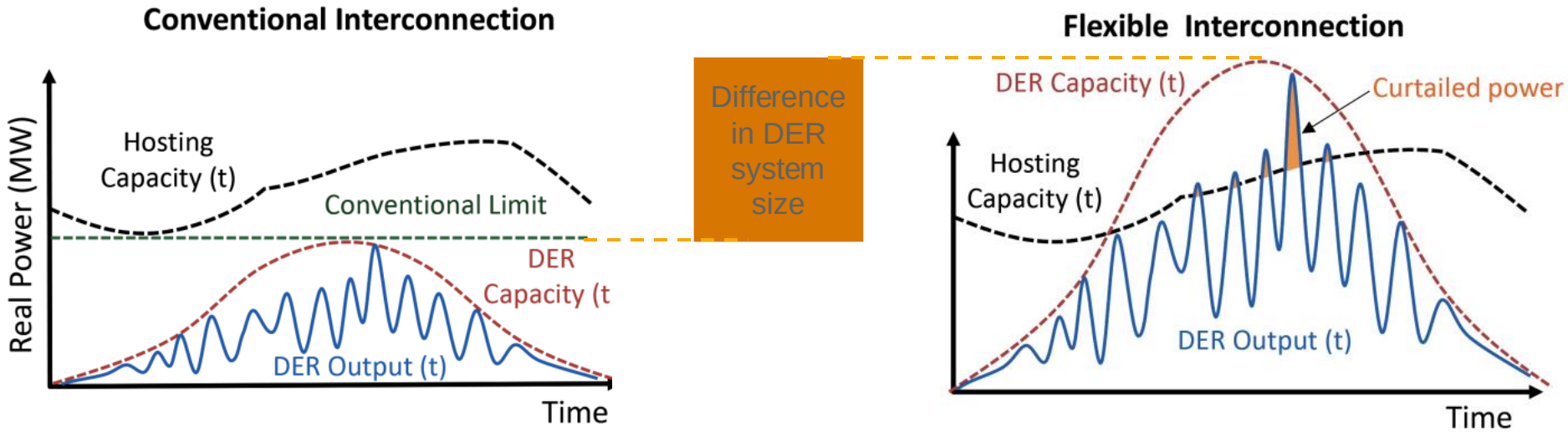
When the grid site does not have room for that system under the lowest range of grid hosting capacity, the utility may close the feeder to new DER interconnections and/or the applicant must decide to;

1. **Cancel** the project
2. **Relocate** project to another site where hosting capacity is available
3. **Downsize** the system to fit remaining hosting capacity
4. **Pay for a grid system upgrade** that expands hosting capacity
5. **Participate in Flexible Interconnection (FI)** to strategically operate within capacity

Conventional vs Flexible Interconnection

Conventional Interconnection (CI) is for free-flowing solar systems whose real power export capacity cannot exceed the lowest range of a grid site's hosting capacity (left).

Flexible Interconnection (FI) is for solar systems that include inverters certified under UL 1741 as '*utility interactive products with grid support functionality*' that use power control systems to operate safely below the full range of a site's grid hosting capacity.



From the image source: EPRI, 2020b: "Under conventional interconnection approaches (left) the proposed system was downsized in order to comply with the site's identified hosting capacity threshold (black dashed line). Whereas, under a flexible interconnection approach (right) the proposed system was built larger and allowed to operate so long as its real power (blue line) is managed by power control systems within a UL 1741 certified inverter to stay below the site's hosting capacity threshold at all times."

FI Benefits

The benefits of FI options are shared by DER developers, adopters, utilities and rate-payers because dynamic management of output can:

- Provide a value exchange between customers and their utility
- Help defer or avoid expensive grid upgrades by operating within available grid limits
- Allow a DER to utilize phased interconnection while a grid upgrade is completed or deferred
- Potentially decrease time or cost of interconnection
- Keep DER output below capacity limits and connected to the grid under a wider range of voltage and output levels
  - ✓ Mitigate excess generation to prevent issues like thermal overloads from reverse power flow, or overvoltage from large imbalance of generation and load.
- Optimize utilization of existing utility assets
- Provide more grid service export and curtailment capacity than a CI system, especially when paired with battery storage.

INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

Oregon Public Utility Commission

Hosting Capacity Analysis

Jessica Kerby

Motivation for Technical Assistance

- OR-PUC opened an **interconnection reform investigation** motivated by **cost**, **transparency**, and **procedural constraints** impacting generator interconnection.
- Hosting Capacity Analysis (HCA)
  - Investigate system constraints after policies are adopted
  - Inform location of pilot projects, preemptive upgrades, federal funds

i2X Technical Assistance Goals

- Review interconnection policies and ongoing dockets
- Review existing utility HCA maps and data, identify high-priority improvements
- Participate in staff-led stakeholder meetings to provide technical support.
- Investigate and assess HCA methodologies
- Refine scope and objectives of near-term HCA
  - To support state policy goals, national best practices, and federal funding opportunities
- Help OPUC staff determine if HCA is meaningful to the regulated systems or if additional policy or system upgrade steps are warranted.

HCA Use-Case Utility Profiles

Utility Profile	Large & Urban	Small & Rural	Hybrid
			
HCA Goals	• Provide transparency into available hosting capacity • Aid developers in DER siting • Understand system impacts of DER	• Identify grid needs • Replace portions of interconnection studies • Share regularly updated results to inform stakeholders of potential interconnection challenges	• Scenario-based analysis to inform distribution system planning • Streamline interconnection process and costs • Share regularly updated results to inform stakeholders of potential interconnection challenges

Aligning HCA to meet PUC and Utility Needs



HCA Use Cases Considered:

- Support the **interconnection of DER** by streamlining the interconnection application process, integrating HCA with fast-track screens.
- Support **developer siting** of DER resources by providing reliable, up to date distribution system data, leading to more viable interconnection applications.
- Support **utility distribution planning activities** by identifying DER- and load-constrained feeders and forecasting load growth to identify areas for proactive upgrades.
- Support the **evaluation of progress** towards state clean energy targets.

Lessons Learned: Useful and robust HCA maps and data require a phased, value-creation approach and effective and continual communication.

Connection to DER Roadmap

Solutions 1.4 & 1.5 Actors and Actions — Establish and maintain frequently updated capacity analysis tools that perform repeated studies for increasing amounts of multiple DER technologies at differing locations along a circuit & Broaden the use of hosting capacity analysis.

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Regulators	- Hire or contract with **distribution planning experts** to better **inform and evaluate HCA requirements**. - Ensure that the HCA maps **align with state** and **local policy goals** for DERs.	- **Regulatory oversight** of hosting capacity analysis (HCA) tools, analysis and data validation processes **to ensure HCA quality, transparency, and usefulness**. - **Balance tradeoffs, setting requirements for granularity and update frequency, and providing for utility cost recovery of tool development**.	- Require **periodic metric** reports to **evaluate utility's performance, accuracy of HCA results, and usefulness of HCA efforts**.
Utilities	- Ensure quality control during feeder model development process via rigorous **validation and standardized** error resolution processes. - Allocate sufficient computational resources to manage computational intensity of HCA processing and analysis. - Implement best practices in HCA, including consideration of different DER technologies. - Proactively plan for increased DERs in areas with constrained HC, especially when replacing equipment at the end of life.	- **Establish intended use case of HCA to aid utility processes and support more efficient use of utility resources**. It is important to note that HCA for planning vs. interconnection screening have **different methodologies, update frequency, and data granularity requirements**. - **Evaluate HCA usefulness to aid utility processes and support more efficient use of utility resources.**	- **Work with regulators to dedicate appropriate level of resources to developing and maintaining HCA capabilities.** - **Establish metrics** to track HCA results over time, such as **utilization, accuracy, and role in interconnection processes.** - When evaluating HCA, ensure that equipment size and location information is complete and accurate.
Research community (including DOE)	- Continue to develop specialized analytical tools and **provide impartial assessment of potential interconnection solutions**. - Provide technical assistance and share open-source tools and resources to aid utilities in developing HCA processes. - Validate industry best practice for HCA modeling and visual representation of data.	- **Research and report on** industry **best practices**, as well as **impact of HCA on interconnection process and timelines.** - Perform **cost benefit analysis of HCA benefits and burdens** to aid regulatory processes.	- Engage in **collaborative** processes to **help establish benefits to creating HCA as they relate to meeting policy goals.**

EnPhase

Evaluating the Thermal Impacts of Inadvertent Export on Service Transformers

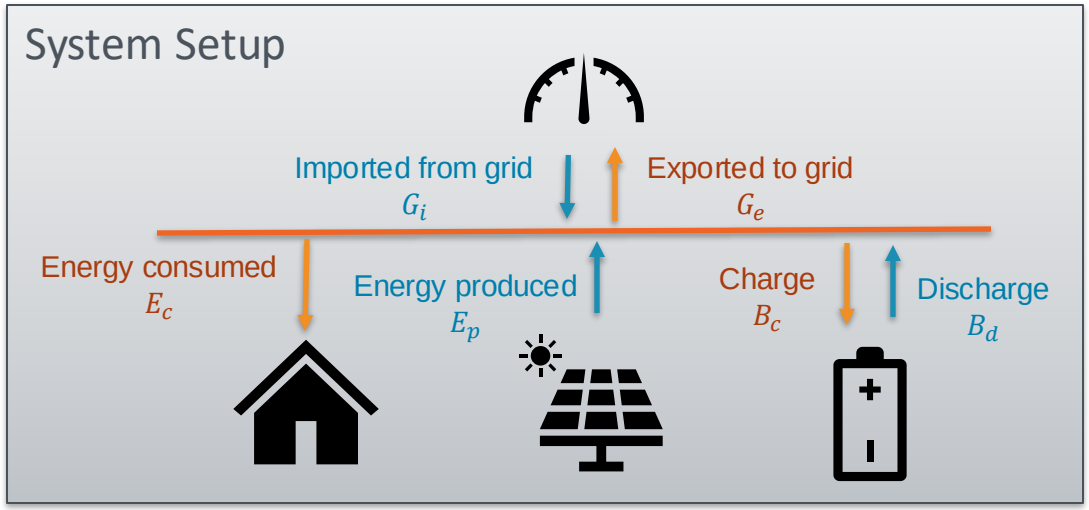
Eran Schweitzer

energy.gov/i2x

Motivating Question

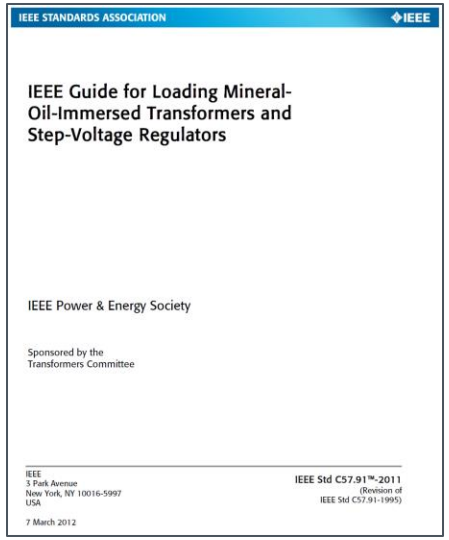
Can inadvertent export from export/import limited installations cause thermal impacts that would adversely impact service transformer lifetime?

If so, how would this impact the response time requirements for Power Control Systems? (range of 2-30 seconds)



Approach

Python based tool that predicts transformer thermal impacts based on IEEE Std. C57.91-2011*


IEEE STANDARDS ASSOCIATION

IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators

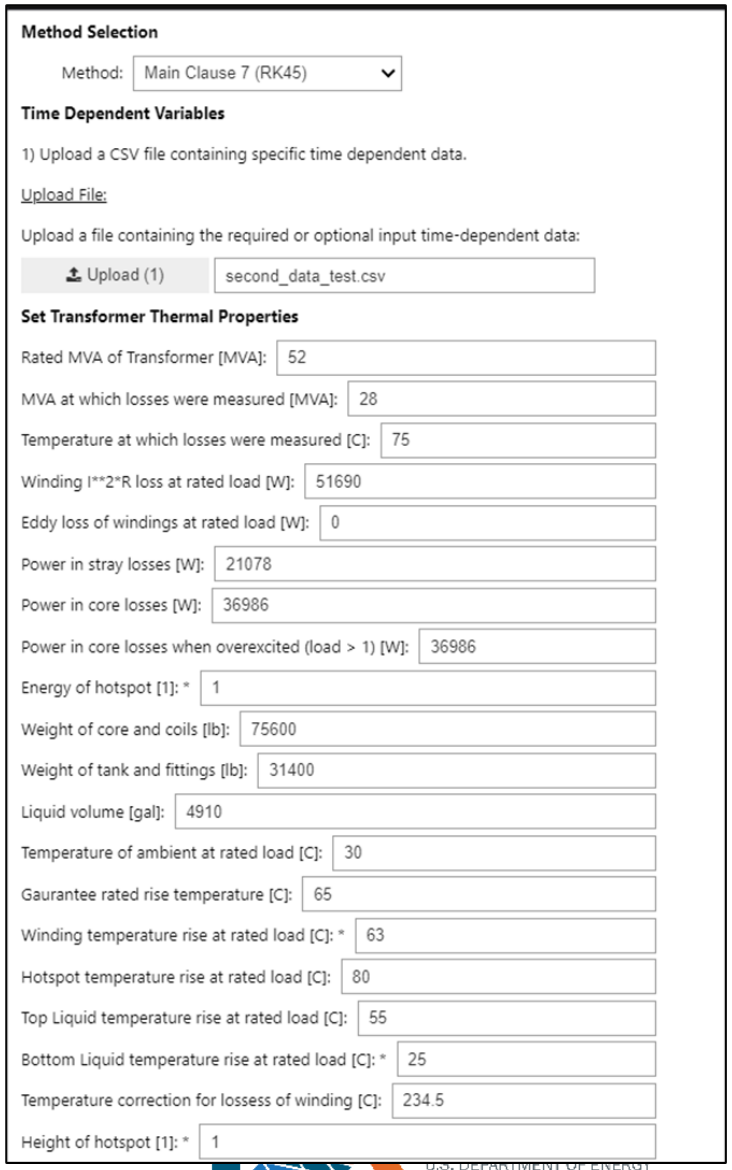
IEEE Power & Energy Society

Sponsored by the Transformers Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

7 March 2012

IEEE Std C57.91™-2011
(Revision of IEEE Std C57.91-1995)


Method Selection

Method: Main Clause 7 (RK45)

Time Dependent Variables

1) Upload a CSV file containing specific time dependent data.

Upload File:

Upload a file containing the required or optional input time-dependent data:

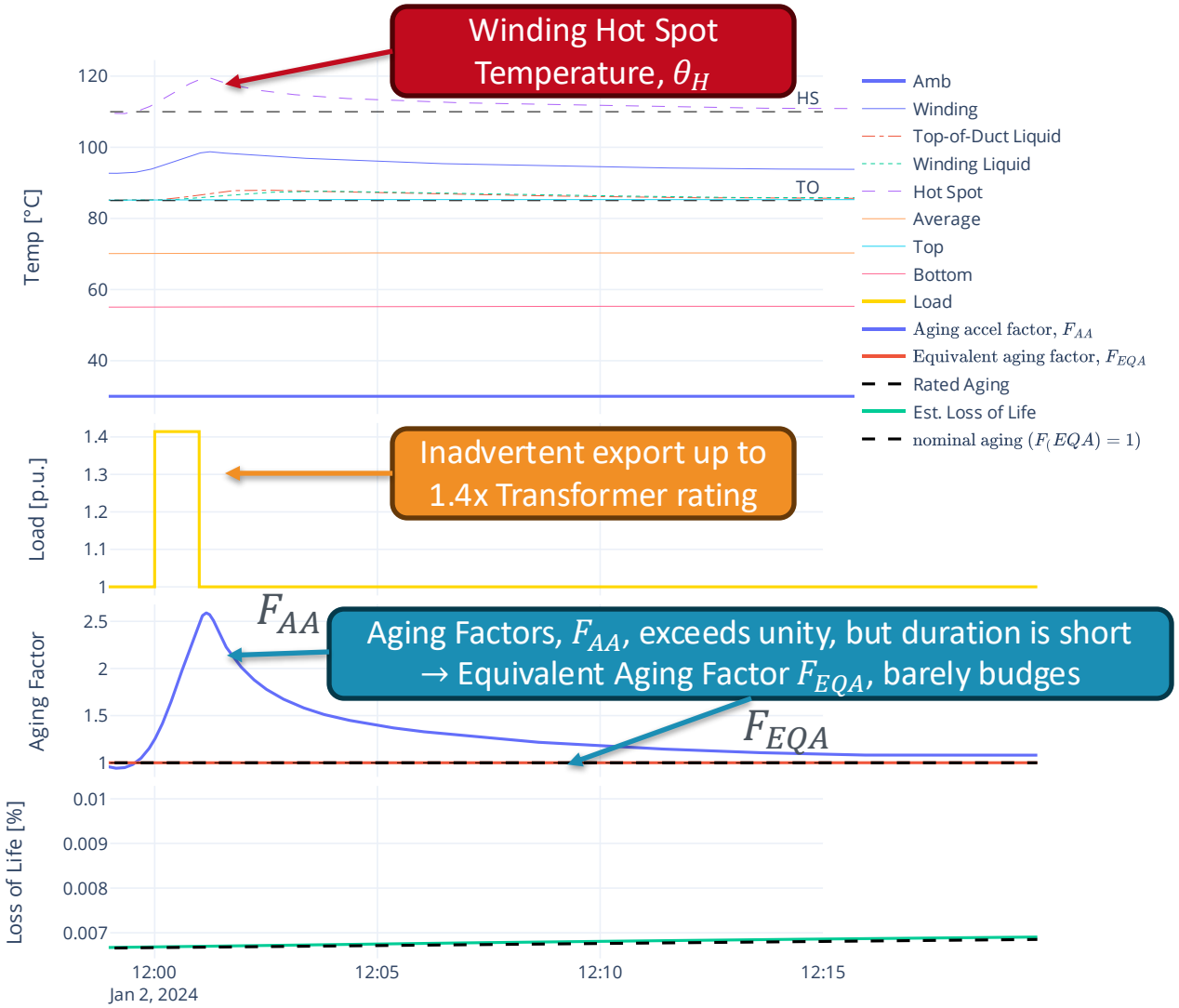
Upload (1) second_data_test.csv

Set Transformer Thermal Properties

Rated MVA of Transformer [MVA]:	52
MVA at which losses were measured [MVA]:	28
Temperature at which losses were measured [C]:	75
Winding I**2*R loss at rated load [W]:	51690
Eddy loss of windings at rated load [W]:	0
Power in stray losses [W]:	21078
Power in core losses [W]:	36986
Power in core losses when overexcited (load > 1) [W]:	36986
Energy of hotspot [1]: *	1
Weight of core and coils [lb]:	75600
Weight of tank and fittings [lb]:	31400
Liquid volume [gal]:	4910
Temperature of ambient at rated load [C]:	30
Gaurantee rated rise temperature [C]:	65
Winding temperature rise at rated load [C]: *	63
Hotspot temperature rise at rated load [C]:	80
Top Liquid temperature rise at rated load [C]:	55
Bottom Liquid temperature rise at rated load [C]: *	25
Temperature correction for lossess of winding [C]:	234.5
Height of hotspot [1]: *	1

* "IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators," *IEEE Std C57.91-2011 (Revision of IEEE Std C57.91-1995)*, https://doi.org/10.1109/IEEESTD.2012.6166928 pp. 1-123, 2012.

