# Distributed Energy Resources Interconnection

Integrated Distribution System Planning 2.0: Planning for Load Growth and Local Resources

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# Agenda

- What Is Interconnection and Why Is It Important?
- Policy and Regulatory Considerations for DER Interconnection
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  - Key regulatory activities for interconnection
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# What Is Interconnection and Why Is It Important?

Interconnection is the result of the process of adding a DER to a distribution system (IEEE Standard 1547-2018). The term may refer to the technical, procedural, and legal requirements of the interconnection process or the interface between the DER and the utility's distribution system — the physical location at which the DER provides certain electrical and interoperability capabilities.

Interconnection allows utility customers and third-party service providers to connect solar energy systems, energy storage, and other generating systems at customer premises and operate them in parallel with the utility system. In addition to providing services to meet their own electricity needs, customers can use interconnected DERs to sell power or ancillary services to the utility at the distribution or bulk electric system - for example, through a DER aggregator.

Berkeley Lab (2024), Interactive Decision Framework for Integrated Distributed System Planning

# Policy and Regulatory Considerations for DER Interconnection

# Value of Improved Interconnection (1)

## Expedites system and societal benefits of DERs

- Avoided system costs
- Delivery of grid services
- Reduced emissions and air pollutants
- Contributions to grid reliability and resilience
- Improved customer choice
- Increased market competition

## Improves customer experience

- Reduced time and cost to interconnect
- Expedited bill savings and utility customer resilience
- Greater satisfaction with utility

## Supports DER development

- Identification of favorable areas for interconnection
- Reduced uncertainty for interconnection costs and timelines
- Improved process efficiencies for better business outcomes
- Contributions to economic growth and workforce development

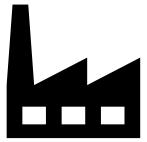
Sources: DER Interconnection Roadmap, National Efficiency Screening Project

# Value of Improved Interconnection (2)

| Stakeholder | What's at stake? |
|---|---|
| Utilities | • Customer satisfaction<br>• Costs associated with staffing, software, and management<br>• Grid management opportunities and challenges<br>• Changes to system costs and revenue opportunities |
| Developers and Customers | • Cost and time to interconnect local resources<br>• Business opportunities and risk of unexpected, high costs<br>• Opportunities for bill savings and home resilience |
| Regulators | • Maximizing the value of DERs for customer benefit<br>• Prudent and efficient use of customer funds<br>• Utility accountability |
| Other State Agencies and Stakeholders<br><br>(e.g., State Energy Offices, Utility Consumer Advocates, Permitting Agencies, Industry Representatives) | • Prudent use of customer funds<br>• Achievement of state energy policy goals<br>• Progress towards desired outcomes (e.g., reduced air pollution, making use of local resources) |

Source: National Efficiency Screening Project

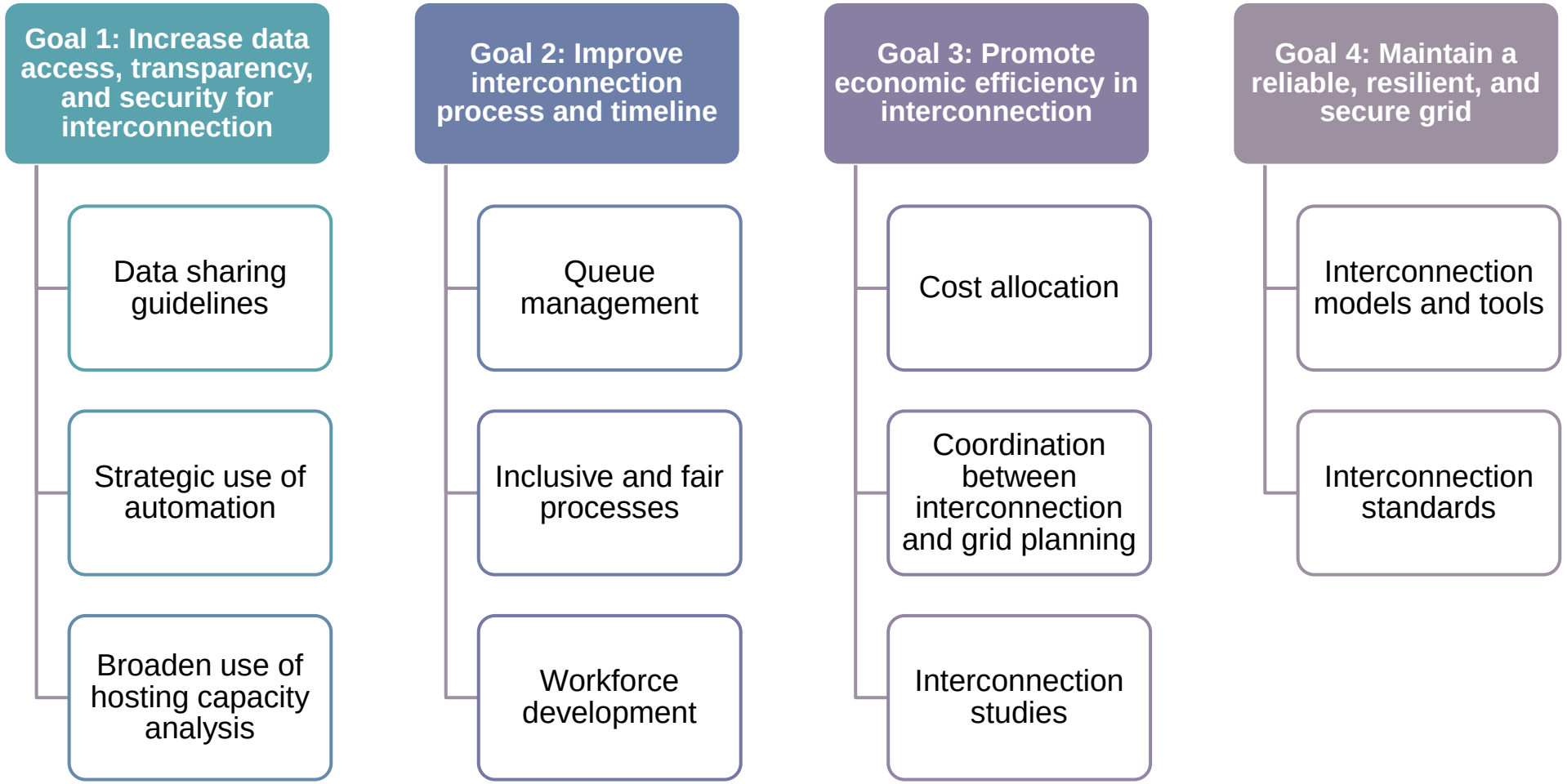
# Roles and Responsibilities



| Stakeholder | Responsibilities |
|---|---|
| Utilities | • Implement interconnection processes and studies<br>• Develop internal process efficiencies<br>• Share data<br>• Pursue regulatory and process changes |
| Developers and Customers | • Request interconnection<br>• Provide data and information to utilities<br>• Ensure conformity with interconnection requirements |
| Regulators | • Oversee and monitor interconnection processes<br>• Direct changes to standards, processes, reporting requirements, and cost recovery<br>• Facilitate working groups |
| Other State Agencies and Stakeholders<br><br>(e.g., State Energy Offices, Utility Consumer Advocates, Permitting Agencies, Industry Representatives) | • Participate in working groups<br>• Process permitting applications<br>• Advocate for regulatory and other process changes<br>• Draw on experiences and leading practices from other states |

