Utility and Grid Operator Resources for Future Power Systems Webinar Series

Distributed Energy Resource Integration

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NREL Webinar Series

July 29, 2025

Content credit: Erik Pohl, Abodh Poudyal, and Sherin Ann Abraham

Agenda

1. DERs and Industry Baseline
2. A Holistic View of DER Integration
3. DER Interconnection Standards: Considerations and Modeling
4. Interconnection Screening and Study Process
5. Interconnection Automation and Hosting Capacity
6. Looking Forward: AMI Analytics and NWAs
7. Wrap-Up

DER: distributed energy resource
AMI: advanced metering infrastructure
NWAs: non-wires alternatives

DER Definitions and U.S. Adoption

DER Definition(s)

- IEEE 1547-2018 definition:

*“Distributed energy resource (DER): A source of electric power that is **not directly connected to a bulk power system**. DER includes both **generators and energy storage** technologies **capable of exporting active power** to an EPS [Electric Power System]. An interconnection system or a supplemental DER device that is necessary for compliance with this standard is part of a DER.*

NOTE 1—Controllable loads used for demand response are not included in the definition of DER.”

Table 1. Definitions of Distributed Energy Resources

Definition	Source
A Distributed Energy Resource (DER) is any resource on the distribution system that produces electricity and is not otherwise included in the formal NERC definition of the Bulk Electric System (BES)	NERC[a]
Distributed energy resources are small, modular, energy generation and storage technologies that provide electric capacity or energy where you need it.	NREL[b]
[Distributed Energy Resources (DER) are] technology advancements in connected loads, solar photovoltaics (PV) and energy storage.	EPRI[c]
DER as used in this report includes distributed generation, distributed energy storage, energy efficiency, demand response and electric vehicles.	PNNL[d]

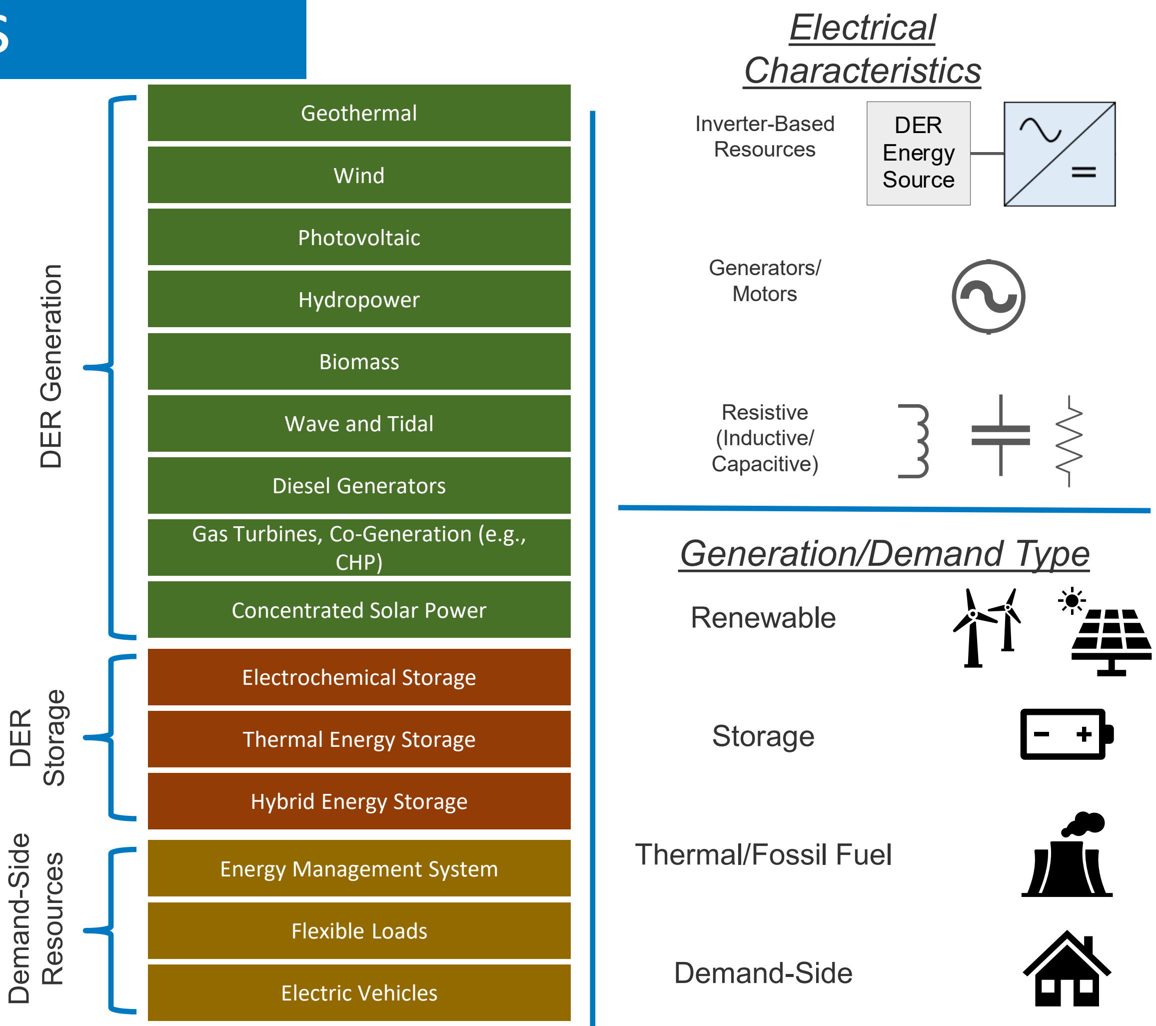
(a) North American Electric Reliability Corporation
(b) National Renewable Energy Laboratory
(c) Electric Power Research Institute
(d) Pacific Northwest National Laboratory

Source: McDermott, Thomas E., Killian McKenna, Miguel Heleno, Bilal Ahmad Bhatti, Michael Emmanuel, and Sydney Forrester. Distribution System Research Roadmap; Energy Efficiency and Renewable Energy. No. PNNL-31580. Pacific Northwest National Lab.(PNNL), Richland, WA (United States), 2022.

“IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces,” IEEE Std 1547-2018 (Revision of IEEE Std 1547-2003), pp. 1–138, Apr. 2018, doi: 10.1109/IEEESTD.2018.8332112.

Types of DERs

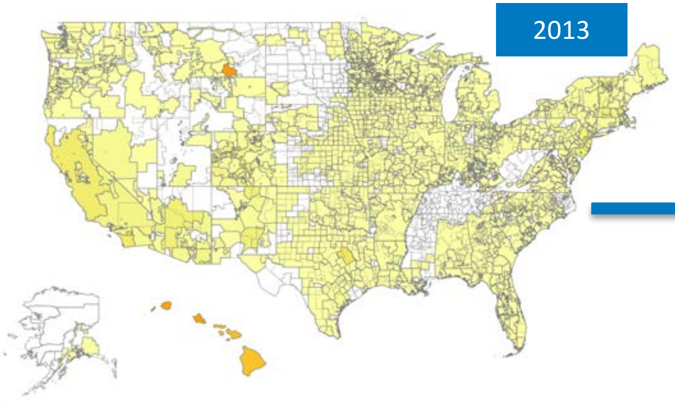
- DERs can be classified to include DER generation, storage, and demand-side resources (although many definitions exclude resources not capable of export).
- Size of DERs can range from 10s of watts to multi-megawatt (MW) systems, front-of-meter to behind-the-meter applications.
- Connecting voltage can range from 120/240-volt split-phase systems to three-phase 34.5 kilovolt (kV) connections.



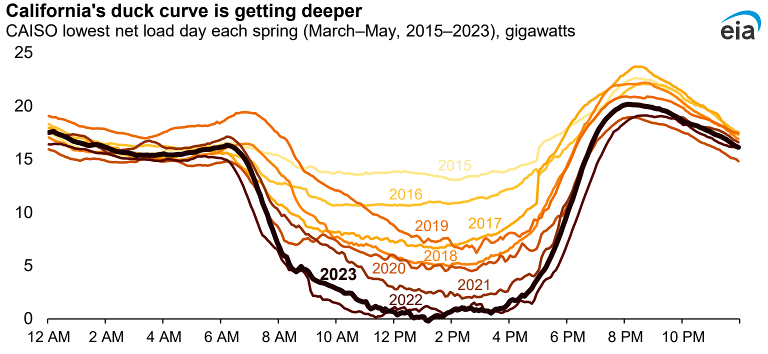
CHP: combined heat and power

Industry Benchmarking: Net Metered DER Capacity in the United States

Net Metered DER Capacity as Percentage of Summer Peak Load

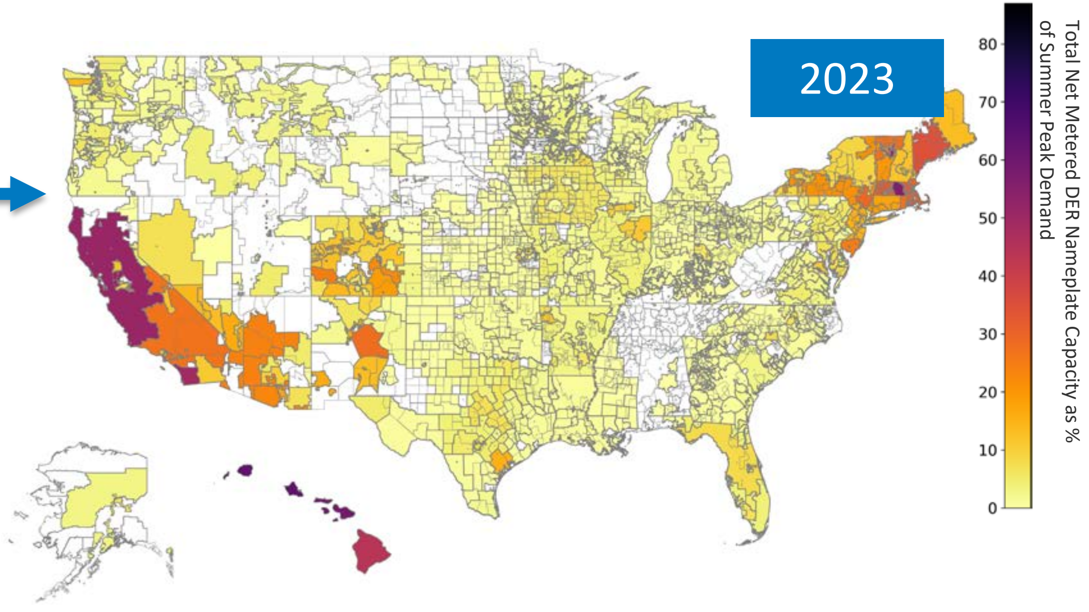


Data source: Energy Information Administration (EIA) 861



Source: EIA, "As solar capacity grows, duck curves are getting deeper in California", June 21, 2023, URL: https://www.eia.gov/todayinenergy/detail.php?id=56880#