Example



Aging Acceleration Factor (F_{AA}) :

Measures the relative aging with respect to the hot-spot temperature, θ_H, and a reference temperature of 110 C

$$F_{AA} = e^{\left[\frac{15000}{383} - \frac{15000}{\theta_H + 273}\right]}$$

Scenario	F_{AA}
Operation below $\theta_{\text{ref}} = 110\ ^\circ C$	< 1
Operation at $\theta_{\text{ref}} = 110\ ^\circ C$	1
Operation above $\theta_{\text{ref}} = 110\ ^\circ C$	> 1

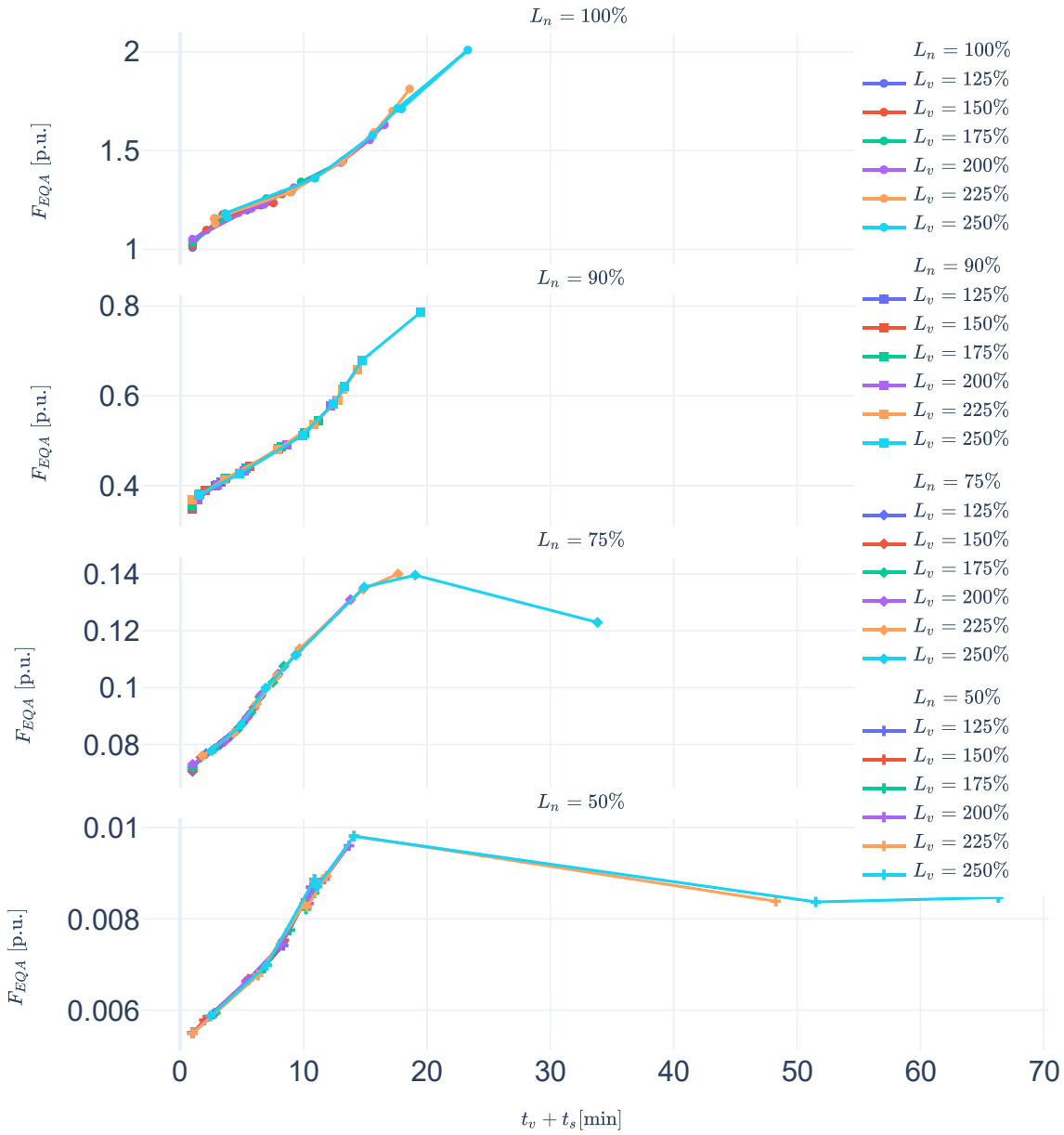
Equivalent aging Factor (F_{EQA}) (eq 3 Sec 5.2):

The cumulative effect of the aging acceleration factor over a set of time intervals:

$$F_{EQA} = \frac{\sum_n F_{AA}[n]\Delta t[n]}{\sum_n \Delta t[n]}$$

Results

- Test matrix with different initial loading, L_n, inadvertent loading, L_v, and duration t_v.
- In all scenarios except for with 100% initial loading, no adverse aging occurs: $F_{EQA} < 1$



Unless 100% initial loading is considered, any PCS response time below 30 seconds does not lead to service transformer thermal impacts

Estimated Loading Level

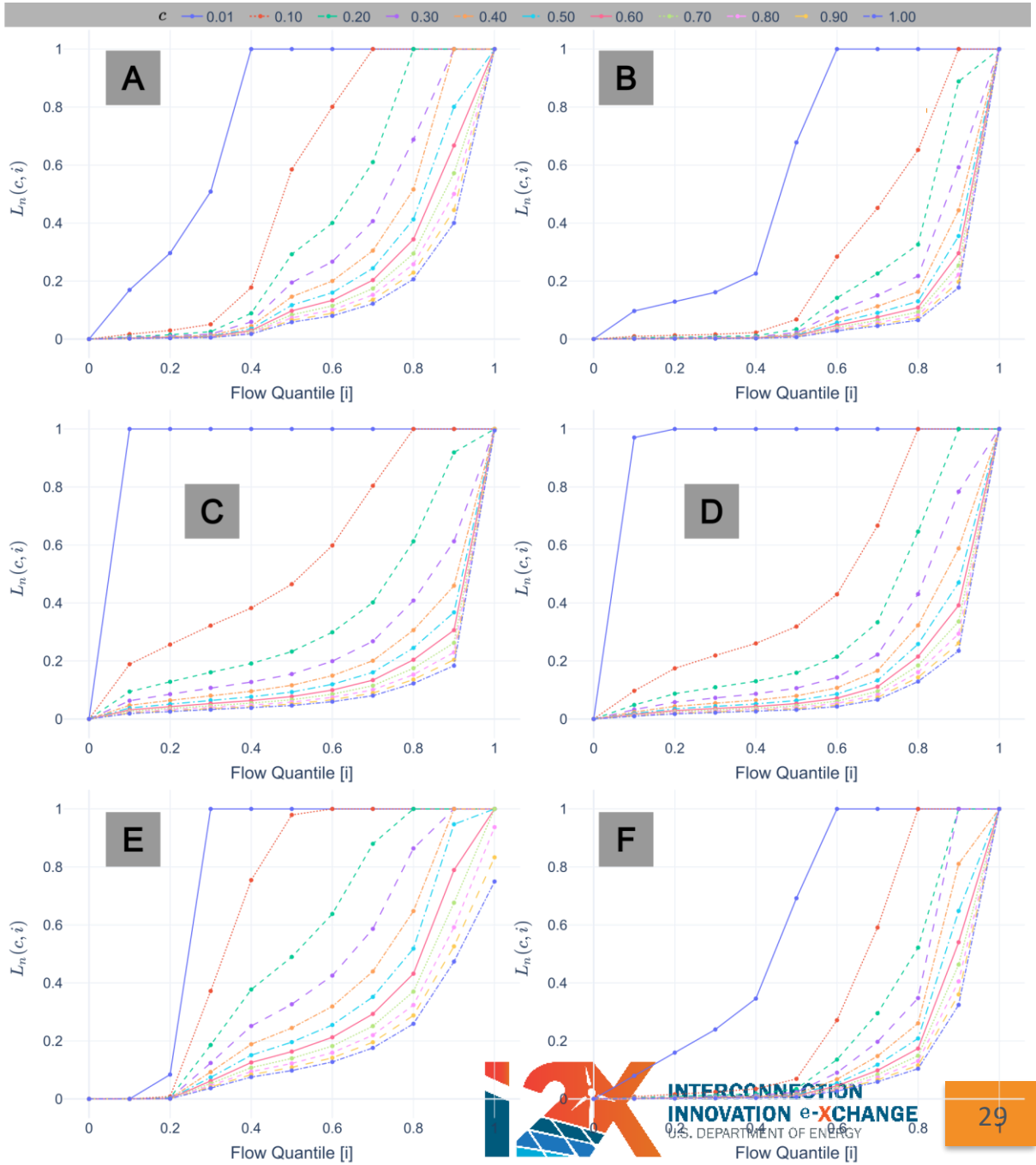
- More than a year of 15-minute data at 6 locations
- Extract system exchange with solar and storage, $p[t]$, and without (gross load), $p^0[t]$.
- Assume transformer rating is related to max gross load, number of customers, k, and coincidence factor, c, as

$$T_r = c \times k \times \max p^0$$

- Normal loading as a function c, and percentile, i of system exchange with solar and storage:

$$L_n(c,i) = \min\left(1, \frac{q_{i(p)}}{T_r/k}\right) = \min\left(1, \frac{q_i(p)}{c \times \max p^0}\right)$$

Unless very low coincidence factors are assumed (<0.3), a nominal loading of 100% is too pessimistic.



Conclusion

Can inadvertent export from export/import limited installations cause thermal impacts that would adversely impact service transformer lifetime?

If so, how would this impact the response time requirements for Power Control Systems? (range of 2-30 seconds)

Only at 100% normal loading, which is likely not a reasonable assumption

For thermal impacts**, there is no need to force a response below 30 seconds

**Other impacts, such as interaction with line regulation may benefit from faster response times.

Solar and Storage Industries Institute

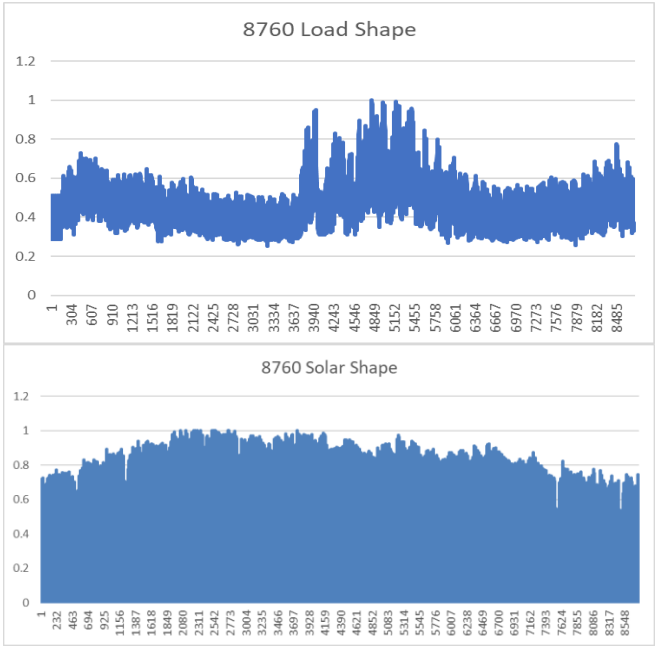
Economic Feasibility Calculator of Flexible Interconnection Options for Developers

Todd Wall

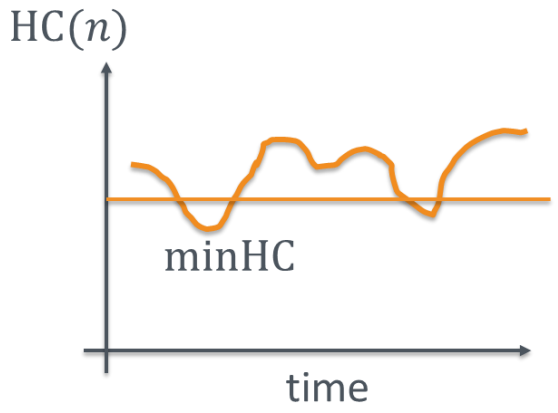
energy.gov/i2x

SSII Approach

- Using the IEEE 9500 Node Feeder model, will perform an “8760” hosting capacity analysis for a typical load and solar year.
- Results will produce maximum hosting capacity for community and/or storage projects for all 8760 hours, which is an estimate of what is achievable under FIX.
- Having calculated annual HCA, will compare total energy exports and curtailment periods to traditional fixed output and translate to economic gains achievable by using FIX.





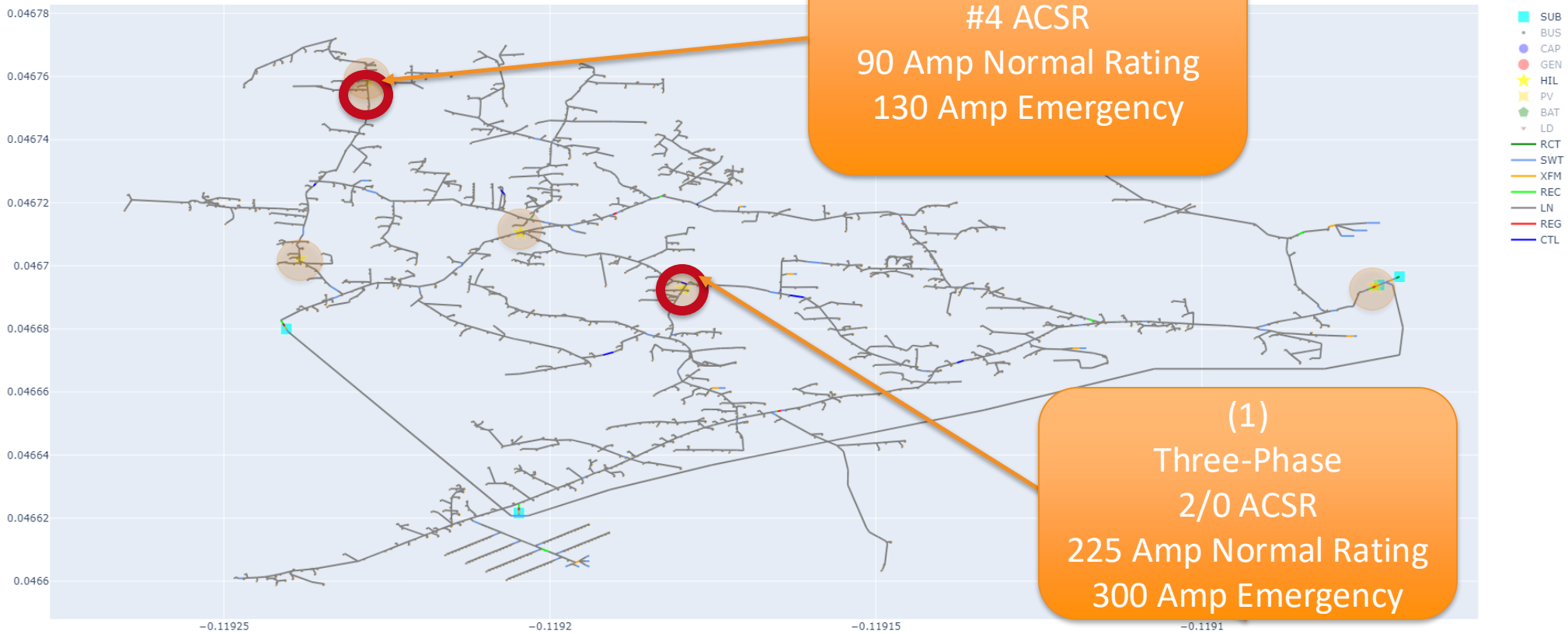


Parameters Determining Curtailment Magnitude

- Thermal equipment ratings
- Voltage Limits: Maximum (1.05), minimum (0.95)
- Limits not considered:
  - Rapid Voltage Change (RVC) (3%) is excluded:
    - From IEEE 1547-2018: “Subclause 7.2.2 is not intended to address issues associated with slow voltage variations, which can be caused by cloud shadow”
  - Islanding/reverse power flow:
    - National Grid examples allow for reverse power flow
    - Islanding considerations are undergoing updates given incompatibility with fault-ride-through requirements.

Location Selections

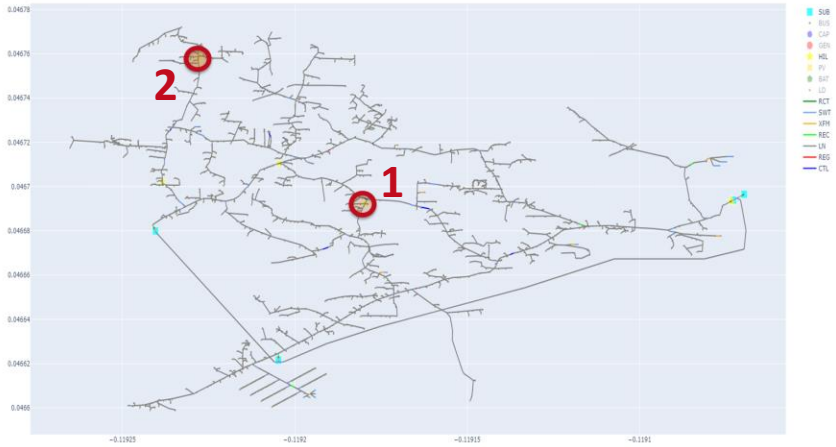
- Hosting capacity is correlated with feeder location, therefore multiple locations were assessed.