Source: National Efficiency Screening Project

# U.S. Department of Energy's DER Interconnection Roadmap

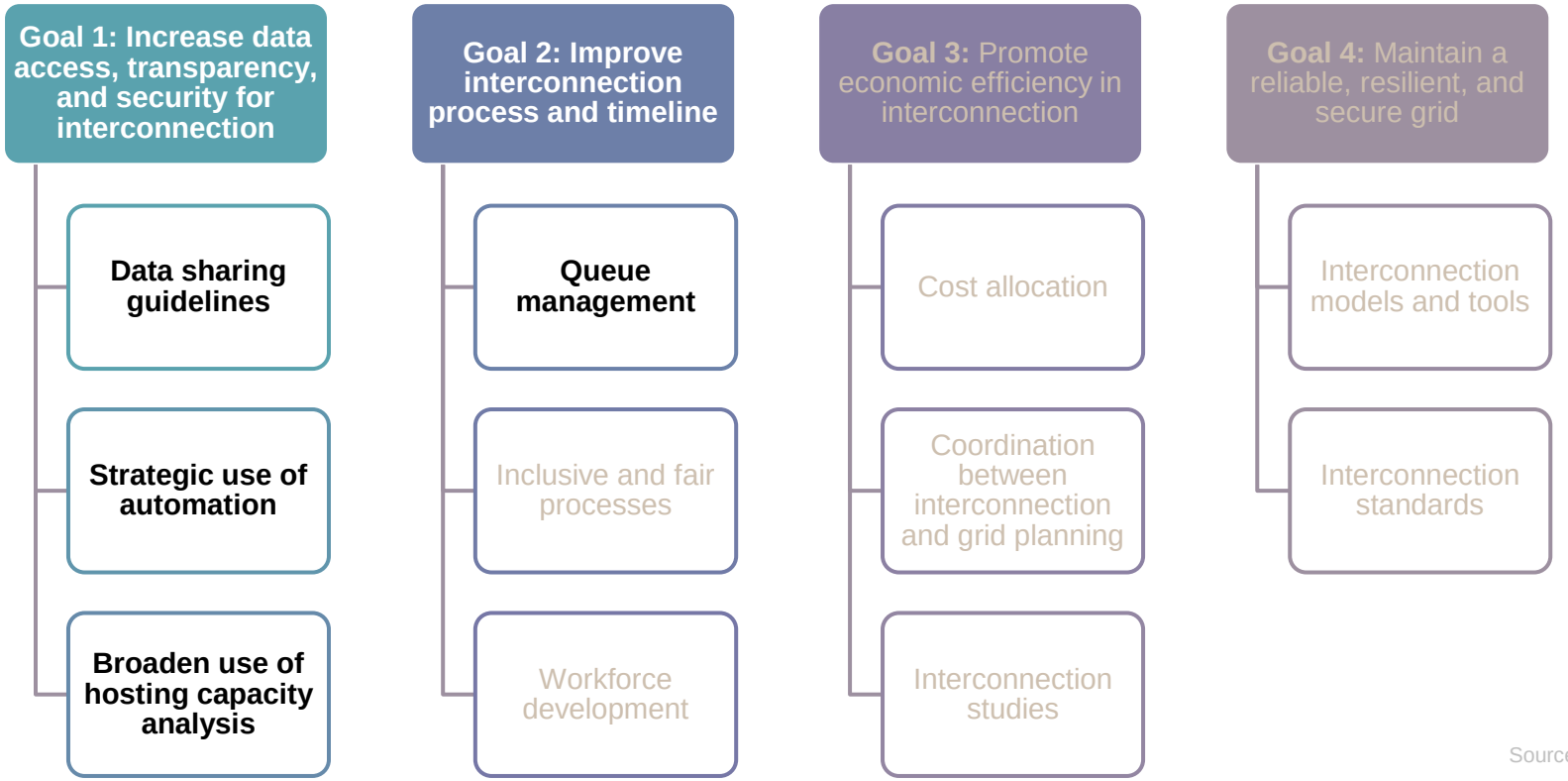



Source: U.S. Department of Energy (DOE) DER Interconnection Roadmap

# Key Regulatory Activities for Interconnection

# Interconnection Process Improvements

- Process improvements facilitate a smoother interconnection experience overall.
- Projects that are waiting to interconnect to the grid are in the “interconnection queue.”
- Better managing the interconnection process and queue requires a multi-pronged approach, including data access and reporting, education, and clear communication of requirements and expectations.



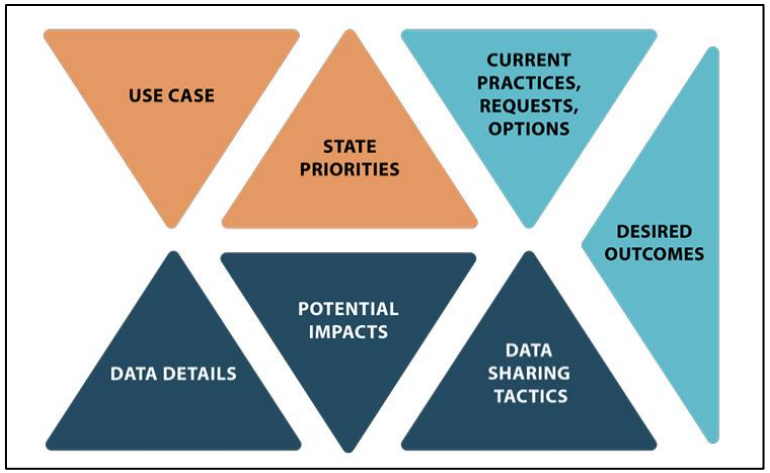

Source: DOE DER Interconnection Roadmap

# Interconnection Process Improvements – Data Sharing

- Regulators establish expectations for providing data on grid condition and hosting capacity.
- Considerations include:
  - Soliciting stakeholder input to inform data needs and availability
  - Clarifying data required from utilities and developers
  - Considering sensitivity of data and taking appropriate precautions
  - Considering tradeoffs between granularity and frequency of updates with resource intensity
- Public reporting sites for interconnection queue data support transparency.

| DER Applications | Generated by Utilities |
|---|---|
| • Technology<br>• Rated power (kW)<br>• Stored energy (kWh)<br>• IEEE 1547 Reactive Power Category, commonly referred to as "voltage and reactive power capability"[59]<br>• IEEE Std 1547 Disturbance Category, commonly referred to as "voltage and frequency ride-through capability"<br>• Location (census block group) | • Queue position<br>• Application date and interconnection agreement date<br>• Dates of system impact study start and completion<br>• Construction completion date and permission to operate date<br>• Status (active, operational, withdrawn, suspended)<br>• Technical screen failures and results, if applicable[60]<br>• Group study status, if applicable<br>• Estimated cost of studies and fees ($ quoted by the utility)<br>• Estimated cost of all system upgrades, including facilities charges and network upgrades ($ quoted by the utility)<br>• Final cost of interconnection, including costs of all studies and any required system upgrades ($ billed by the utility) |

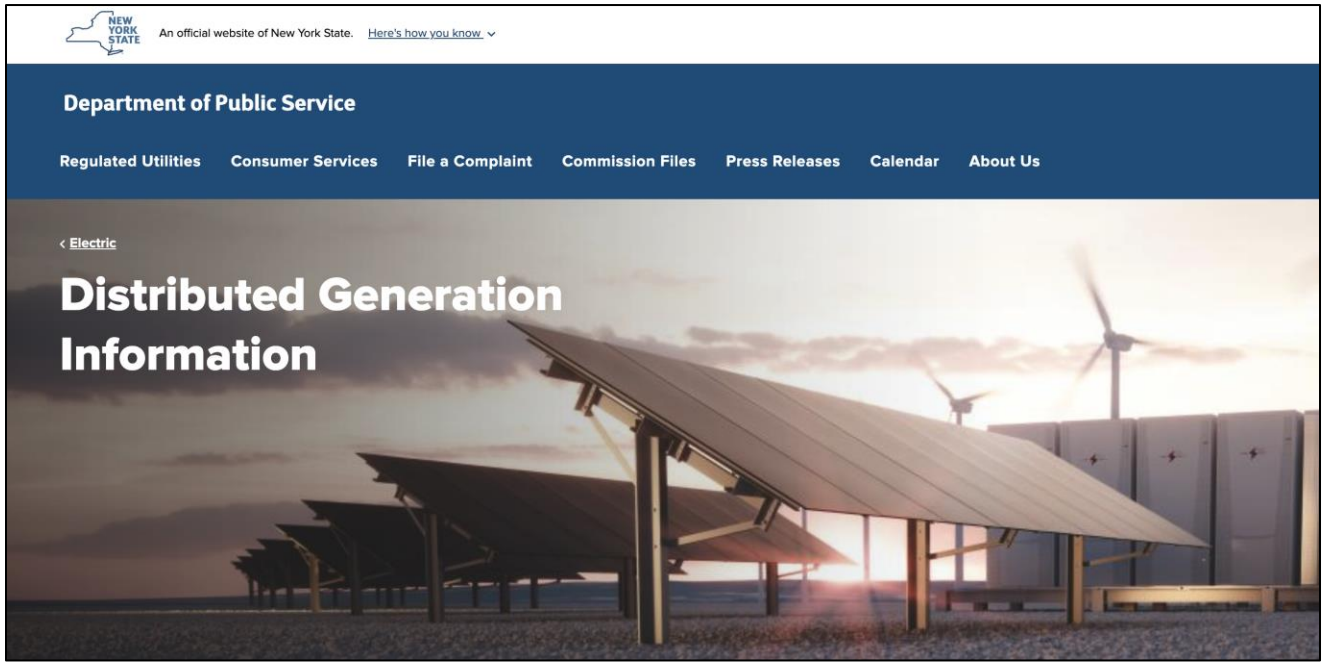
Grid Data Sharing Analysis Framework

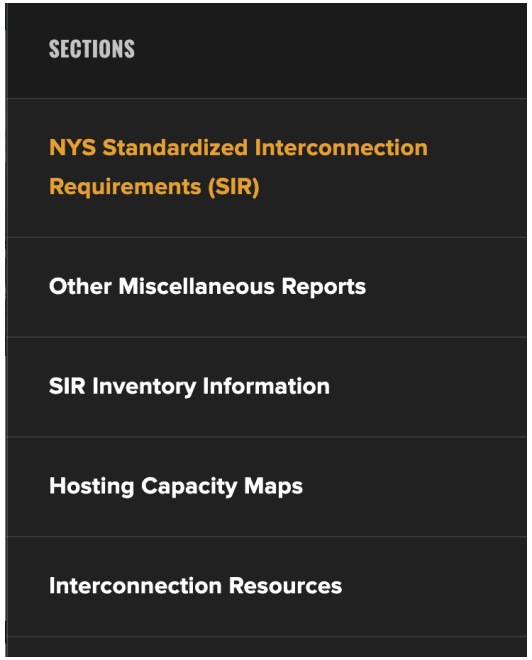



Sources: NARUC Grid Data Sharing Playbook, DOE DER Interconnection Roadmap

# Data Sharing: State Example

- New York State provides consolidated interconnection information on a public webpage.
  - The page links to standard and utility-specific interconnection requirements, hosting capacity maps, interconnection queue data, and other resources.
  - New York's standardized queue data provide equipment, timeline, and cost information.