Net Metered DER Capacity as Percentage of Summer Peak Load



Data source: NREL analysis of EIA 861

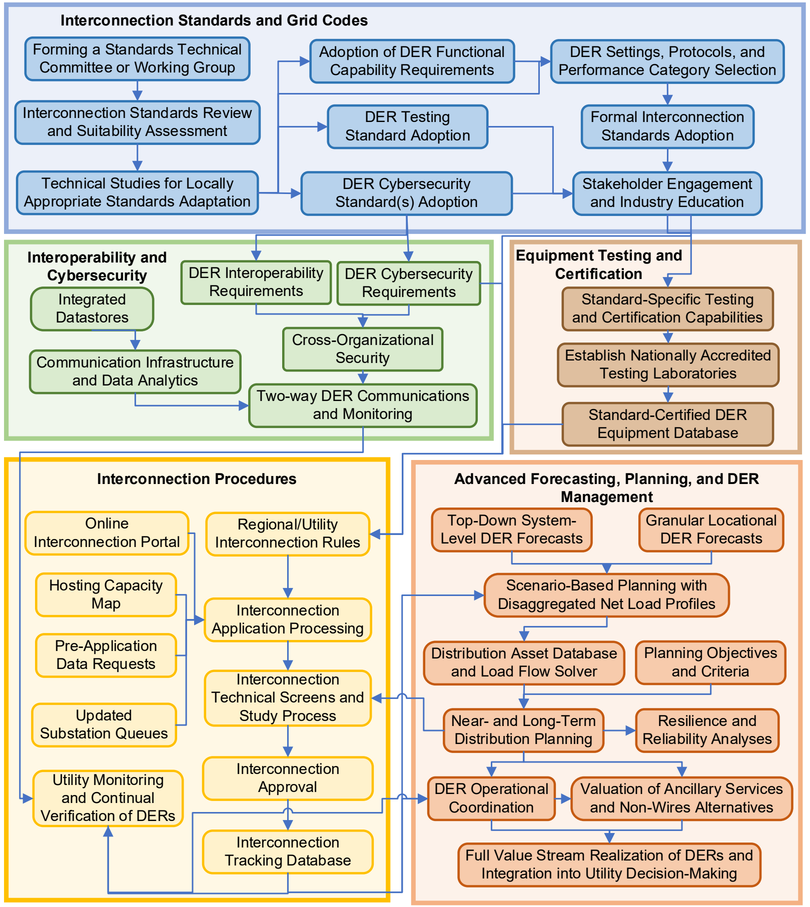
There has been over **45 gigawatts (GW)** of net metered DER capacity installed nationwide, with close to **90% of that capacity being small-scale solar rooftop** installations (NREL EIA, 2022).

A Holistic View of DER Integration

DER Integration: Core Components

- NREL has been working across multiple streams of best practices for *DER Integration,* including activities of:
  - **Interconnection standards and grid codes**
  - **Interoperability and cybersecurity**
  - **Equipment testing and certification**
  - **Interconnection procedures**
  - **Advanced forecasting, planning, and DER management.**

Holistic DER Planning Framework



Adapted from Pohl & McKenna, 2024: *https://www.osti.gov/servlets/purl/2474838.*

DER Integration Resources

Interconnection Standards and Grid Codes	
CSA C22.3 No. 9 – 2020	*Interconnection of Distributed Energy Resources and Electricity Supply Systems*: Issued under Part III of the Canadian Electric Code, outlining requirements for DER interconnection (<50-kilovolt [kV] interconnections) and DER equipment testing and certification.
EN 50549 – 2019	*Requirements for Generating Plants to be Connected in Parallel with Distribution Networks*: European standard providing requirements for generating plants connected at low- or medium-voltage distribution networks and serving as a technical reference for functionalities defined in the European Network Code's Requirements for Generators.
IEC TS 62786 – 2017	*Distributed energy resources connection with the grid:* An IEC Technical Specification providing the principles and technical requirements for DER interconnections.
IEEE NESC – 2023	*National Electrical Safety Code:* Updated by IEEE every 5 years, this sets rules for ensuring worker and public safety and defines rules for the construction, installation, operation, and maintenance of electric infrastructure, communications, and related equipment.
IEEE Std 1547 "Family of Standards" [	*IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*: IEEE's suite of DER interconnection standards and guides, with the benchmark standard being IEEE 1547-2018. Accompanying standards and guides include testing procedures, impact studies, energy storage interconnections, and cybersecurity.

Equipment Testing and Certification	
ANSI/UL 1741 – 2023	*Inverters, Converters, Controllers, and Interconnection System Equipment for Use With Distributed Energy Resources*: A product safety standard covering the testing and certification of advanced inverters used for grid-connected systems as defined in IEEE 1547.
CAN/CSA C22.2 No. 107.1 – 2021	*Power Conversion Equipment*: Issued by the CSA Group and part of the Canadian Electrical Code, this provides testing and certification for power converters.
CAN/CSA 22.2 No. 330 – 2023	*Photovoltaic rapid shutdown systems*: Establishes provisions for rapid shutdown photovoltaic (PV) systems and is to be used in conjunction with CAN/CSA C22.2 No 107.1-2021.
IEC 62109	*Safety of power converters for use in photovoltaic power systems:* A multi-part international standard covering safe use of power converters with photovoltaics.
IEC 62116 – 2014	*Utility-interconnected Photovoltaic Inverters - Test Procedure of Islanding Prevention Measures*: Outlines testing procedures for anti-islanding performance for grid-connected PV systems.
IEC 62446	*Photovoltaic (PV) systems - Requirements for Testing, Documentation, and Maintenance*: A multi-part standard that defines the required information exchanges and documentation between the commissioning entity and the customer for the installation of a grid-connected PV system as well as the necessary commissioning testing, inspection criteria, documentation, and maintenance to ensure a safe installation and sound interconnection.
IEC 61215	*Terrestrial photovoltaic (PV) modules - Design qualification and type approval:* A two-part standard describing environmental stress tests and test procedures to assess whether a module can withstand prolonged outdoor exposure.

Interoperability and Cybersecurity	
ASHRAE 135 – 2020	*BACNET™— A Data Communication Protocol for Building Automation and Control Networks*: Defines a building automation and control networking protocol for applications such as heating, ventilation, and air conditioning; fire safety; energy management; lighting; physical access; and elevators.
ASHRAE 201 – 2020[1]	*Facility Smart Grid Information Model*: Provides an object-oriented information model to manage loads and generation in coordination with a utility smart grid.
EPRI Common File Format v 2.0 – 2022	*EPRI Common File Format v 2.0*: A file formatting guidance document, developed in alignment with IEEE 1547.1-2020, to standardize the exchange and formatting of DER configuration data and settings.
IEC 61850-7-420 – 2021	*Communication networks and systems for power utility automation - Part 7-420: Basic communication structure - Distributed energy resources and distribution automation logical nodes:* Provides DER information models to be used with the IEC 61850 communication protocol and distribution automation systems including full support of the advanced functionalities in IEEE 1547, EN 50549, and IEC 62786.
IEC 60870-5-101 – 2015[1] **IEC 60870-5-104 – 2016[1]**	*Telecontrol equipment and systems - Part 5-101: Transmission protocols - Companion standard for basic telecontrol tasks*: Provides the communication profile and interoperability for telecontrol communications sent between central telecontrol stations and distributed outstations for the automation of electric power systems. *Telecontrol equipment and systems - Part 5-104: Transmission protocols - Network access for IEC 60870-5-101 using standard transport profiles*: Expands upon 60870-5-101 to obtain network access using standard transport profiles. It is used for monitoring and controlling geographically dispersed processes.

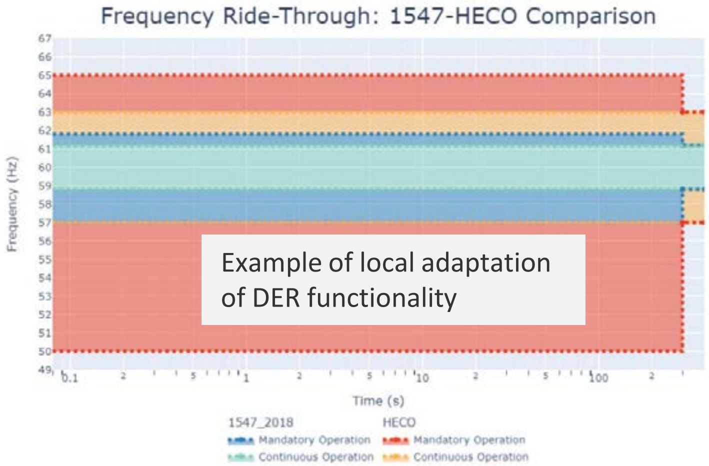
Interconnection Procedures	
FERC SGIA – 2023	*Small Generator Interconnection Application*: Outlines the contractual agreements and application materials for interconnecting generators under 20 MW.
FERC SGIP – 2023	*Small Generator Interconnection Procedures*: Outlines the technical screening procedures necessary for interconnecting generators under 20 MW.
IEEE 1547.7 – 2013	*IEEE Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection*: Provides criteria, scope, and extent for engineering studies of the impact of DERs on a distribution system.
IEEE 1547.9 – 2022	*IEEE Guide for Using IEEE Std 1547 for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems*: Provides additional guidance and considerations for interconnecting energy storage DERs beyond what is included within the IEEE 1547-2018 base standard.
IREC BATRIES Toolkit	*Building a Technically Reliable Interconnection Evolution for Storage (BATRIES) Toolkit - The Toolkit and Guidance for the Interconnection of Energy Storage and Solar-Plus-Storage*: Provides DER interconnection guidance specific to energy storage systems or solar-plus-storage systems.