Hosting Capacity Results

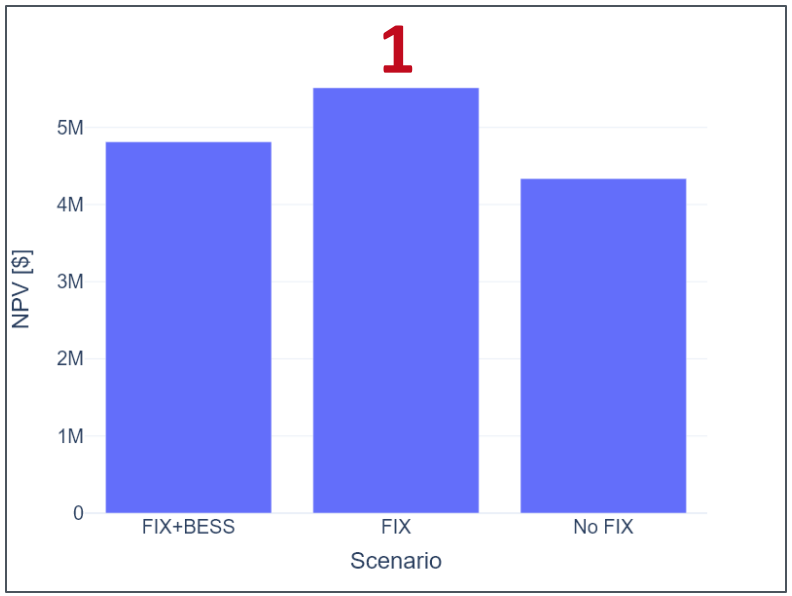
- Three scenarios:
  - NO FIX: Operation at Minimum HC Level → No curtailment
  - FIX: Operation with Curtailment
  - FIX + BESS: Operation with Curtailment and Battery Storage

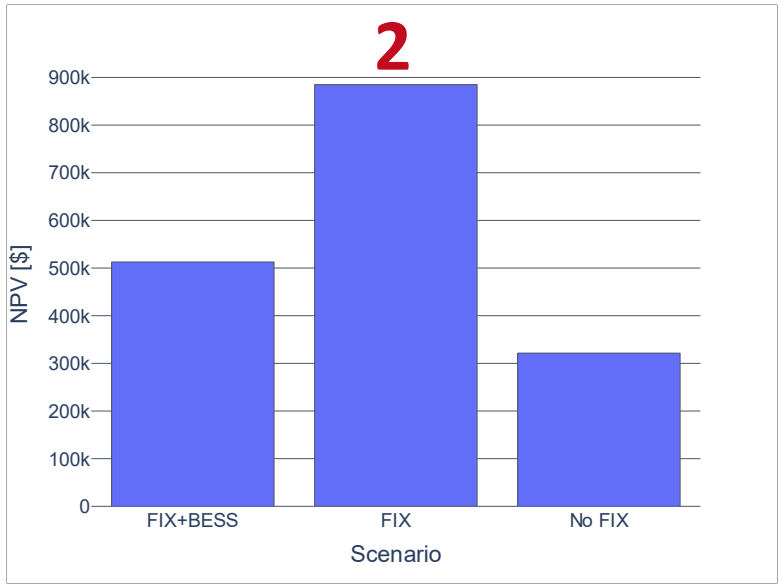
	(1) Max Nameplate – 5550 kW			(2) Max Nameplate – 1217 kW		
	NO FIX	FIX	FIX + BESS	NO FIX	FIX	FIX + BESS
PV [kW]	3493	4500	4500	259	875	875
BESS [kW/kWh]	0	0	1000/2000	0	0	620/1240
Output (1 year) [MWh]	6119	7832 (<28.0%)	7865 (<28.5%)	454	1387 (<205%)	1489 (<228%)
Curtailment (1year) [MWh]	0	34 (0.43%)	0.4 (0.00%)	0	143 (10%)	41 (2.8%)

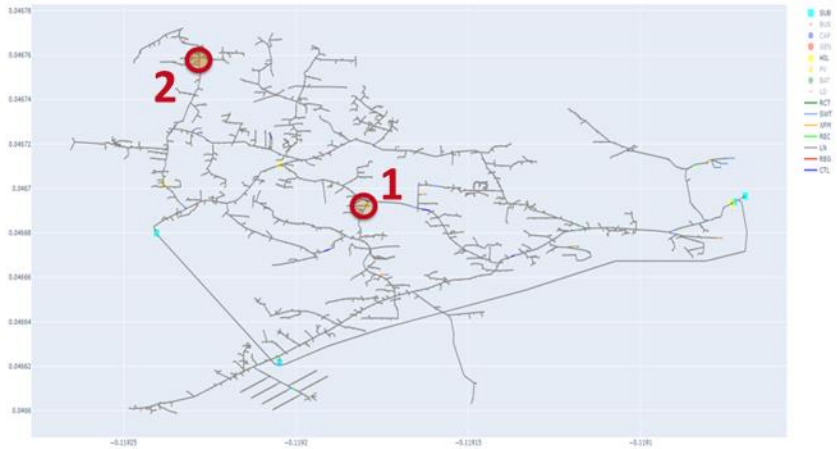


Net Present Value Comparison

- Physical location of interconnection shows a marked affect on the benefits of FIX.
- For location 1, if an upgrade would close the hosting capacity gap, then it would need to be less than $45k to be advantageous over FIX.
- For location 2, the upgrade would need to be less than $200k.







Key Take Aways

- In terms of NPV, interconnecting with FIX is a better option than the alternatives in multiple cases.
  - Including a BESS reduces the NPV since the added value in generation does not fully compensate for the additional CAPEX
- But, when compared to paying for upgrades, FIX+BESS is preferable than just about any upgrade, while FIX Only has a curtailment opportunity cost that justifies more substantial upgrades.

Bottom Line:
FIX + BESS is the least-regret option with a higher NPV compared to reduced systems.

Thank You

energy.gov/i2x

NREL Overview of TA Requests relative to i2X

Presenters

1. Killian McKenna
2. Sanjana Vijayshankar

Program Manager

1. Jeff Cook

NREL-Supported TA Requests

i2x Technical Assistance Project 1	• Integrating and Automating Advanced Interconnection Evaluation
i2x Technical Assistance Project 2	• Limited generation profiles and DER Power control systems for flexible interconnection
i2x Technical Assistance Project 3	• Hosting Capacity Analysis
i2x Technical Assistance Project 4	• Assessment of PV Hosting Capacity, Upgrade Costs, and Flexible Interconnection Strategies for the 8500 Feeder

i2x Technical Assistance Project 1: Integrating and Automating Advanced Interconnection Evaluation

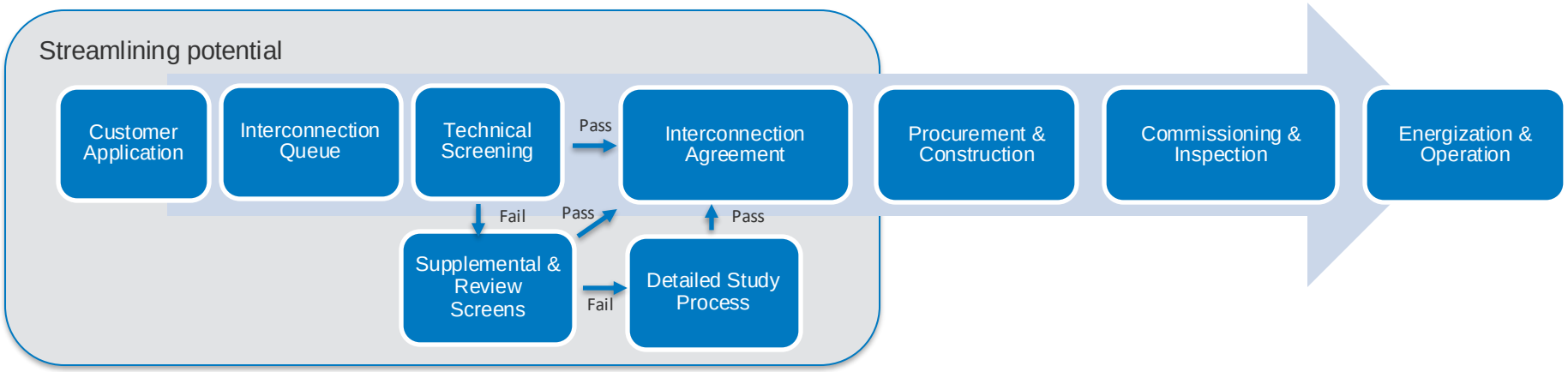
NREL team: Sherin Ann Abraham, Darice Guittet, Killian McKenna

Partners:

- 1 Municipal utility
- 1 Cooperative utility
- 2 Investor-owned utilities

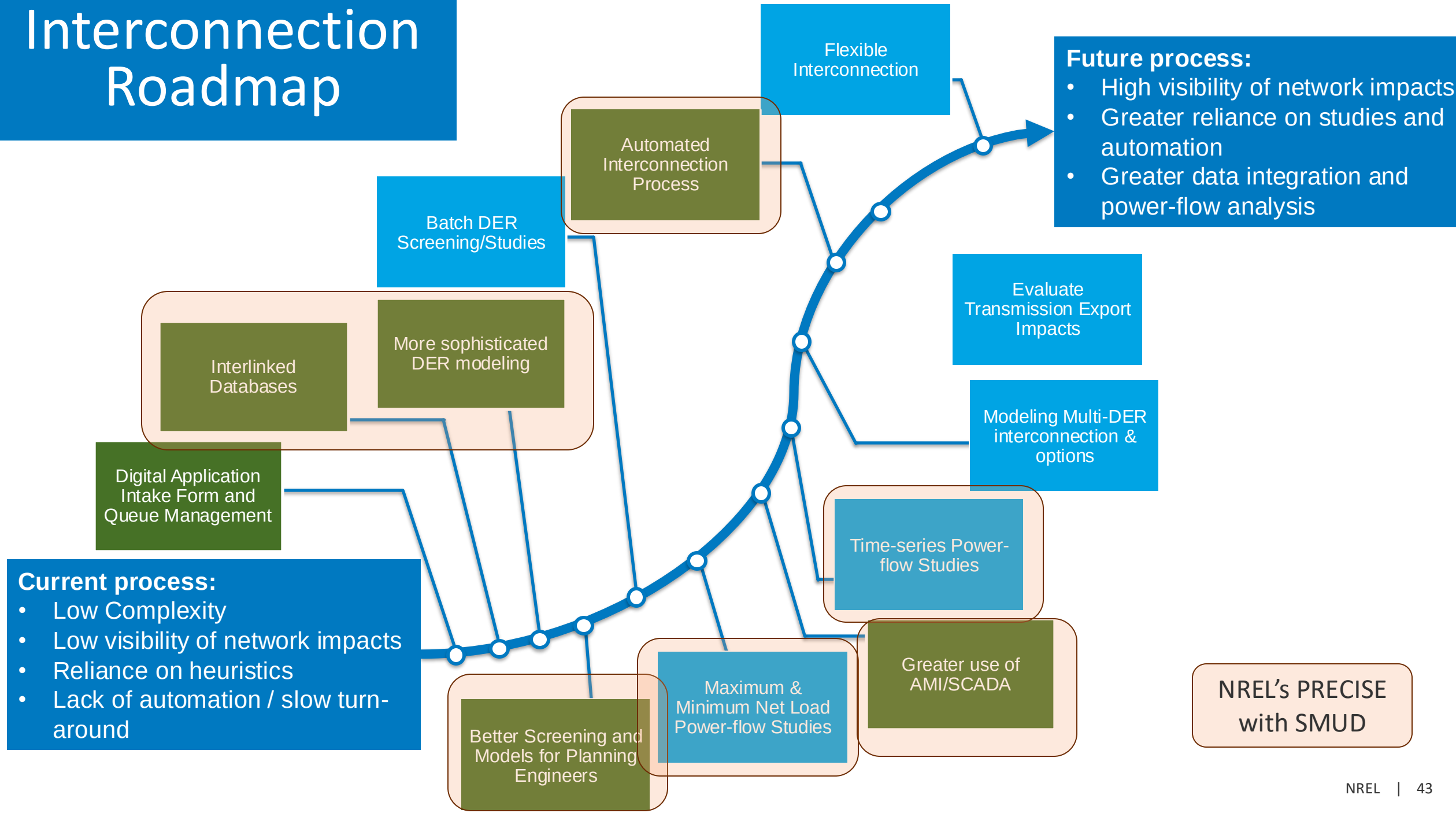
Technical Assistance Overview

The Interconnection Process



- Assessing current utility interconnection practices, experiences, data availability and fidelity, and current level of data integration.
- Defining requirements of advanced interconnection technical assessments, with user-oriented design for what technical screens should entail, what network impacts should be examined, level of automation, and when should supplemental screens be used.
- Roadmap for data integration and automation to perform automated detailed interconnection technical screens.

Interconnection Roadmap



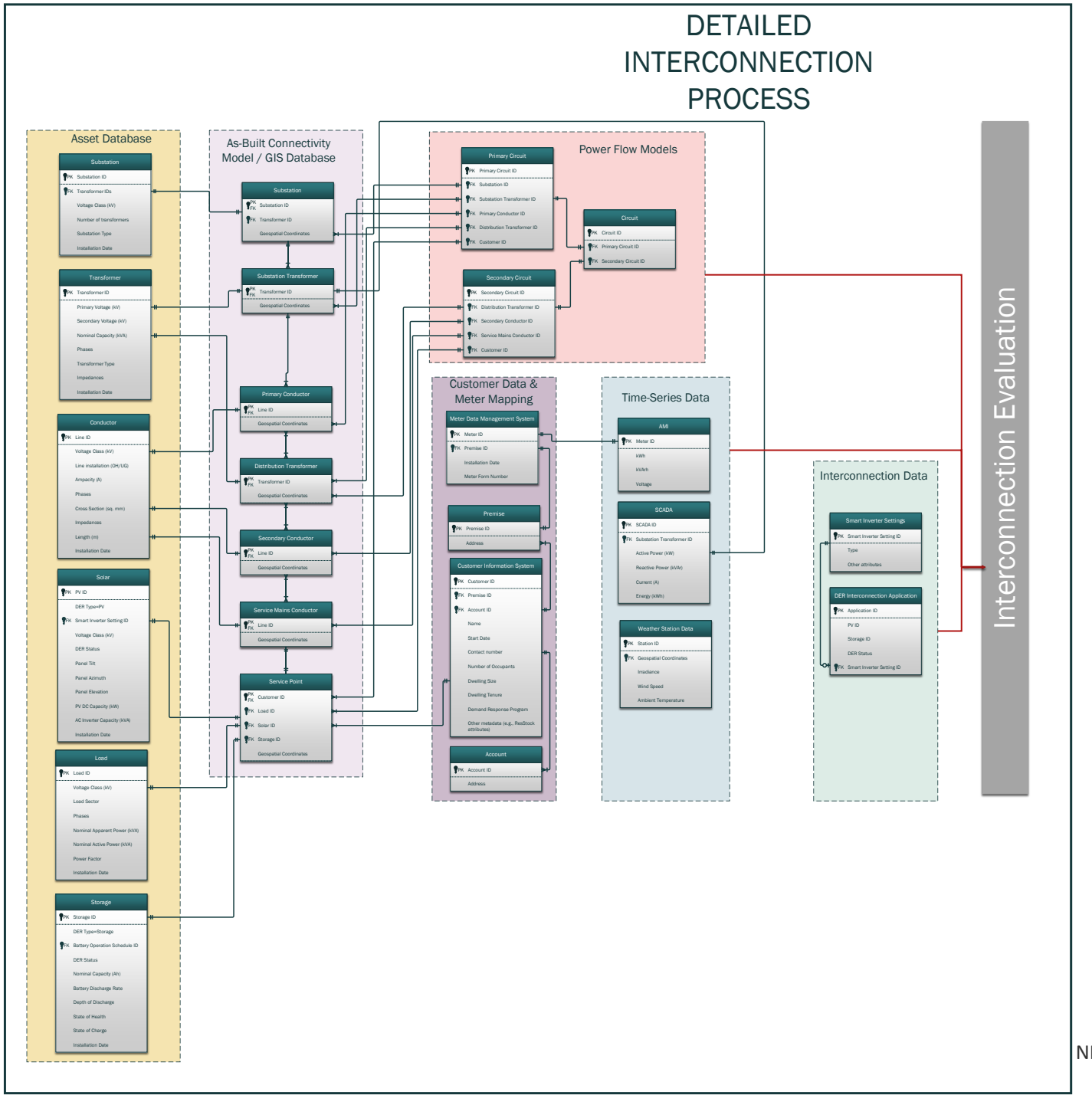
Future process:
- High visibility of network impacts
- Greater reliance on studies and automation
- Greater data integration and power-flow analysis

Current process:
- Low Complexity
- Low visibility of network impacts
- Reliance on heuristics
- Lack of automation / slow turn-around

NREL's PRECISE with SMUD

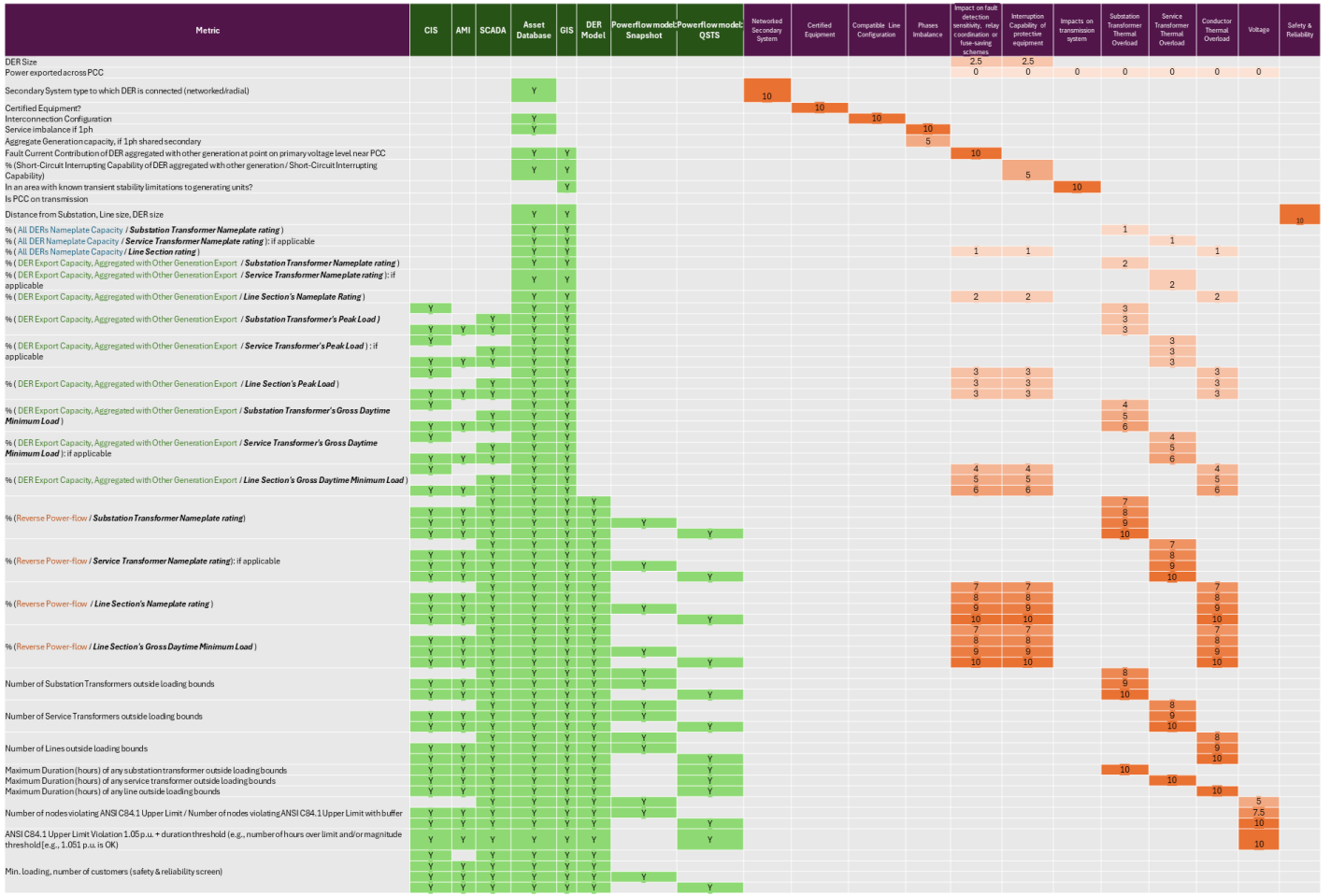
Utility Database Schema – What data do we need, how does it map?