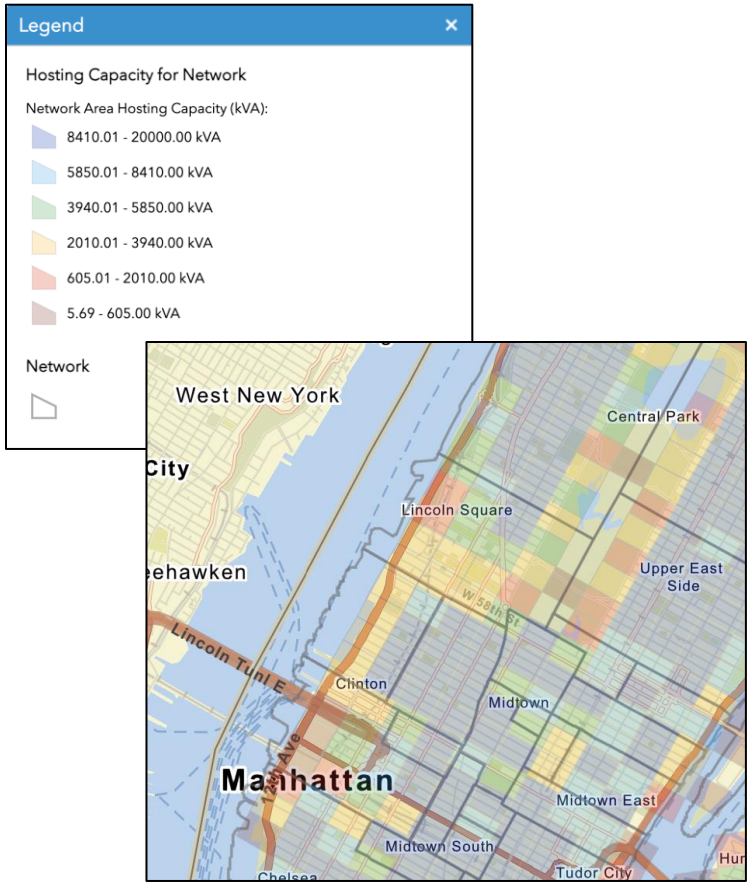



Source: New York Department of Public Service

# Data Sharing: Utility Example

ConEdison's Hosting Capacity Map and Queue Data




| Company | Developer | Application / Job # | Division | City/Town | County | Zip Code | NYISO Load Zone | Circuit ID | Substation |
|---|---|---|---|---|---|---|---|---|---|
| CECONY | MOMENTUM SOLAR | SDG-80851 | CENY-BK | Brooklyn | Kings | 11234 | J | 4B09 | Bensonhurst_2 |
| CECONY | NYSS LLC | SDG-80850 | CENY-SI | Staten Island | Richmond | 10314 | J | 1R81 | FRESH_KILLS |
| CECONY | Green Hybrid Energy Solutions, Inc. | SDG-80849 | CENY-W | White Plains | Westchester | 10601 | I | WHITE2 | White_Plains |
| CECONY | MOMENTUM SOLAR | SDG-80848 | CENY-W | Yonkers | Westchester | 10703 | I | 99U4 | Granite_Hill |
| CECONY | MOMENTUM SOLAR | SDG-80847 | CENY-W | Yonkers | Westchester | 10704 | I | 79U3 | Granite_Hill |
| CECONY | MOMENTUM SOLAR | SDG-80846 | CENY-Q | Springfield Gardens | Queens | 11413 | J | 9573 | Jamaica |
| CECONY | MOMENTUM SOLAR | SDG-80845 | CENY-Q | Jamaica | Queens | 11435 | J | 5Q42 | Jamaica |

| | *APPLICATION REVIEW* | | | | *PRELIMINARY REVIEW* | | | *CESIR* | | | | SIR Costs | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 business days | | | | 15 business days | | | 60 / 100 business days | | | | *CESIR Costs* | Project Installation / Upgrade Costs | |
| Protective Equipment | Start Date | End Date | Calculated Duration | Application Approved Date (Utility) | Start Date (Must Match Application Approved Date) | End Date | Calculated Duration | Payment Received Date | Start Date | End Date | Calculated Duration | CESIR Study cost paid by applicant | Estimated Upgrade Costs Identified by Utility (CESIR or Not) | Actual Project Costs Paid by Applicant |
| Inverter | 12/31/24 | | | | | | | | | | | $0.00 | $0.00 | $0.00 |
| Inverter | 12/31/24 | | | | | | | | | | | $0.00 | $0.00 | $0.00 |
| Inverter | 12/31/24 | | | | | | | | | | | $0.00 | $0.00 | $0.00 |
| Inverter | 12/31/24 | | | | | | | | | | | $0.00 | $0.00 | $0.00 |
| Inverter | 12/31/24 | | | | | | | | | | | $0.00 | $0.00 | $0.00 |

Source: New York Department of Public Service, ConEdison

# Interconnection Process Improvements – Regulatory Considerations

- With stakeholder input, regulators can guide interconnection process improvements by:
  - Establishing high-level objectives related to interconnection improvements
  - Establishing performance expectations or requirements aligned with objectives
- Specific activities include:
  - Reviewing and approving interconnection tariffs
  - Developing fast-track processes for interconnections meeting certain standards
  - Setting time limits on steps within the interconnection process (e.g., interconnection studies)
  - Establishing utility rewards or penalties for interconnection performance
  - Encouraging pilots for emerging practices (e.g., automated interconnection processes, flexible interconnection)

Roadmap Targets

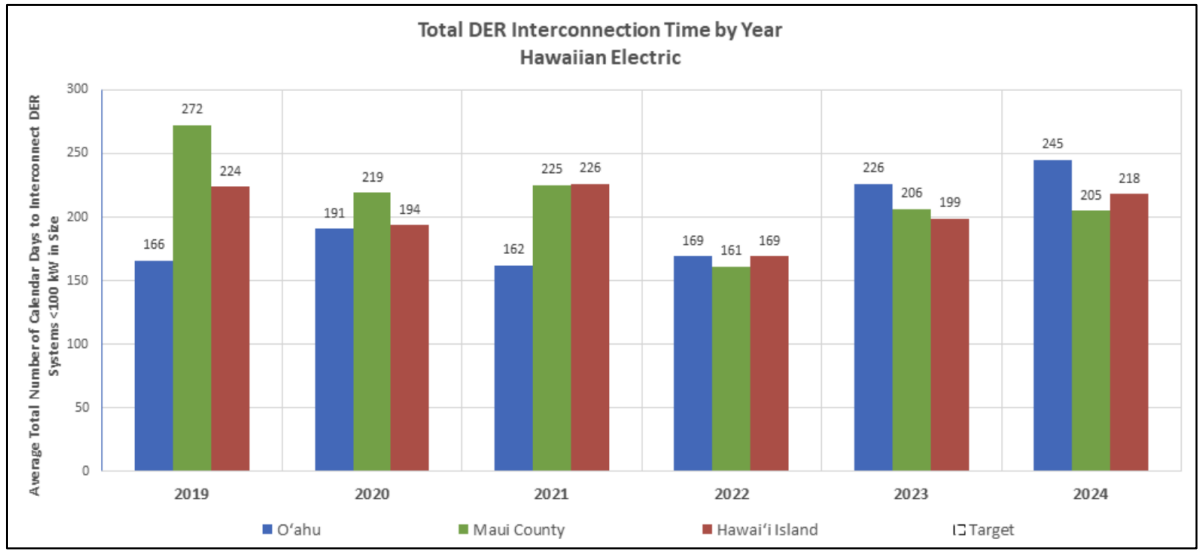
| | Target | System Size* | 2030 Target Value |
|---|---|---|---|
| Timing | (1) Median time from DER interconnection request to agreement[§] | < 50 kW | Within 1 day[†] |
| | | 50 kW–5 MW | < 75 days |
| | | ≥ 5 MW | < 140 days |
| Access | (2) Completion rate from entering the queue to execution of interconnection agreement | < 50 kW | > 99% |
| | | 50 kW–5 MW | > 90% |
| | | ≥ 5 MW | > 85% |
| Data | (3) Availability of public state-level interconnection queue data | All | 50 states, Washington, D.C., and territories have public, detailed, and current queue data |
| Reliability | (4) No BPS disturbance events exacerbated by inaccurate DER modeling | All | 0 |
| Resilience | (5) Lower Customer Average Interruption Duration Index (CAIDI)[‡] | All | 25% improvement (e.g., from 4 to 3 hours per occurrence) |

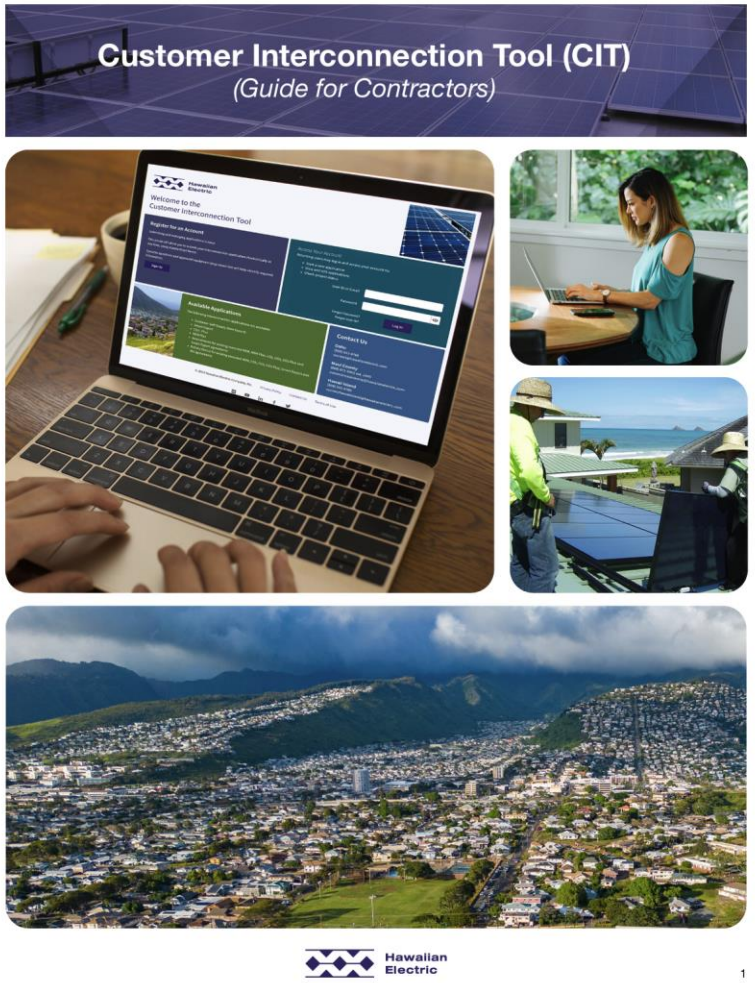
* System size thresholds will vary across utilities and jurisdictions.
[§] For systems that do not trigger system upgrades.
[†] Defined as 1 business day.
[‡] CAIDI with loss of load removed but major event days included.

Source: DOE DER Interconnection Roadmap

# Regulatory Requirements: State Example

- The Hawaii PUC requires publication of DER interconnection timelines and established a performance incentive mechanism to reward or penalize utilities for meeting interconnection timelines.
  - Hawaiian Electric can earn up to $2.1M or incur a maximum penalty of $630k annually.
  - The utility has historically earned the maximum reward and significantly reduced interconnection timelines.