Advanced Forecasting, Planning, and DER Management	
DOE DSPx – 2020	*Modern Distribution Grid*: A four-part series providing a holistic, transparent, multi-objective and performance-driven decision framework to inform investment decisions and grid modernization initiatives. The four parts address key functional requirements for future grids, technology maturity assessments to achieve those functional requirements, a decision guide for implementation of functionalities, and overall grid modernization strategy and implementation.
IEEE 2030.11-2021	*IEEE Guide for Distributed Energy Resources Management Systems (DERMS) Functional Specification*: Guidance document on the functional implementation of a DER management system, including interoperability requirements, transmission and distribution coordination, and communication and information infrastructure requirements.
NARUC Comprehensive Planning Library	*NARUC Comprehensive Planning Library*: An online resource guide related to comprehensive electricity planning, including topics related to data access, ratemaking, distribution system planning, emerging distribution system planning practices, forecasting, grid modernization, planning coordination, planning criteria, procurement strategies, resilience, rural DER integration, scenario and risk analysis, solution evaluation, stakeholder engagement, and utility best practices for integrated planning.
PNNL Grid Architecture	*Grid Architecture*: Provides a theoretical framework using a combination of system architecture, network theory, control engineering, and software architecture to conceptualize and manage a hyper-complex grid of the future.

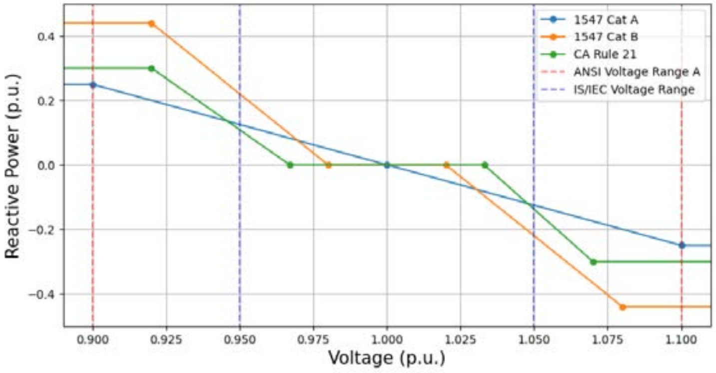
Adapted from Pohl & McKenna, 2024:
https://www.osti.gov/servlets/purl/2474838

DER Integration: Interconnection Standards and Grid Codes

- Interconnection standards and grid codes provide the baseline requirements for the performance, operation, testing, safety, and maintenance of DERs.
- Standardize DER performance across large regional grids to enable higher confidence that DERs in all regions of their system will perform as expected and simplify modeling, monitoring, and verification.
- Utility adoption should be locally-appropriate and may start with enabling capabilities, followed by choices on settings.
- Early adoption is key.



Source: NREL visualization of IEEE 1547-2018 and Hawaiian Electric ride-through settings



Source: IEEE 1547 Category A and B and ANSI and IS/IEC voltage ranges

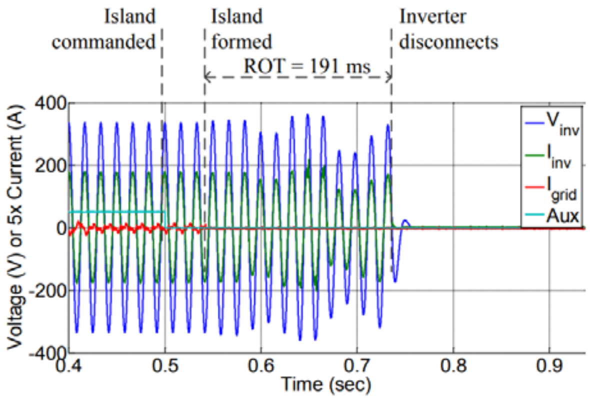
DER Integration: Equipment Testing and Certification

- Utilities may require standard-certified equipment.
- **UL 1741 is harmonized with IEEE 1547-2018** and the accompanying IEEE testing standard 1547.1-2020.
- Certification can instill confidence that DERs will perform as required.
- Leveraging existing databases on certified equipment (e.g., [California Electric Commission's Solar Equipment Lists Program](https://www.energy.ca.gov/programs-and-topics/programs/solar-equipment-lists)).
- Commissioning and periodic interconnection tests/remote monitoring to ensure agreed-upon settings remain **for the lifespan of the DER equipment**.

California Energy Commission, Solar Equipment Lists Program, https://www.energy.ca.gov/programs-and-topics/programs/solar-equipment-lists.

Equipment Testing Categories in IEEE 1547.1-2020

Type tests
Interoperability tests
Production tests
DER evaluations
Commissioning tests
Periodic interconnection tests



Run-on time for typical anti-islanding test

Source: Hoke et. al. "Experimental Evaluation of PV Inverter Anti-Islanding with Grid Support Functions in Multi-Inverter Island Scenarios", 2016. https://docs.nrel.gov/docs/fy16osti/66732.pdf.

DER Integration: Interoperability and Cybersecurity

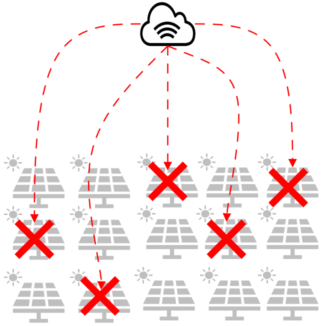
- **Operational visibility** of DER performance to benefit distribution system planning
- Early protocols to simply communicate DER settings and utility required profiles
- **Electric Power Research Institute (EPRI) Common File Format**: file formatting guidance, in alignment with IEEE 1547.1-2020
- Increased adoption of internet-connected, remote-accessible, grid-interactive devices presents **new cybersecurity risks** for utilities, developers, and even consumers
- Unique cybersecurity challenges for DERs (e.g., cross-organizational security and risk distribution)
- **IEEE 1547.3-2023**: protocols for communication between DERs and utility control systems, ensuring integration and coordination.


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Industry Recommendation
Inverter-Based Resource Performance Issues

Initial Distribution: March 14, 2023

North American Electric Reliability Corporation (NERC), Industry Recommendation – Inverter-Based Resource Performance Issues, 2024, URL: https://www.nerc.com/pa/rrm/bpsa/Alerts%20DL/NERC%20Alert%20R-2023-03-14-01%20Level%202%20-%20Inverter-Based%20Resource%20Performance%20Issues.pdf.



DER Information Categories (as defined in IEEE 1547-2018)

Nameplate information
Configuration information
Monitoring information
Management Information

Source: EPRI. "Common File Format for DER Settings Exchange and Storage: Version 2.0." https://www.epri.com/research/products/000000003002025445.

DER Integration: Grid Impacts

- **Scaling study complexity to the probability for adverse grid impacts**
- The integration examination of the aggregate impacts of many small-scale DERs is critical
- Major categories of DER impacts:
  - **Thermal limits**
  - **Voltage and power quality**
  - **Protection systems**
  - **Operational flexibility**
  - **Bulk power system impacts and system stability.**

Federal Energy Regulatory Commission (FERC) Small Generator Interconnection Procedures (SGIP) Key Concepts and Procedures

Certification criteria

Preapplication reports

Queue positions

The 10 kilowatt (kW) inverter process

Fast-track process

Supplemental review

The study process

The feasibility study

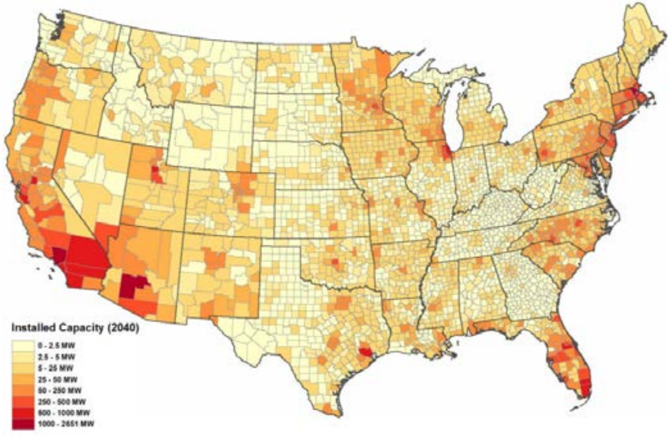
A system impact study

A facilities study

DER Integration: Advanced Forecasting, Planning, and Management of DERs

- Incorporating DERs into load forecasting and planning exercises is becoming increasingly critical.
- Many utilities today employ deterministic load forecasting.
- In the face of growing DERs, utilities may elect to use probabilistic forecasts.
- Top-down vs. bottom-up customer adoption modeling.
- Integrated distribution planning (IDP) represents a unified, objective-driven framework for developing holistic planning and grid investment strategies and enabling the continued reliable integration of grid-edge technologies.

Distributed PV Adoption Example Scenario Analysis – Mid-Cost Scenario – Projected Installed Capacity by the Year 2040



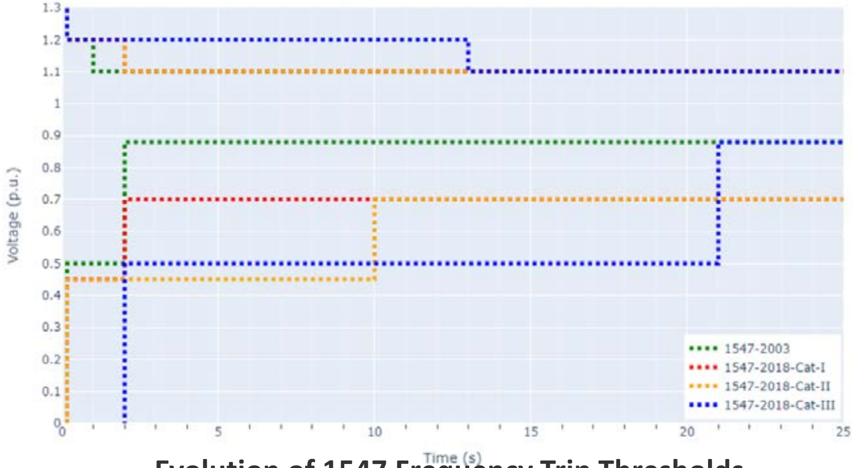
NREL, The North American Renewable Integration Study: A U.S. Perspective, 2021, URL: https://docs.nrel.gov/docs/fy21osti/79224.pdf

DER Interconnection Standards

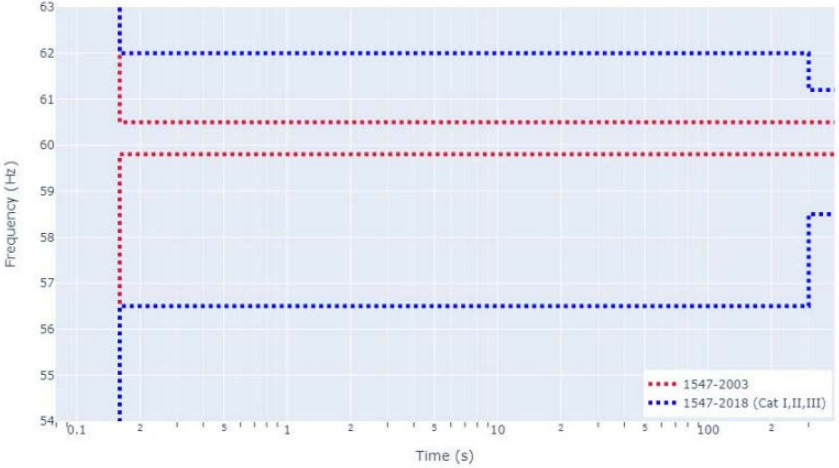
Evolution of IEEE 1547 Interconnection Standards

- Do nothing → Do no harm → Do something.
  - **Must** trip → **May** ride through → **Must** ride through for grid disturbances.
  - **Must not** regulate→ **May** regulate → **Must be capable of** regulating voltages.
- "Do nothing" and "do no harm" are low consequence strategies at low adoption levels where widespread loss of DERs is inconsequential to distribution or bulk power system operations.
- More proactive strategies can help alleviate future risks for high DER adoption scenarios (e.g., 50.2 hertz [Hz] problem).