AMI / Asset / GIS / Power-flow / SCADA / CIS / DER Intake



Comprehensive Screen & Study Metrics

- ***Defining clear metrics for assessing interconnection grid impacts***
- ***Over 70 metrics for interconnection***, required datasets, orders for metric screening processes
  - What to look at when screens fail?
  - What are the metrics to examine?
  - What are the datasets require?



i2x Technical Assistance Project 2:

Limited generation profiles and DER Power control systems for flexible interconnection

NREL team: Darice Guittet, Sherin Ann Abraham, Killian McKenna

Activities

- **Flexible Interconnection Needs Assessment -** what a successful implementation of flexible interconnection/limited generation profiles/time-series export/import limits would look like. This will include what needs to be considered (uncertainty in net load conditions, future upgrades, load and DER growth) and what needs to be included in the analysis.
- **Analysis Scenarios:** Examine nameplate vs PCS screens, probability of network violations, time-series import/export limits and use-cases for flexible interconnection
- **Roadmap for Enabling Flexible Interconnection -** The roadmap will outline options for how a utility can perform the technical analysis required for leveraging DER PCS as part of interconnection studies. This will recommend ways such that utilities avoid import/export limit calculations becoming a burden to their planning engineers and exacerbating the DER logjam experienced by utilities.

Spectrum of Flexible Interconnection Solution

Increasing complexity and coordination / Reduced unnecessary import/export limitations

Fixed import/export limits

- Time-series (monthly/daily/hourly) profile issued to load/DERs
- E.g., CPUC Limited Generation Profile

Flexible Customer Oriented Solutions

- Load/DER import/export limiting device with local management scheme
- Customer monitors local network constraint

Flexible – Local Distribution Management

- Remote intertrip (remote unconditional tripping)
- Local measurement and dispatch of customer devices/DERs

Flexible – Area Distribution Management

- Area control, e.g., advanced distribution management system (ADMS) + distributed energy resource management system (DERMS)
- Advanced and coordinated constraint management

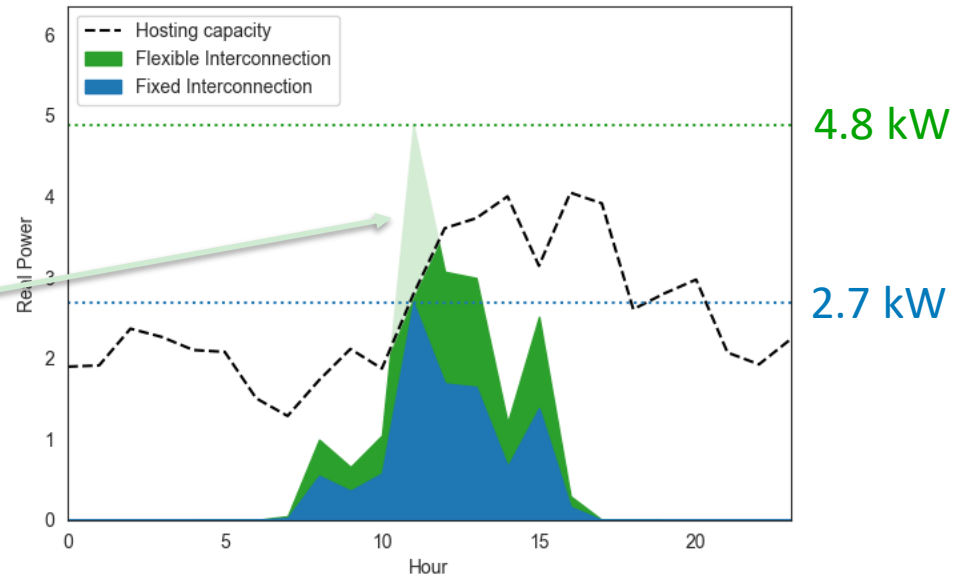
- NREL are focusing on fixed export limit profiles, examining limited generation profiles proposed by the California Public Utilities Commission
- The focus is on examining how NREL's PRECISE interconnection tool can be leveraged to generate flexible interconnection profiles

Flexible Interconnection

PRECISE is working to enable flexible interconnection

- Utilizing DER control schemes to manage export to stay within grid constraints
- DER export capacity is time-varying and location-dependent

Single-site hosting capacity with oversized DER requires curtailing or shifting DER production

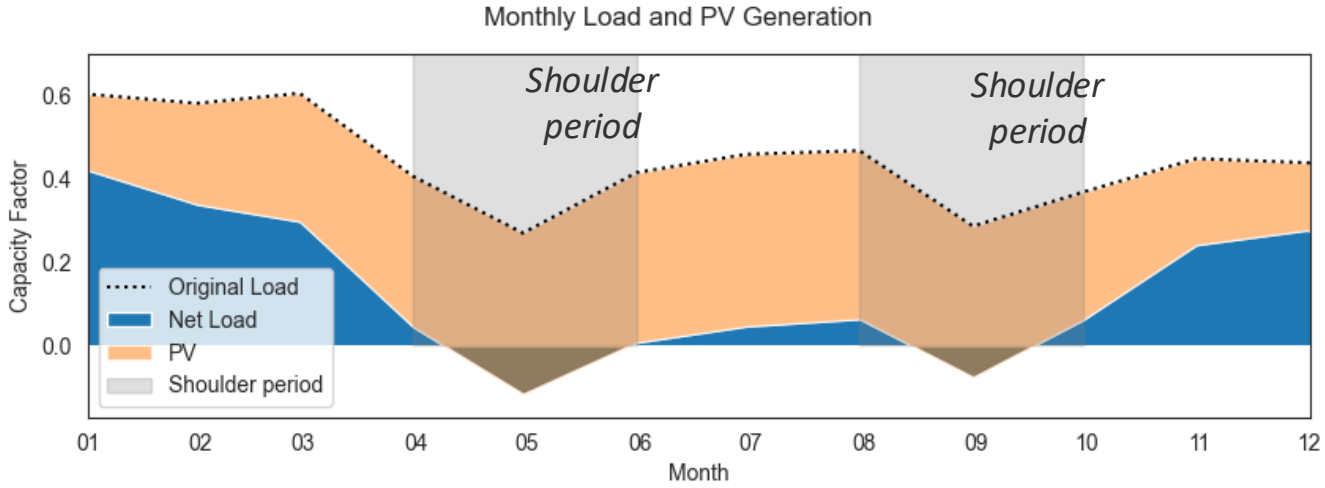


Flexible interconnection restricts DER production during limited periods

Conventional interconnection reduces DER nameplate

Use Cases

- Shoulder periods with low net load limits DER interconnection capacity
- Reducing DER exports only during constrained periods provides multiple benefits:



Utility

Enhanced hosting capacity

Utilization of existing infrastructure

Stopgap for upgrades

DER Customer

More DER interconnection

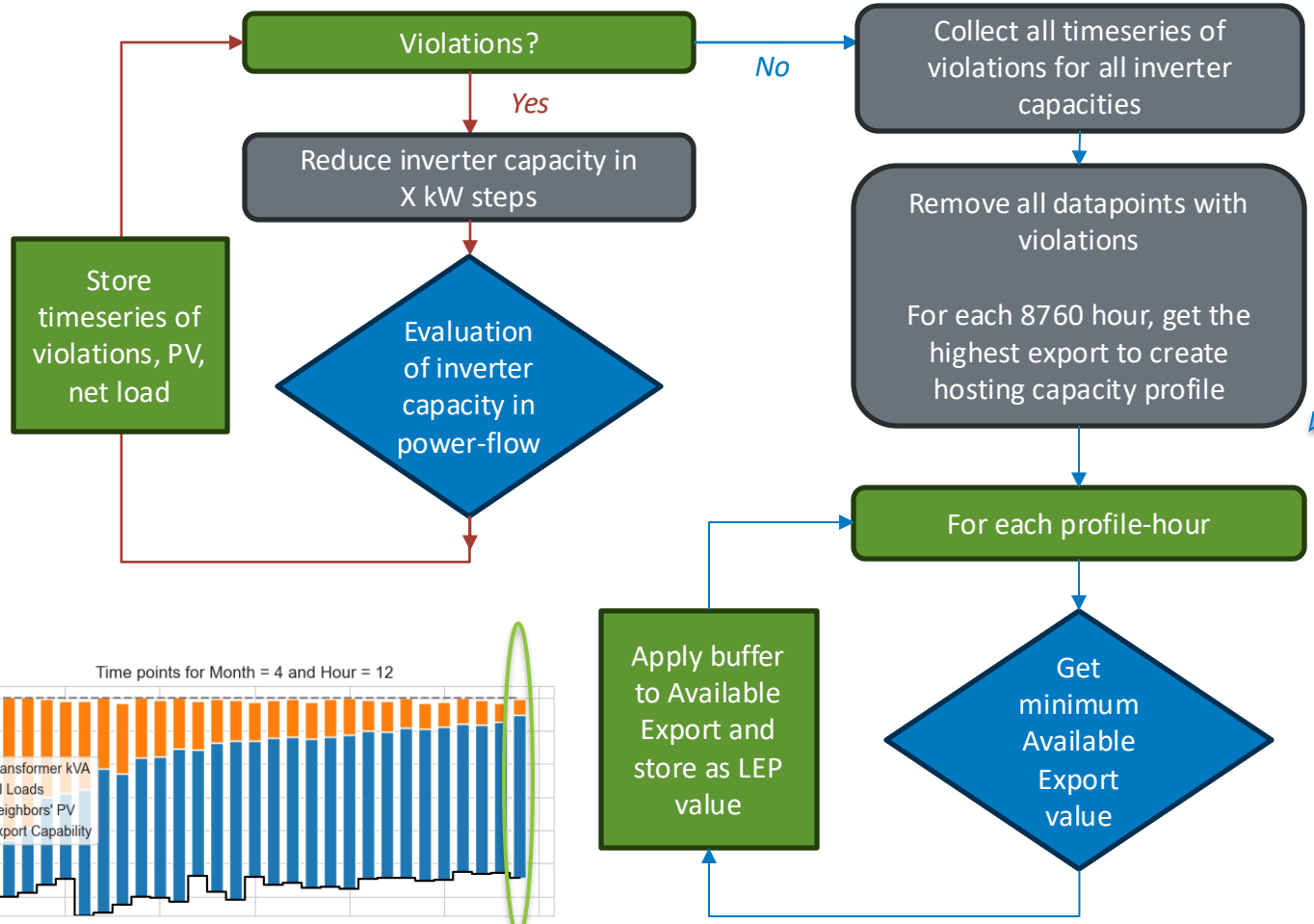
DER output when needed most

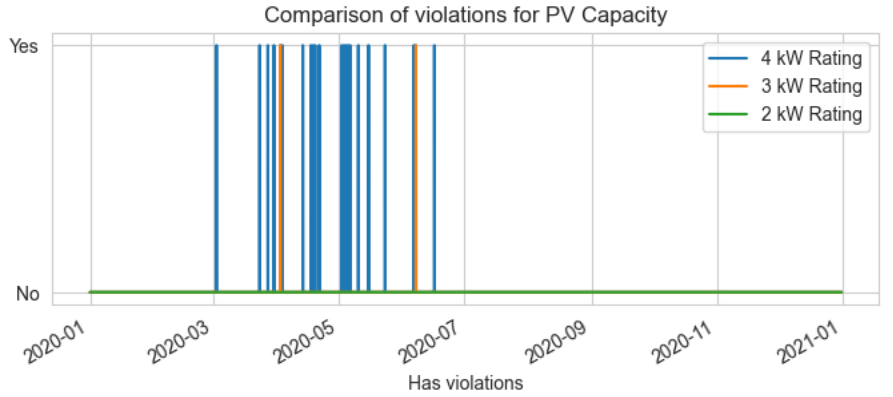
More renewables and electrification

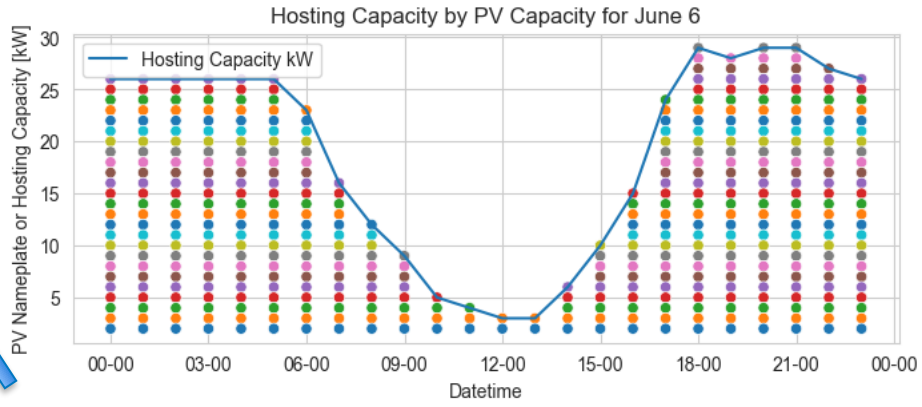
Revenue from faster connection

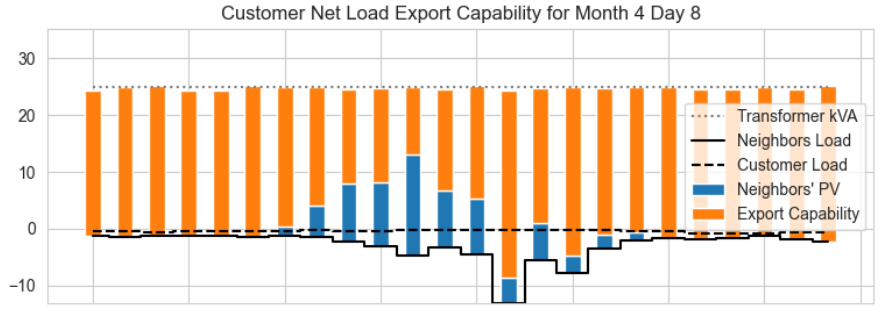
Deferral or avoidance of upgrade costs

Examining Limited Export Profiles









Presentation for limited circulation

i2x Technical Assistance Project 3: Hosting Capacity Analysis

NREL Lead: Kwami Senam A. Sedzro, PhD

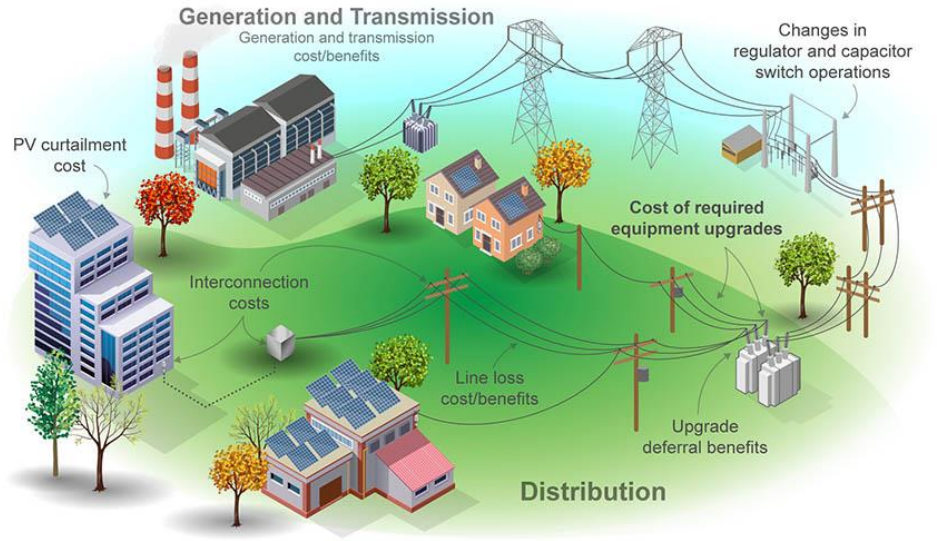
Hosting Capacity Analysis

- **Key Ask:** Evaluate the design and recommend improvements to an approved hosting capacity analysis (HCA) pilot project
- **Key Accomplishments:**
  - NREL reviewed the methodology to ensure that metrics and assumptions were in line with industry's best practices
  - NREL made recommendations to address gaps
    - Rerun the HCA after model enhancement that accounts for *advanced inverter functions* for new solar PV plants
      - The current model was set to unity power factor
    - Quality-check hosting capacity numbers through an impact study of a deployment scenario at capacity equal to the maximum hosting capacity, because model does not use full power flow study in its incremental HCA

PV Hosting Capacity Analysis Best Practices
System modeling (power-flow, fidelity)
Voltage operating margin
Voltage deviation (sudden change or "flicker") thresholds
Thermal loading operating limits
Protection impact limits
Consider daytime minimum load conditions
Account for loading-relevant device settings
Reflect actual smart inverter setpoints



Example of an NREL hosting capacity map



Presentation for limited circulation

i2x Technical Assistance Project 4: Assessment of PV Hosting Capacity, Upgrade Costs, and Flexible Interconnection Strategies for the 8500 Feeder

NREL team: Sanjana Vijayshankar
Deepthi Vaidhynathan
Jennifer King

Background

DER Exponential Growth:

- The current trajectory of DER growth poses a challenge to traditional grid management practices.
- The surge in the number of grid-tied DERs, such as solar panels and energy storage systems, is outpacing the capacity of centralized control systems.
- As a result, this rapid increase in DER deployment is triggering the need for fixed and/or flexible interconnection solutions to ensure grid stability.