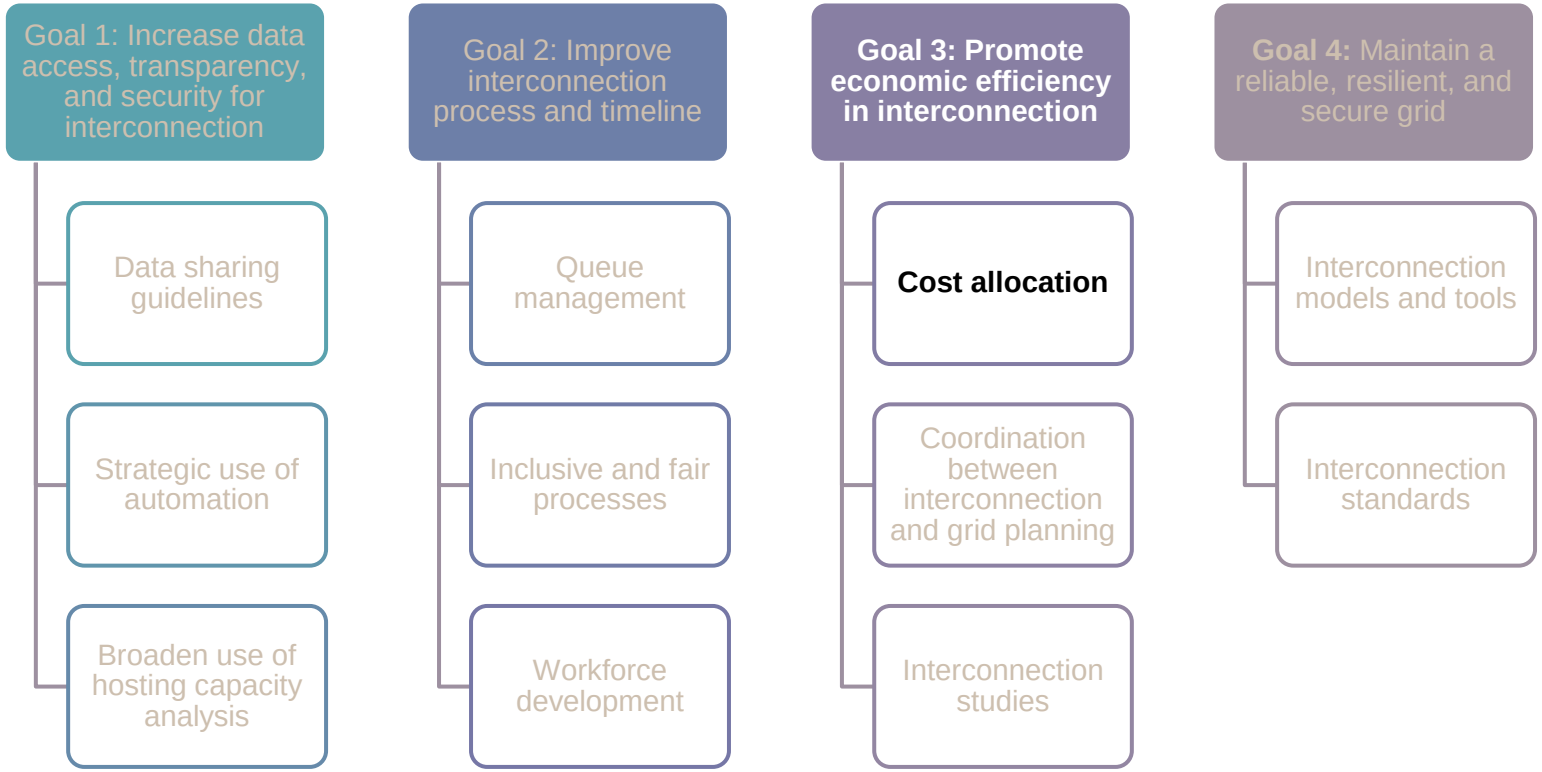



Source: Hawaiian Electric

# Cost Allocation

- Typical practice uses a “cost-causer pays” model, where the project that triggers the need for the upgrades pays the full cost, despite other customers also using upgraded infrastructure.
- Regulators and stakeholders can explore interconnection cost allocation reform.



# Cost Allocation – Challenges and Mitigations

| Issue | Description | Possible Mitigations |
|---|---|---|
| Free riders | DERs that trigger upgrades pay, allowing other interconnecting resources to benefit from that equipment without paying. | • Incorporate grid usage costs into tariffs<br>• Require future beneficiaries to reimburse customer who paid for upgrade they benefit from<br>• Implement a reserve fund from all interconnection customers |
| Cost uncertainty | Without information on grid congestion and required upgrades, customers may face unexpected and high costs to interconnect. | • Provide up to date and granular grid data<br>• Consider proactive grid upgrades in planning processes |
| High costs for certain customers | Causer-pays cost allocation and serial review of applications may result in exorbitant charges to a single customer. | • Consider group interconnection studies<br>• Consider multiple benefits of resources in cost allocation (e.g., contributions to resolving pre-existing grid issues) |

Sources: DOE DER Interconnection Roadmap, McDonnell, M., R. Nelson, and N. Mims Frick, 2025

# Cost Allocation Reform: State Example

- Massachusetts adopted provisional reforms to cost allocation for interconnection.
- Utilities can propose to recover interconnection costs from ratepayers and be reimbursed by interconnections over time if the costs will:
  - Be incurred in identified areas affected by high interconnection costs
  - Enable multiple interconnections
  - Not exceed a cost cap of $500/kW per customer
  - Be recovered within established timeframes

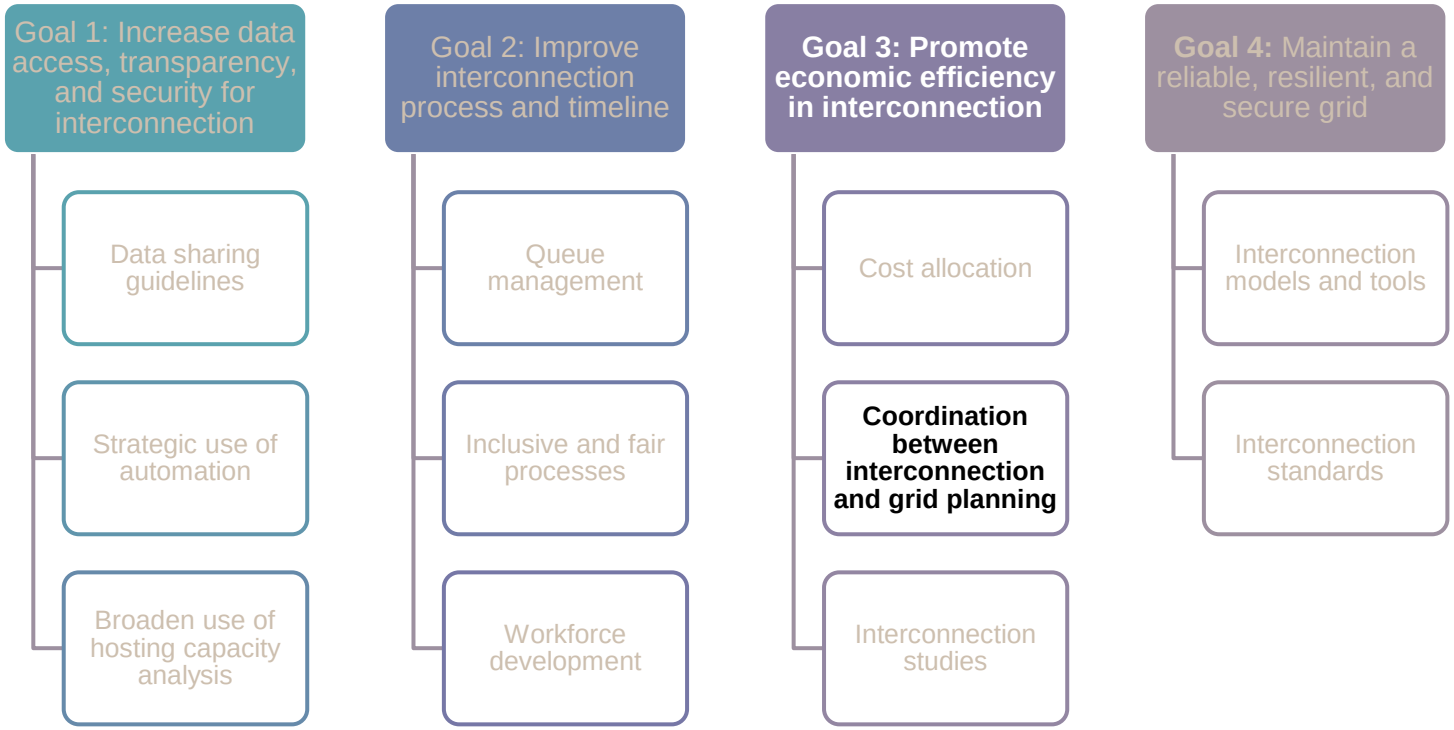
Eversource Initial Proposal

| Objectives | Status Quo | Eversource Balanced Approach<br>Parallel Planning & Allocation |
|---|---|---|
| 1. Enable DERs in the current queue | ✓ Yes – upgrade sized to current DER queue | ✓ Upgrades tested in DER Interconnection Planning Studies to mitigate all identified system constraints from Loadflow and Dynamic analyses |
| 2. Mitigate DER Cost Barriers | ✘ Requires first movers to front Capital. Likely favors large developers | ✓ Where the upgrades are aligned with long-term planning needs, that portion of EDC benefits and associated cost (allowed rate recovery) are carved out – resulting in reduction to DER allocation: Mitigating 'first mover' cost barrier |
| 3. Minimize Free-Rider Opportunities | ✘ 2nd mover partially incentivized to wait for upgrade costs funded by 1st mover | ✓ A unique $/kW rate established in each study area for all current and future interconnections downstream of that station ensures future DER customers pay exactly the same Interconnection cost as the current customers |
| 4. Maintain efficient price signals | ✘ Inefficient because prices surges after short-sighted upgrade out of capacity | ✓ Pre-Upgrade: DER allocation reduced only in stations where system benefits and DER interconnections align<br>Post-Upgrade: $/MW rate + MWs Enabled ensures that future DERs migrate to stations with increased capacity not locations where $/MW is high |
| 5. Avoid wasteful expenditure | ✘ EDC would be placed in reactive mode replacing long-life assets | ✓ If upgrades are sized to be short-sighted, DER development would stall. Because upgrades would be sized to future grid needs EDC would NOT need to go back into station replacing assets that otherwise are 30-40 yr. life |
| 6. Support MA Clean Energy Goals | ✘ Upgrade reactive to prevailing DER queue. Queue backlog with new incentives | ✓ Eversource Balanced approach ensures the tactical solutions to address near term DER queue interconnection & allows MA Clean Energy Goals |
| 7. Ensure upgrades built in-synch with future grid reliability needs<br>EVERSOURCE | ✘ Upgrade reactive to prevailing DER queue | ✓ Scenario Planning incorporating growth in EV, EE, Rooftop Solar in addition to DER PV and Storage conducted on an annual basis ensures infrastructure needs are identified, planned and constructed proactively |