Evolution of 1547 Voltage Trip Thresholds



Evolution of 1547 Frequency Trip Thresholds

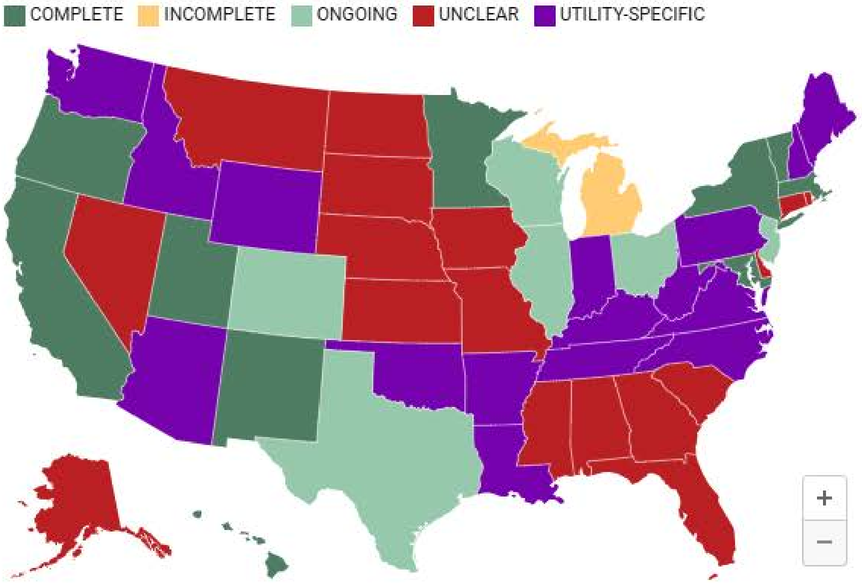


Credit: Erik Pohl, NREL

Industry Benchmarking: 1547-2018 Adoption

State & Utility Adoption Map

State Adoption Status



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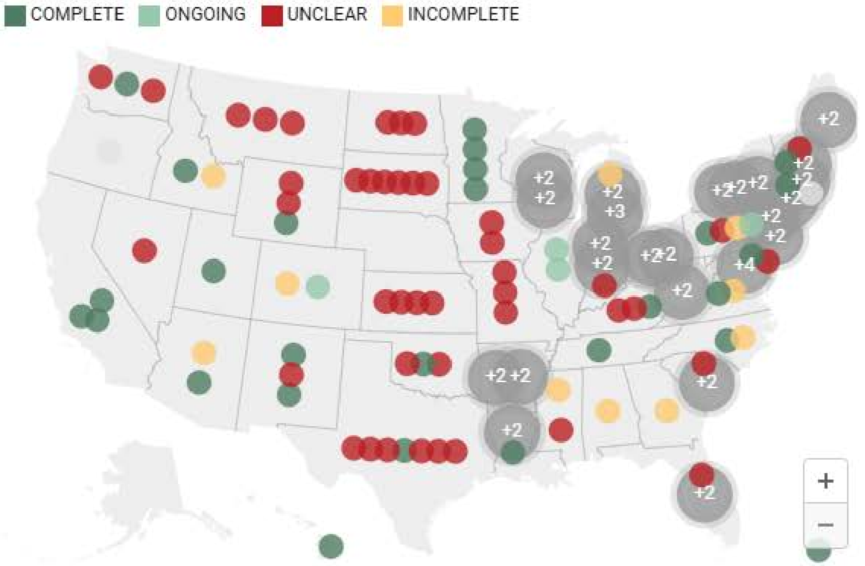
Utility Adoption Status



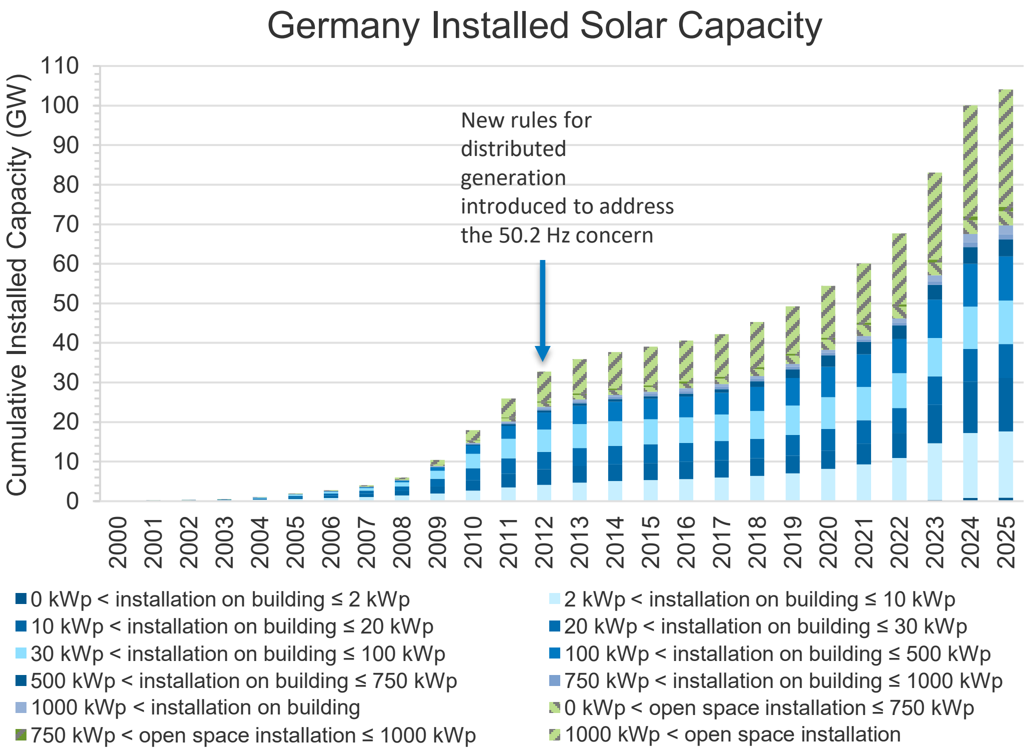
	ADOPTION STATUS	
LABEL	STATE	UTILITY
COMPLETE	The state's regulatory commission, or all regulated utilities, have completed the IEEE 1547-2018 adoption process—meaning they have selected and formally publicized an implementation date by which inverters certified to the standard (UL 1741 SB) are required, and have either set state-wide inverter settings requirements or have officially delegated some or all settings selection authority to their utilities. Note that the implementation date could be in either the past or in the future.	The utility has completed the IEEE 1547-2018 adoption process—meaning they have selected and formally publicized both an implementation date by which inverters certified to the standard (UL 1741 SB) are required, and territory-wide inverter settings requirements. This includes utilities that have determined that some settings are site-specific and thus undefined. Note that the implementation date could be in either the past or in the future.

Source: Interstate Renewable Energy Council "IEEE 1547-2018 Adoption Tracker", 2024. [*https://irecusa.org/resources/ieee-1547-2018-adoption-tracker/*](https://irecusa.org/resources/ieee-1547-2018-adoption-tracker/).

Importance of DERs for System Stability: Case Study

Germany and Retrofitting PV Inverters

- Late 2000s Germany had over 14 GW of low-voltage solar PV.
- These systems were programmed to trip at an **over-frequency** event of **50.2 Hz.**
- Given typical primary control reserve capacities of 3 GW this would have been detrimental and caused a severe **under-frequency** event.
- Result was an expensive and timely retroactive setting of all inverters.
- Proactive adoption with low levels of DERs and field verification of ride-through settings is critical and can avoid risk or expensive retrofits.
- **How will grid conditions change in the future that may render today's responses ineffective?**



Data Source: Energy-Charts.info

kWp: kilo-Watt-peak

Boemer & Burges, "Overview of German Grid Issues and Retrofit of Photovoltaic Power Plants in Germany for the Prevention of Frequency Stability Problems in Abnormal System Conditions of the ENTSO-E Region Continental Europe", 2011.

NREL IEEE 1547-2018 Resources

- Over 40 reports covering primers, design for adoption, implementation, protection, anti-islanding, reactive power control, power quality, and more.
- Several reports are authored by key contributors to the 1547-2018 standard.


IEEE 1547-2018 Resources

NREL

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Educational Materials

Learn about the revised Institute of Electrical and Electronics Engineers Standard 1547-2018 (IEEE Std 1547-2018) through these educational materials, which include webinars, white papers, and other resources.

The revised version features new concepts and new technical requirements, which enable the use of modern distributed energy resources to improve performance of the electric grid during day-to-day operations and improve grid resilience during abnormal grid conditions.

The revised standard was published in April 2018 and is now available from IEEE. Qualified parties may request a discounted copy.

Visit: https://www.nrel.gov/grid/ieee-standard-1547/.