Challenges in DER Projects:

- DER projects are encountering escalating difficulties in connecting to the distribution grid.
- The volume, location, and design of projects seeking to interconnect, combined with other challenges like supply chain issues lead to delays and increased costs.
- Interconnection delays hinder the progress of decarbonization goals in the state.

TA Partner Initiatives:

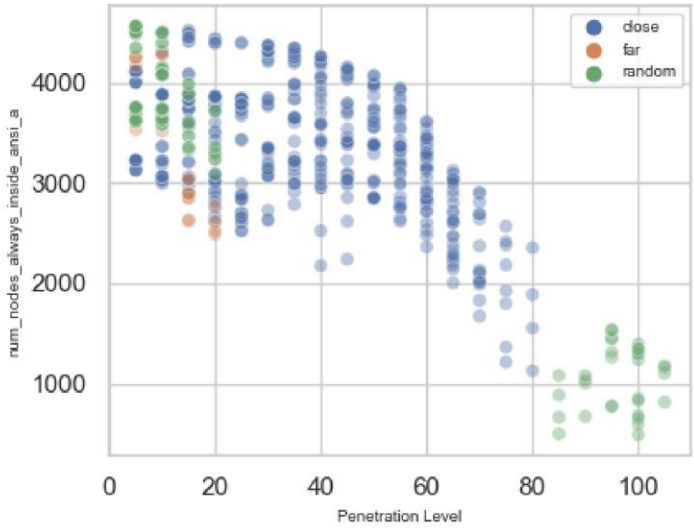
- The TA partner is proactively addressing challenges.
- Initiatives focus on a fundamental transformation of power grid planning strategies to accommodate the evolving energy landscape.
- The partner is exploring revisions to the cost-sharing model for grid upgrades, aiming to distribute costs in a manner that better advances the state's clean energy goals.

Presentation for limited circulation

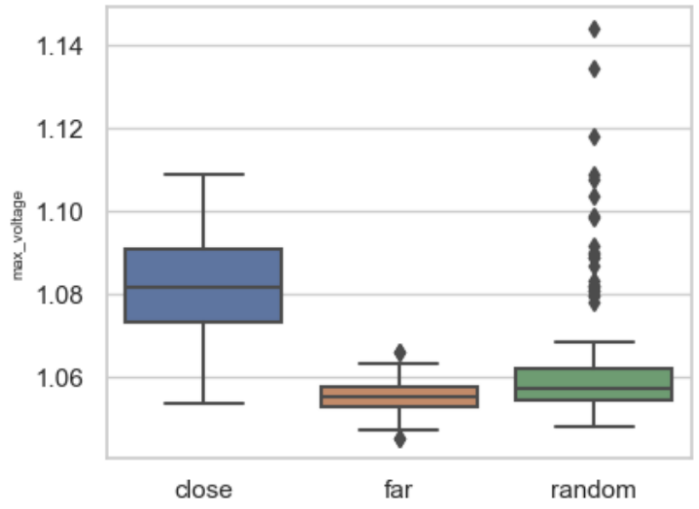
Hosting Capacity Analysis

- We use authentic PV profiles and load data to conduct thorough power flow simulations at a hypothetical/representative feeder.
  - Baseline scenario: thermal and voltage violation metrics in the absence of any PV.
  - Modeled scenarios: Close, Far, and Random Placement
- These scenarios offer valuable insights into optimizing both the feeder and PV placement strategies.
  - Escalating PV penetration increases probability for voltage violations.
  - This is more likely when PV is closely positioned, as opposed to distanced or random.
- This analysis supports optimal positioning and capacity for PV deployment.

Feeder	Placement	Sample	Penetration Level
IEEE 8500	close	1	5 %
	far	2	10 %
	random	3	15 %
		⋮	⋮
		10	120 %



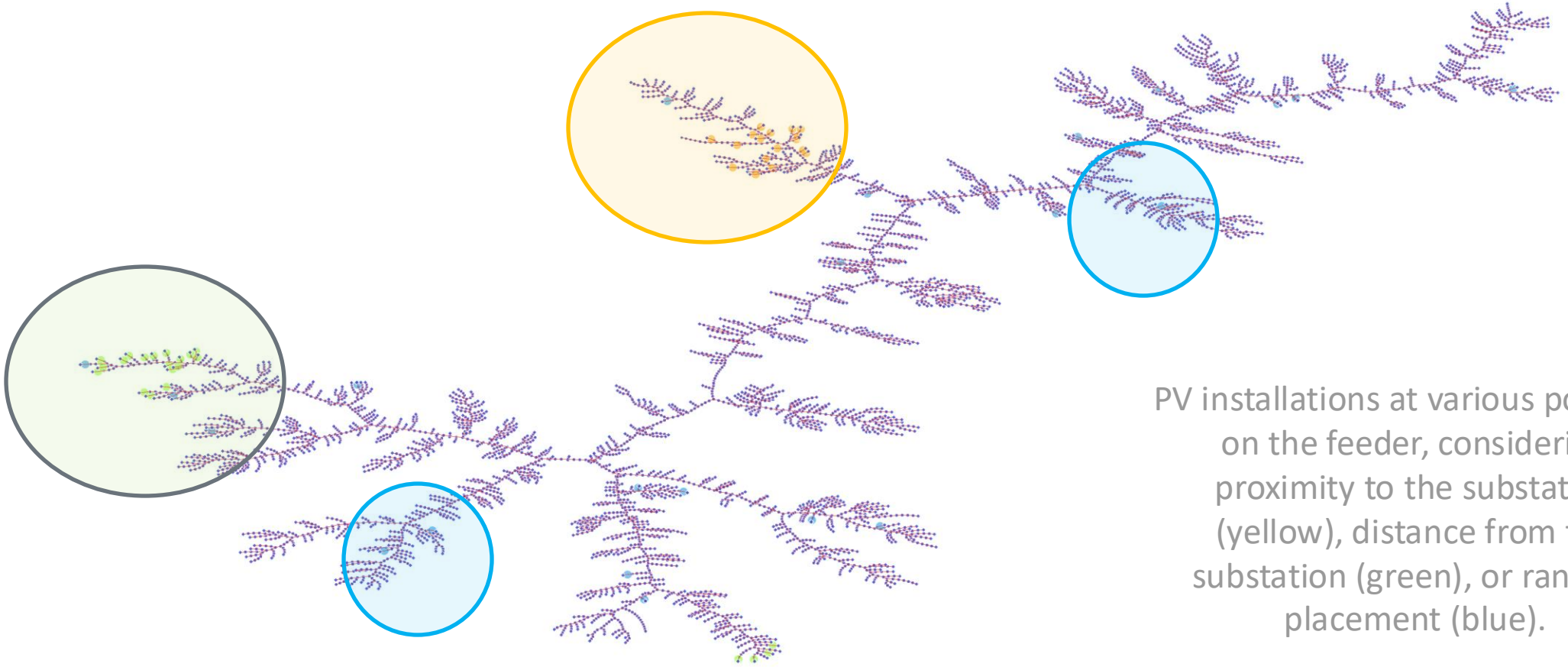
(1)



(2)

Presentation for limited circulation

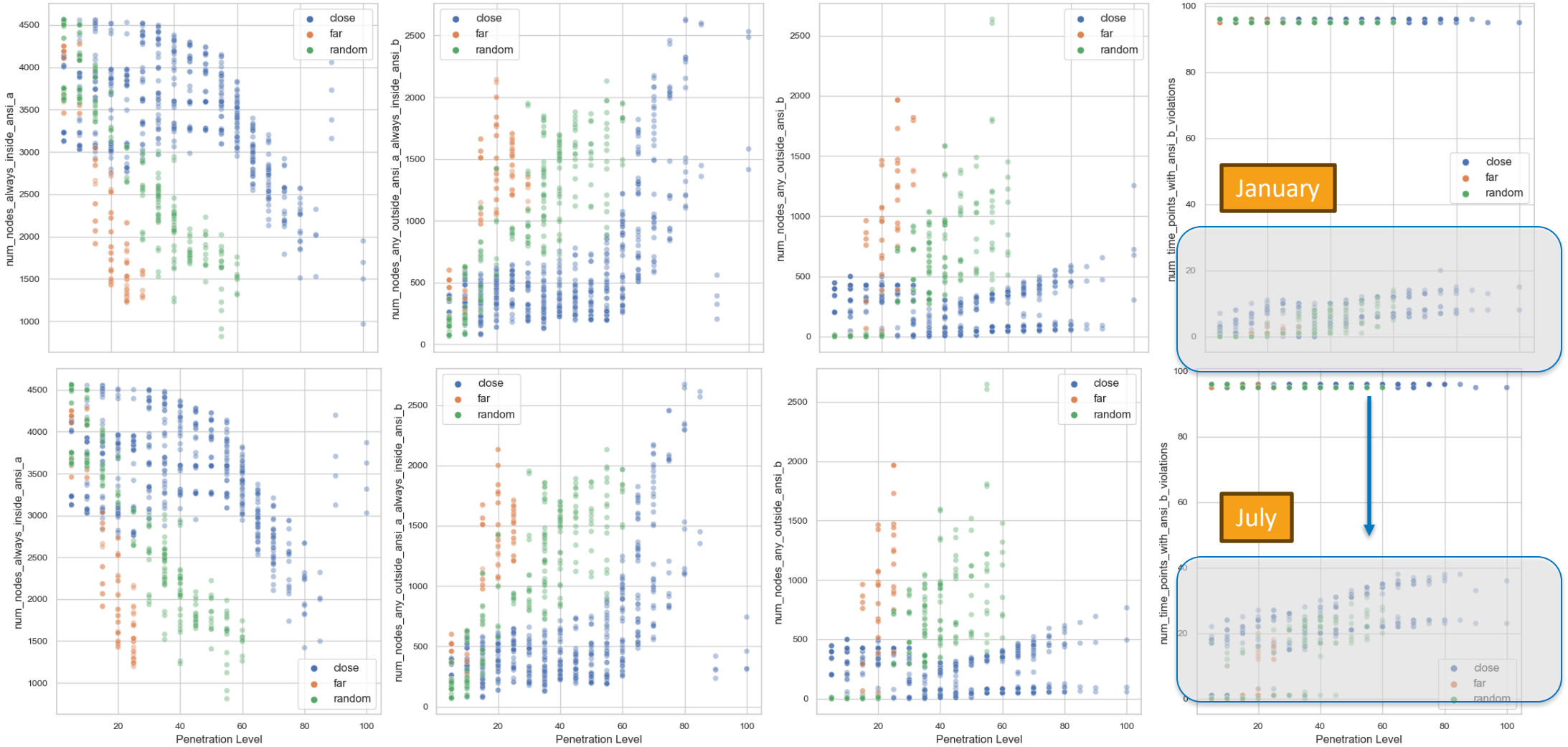
PV placement strategies



PV installations at various positions on the feeder, considering proximity to the substation (yellow), distance from the substation (green), or random placement (blue).

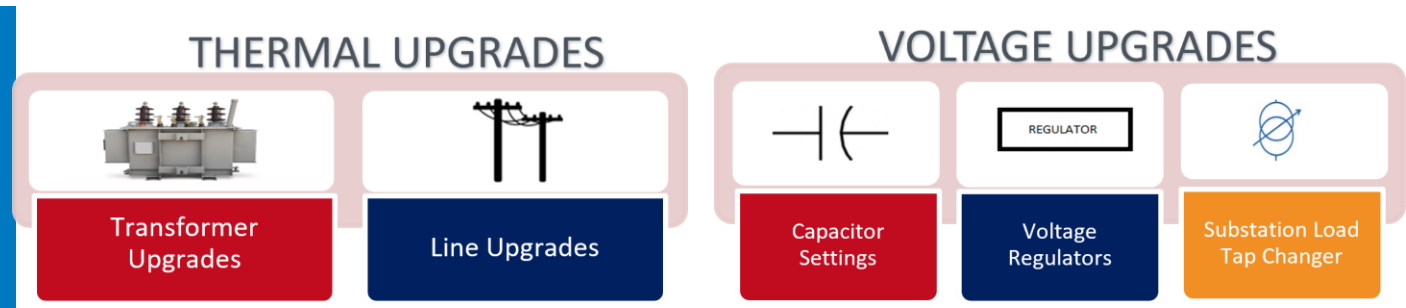
Presentation for limited circulation

Seasonal Variation



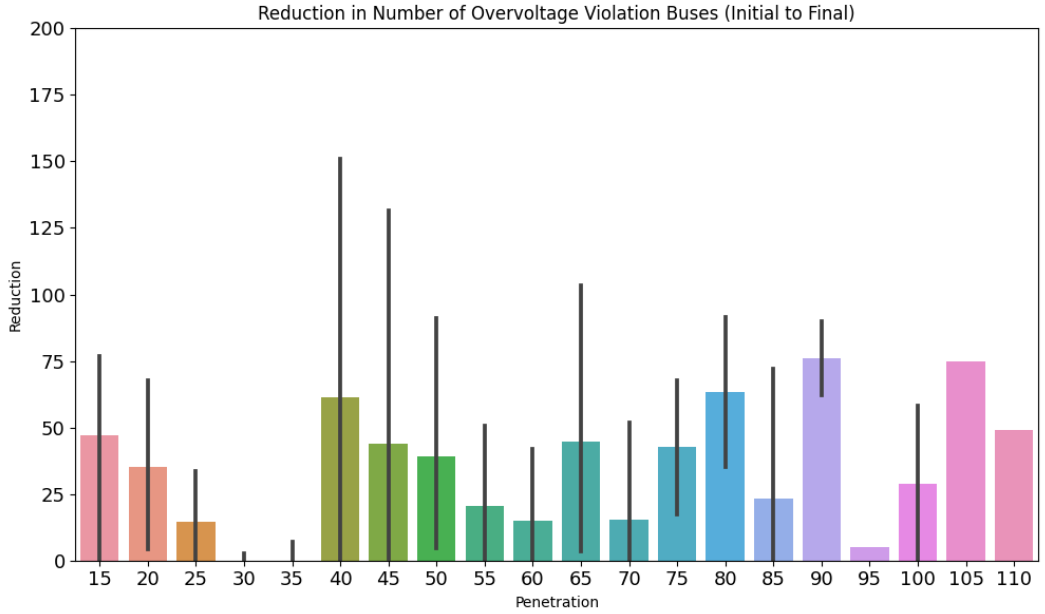
- As penetration levels rise, there is a decrease in the number of nodes within ANSI A bounds.
- This is accompanied by an increase in nodes falling within ANSI B bounds (and) exceeding ANSI A limits.
- For the selected day under examination, we observe minimal deviations across the plots, except for the occurrence of ANSI B violations at different time points.
- Number of time points with violations outside ANSI B is consistently highest in July across all months

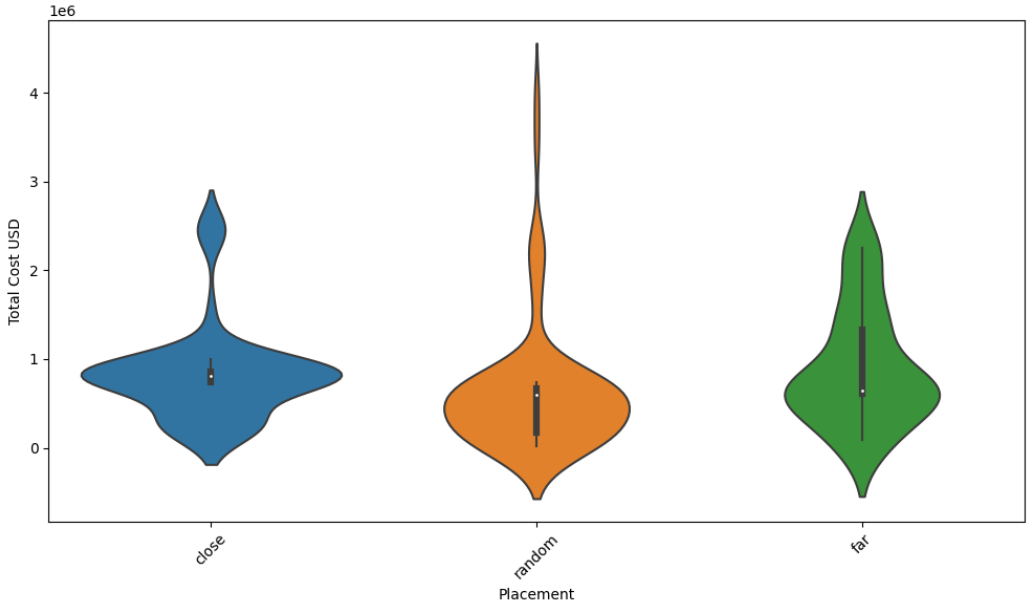
Upgrades



Courtesy: DISCO NREL

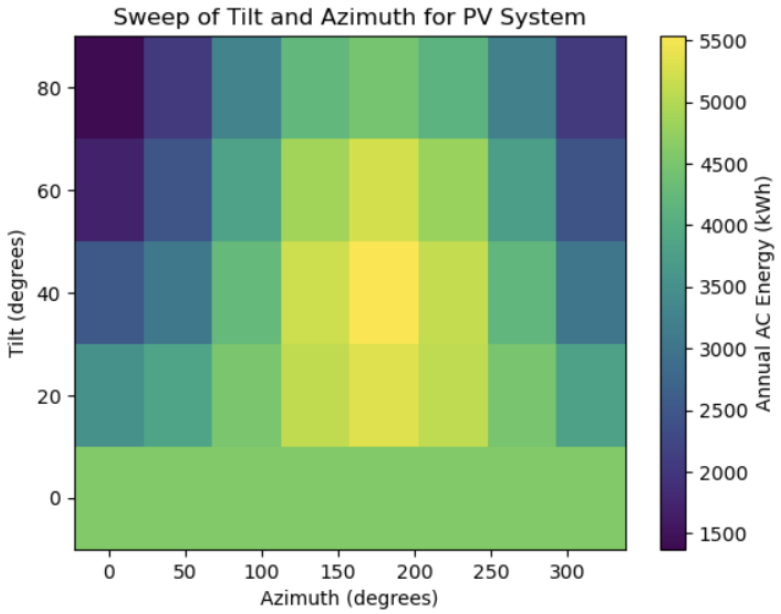
- Once we perform the upgrade, the number of over-voltage violation buses reduces significantly, the data is shown with respect to penetration.
- No correlation is observed between this reduction and penetration although intuitively, we would think that as penetration increases, it would require more infra upgrades, and thus more cost.
- We conducted a comprehensive cost analysis for various penetration levels and placement criteria. Detailed changes, including in-line voltage regulator settings, lines, substation LTC, substation transformers, and their respective cost breakdowns, are provided.
- Bottom right shows cost ranges associated with each placement strategy. Notably, the random placement strategy exhibits numerous data points around $500,000, a figure significantly lower than those observed for the far and close placement strategies.

