RMI
ENERGY. TRANSFORMED.

Near-term Solutions to New Generator Interconnection

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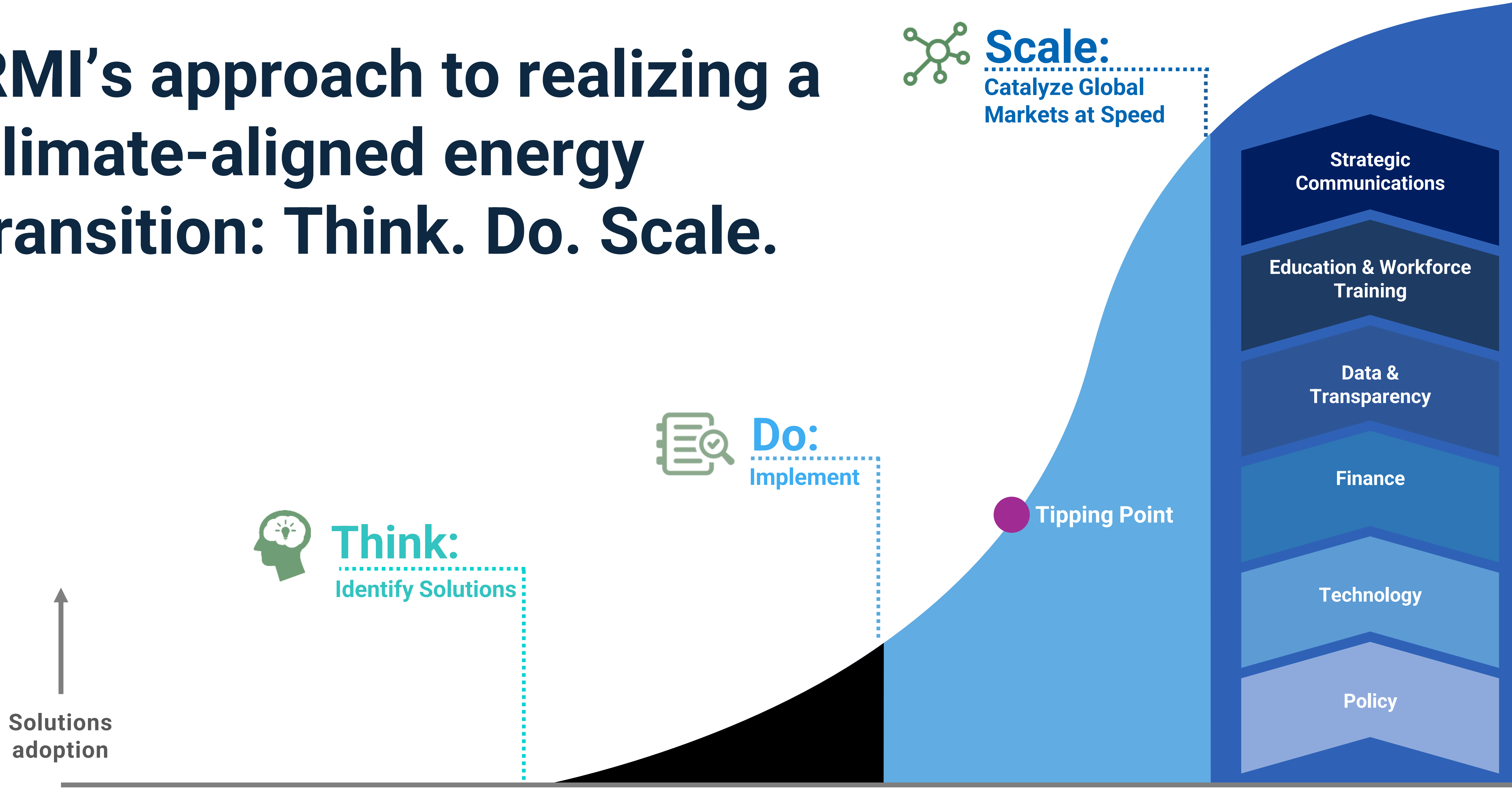
MARCH 2024

RMI’s approach to realizing a climate-aligned energy transition: Think. Do. Scale.