T&D Co-Simulation, PyDSS, and 1547 DER Controls

PyDSS

HELICS

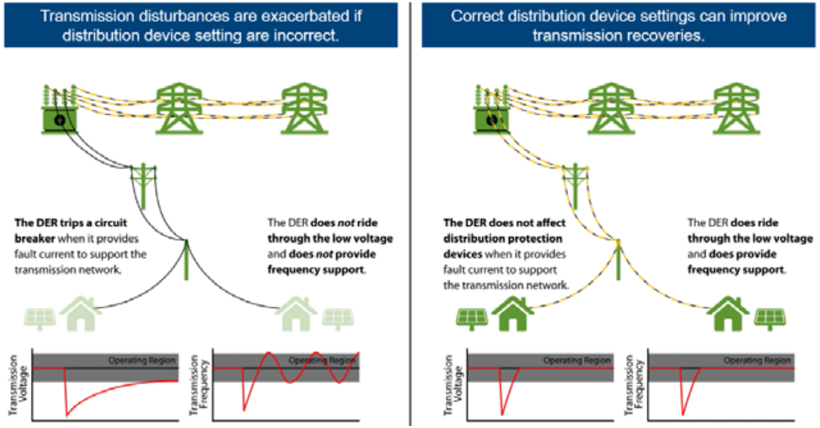
North American Energy Resilience Model

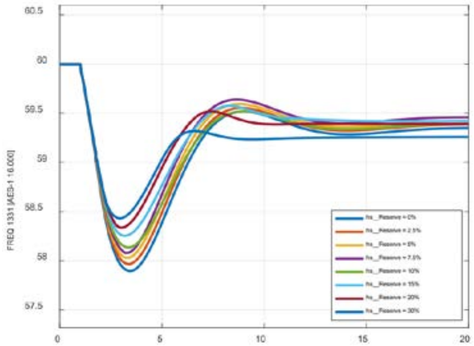
Reliability Need:

- NERC has identified DERs tripping as a reliability issue.
- Industry uncertainty in which settings to implement.
- “Aggregate” transmission models may not capture tripping behavior.
- Tools are needed to recommend DER settings and assess the consequences of substandard settings for varying DER penetrations.

North American Energy Resilience Model Capability:

- High-fidelity “transmission and distribution (T&D) co-simulation” to recommend DER settings and “aggregate” transmission model implementation.
- Address known risks regarding fault-induced delayed voltage recovery (FIDVR) or improper DER frequency response and the opportunities for DER grid support to improve grid recoveries (e.g., frequency droop, or dynamic voltage support).
- Customized device-level DER controls in line with 1547-2018 key grid support functions (within PyDSS).





Frequency response with 4% DER droop slope and varying levels of DER reserve power

Source: Grid Modernization Laboratory Consortium et al., “Fast Grid Frequency Support from Distributed Energy Resources,” NREL/TP--5D00-71156, 1772978, MainId:6899, Mar. 2021. doi: 10.2172/1772978.

Image and Content Credit: Jeremy Keen, Aadil Latif, and Kapil Duwadi

Interconnection Screening and Study Process

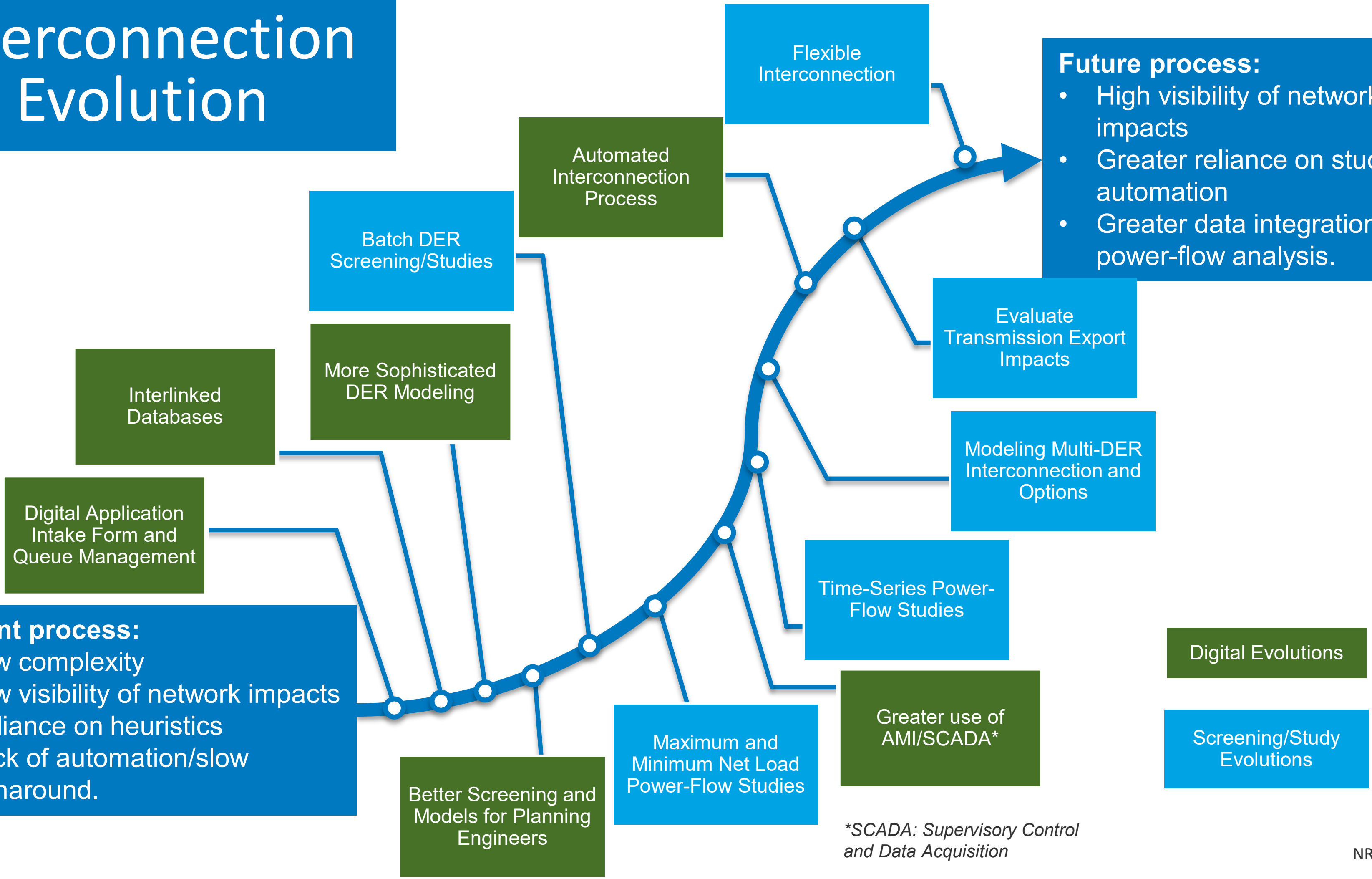
Industry Guidance Documents

Interconnection Procedures, Guides, and Frameworks	
FERC SGIA – 2023	Small Generator Interconnection Application: Outlines the contractual agreements and application materials for interconnecting generators under 20 MW.
FERC SGIP - 2023	Small Generator Interconnection Procedures: Outlines the technical screening procedures necessary for interconnecting generators under 20 MW.
IREC Model Interconnection Procedures – 2023	Model Interconnection Procedures: Provides additional screening guidance and incorporation of select advanced functionalities, flexible interconnection, and considerations for battery energy storage.
IREC BATRIES Toolkit	BATRIES Toolkit: Toolkit and guidance for the interconnection of energy storage and solar-plus-storage.
IEEE 1547.7 – 2013	IEEE Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection: Provides criteria, scope, and extent for engineering studies of the impact of DERs on a distribution system.
IEEE 1547.9 – 2022	IEEE Guide for Using IEEE Std 1547 for Interconnection of Energy Storage Distributed Energy Resources With Electric Power Systems: Provides additional guidance and considerations for interconnecting energy storage DERs, beyond what is included within the 1547-2018 base standard.
SAND2012-1365	Suggested Guidelines for Assessment of Distributed Generation Unintentional Islanding Risk: Sandia National Laboratories' guidance for evaluating the relative risk of an unintentional island formation based on a series of screens.

Interconnection Evolution

Current process:

- Low complexity
- Low visibility of network impacts
- Reliance on heuristics
- Lack of automation/slow turnaround.



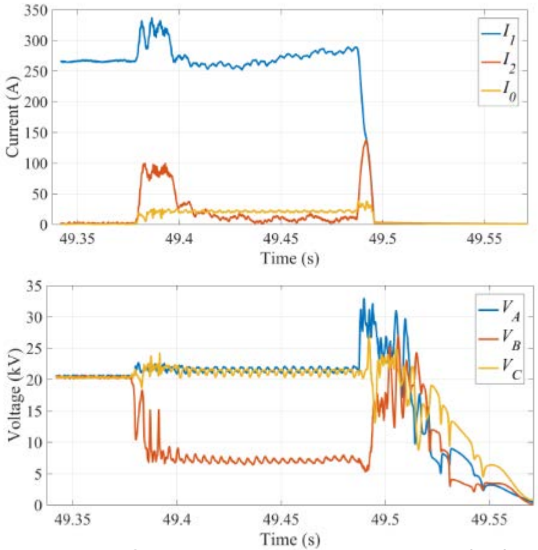
Future process:

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

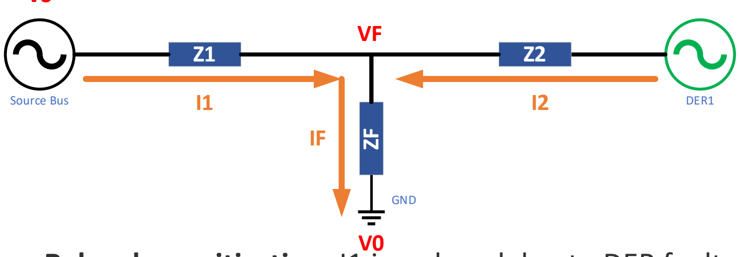
**SCADA: Supervisory Control and Data Acquisition*

Inverter-Based Resources and Distribution System Protection: Background

- Today's distribution system protection use **time-overcurrent (TOC) based protection.**
  - Relying on one-directional fault current from the bulk power system to sense and clear distribution-level faults.
- Fault dynamics can change and so must our assumptions.
  - **Reductions in bulk-system level fault current contributions** as IBRs supplant synchronous generation.
  - **Grid-edge sources of fault current** adding complexity to fault current flows and protection studies.
  - Evolving interconnection requirements changing **how IBRs behave under abnormal and fault conditions.**
- Industry guidance on the topic is somewhat lacking or unclear.
  - High-level heuristics-based screens for smaller DERs (e.g., 10% and 87.5% rules).
  - Little guidance for handling detailed protection studies or especially large aggregations of smaller-scale DERs.



Event recording: DER response to single-line-to-ground fault.



Relay desensitization: I1 is reduced due to DER fault current contributions impacting the sensitivity of upstream protective devices.

Image Source: Gefei Kou, Le Chen, Phillip VanSant, Francisco Velez-Cedeno, and Yilu Liu, "Fault Characteristics of Distributed Solar Generation," IEEE Transactions on Power Delivery, Mar. 2019, doi: 10.1109/TPWRD.2019.2907462.