Source: Eversource Massachusetts, MA DPU

# Distribution System Planning and Interconnection

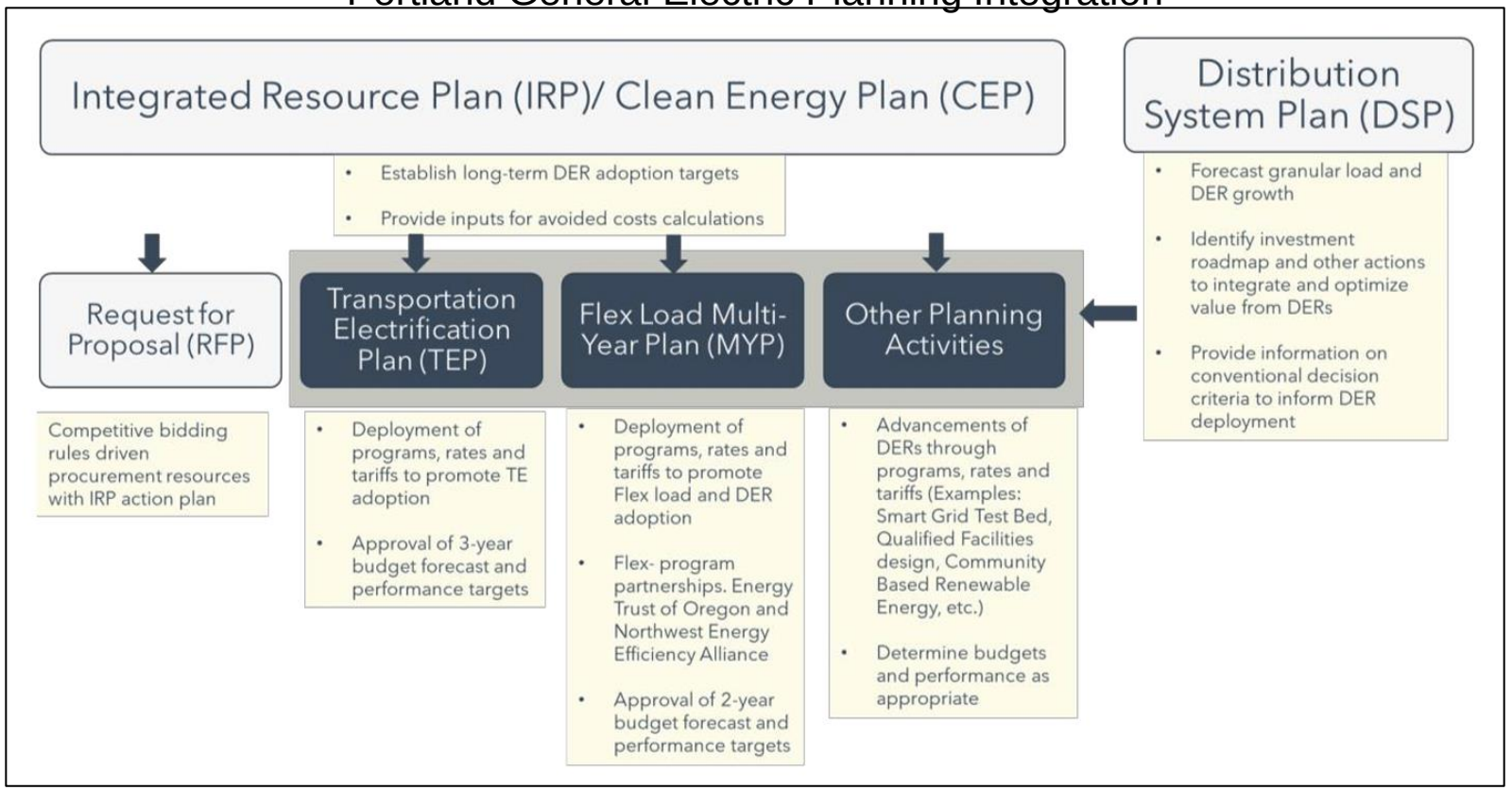
- Growth in local resources and loads are driving the need for utility distribution system investments.
- Separate processes for consideration of distribution system upgrades in distribution planning and interconnection creates inefficient outcomes.
- Integrated distribution planning can improve interconnection outcomes through granular load and DER forecasting, data sharing, and alignment of process timelines.




Source: DOE DER Interconnection Roadmap

# Interconnection and Integrated Distribution Planning: Utility Example

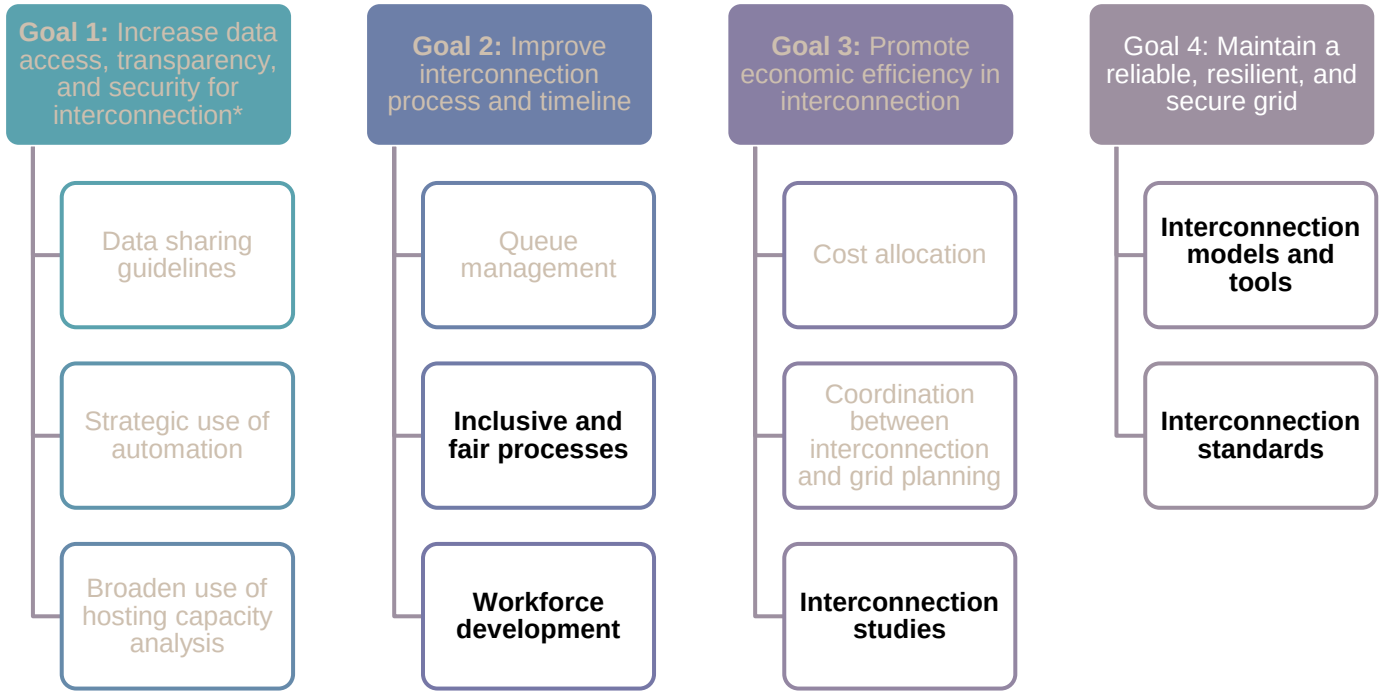
Portland General Electric Planning Integration




Source: Portland General Electric

# Additional State Activities to Support Interconnection

- Identify DER interconnection needs and objectives
- Encourage utilities to draw on leading practices and host working groups to consider issues such as:
  - Interconnection standards, modeling, and tools
  - Interconnection study requirements and processes
  - Emerging interconnection approaches like group studies and flexible interconnection




Source: U.S. Department of Energy (DOE) DER Interconnection Roadmap

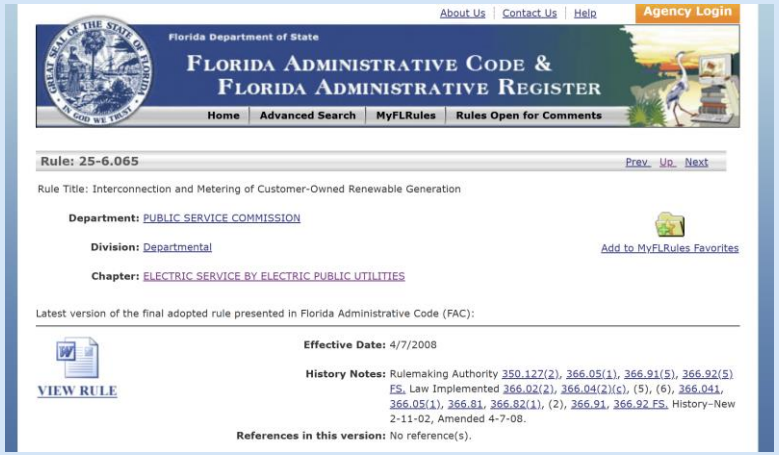
# DER Interconnection Process

# State Interconnection Process Requirements

- Most states/jurisdictions have defined DER interconnection rules and processes covering relevant topics:
  - Process flow, milestones, and timelines
  - Technical and equipment standards
  - Screening and study criteria
  - Dispute resolution
- State rules and practices vary significantly but have common themes
  - Common starting point: NERC Small Generation Interconnection Procedure
  - State differences often driven by levels of DER adoption
    - More DER adoption -> More recent updates, more sophisticated processes, newer standards