Carbon-Free Electricity's change model aligns capital and incentives with solutions for deep decarbonization

Utility transition finance

- **Support utilities in using financial solutions** to transition fossil assets & invest in carbon-free electricity
- **Provide information to investors** to assess utility performance against climate targets

Business models & regulation

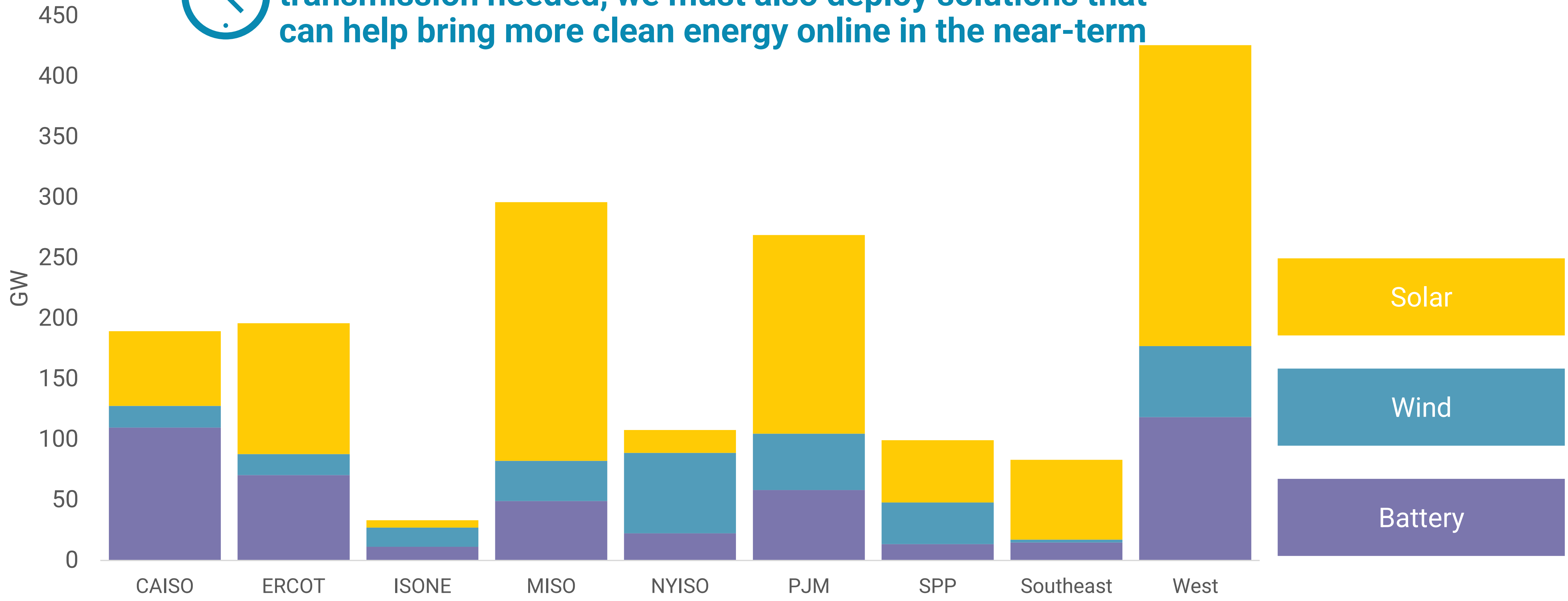
- **Support regulators in aligning utility incentives** and policies with climate, equity, and affordability goals
- **Develop and test business models** for utilities and other companies that can accelerate the energy transition

Grid planning & operations

- **Clarify technical solutions** for grid planning & operations consistent with deep decarbonization
- **Focus on emerging priorities** including transmission, grid-enhancing technologies, competitive market design, virtual power plants, and electrification readiness

US transmission interconnection queues have over 1.3 TW of renewables and storage with 3-5 years of wait time