NREL's PRECISE™ – Automating DER Technical Screens and Leveraging Advanced Inverter Functions

PREconfiguring and Controlling Inverter SEt-points

An **automated interconnection evaluation tool** that quickly assesses the impact of solar on the grid, makes accept or modify decisions, and leverages advanced inverter functions (volt-VAR, volt-watt) to help accelerate grid integration.

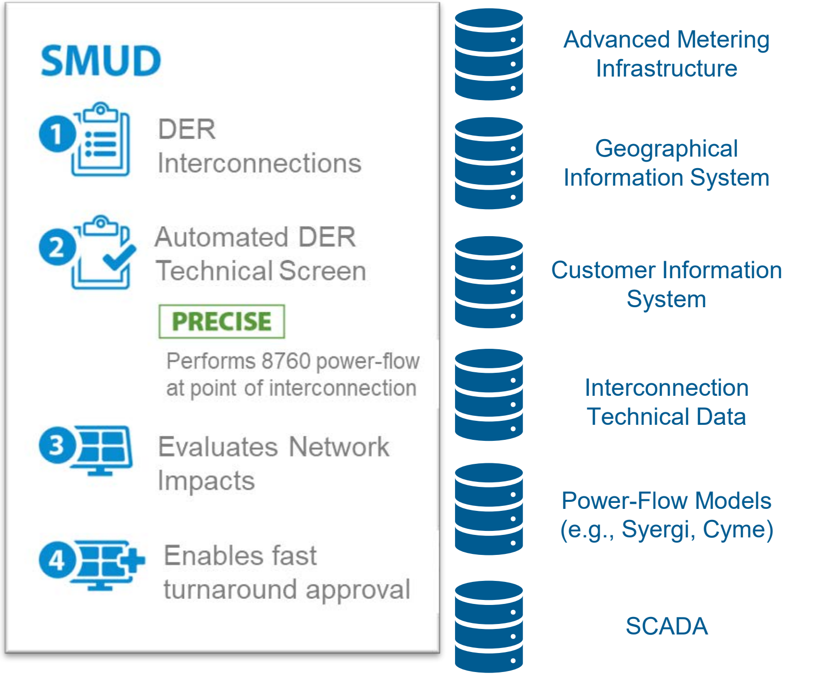
PRECISE helps utilities accelerate the interconnection process through **automated detailed technical screening** and **leverages advanced inverter functions** *as needed.*

Performs detailed technical screen, avoiding conservative DER heuristics.

R&D 100 Award winner for 2019.

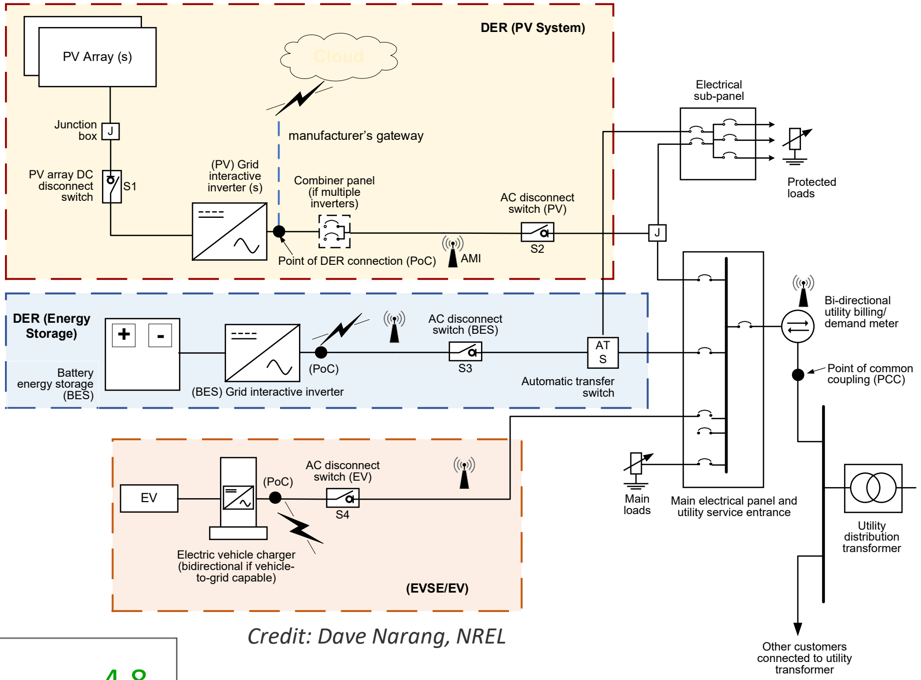
Fully integrated and deployed at Sacramento Municipal Utility District in spring 2022, 1,700 applications and 10 MW of rooftop solar processed in first 6 months.

PRECISE integrates siloed data systems and performs comprehensive QA/QC to model the impact of DERs on the distribution system.



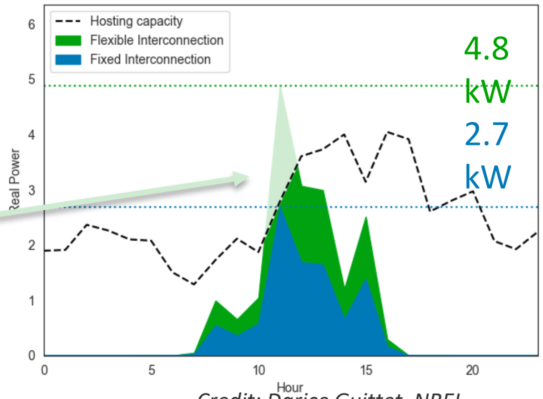
Tackling Multi-DER and Flexible Interconnection

- Next phase is working on evaluating more including DER storage, electric vehicles, vehicle-to-home, vehicle-to-grid, and DER gateways.
- 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.



Credit: Dave Narang, NREL

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



Credit: Darice Guittet, NREL

Flexible interconnection restricts DER production during limited periods.

Conventional interconnection reduces DER nameplate.

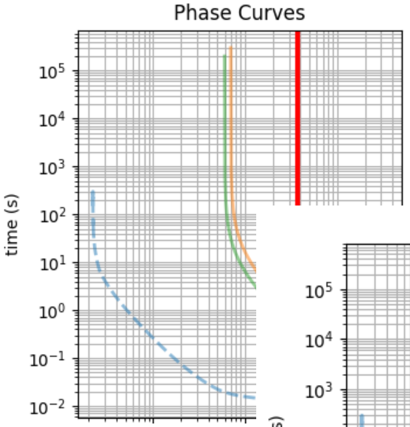
NREL Protection Analysis

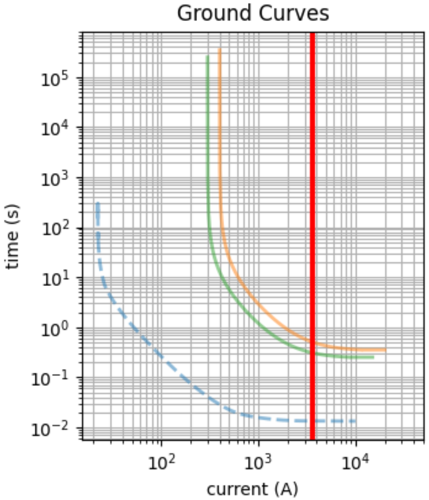
D-SPARC

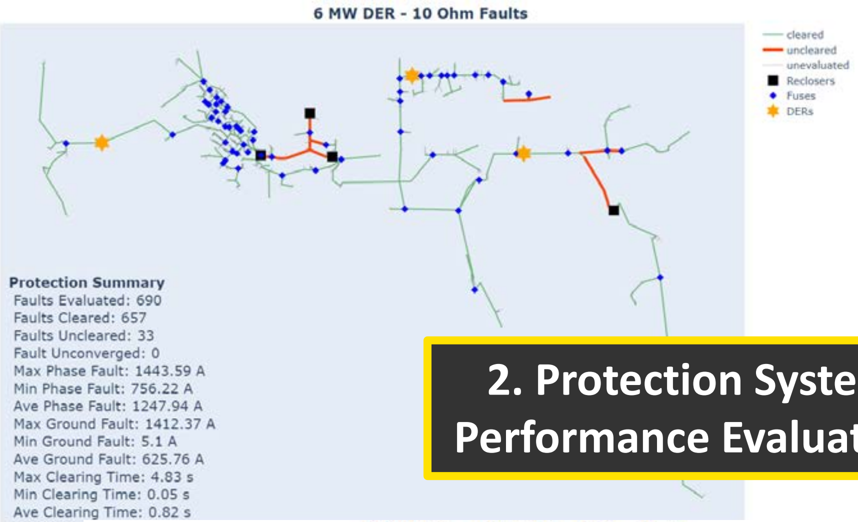
Distribution **S**ystem **P**rotection **A**nalysis and **R**elay **C**oordination

An OpenDSS-based short circuit analysis tool for streamlined protection system evaluation.

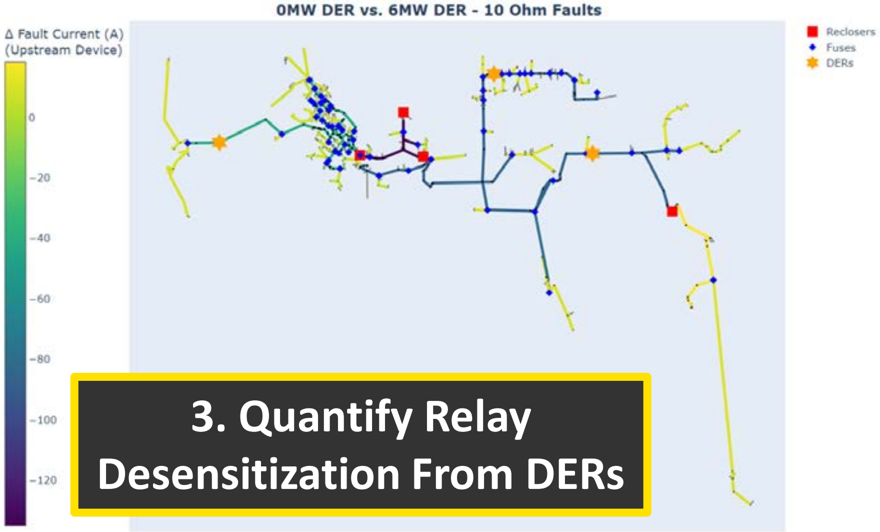
1. Streamlined Coordination Studies







2. Protection System Performance Evaluation



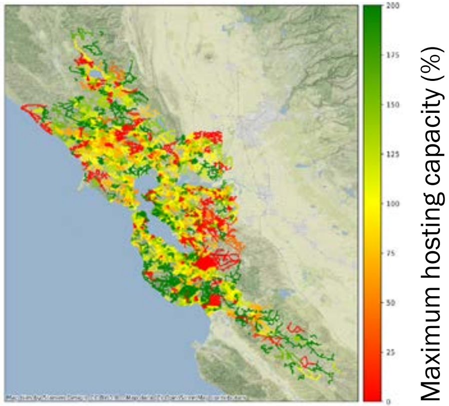
3. Quantify Relay Desensitization From DERs

Evolution of Hosting Capacity Maps Database

- Increasingly, utilities are issuing hosting capacity maps to accelerated developers for distributed generation and load additions.
- There are at least 40 utilities with public hosting capacity maps, many of which are investor-owned utilities, and for whom hosting capacity analysis (HCA) maps are required by state regulators.
- These maps are evolving with increasing fidelity, metrics, and technologies to which they capture.