# State Interconnection Process Examples

## Florida Administrative Code 25-6.065



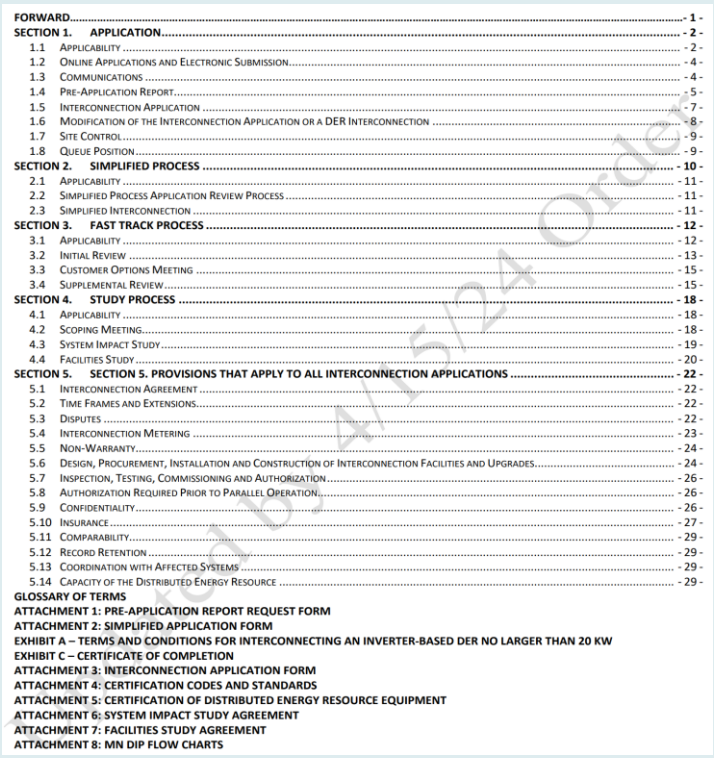

## Illinois Administrative Code Part 466

**TITLE 83: PUBLIC UTILITIES**
**CHAPTER I: ILLINOIS COMMERCE COMMISSION**
**SUBCHAPTER c: ELECTRIC UTILITIES**
**PART 466 ELECTRIC INTERCONNECTION OF DISTRIBUTED ENERGY RESOURCES FACILITIES**

- Section 466.10 Scope
- Section 466.15 Compliance
- Section 466.20 Definitions
- Section 466.30 Waiver
- Section 466.35 Waiver (Renumbered)
- Section 466.40 Technical Standards
- Section 466.45 Pre-Application Report
- Section 466.50 Interconnection Requests
- Section 466.60 General Requirements
- Section 466.70 Lab-Certified Equipment
- Section 466.75 Limited-Export and Non-Exporting Distribution Energy Resources Facilities
- Section 466.80 Determining the Review Level
- Section 466.90 Level 1 Expedited Review
- Section 466.100 Level 2 Expedited Review
- Section 466.110 Level 3 Expedited Review
- Section 466.120 Level 4 Review
- Section 466.125 Material Modifications
- Section 466.130 Disputes
- Section 466.140 Records

- Section 466.APPENDIX A Level 1 Application and Contract
- Section 466.APPENDIX B Certificate of Completion
- Section 466.APPENDIX C Levels 2 to 4 Application
- Section 466.APPENDIX D Levels 1 to 4 Contract
- Section 466.APPENDIX E Interconnection Feasibility Study Agreement
- Section 466.APPENDIX F Interconnection System Impact Study Agreement
- Section 466.APPENDIX G Interconnection Facilities Study Agreement

## Minnesota Distributed Energy Resource Interconnection Process (MN DIP)



# DER Interconnection – Process Differences by DER Size

| | Small | Medium | Large |
|---|---|---|---|
| **DER Size Range** | 0–25 kW | 25–500 kW | 500+ kW |
| **Process Terminology** | • Level 1<br>• Fast Track<br>• Simplified Review | • Level 2 and 3<br>• Fast Track<br>• Supplemental Review | • Level 4<br>• Supplemental Review<br>• Feasibility and System Impact Study |
| **Application Screening** | Site-level screening criteria, may include elements for known circuit limitations (e.g., minimum load) | Screening criteria may be similar to smaller systems but with additional criteria or more extensive review | Screening generally requires applications be modeled in power flow software |
| **Interconnection Costs** | Typically minimal, may require service transformer upgrade | Vary significantly, ranging from minimal to $100k+ or larger | Range from minimal to very high (can reach millions of dollars) |

*Values/statements are illustrative. Specific thresholds and processes vary by state.

# State Comparisons

| | Florida | Illinois | Minnesota |
|---|---|---|---|
| **Max DER Size** | 2 MW (Net Metering) | 10 MVA | 10 MW |
| **Small DER Category** | Tier 1 – ≤10 kW | Level 1 Screening – 25 kW (export capacity) or 50 kW (nameplate) | Simplified Process |
| **Medium DER Category** | Tier 2 – 10 kW to 100 kW | Level 2 Screening (Expedited and Supplemental Review Paths) | Fast Track Process (size limit based on voltage class) |
| **Large DER Category** | Tier 3 – 100 kW to 2 MW | Level 4 – Feasibility, System Impact, and Facilities Studies | Study Process – System Impact Study, Facilities Study |
| **Applicable Technical Standard** | IEEE 1547-2003 (Explicitly Stated) | IEEE 1547-2003 (Separate Smart Inverter Requirements for Net Metering) | IEEE 1548-2018 (fully adopted, additional details in State TIIR and Utility Technical Specifications Manuals) |

Source for Florida: 25-6.065 : Interconnection and Metering of Customer-Owned Renewable Generation - Florida Administrative Rules, Law, Code, Register - FAC, FAR, eRulemaking

# Level 1 and 2 Screening Criteria: State Example

## Illinois Level 1 Criteria

- Aggregate DER export capacity may not exceed 100% of the minimum load
- Aggregate DER nameplate capacity on the load side of spot network protectors shall not exceed 5% of the spot network's maximum load
- Aggregate export capacity on shared secondary line may not exceed 20 kVA
- May not create an imbalance between the two sides of the 240 volt service of more than 20% of the nameplate rating transformer

## Illinois Level 2 Expedited Criteria

- May not contribute more than 10% to the distribution circuit's maximum fault current
- Shall not cause protective devices to have fault currents exceeding 90% of their short circuit interrupting capability
- When connected to a 3-phase, 3-wire primary line, a 3-phase or single-phase generator shall use a phase-to-phase primary connection
- When connected to a 3-phase, 4-wire primary line, a 3-phase or single-phase generator shall use a grounded line-to-neutral primary connection
- DER nameplate capacity may not exceed 10 MVA in an area where there are known or posted transient stability limitations to generating units located in the general electrical vicinity

# Interconnection Technical Topics

# DER Interconnection – Technical Standards

- IEEE 1547 – Standard Covering DER Interconnection
- UL 1741 – Hardware Testing and Safety Standard to Ensure Compliance with IEEE 1547 Requirements

## IEEE 1547 – 2003 Basic Inverters

- Requires unity power factor
- No voltage regulation
- Required to trip immediately for voltage/frequency issues
- Hardware Certification
  - **UL 1741 (2005)**

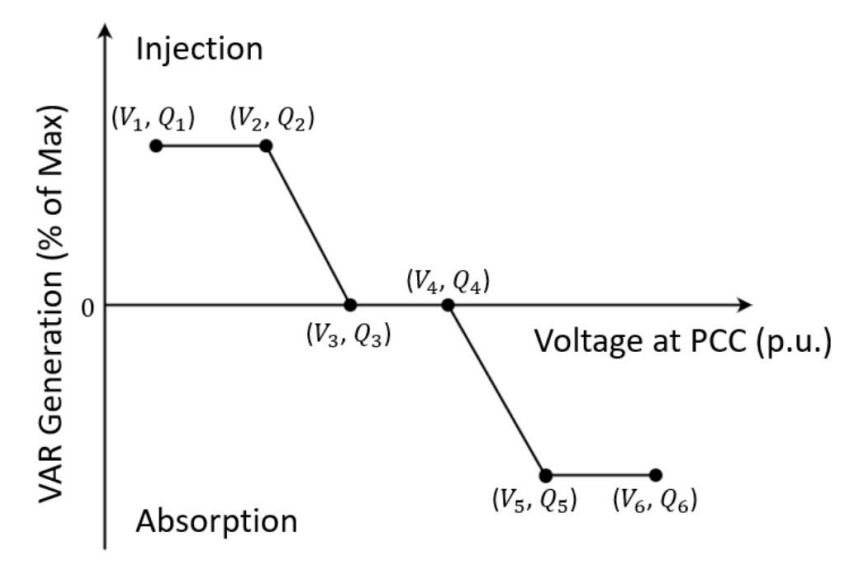
## IEEE 1547a – 2014 Early Smart Inverters

- Developed in response to voltage regulation and bulk system stability challenges
- Includes Volt/Var and Volt/Watt curves for voltage regulation
- Includes Voltage and Frequency Ride-Through for Bulk Power Stability
- Hardware Certification
  - **UL 1741 SA**

## IEEE 1547 – 2018 Full Interoperability

- Expands and formalizes 1547-2014a into full interoperability standard
- Includes roles and decisions for various parties within interconnection Process
  - Utilities
  - Manufacturers
  - PUCs
- Hardware Certification
  - **UL 1741 SB**

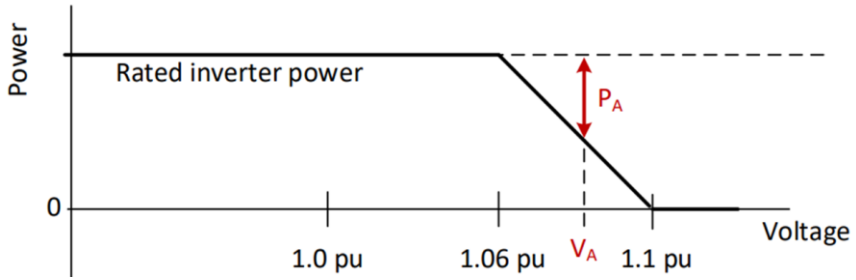
# DER Voltage Support Functions




**Volt/VAR Curve (VVC)**

A VVC is a customizable curve that adjusts a DER inverter's **reactive power compensation** based on the **voltage measured** at the **inverter**.