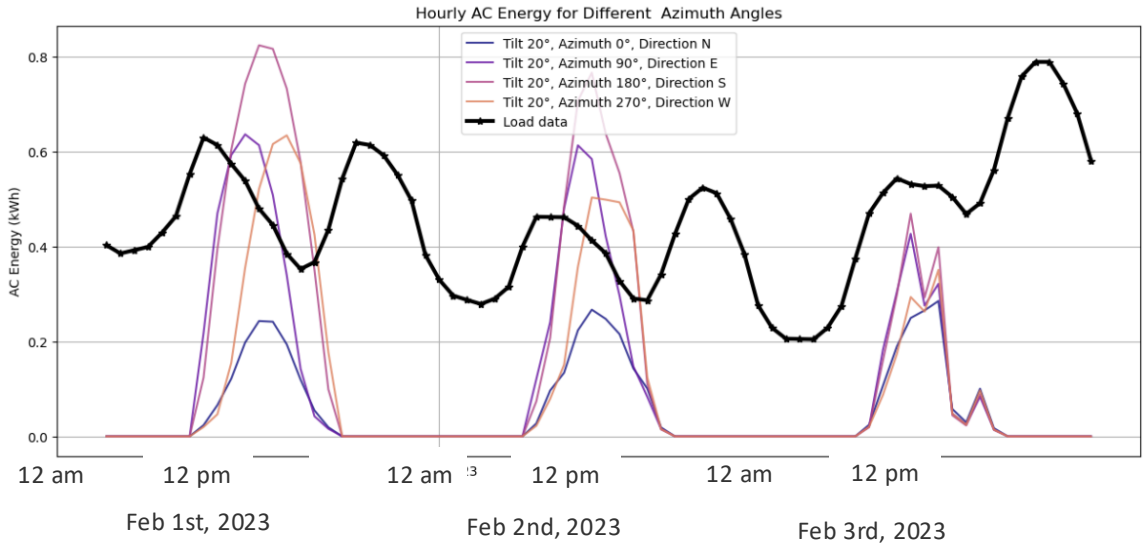




Effects of Azimuthal Placement

- The placement of PV panels on rooftops significantly influences power production, particularly in relation to azimuth positioning.
- To identify the most effective azimuth placement, we conduct multiple sweeps using PVWatts, exploring various azimuth and tilt configurations.
- Azimuth impacts
  - South-facing: optimal power production.
  - West-facing: Temporal delay, resulting in later peak energy production throughout the day.
- South- and west-facing orientation can provide different benefits to the PV system owner and grid operator.





Presentation for limited circulation

Solar Strategic Analysis & Institutional Support at NREL

With guidance from the U.S. Department of Energy Solar Energy Technologies Office (SETO), NREL researchers produce innovative and actionable solar analysis work within SETO's Strategic Analysis and Institutional Support Team (SAIS).

- Produce analysis designed to reduce solar installation costs
- Assess existing and new solar market opportunities
- Develop tools that inform decision making

Scan the code to visit the Solar Market Research and Analysis site on nrel.gov to access more solar analysis findings, data, and tools.

Thank you!

NREL I2X Team

Killian.McKenna@nrel.gov

Sanjana.Vijayshankar@nrel.gov

Jeff.Cook@nrel.gov

Scan the code to sign up for the Solar Market Research and Analysis newsletter—the latest solar analysis from NREL sent to your inbox.

Presentation for limited circulation

i2X Webinar: DER Flexible Interconnection Strategies and Approaches

Presenters: Matthew J. Reno, Joseph A. Azzolini
Emails: mjreno@sandia.gov, jazzoli@sandia.gov

Sandia National Laboratories

INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

U.S. DEPARTMENT OF ENERGY NNSA

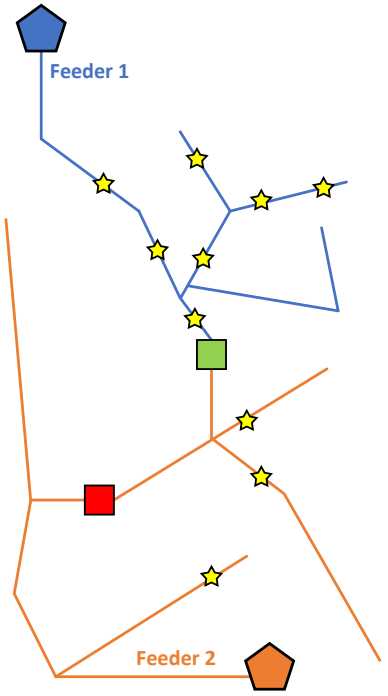
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline

1. **Interconnection screening tool for installing DER in downtown LV spot and grid networks**



2. **Feeder reconfigurations for improving DER hosting capacity**



Interconnection Screening Tool for Installing DER in Downtown LV Spot and Grid Networks



SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy



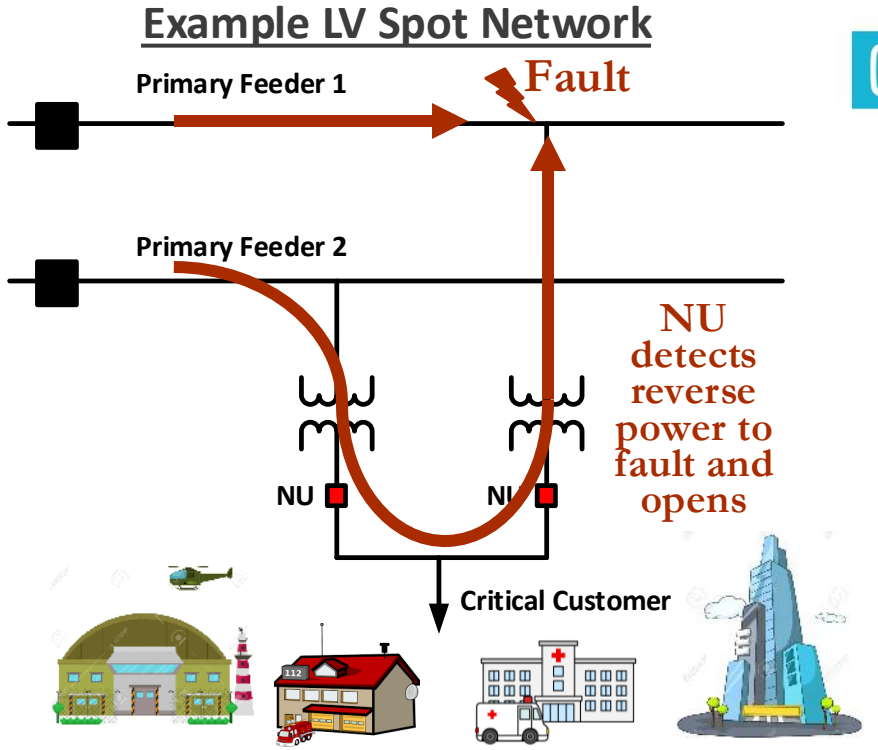
INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

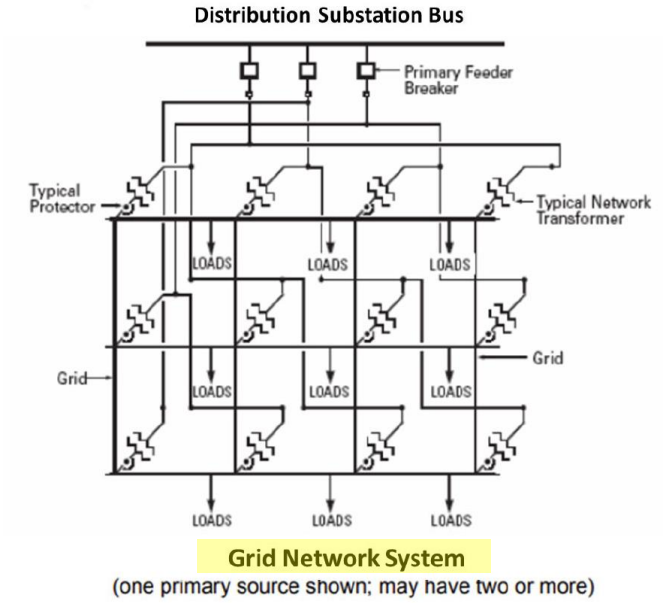


Sandia National Laboratories

Background and Challenges

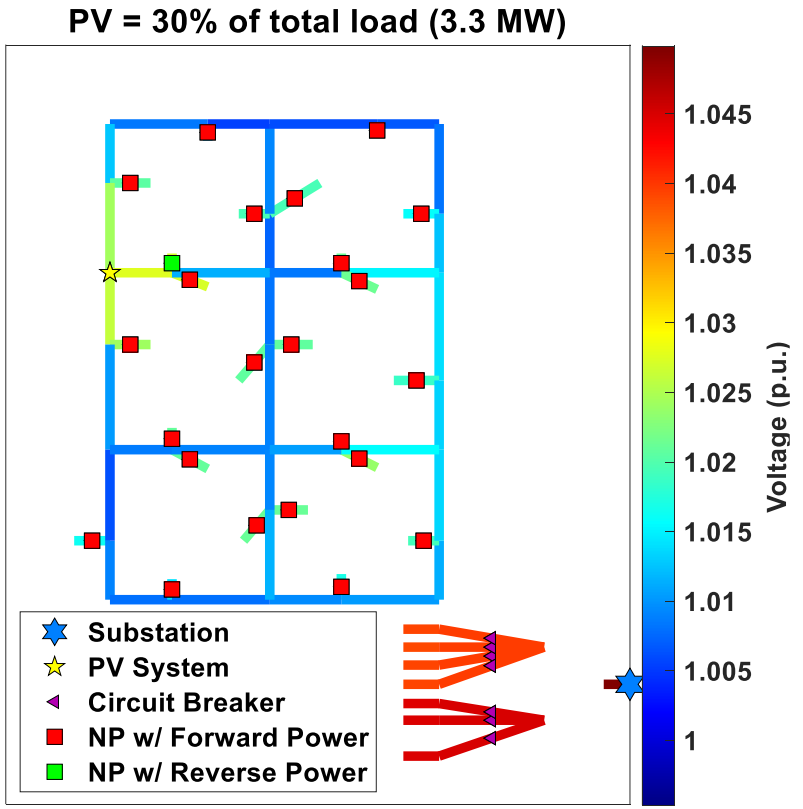
- Most critical customers (e.g., hospitals, supermarkets, defense infrastructure, dense urban areas, etc.) are connected through a low-voltage (LV) network
  - This **redundancy provides high reliability**, without even momentary outages for the customer
- During a large event with a transmission outage, the customer still loses power (**low resilience**)
- Critical customers in LV networks need the ability to interconnect DER for grid support and backup services
- Conventional LV network protection schemes **prohibit backflow of power** on medium-voltage (MV) feeders
  - Essentially, DER **not allowed to impact existing protection**, so only small DER can interconnect to ensure no possibility of momentary backfeed





Background and Challenges

- Unlike radial systems, backflow can occur even when generation on the LV network is less than the total load
- Thus, guidelines in existing standards (e.g., IEEE 1547.6) significantly limit DER installed capacity on LV networks
  - Up to **6.6%** penetration of the **annual minimum load**
  - Up to **11 kW** w/ aggregate limit of **2% of minimum load**
- New revision of IEEE 1547 is underway
  - Sandia is contributing in various areas, including research on new protection schemes and updated interconnection screening procedures



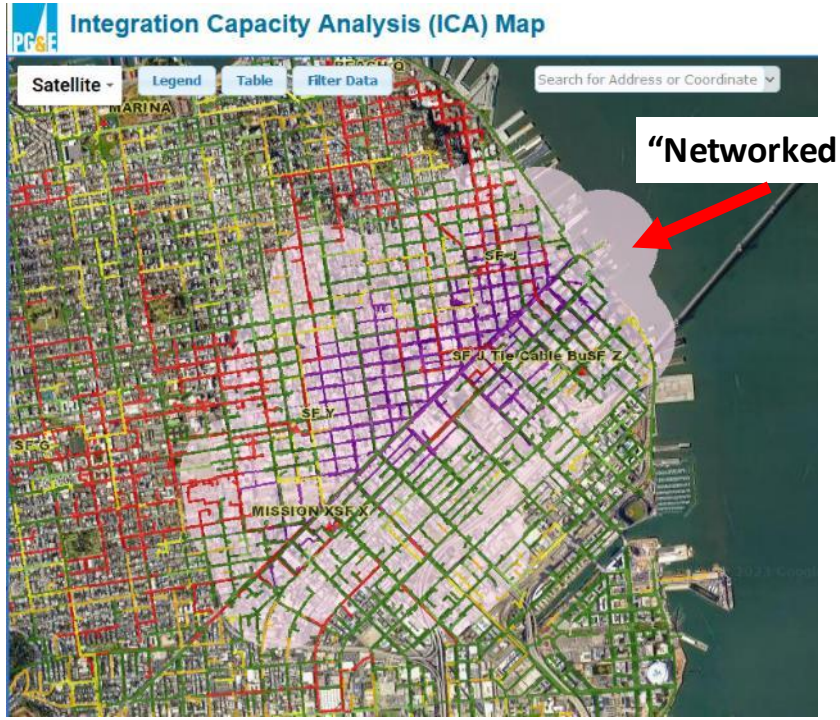
Example LV Grid Network (IEEE 342-node Test System)

Existing Practices

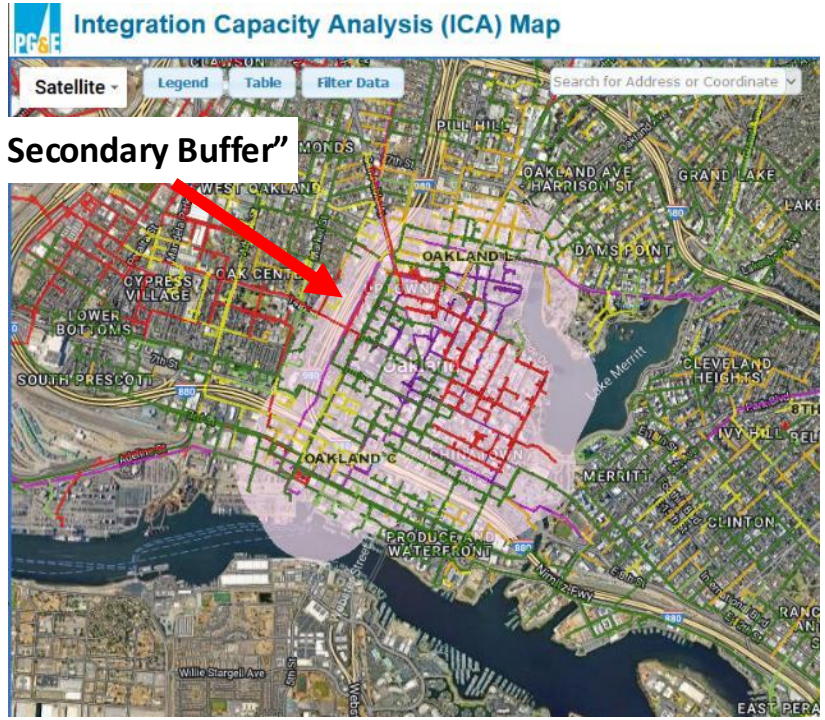
- Utility interconnection maps just show a large red area for grid network where DER interconnections are restricted



Albuquerque, NM



San Francisco, CA



Oakland, CA

Existing Practices

Utility survey of existing practices for LV **Spot Networks** and **Grid Networks**

Sandia is currently working on **new simplified screening procedures** based on various network characteristics that could enable **more DER** interconnections