Evolution ↓

Fidelity	Technology	Metrics
Substation and bank	Distributed generation	Over-voltage
Feeder head	Load	Thermal overload
Feeder nodal	Flexible generation profiles	Anti-islanding
Service transformer	Flexible load profiles	Flicker
		Voltage unbalance
		Maximum voltage deviation
		Regulator deviation
		Protection desensitization
		Snapshot (peak, minimum daytime load)
		Time-series

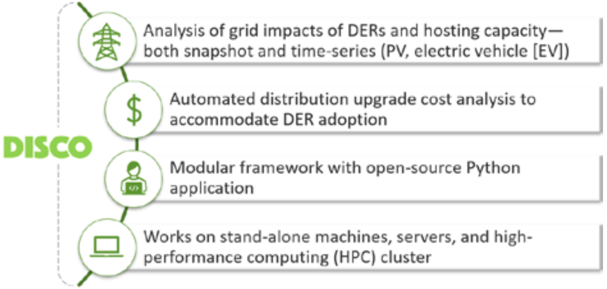


NREL, 2023, "PV Hosting Capacity Estimation: Experiences with Scalable Framework", URL: https://docs.nrel.gov/docs/fy22osti/81851.pdf

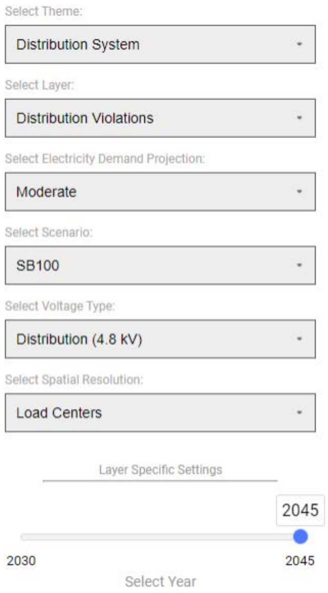
U.S. Department of Energy, U.S. Atlas of Electric Distribution System Hosting Capacity Maps, 2024 URL: https://www.energy.gov/eere/us-atlas-electric-distribution-system-hosting-capacity-maps
NARUC, Grid Data Sharing: Brief Summary of Current State Practices, 2023 URL: https://pubs.naruc.org/pub/145ECC5C-1866-DAAC-99FB-A33438978E95

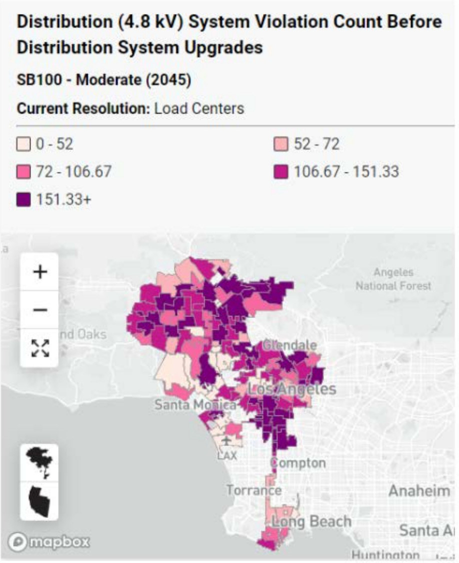
NREL's DISCO: Next-Generation Hosting Capacity

DISCO was used to simulate upgrades for all of the Los Angeles Department of Water and Power's service area.

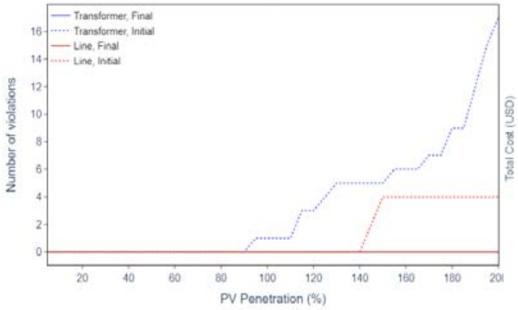


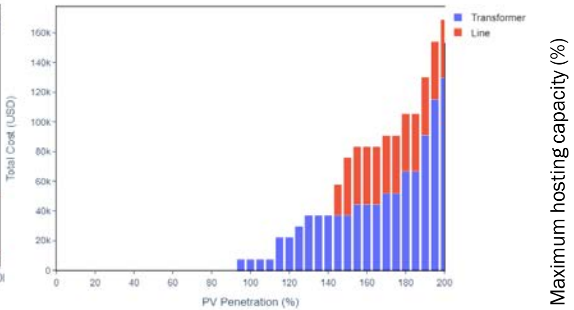
Hosting capacity: NREL's Distribution Integration Solution Cost Options (DISCO) performs detailed three-phase unbalanced power-flow solar and electric vehicle hosting capacity and upgrade analysis.





Source: LA100: The Los Angeles 100% Renewable Energy Study



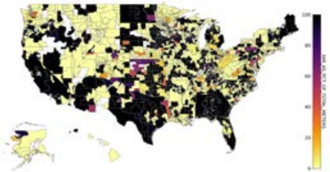


DISCO can assess incremental upgrades needed as DER deployment increases.

DER Monitoring and AMI Analytics

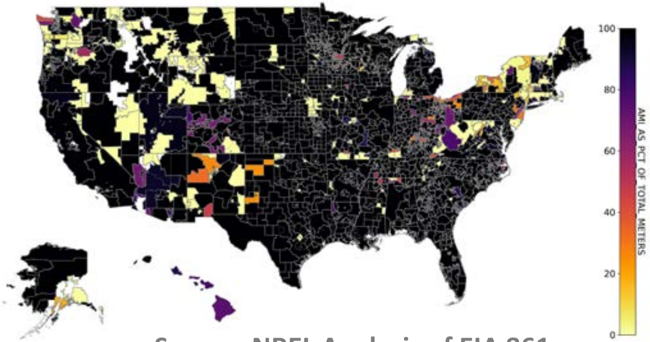
Industry Benchmarking: AMI Deployment in the United States

- Utilities have progressed from legacy electromechanical meters, to automated meter reading (AMR), to AMI.
- U.S. deployment of AMI has increased to covering over 72% of all meters as of 2022, with AMI offering the potential of multiple metrics (energy, voltage, current, reactive power, and power quality metrics).
- AMI can enable the ability for investigations of net load and power quality, enabling greater insights into DER performance.

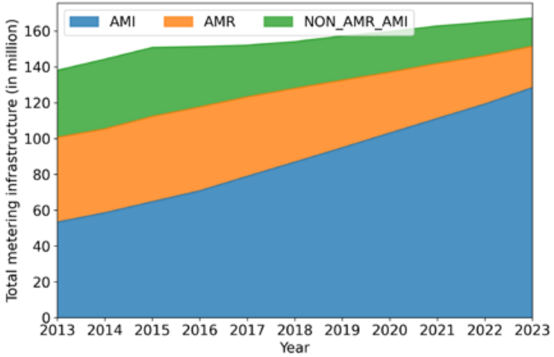


AMI Meters Percentage of All Meters (2013)

AMI Meters Percentage of All Meters (2023)



Source: NREL Analysis of EIA 861



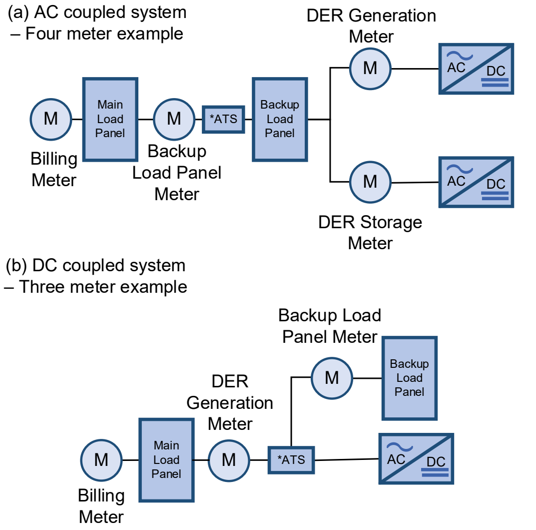
Source: 2013–2023 NREL Analysis of EIA 861

NREL, "Advanced Metering Infrastructure for Distribution Planning and Operation: Closing the Loop on Grid-Edge Visibility", 2022, URL: [*https://www.osti.gov/biblio/1922397*](https://www.osti.gov/biblio/1922397)

AMI Design Choices and DER Visibility

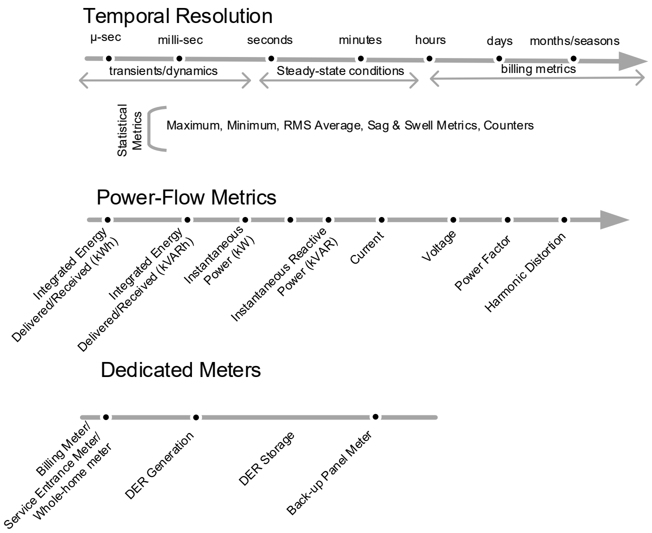
DER and disaggregation:

- Deploying more meters may give greater visibility but at a cost.
- Less meters means less visibility, but opportunities to leverage DER disaggregation techniques.