- If voltage is within the curve's deadband, no reactive power support is needed
- If voltage exceeds the curve's max deadband point, reactive power is absorbed
- If voltage exceeds the curve's min deadband point, reactive power is injected




Source: Volt/Watt Curve Showing Max Possible Curtailment

Volt/Watt Curve (VWC)

A VWC is a customizable autonomous curve that will adjust a DER inverter's real power output based on the voltage measured at the inverter

- Can be used in addition to a VVC to address overvoltage

# Voltage and Frequency Ride-Through

- Inverter must remain connected and generating for some system disturbances to prevent large-scale simultaneous tripping
  - Voltage Ride-Through (High and Low)
  - Frequency Ride-Through (High and Low)
  - Default enabled for 1547-2018 compliance
  - Often based on ISO/RTO recommendations
- Operating Modes
  - Continuous Operation: “Do your thing”
  - Mandatory Operation: Thou shalt not trip until allowed
  - Momentary Cessation: Stop operating but don’t shut down, “be ready for round 2”

*Table 5: Low/High Voltage Ride Through (L/HVRT) minimum requirement – ACTIVATED*

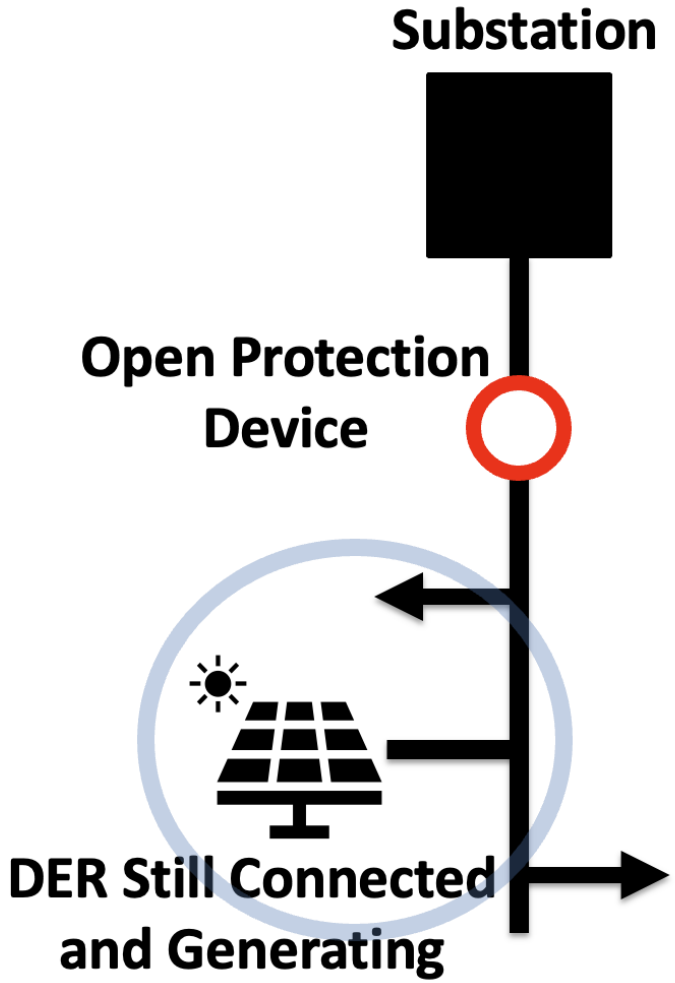
| Region | Voltage range (% of nominal voltage) | Operating Mode/Response | Min. ride-through time (s) | Max. Trip Time (s) |
|---|---|---|---|---|
| *HIGH VOLTAGE 2 (HV2)* | V ≥ 120 | Cease to Energize | N/A | 0.16 |
| *HIGH VOLTAGE 1 (HV1)* | 110 < V < 120 | Momentary Cessation | 12 | 13 |
| *NEAR NOMINAL VOLTAGE (NN)* | 88 ≤ V ≤ 110 | Continuous Operation | Infinite | N/A |
| *LOW VOLTAGE 1 (LV1)* | 70 ≤ V < 88 | Mandatory Operation | 20 | 21 |
| *LOW VOLTAGE 2 (LV2)* | 50 ≤ V < 70 | Mandatory Operation | 10 | 11 |
| *LOW VOLTAGE 3 (LV3)* | V < 50 | Momentary Cessation | 1 | 1.5 |

*Table 6: Low/High Frequency Ride Through (L/HFRT) minimum requirement – ACTIVATED*

| Region | System Frequency Default Settings | Minimum Range of Adjustability | Ride-Through Until | Ride-Through Operational Mode | Maximum Trip Time |
|---|---|---|---|---|---|
| HIGH FREQ 2 (HF2) | f > 62 | 62.0 – 64.0 Hz | No Ride-Through | NA | 0.16s |
| HIGH FREQ 1 (HF1) | 60.5 < f ≤ 62 | 60.1 – 62.0 Hz | 299 | Man. Operation | 300s |
| NEAR NOMINAL (NN) | 58.5 ≤ f ≤ 60.5 | NA | Indefinite | Con. Operation | NA |
| LOW FREQ 1 (LF1) | 57.0 ≤ f ≤ 58.5 | 57.0 – 59.9 Hz | 299 | Man. Operation | 300s |
| LOW FREQ 2 (LF2) | f < 57.0 | 53.0 – 57.0 Hz | No Ride-Through | NA | 0.16s |

# Islanding – IEEE 1547

- Islanding - When a DER is energizing a portion of the grid that is not connected to the traditional utility source
- Unintentional Island
  - DER must not energize the distribution system within 2 seconds after detecting loss of utility source (e.g., during an outage)
- Intentional Island
  - DER, if designed to do so, can separate from the typical source and remain energized
  - "Backup power"



# Grid-Following vs. Grid-Forming Inverters

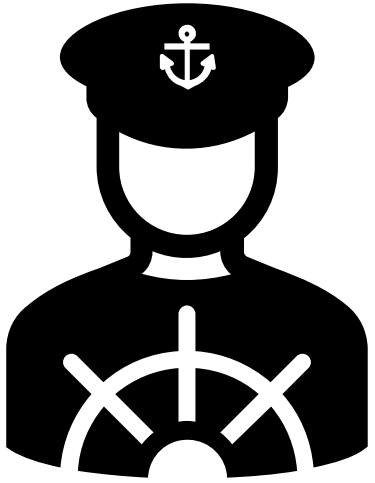
## Grid-Following Inverters

- Requires another source to operate and generate power
- Cannot sustain without a source to "follow"

Following the system

## Grid-Forming Inverters

- Can act as a stand-alone source
- Frequently used for back-up power
- Can operate in grid-following mode until needed



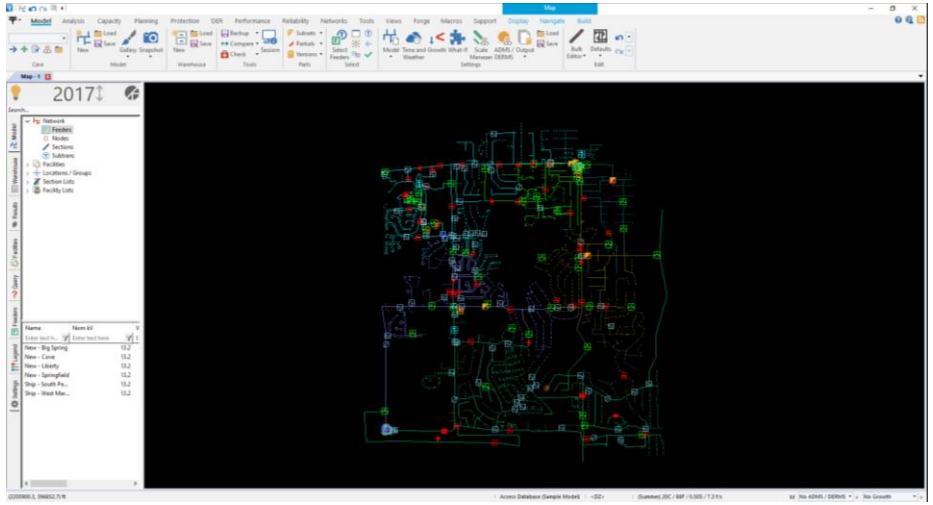
Leading the system

NREL Introduction to Grid Forming Inverters: A Key to Transforming our Power Grid

# Studying Large DER Interconnections - Modeling

## Modeling Considerations

- Distribution System Modeling
  - Build Base Model
  - Model Minimum and Maximum Load Scenarios Before/After DER
- DER Modeling
  - Assume Max Nameplate Output
  - Model Reactive Power Performance
    - Unity/Fixed PF Vs Volt/Var Curve
  - Modeling Other DERs in Queue