Spot Networks

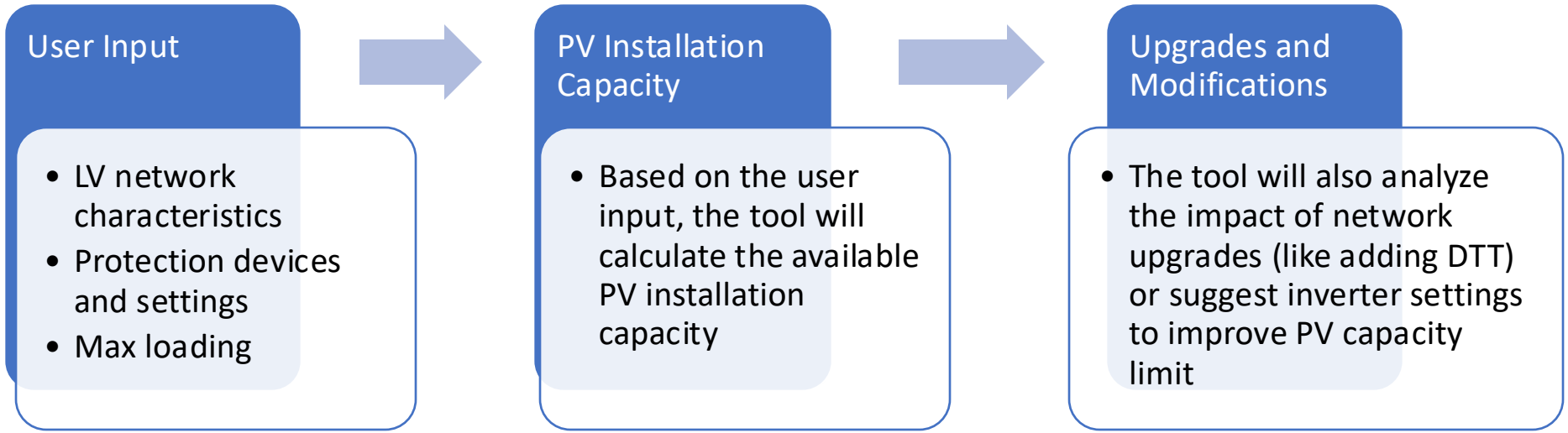
Company	Max Spot Network Generation Allowed (KW)	Max Spot Network Generation Allowed (% of Load)
Public Service Company of New Mexico (PNM)	2000 KW Based on Table Lookup for 12KV	50% of Min Load, Aggregated Generation
American Electric Power - Ohio (AEP)	50 KW, Aggregated Generation	5% of Max Load, Aggregated Generation
Austin Energy (AE)	2000 KW max generator application size	No amount specified. Minimum import limits enforced to avoid export under any conditions
Avangrid CMP (CMP)	*No amount specified*	5% of Max Load, Aggregated Generation
Avangrid UI (UI)	50 KW, Aggregated Generation	5% of Max Load, Aggregated Generation
Commonwealth Edison (ComEd)	50 KW, Aggregated Generation	5% of Max Load, Aggregated Generation
Con Edison (ConEd)	5000 KW max generator application size. Option available to employ alternate NP settings or Comms Aided Tripping of DG.	No maximum specified. Option available to employ alternate NP settings or Comms Aided Tripping of DG.
CPS Energy (CPS)	*No amount specified*	25% of Max Load, Aggregate Generation
Dominion (DOM)	*No amount specified*	*No amount specified*
El Paso Electric (EPE)	*No amount specified*	*No amount specified*
Entergy New Orleans(ENT)	**No Generation Allowed**	**No Generation Allowed**
Eversource CT (ES-CT)	50 KW, Aggregated Generation	5% of Max Load, Aggregated Generation
Eversource MA (ES-MA)	50 KW, Aggregated Generation	5% of Max Load, Aggregated Generation
Florida Power and Light (FPL)	*No amount specified*	*No amount specified*
Hawaiian Electric Company (HECO)	*No amount specified*	*No amount specified*
National Grid NY (NGRID)	5000 KW max generator application size.	50% of Min Load, Aggregated Generation
PEPCO	No amount specified. Minimum import limits enforced to avoid export under any conditions	No amount specified. Minimum import limits enforced to avoid export under any conditions
Pacific Gas and Electric (PG&E)	*No amount specified*	50% of Avg Load
Southern California Edison (SCE)	50 KW, Aggregated Generation	5% of Max Load, Aggregated Generation
Seattle City Light (SCL)	*No amount specified*	*No amount specified*
Sacramento Municipal District (SMUD)	*No amount specified*	*No amount specified*

Grid Networks

Company	Simplified Process Screening Used? (Y/N)	Individual Location Max Gen-to-Load Requirement (%)	Individual Location DG Capacity Limit (KW)	Aggregate Gen-to-Load Requirement (%)
Public Service Company of New Mexico (PNM)	Y		2000 KW	50% of Min
American Electric Power - Ohio (AEP)	N			
Austin Energy (AE)	Y	25% of Min Customer Load		
Avangrid CMP (CMP)	Y		25 KW	
Avangrid UI (UI)	Y		25 KW	
Commonwealth Edison (ComEd)	Y		50 KW	5% of Max
Con Edison (ConEd)	Y		50 KW	15% of Min Load, Aggregated Generation
CPS Energy (CPS)	N			
Dominion (DOM)	N			
El Paso Electric (EPE)	N			
Entergy New Orleans(ENT)	N/A			
Eversource CT (ES-CT)	Y		25 KW	
Eversource MA (ES-MA)	Y	6.7% of Customer Min Load	15 KW	
Florida Power and Light (FPL)	N			
Hawaiian Electric Company (HECO)	N			
National Grid NY (NGRID)	Y		50 KW	15% of Min Load, Aggregated Generation
PEPCO	Y		50 KW	5% of Max Load, Aggregate Generation
Pacific Gas and Electric (PG&E)	Y			10% of Min Load, Aggregated Generation
Southern California Edison (SCE)	Y			5% of Max Load, Aggregated Generation
Seattle City Light (SCL)	N			
Sacramento Municipal District (SMUD)	N			

DER-LV Interconnection Screening Tool

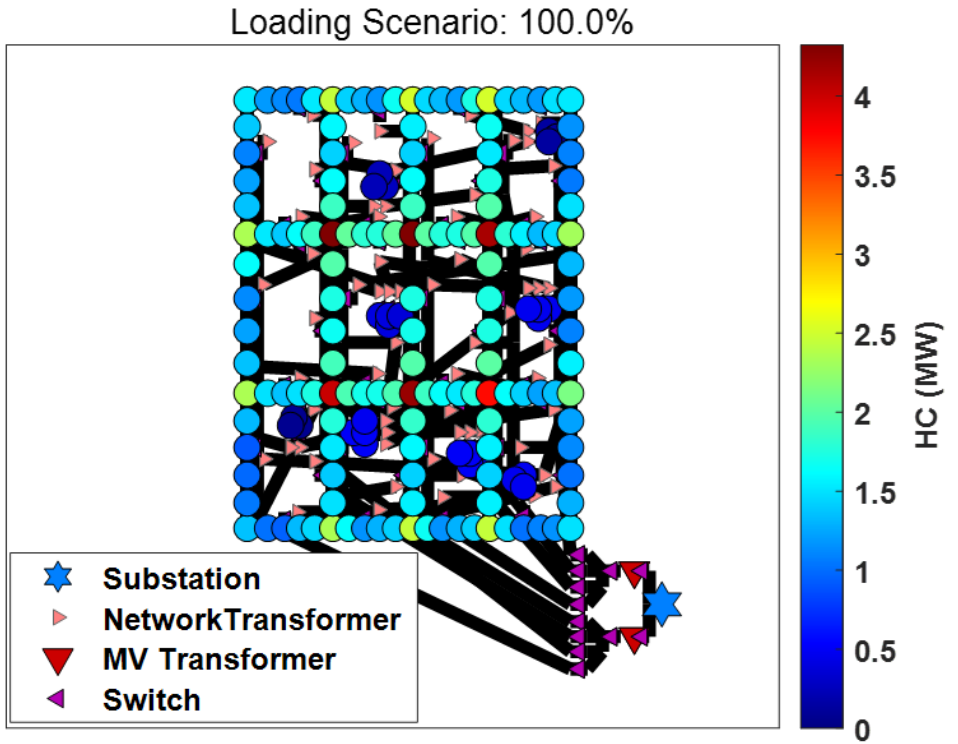
- We are currently working on developing a new screening tool for DER interconnections in LV grid and spot networks[1]
- The goal is to provide identify DER capacity limits at each LV customer location based on various characteristics of the network, ***without*** requiring detailed engineering studies



[1] J. A. Azzolini, M. J. Reno, M. E. Ropp, Z. Cheng, E. Udren, J. Holbach, "Increasing DER Hosting Capacity in Meshed Low-Voltage Grids With Modified Network Protector Relay Settings," IEEE ISGT-LA, 2023.

DER-LV Interconnection Screening Tool

- First, we began developing a detailed **hosting capacity analysis (HCA)** framework that incorporates the unique protection constraints of LV networks
  - Voltage and thermal constraints are also evaluated
  - This code will be soon be open-source and public
- The HCA results on the right show the **maximum HC values** for all locations on the IEEE 342-node LV Network Test System (LVNTS)
  - The **protection constraint** was the most limiting factor at all locations
- Locations at the **meshed nodes** had significantly more capacity
  - Ultimately, the screening tool will take this and other findings into account, resulting in a more **precise** and **customized** set of guidelines

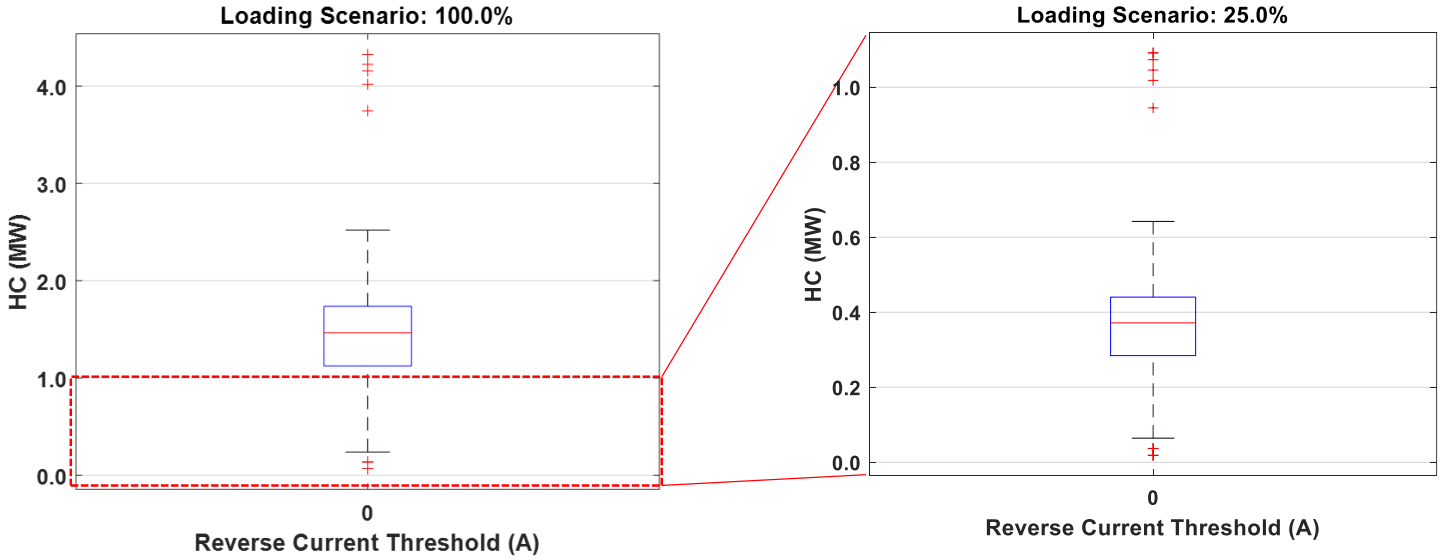


IEEE 342-node LVNTS*

*https://cmte.ieee.org/pes-testfeeders/resources/

Conclusions and Next Steps

- Existing guidelines and practices for DER interconnections in LV grid and spot networks are **overly conservative**
  - There is a significant need for **updated guidelines and tools** for flexible DER interconnections in LV networks
- Using the model-based HCA framework, we will manipulate a **variety of LV network characteristics** to determine their impact on DER HC (e.g., loading conditions, transformer configurations, outaged lines, protection settings)
  - These analyses will then be repeated on multiple LV spot and grid network models (under development) that are based on actual utility systems



Feeder Reconfigurations for Improving DER Hosting Capacity







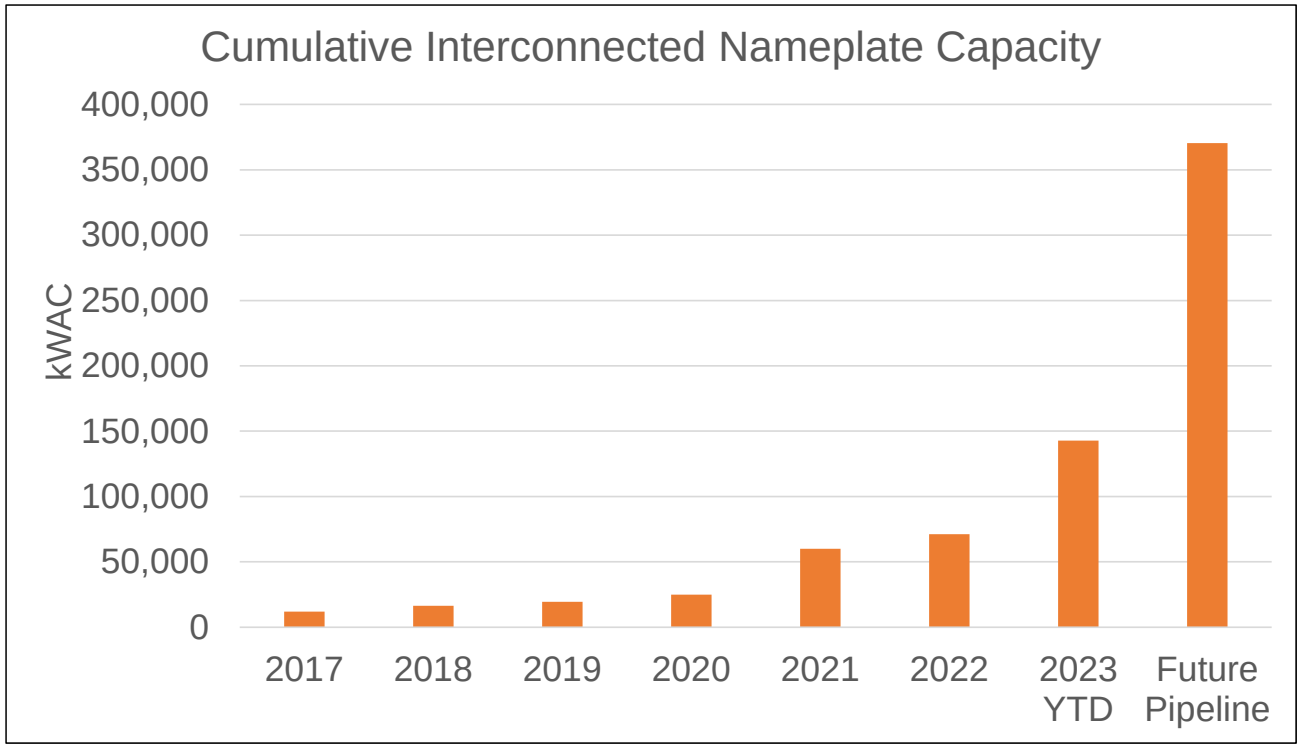
Introduction

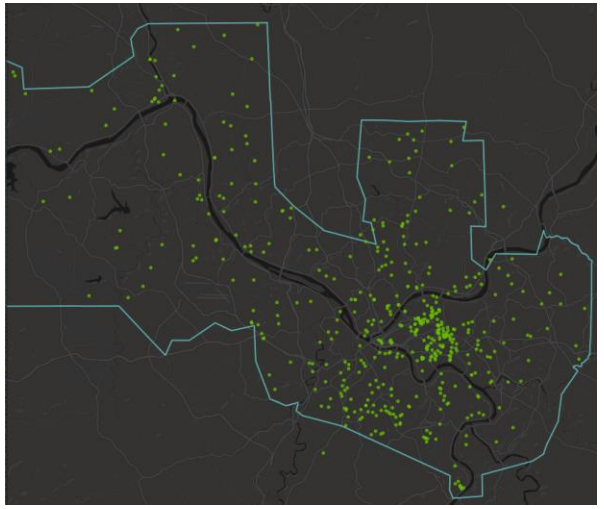
Duquesne Light Company (DLC)

- 600,000 customers across two counties in southwestern PA, including the city of Pittsburgh

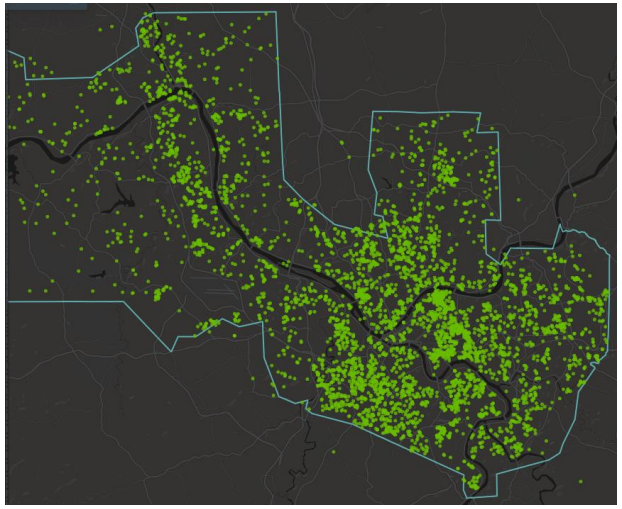
Solar adoption trends:

- Distributed Generation is growing exponentially
- Average of **175** new interconnection applications **monthly** over the last two years
- **62%** annual increase from 2021 to 2022





DER Interconnections, 2016



DER Interconnections, 2022

DLC Need

- Interconnection requests take a considerable amount of engineering resources to complete
  - As requests become more frequent the System Planning group at DLC either needs to increase staffing or to **improve the study process through automation** and **expand study tools**
- Existing practices are extremely conservative, only considering worst-case scenarios
  - **Not able** to evaluate DERMS, volt-var or volt-watt settings, or flexible interconnections, that would enable greater utilization of our assets and reduce infrastructure investment to handle more DER

Opportunities for Improvement

- DLC has many **circuit ties** and **switching capabilities** compared to similar utilities
  - Switching capabilities are often used in emergency situations, these connections are periodically studied to their potential to balance load across the network and improve system reliability
  - Considering switching operations rapidly increases the permutations of network configurations to be studied, **necessitating an automated process**
  - Being able to **provide more flexibility** in offering alternative solutions that may be less costly will encourage solar developers to work in DLC territory

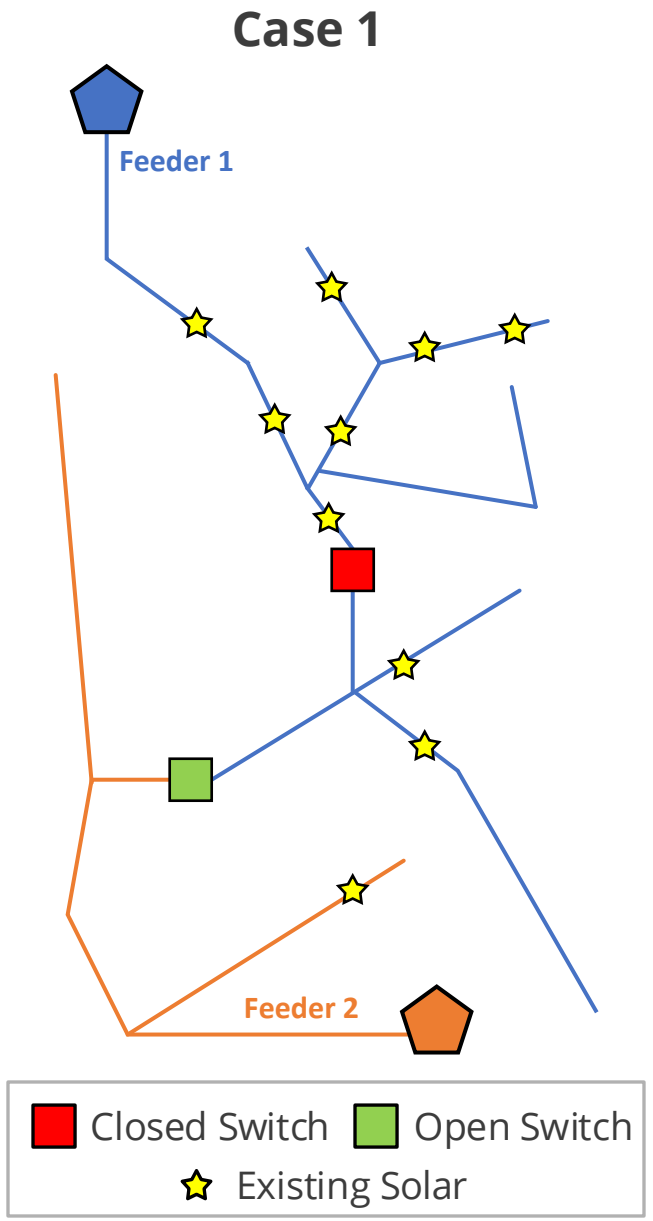
DLC Need—Optimal Feeder Configurations

Example Case 1:

- In this example, Feeder 1 already has a high penetration of existing distributed solar
- In this scenario, Feeder 1 is approaching its PV hosting capacity limit
- However, there are sections of the feeder that have minimal solar installations

Solution:

- Re-configure the feeders to increase the total hosting capacity of the system



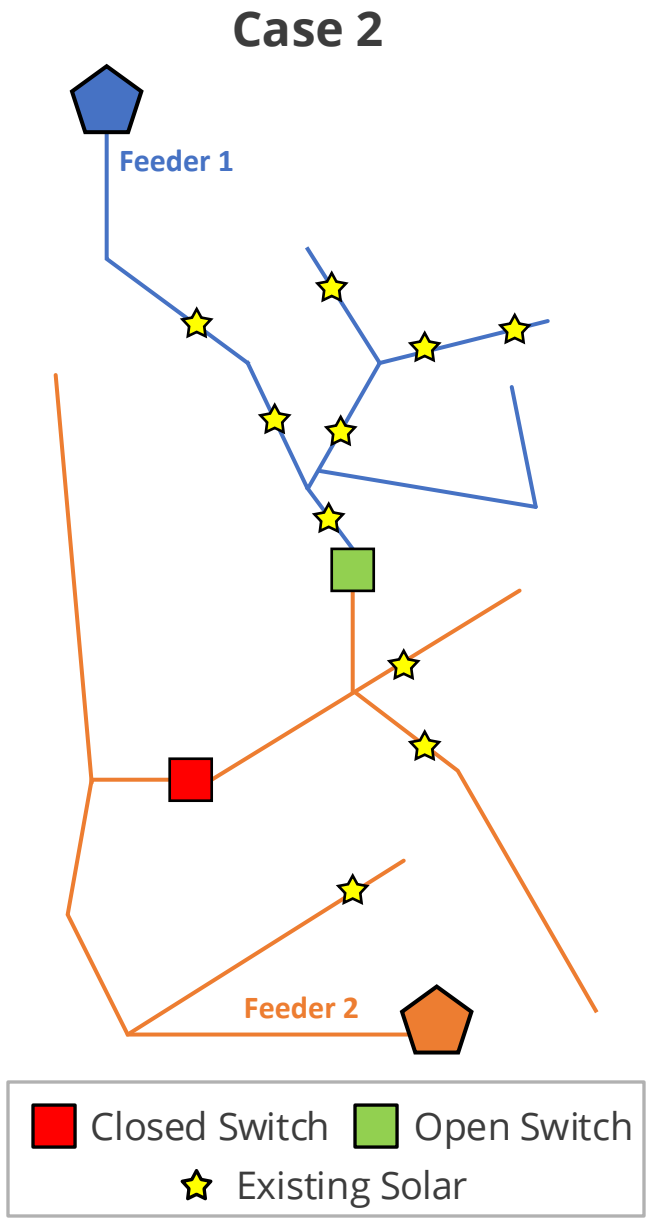
DLC Need—Optimal Feeder Configurations

Example Case 2:

- In this example, the only changes were that the states of the two switches were reversed
- This allowed Feeder 2 to pick up several sections of Feeder 1

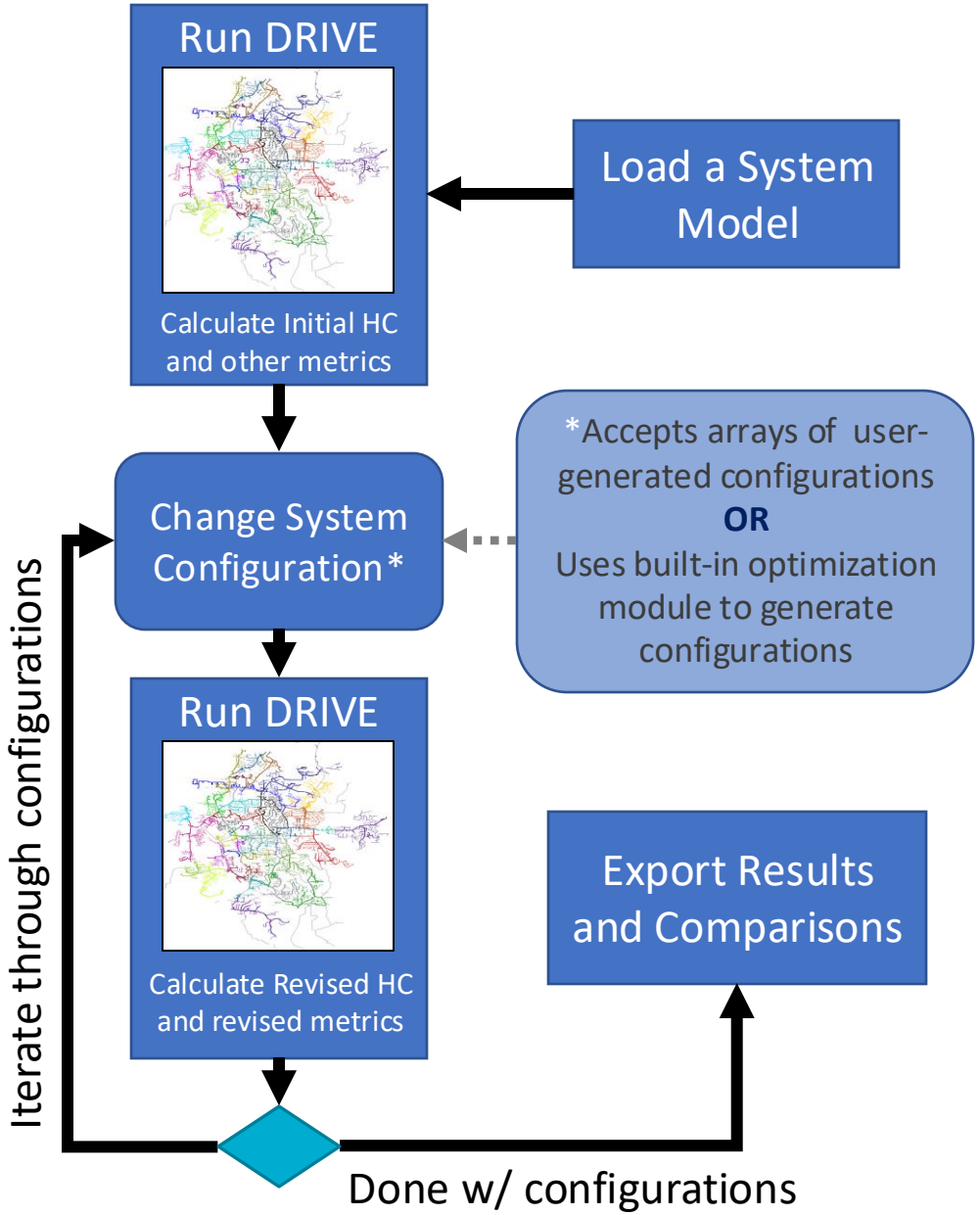
Results:

- Feeder 2 still has plenty of available hosting capacity
- Feeder 1 may also recoup some hosting capacity, as two of the PV systems at the end of the feeder were transferred to Feeder 1
- Overall, total system hosting capacity was increased



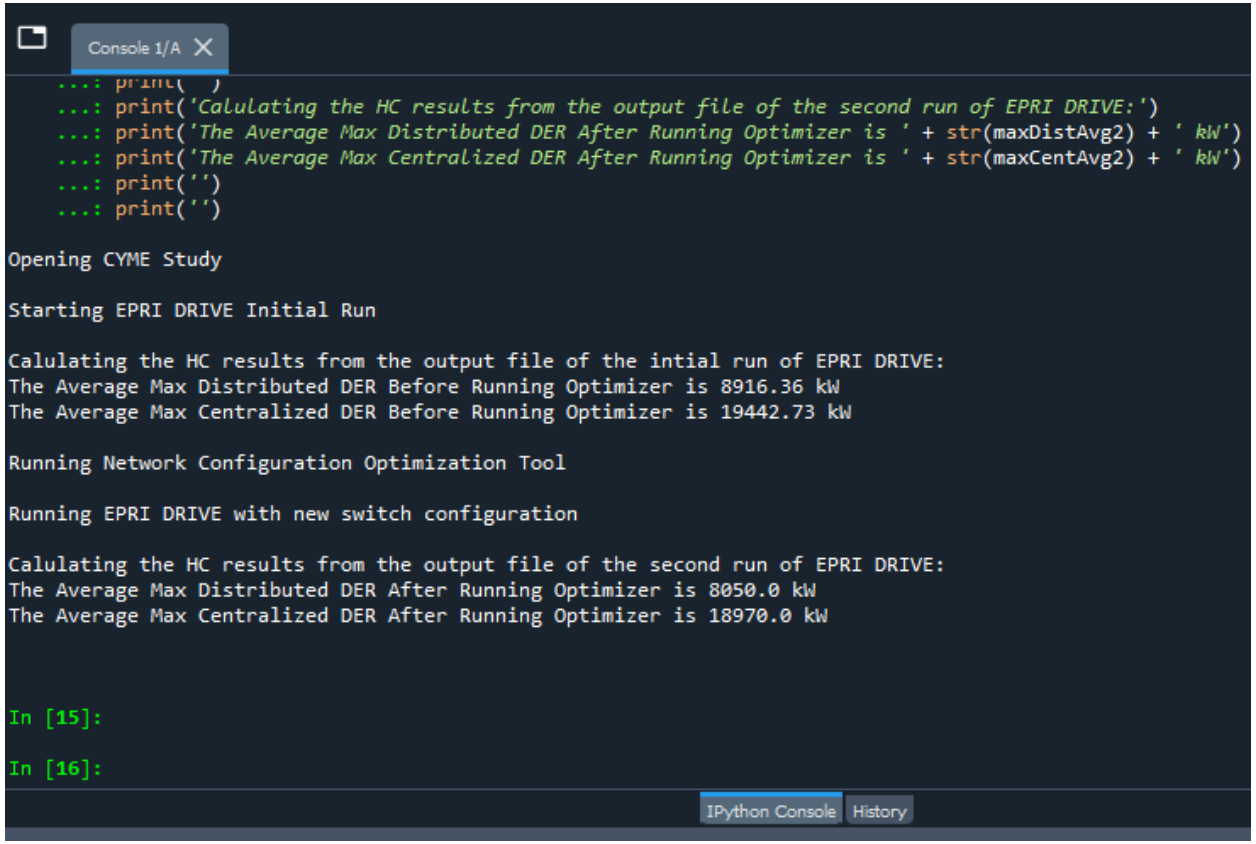
Optimal Feeder Configurations to Support DER Interconnections

- Leverage python scripting and several analysis modules in CYME to implement a custom, *automated* solution for evaluating the DLC objectives
- For example, the network configuration module can be run to generate a subset of possible switching operations
  - Large systems may have **near-infinite possible permutations** of switch states, so optimization methods are required
- We can iterate through the valid configurations and use the EPRI DRIVE module to evaluate the impacts to hosting capacity (HC) or other system metrics
- With different load and generation models, we can analyze the impacts of seasonality on the results



Code Implementation

- Use Python Scripts with the CymPy Library to leverage data analysis and automation of Python with CYME tools
- The CymPy Library allows function calls using Python directly into CYME
- Automate CYME analysis with modules such as Network Configuration Optimization and EPRI DRIVE
- The CymPy Library can save analysis out to CSV files



Sample Commands:
import cympy
cympy.study.open(C:\path\to\model\testModel.sxst
nco = cympy.sim.NetworkConfigurationOptimization()
nco.SetValue('MinimizeVoltageExceptions', 'Objective')
nco.run
Cympy.rm.Save('Network Configuration Optimization – Summary', ...)

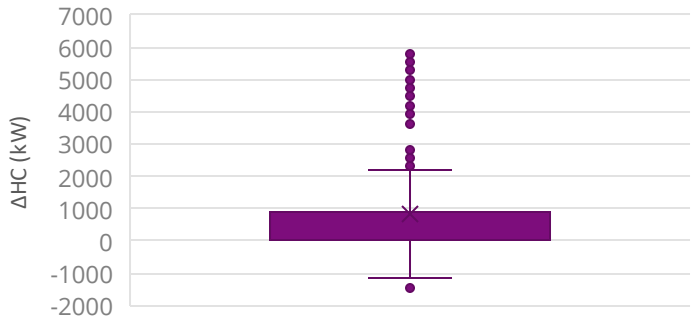
This approach allows the **automation** of analysis and integration into a utility workflow without manually using the CYME GUI

Feeder Reconfiguration Options

Different initial conditions can change the results, so iterating through this analysis manually would be tedious and time-consuming

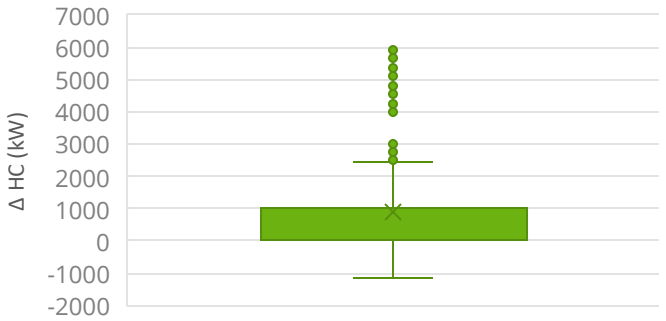
Objective	-	Minimize Losses	-	Minimize Losses
Load Model	Light Load	Light Load	Peak Load	Peak Load
System Losses	623 kW	608 kW **(2.45% reduction)**	3,536 kW	3,373 kW **(4.61% reduction)**
# of Overloaded Elements (MVA Affected)	2	2	30 (1.51 MVA)	26 (1.10 MVA)
# of Elements w/ under-voltage	4	4	1656	1476
Average Node-level HC	3,402.03 kW	3,515.34 kW **(+3.33% increase)**	3,402.03 kW	3,515.05 kW **(+3.32% increase)**

Node-level Changes in HC (Light Load)



Median: 40 kW
Mean: 817 kW
75th percentile: 900

Node-level Changes in HC (Peak Load)



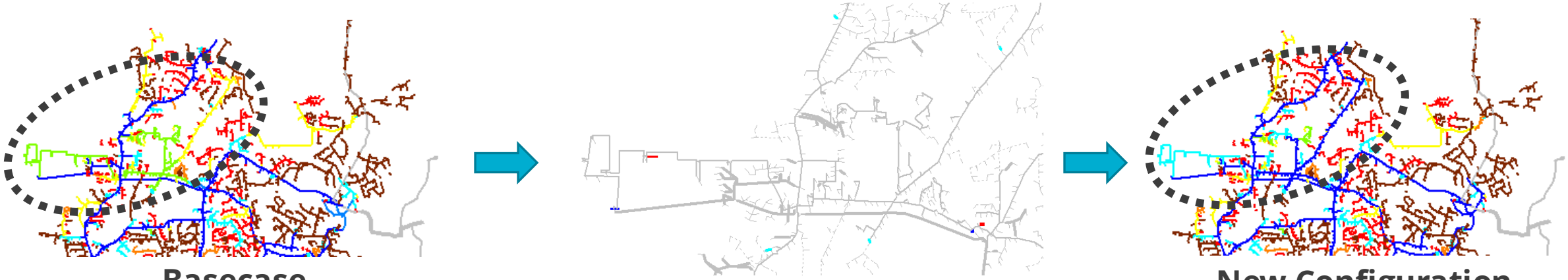
Median: 50 kW
Mean: 863 kW
75th percentile: 990

Reconfiguration Impacts on DER Hosting Capacity

- While max system-wide HC may not change drastically, certain locations or branches can have significant impacts
- Overall, this automation script can be adapted for many uses:
  - Maximize total hosting capacity for a feeder (general investment planning)
  - Increase hosting capacity at a particular location because of a large DER interconnection request (interconnection process)

Greater than (kW)	Lower than or equal to (kW)	Circle	Size	Line width	Color
0.0	1250.0	No	100.0 %	2	
1250.0	2500.0	No	100.0 %	2	
2500.0	3750.0	No	100.0 %	2	
3750.0	5000.0	No	100.0 %	2	
5000.0	6250.0	No	100.0 %	2	
6250.0	7500.0	No	100.0 %	2	
7500.0	8750.0	No	100.0 %	2	
8750.0	50000.0	No	100.0 %	2	

Example Configuration Change



Basecase

Navy Blue: Open → Closed
Red: Closed → Open

New Configuration

Conclusions

- The proposed approach will enable tangible improvements in the **automation and flexible interconnection practices** for evaluating PV requests
- The approach maximizes the use of existing tools whenever possible to ensure that the results are robust and reliable
  - Distribution systems may have **10s or 100s of circuit switches**, meaning there are near-infinite unique configurations to consider
- The **script-based tool** integrates with CYME to evaluate feeder reconfigurations and propose sets of switching states to optimize the system for enhanced hosting capacity
- The tool can be utilized dynamically to ensure optimality is maintained across **seasonal changes** and as new PV installations come online over time
- This can also be used to **evaluate specific configurations** to inform planning and operations teams





THANK YOU

Questions?

Matthew J. Reno— mjreno@sandia.gov
Joe Azzolini — jazzoli@sandia.gov

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY



Q&A

INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

Thank You!

Website: energy.gov/i2X

Email: i2x@ee.doe.gov