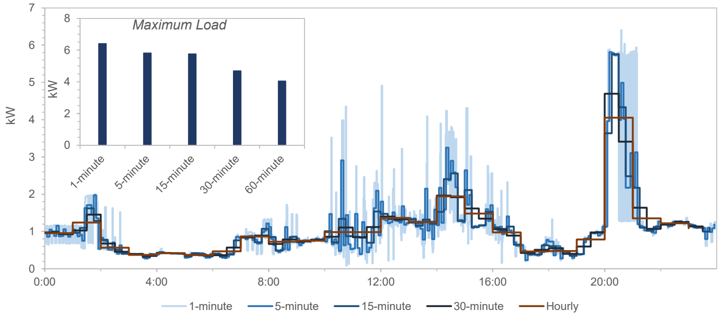


*Automatic Transfer Switch

Data Collection and Metrics



- **Impact of time resolution:** Increasing number of utilities are collecting metering data at hourly, 30-minute, and 15-minute intervals. Some utilities are transitioning to 5-minute interval data.

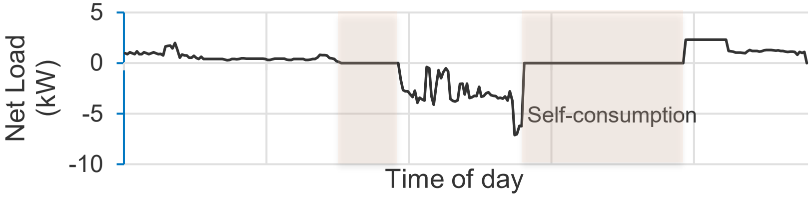


NREL, *"Advanced Metering Infrastructure for Distribution Planning and Operation: Closing the Loop on Grid-Edge Visibility", 2022, URL: https://www.osti.gov/biblio/1922397*

DER Monitoring: AMI and Other Applications

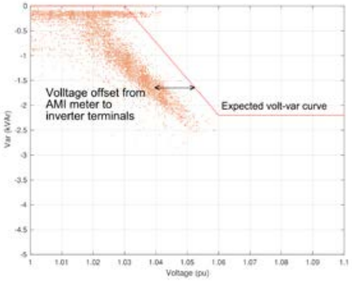
- While AMI is useful for DER monitoring, there are also many other forms that can be useful, including:
    - DER settings databases
    - Vendor and inverter data collection and monitoring platforms (frequently cloud-based)
    - DER integration to DER management systems (DERMS) for enhanced visibility and control (e.g., through DER gateways)
    - Additional grid-edge monitoring systems, including phasor measurement units (PMUs), remote current and potential transformers (CTs, PTs), and AMI 2.0 systems.

Battery Operation and Programming Identification

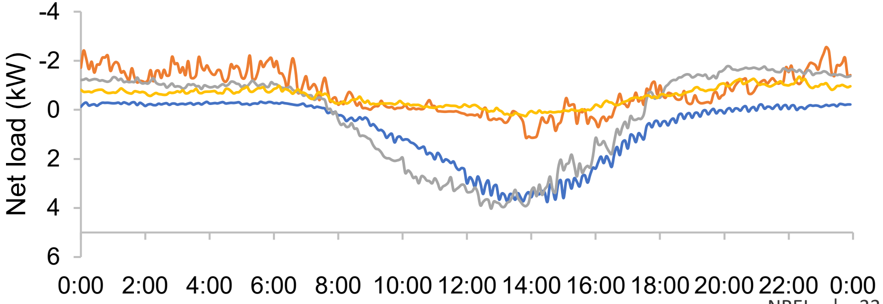


Advanced Inverter Function Activation and Validation

Estimated curtailment calculations from volt-VAR and volt-watt



Customer Program Segmentation and Performance



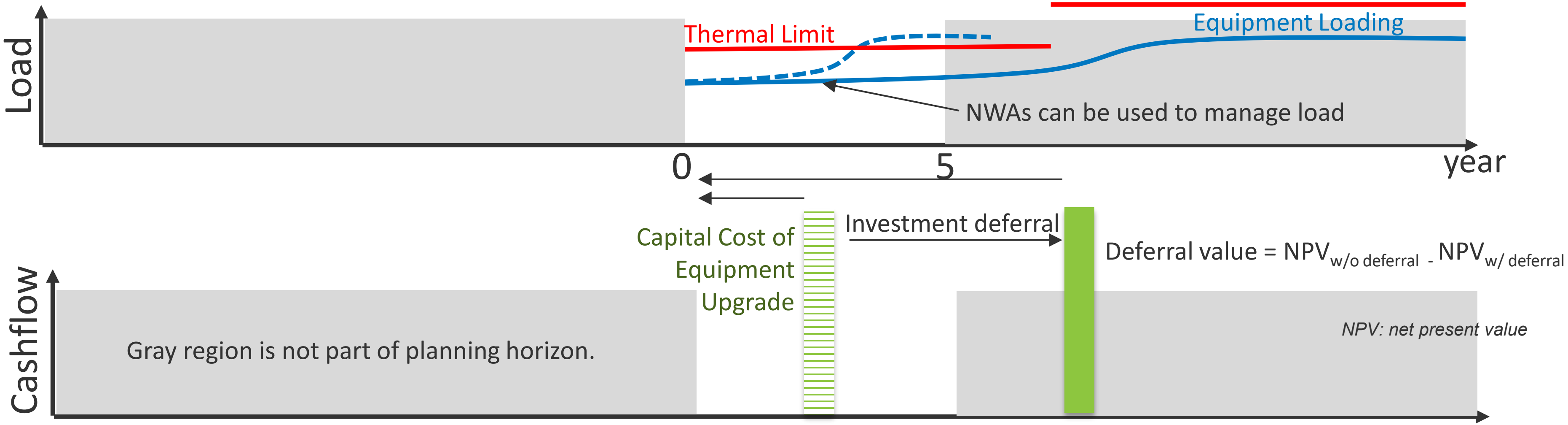
NREL, "Advanced Metering Infrastructure for Distribution Planning and Operation: Closing the Loop on Grid-Edge Visibility", 2022, URL: https://www.osti.gov/biblio/1922397

DERs and Integrated Distribution Planning

DER Deferrals and NWAs

Slide Credit: Jeremy Keen

Non-wires alternative (NWA): *An electricity grid project that uses non-traditional T&D solutions, such as distributed generation, energy storage, energy efficiency, demand response, and grid software and controls, to defer or avoid the need for conventional T&D infrastructure investments.*[1]



NWA Opportunities Are Rare

1. Overloaded assets and deferral opportunities are uncommon (more assets just old).
2. There have been limited real-world NWA deployments.

NWA Logistics Are Challenging

1. Battery economics are tight.
2. Load developers change plans.
3. Wire and non-wire comparisons are not on a "level playing field."

[1] *Paul De Martini, DSPx: Planning for Grid Modernization & C-E/Prioritization Framework, Michigan PSC Distribution Planning Stakeholder Meeting, 2019, URL: https://www.michigan.gov/-/media/Project/Websites/mpsc/workgroups/elec-dist-planning/Full_Slides_-_ver_8.pdf?rev=5f6708216e9145ef95cb60b3ff01a716.*

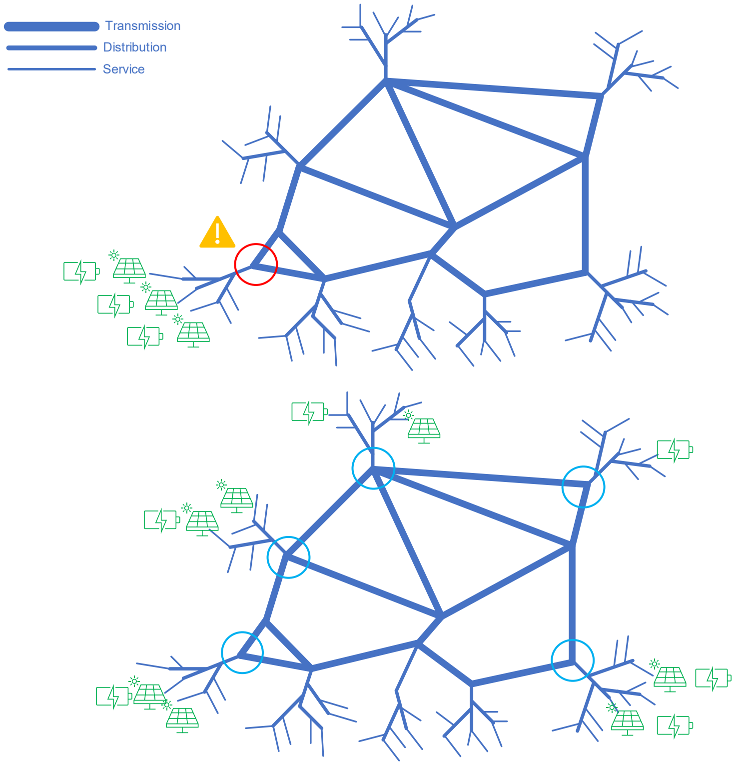
DERs and Specified vs. Non-Specified Deferral Values

Specified (targeted) deferral value: "Value associated with deferring the purchase and installation of specific infrastructure that has been identified by a utility … as needed for grid reliability, resiliency, or safety."

- Begins with an identified grid need and deferral opportunity.
- Solutions are locationally specific (targeted).

Unspecified (untargeted) deferral value: "Value associated with deferring the purchase and installation of generic infrastructure that has not been specifically identified by a utility … as needed for grid reliability, resiliency, or safety, but is estimated to be needed."

- May or may not begin with an identified grid need and deferral opportunities may or may not arise.
- Solutions are generally not locationally specific (untargeted).



Source: CPUC, "Energy Division Staff Proposal on Avoided Cost and Locational Granularity of Transmission and Distribution Deferral Values," California Public Utilities Commission. [Online]. Available: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M299/K659/299659977.PDF

Additional NREL Tools and Capabilities

High temporal and spatial resolution solar and wind dataset.

System Advisor Model

Investigate technical, economic, and financial feasibility of renewable energy projects.

dGen

Simulate and forecast DER adoption for residential, commercial, and industrial sectors

NREL's PVWatts® Calculator

Estimate energy production and performance of potential grid-connected PV installations.

EVOVE

Evaluate net load profiles with a combination of solar, battery, and electric vehicle technologies.

REopt

Evaluate DER viability, costs, emissions, resilience, and outage sustainability duration for a building, campus, or microgrid.

NSRDB: National Solar Radiation Database
WRDB: Wind Resource Database

Thank You

www.nrel.gov

NREL/PR-6A40-92436

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This work was authored by NREL for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Policy. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

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