Synergi Electric Sample Model and Interface

# Studying Large DER Interconnections – Issues and Resolutions

## Identify Criteria Violations

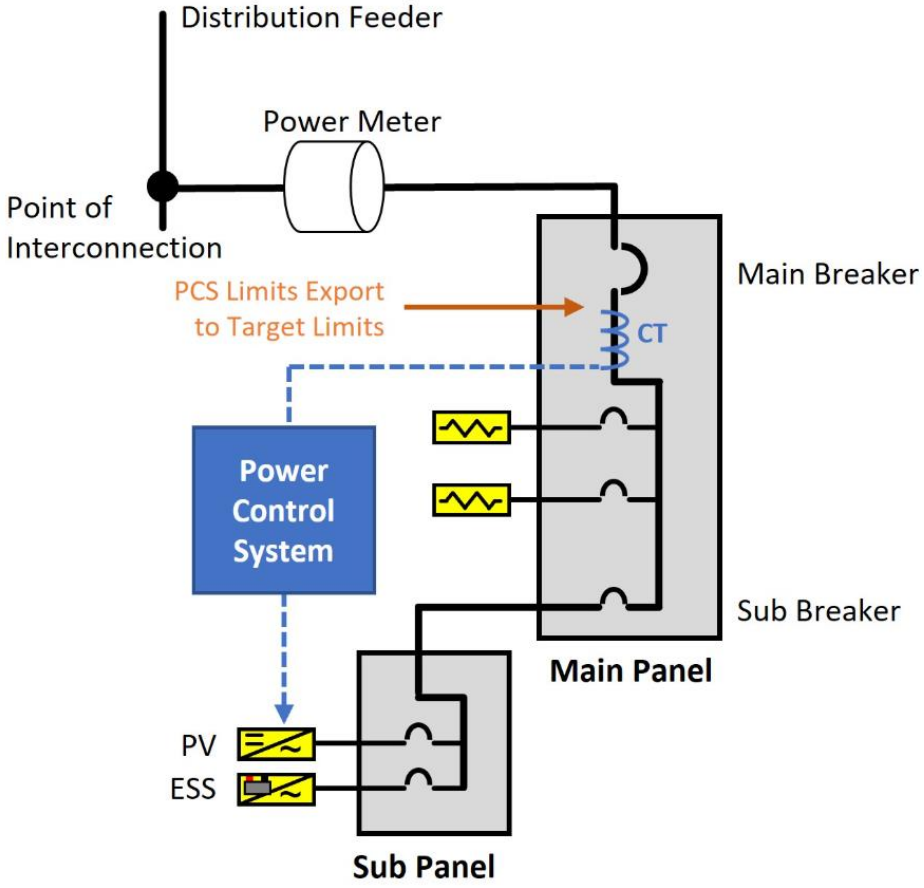
- Overvoltage Condition
- Thermal Overload
- Voltage Stability / Rapid Voltage Change
- Fault Current Issues
- Unintentional Islanding Risk
- Reverse Power Flow Issues

## Resolve Via Modifications

- DER Reactive Power Modification
- Voltage Regulating Equipment
- Equipment Replacement / Reconductor
- Protection Equipment Modification
- Reverse Flow Control Enablement

# Static Flexible Interconnection

- Flexible Interconnection uses control systems and other techniques to reduce interconnection costs or improve interconnection timelines
  - Static: Performance limits and characteristics are set at the time of interconnection
  - Dynamic: Performance limits are set dynamically based on actual grid conditions
- Common Static FlexIX: Import/Export Limits via Power Control System (PCS)
  - Existing Standard: UL 1741 PCS CRD
  - Forthcoming Standard: UL 3141




Example PCS Implementation (EPRI)

# Static Flexible Interconnection – Benefits and Challenges

**Benefits**

- Allows for more accurate, less conservative assumptions during the interconnection study
- Enables more DER to be interconnected at a lower cost

**Challenges and Drawbacks**

- Implementations and hardware are more site-specific for large installations, as standards and equipment are still relatively nascent
- Reliance on customer equipment to prevent utility safety & reliability issues creates accountability challenges
- Customer hardware requirements and utility redundant mechanisms to ensure performance may create additional costs

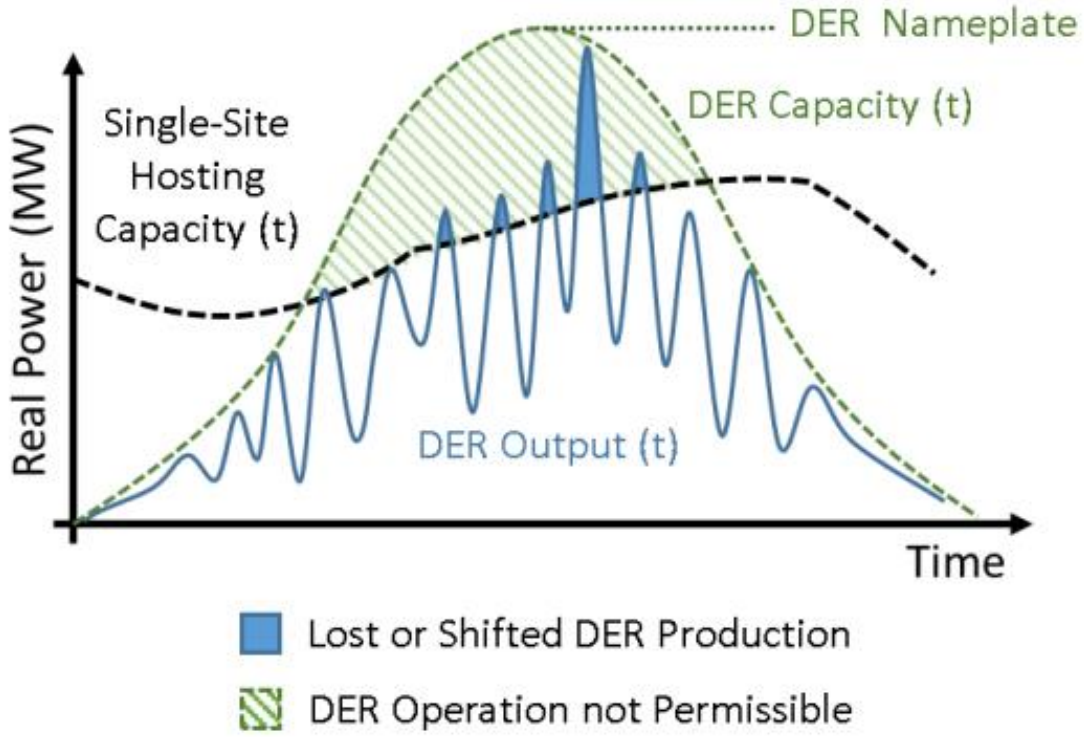
# Dynamic Flexible Interconnection

Direct Real Power Management

Limit the maximum real power capability based on system constraints to prevent violations

- Real-Time Setpoints
- Real-time or Day-Ahead Scheduled Limits (Dynamic Operating Envelopes)

- Real-time Management Example New York NYSEG & RG&E Flexible Interconnection Pilot
- Dynamic Operating Envelopes Example: Australia




Source: EPRI Understanding Flexible Interconnection

# Dynamic Flexible Interconnection

**Benefits**

- Reduces DER interconnection costs
- Increases utilization of existing infrastructure

**Challenges and Drawbacks**

- Requires significant distribution operations infrastructure to support at-scale (ADMS/DERMS/Communications)
- Interconnection study process is significantly more complex
- Curtailment of real power can impact project economics, create uncertainty
- Can be difficult to predict future curtailment, especially due to distribution system changes

# Wrap-up

# Questions States Can Ask

- Has the state/utility adopted the current version of the IEEE 1547 Standard (2018)? If not, what process steps would be needed to update the standard to this standard?
- What are the steps in the utility's interconnection process and how long does each take? How can wait times be reduced?
- How are DER interconnections being screened and studied? What improvements can be made?
- How does the utility staff its interconnection management team, and do they have sufficient resources?
- What hosting capacity and other grid data do the utilities currently make available to DER developers and the public? What would the utility need to do to provide more granular data and more frequent updates — and what are the costs and benefits?
- What is the current cost allocation method for DER interconnection? What methods might be tested to improve economic efficiency, considering other beneficiaries of the interconnection upgrades?
- How are utilities coordinating grid planning with interconnection processes?
- Could the utilities use dynamic flexible interconnection to reduce wait times and interconnection costs? What technologic or process hurdles may need to be overcome?

# Actions States Can Take

**State Regulators**

- Adopt IEEE 1547-2018 Standard and capabilities
- Establish objectives for interconnection improvements and review state DER interconnection rules and processes for potential improvements, including updates to referenced standards
- Provide guidance on robust data sharing and reporting, including regular updates on DER hosting capacity, grid conditions, and interconnection queues
- Consider changes to interconnection processes to reduce wait times, making full use of available technical solutions such as automation and flexible interconnection
- Coordinate interconnection and grid planning processes
- Examine technical standards for DER interconnection studies and resulting required system upgrades and interconnection costs
- Facilitate updates to DER interconnection rules to improve outcomes and incorporate new technology capabilities, such as flexible interconnection and limited import/export
- Explore smart inverter voltage management functions to mitigate DER-driven voltage issues and leverage import/export limitation capabilities of Power Control Systems
- Adopt cost allocation principles and pilot new cost allocation approaches

**State Energy Offices and Utility Consumer Advocates**

- Provide feedback on usefulness of interconnection tools, educational materials, and data sets
- Participate in forums considering updates to interconnection standards and processes, cost allocation, and planning practices

# Resources for More Information

- DOE Office of Energy Efficiency & Renewable Energy, *Distributed Energy Resource Interconnection Roadmap*, 2025
- DOE Interconnection Innovation e-Xchange, *Interconnection Resources*
- Interstate Renewable Energy Council (IREC), *IREC Model Interconnection Procedures 2023*
- Building a Technically Reliable Interconnection Evolution for Storage (BATRIES), *Solutions to Improve Energy Storage Interconnection*
- IREC, *IEEE 1547-2016 Adoption Tracker,* 2024
- Lisa Schwartz, Guillermo Pereira, Paul De Martini, Josh Schellenberg, Jason Ball, Natalie Mims Frick, Lawryn Kiboma, David Narang, Jeremy Keen and Michael Ingram, Berkeley Lab Interactive Decision Framework for Distribution System Planning (2024) — *see "Interconnection" section in "Distribution System Analyses" box*

# ENERGY MARKETS & POLICY

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