Because it takes years to build the new interregional transmission needed, we must also deploy solutions that can help bring more clean energy online in the near-term



Two near-term solutions to make the most out of our existing grid

These are complementary solutions to the desperately needed long-term solution of interregional transmission buildout and proactive planning

Grid-enhancing technologies (GETs)

Fall ESIG workshop: only half the audience had heard of GETs

Show of hands: If you have heard of grid-enhancing technologies before raise your hand

Clean Repowering

- Surplus interconnection service

- Generator replacement

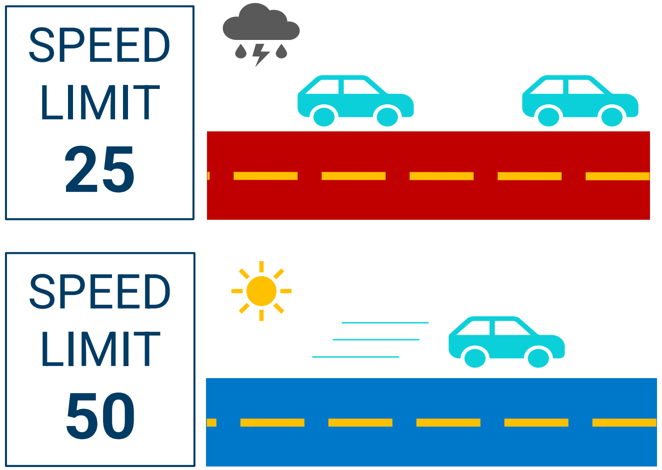
GETs in Transmission Interconnection

Grid-enhancing technologies (GETs) at-a-glance

Dynamic line ratings (DLR)

Adjust the carrying capacity of transmission lines based on real-time weather measurement

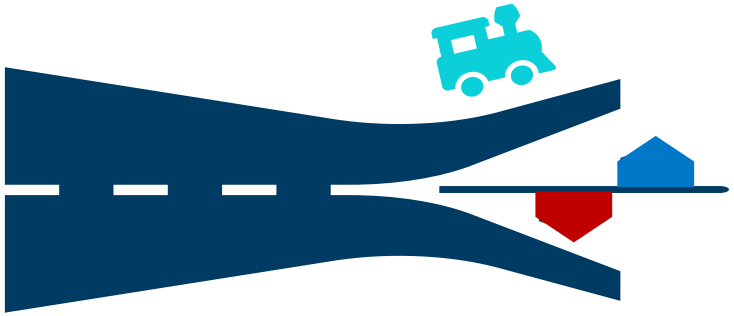
Transit analogy: real-time adjusted speed limits



Power flow controllers (PFC)

Push power away from overloaded lines with capacity constraints onto lines with spare capacity

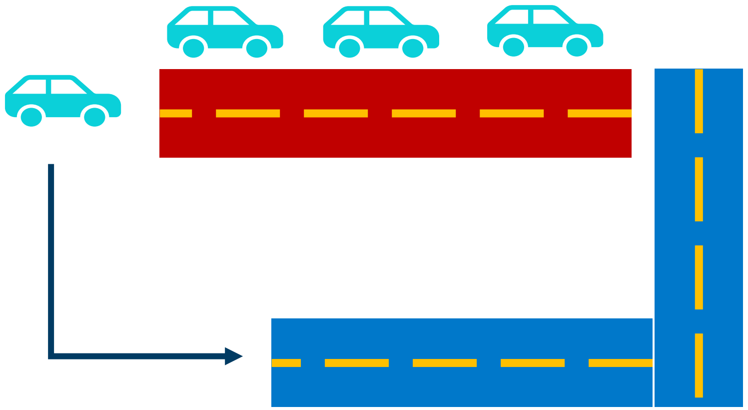
Transit analogy: railroad switching stations that direct trains to free tracks



Topology optimization (TO)

Software solution that automatically routes power flows around congested areas

Transit analogy: re-routing drivers around traffic



Our rigorous analysis emulates PJM's own interconnection study methodology

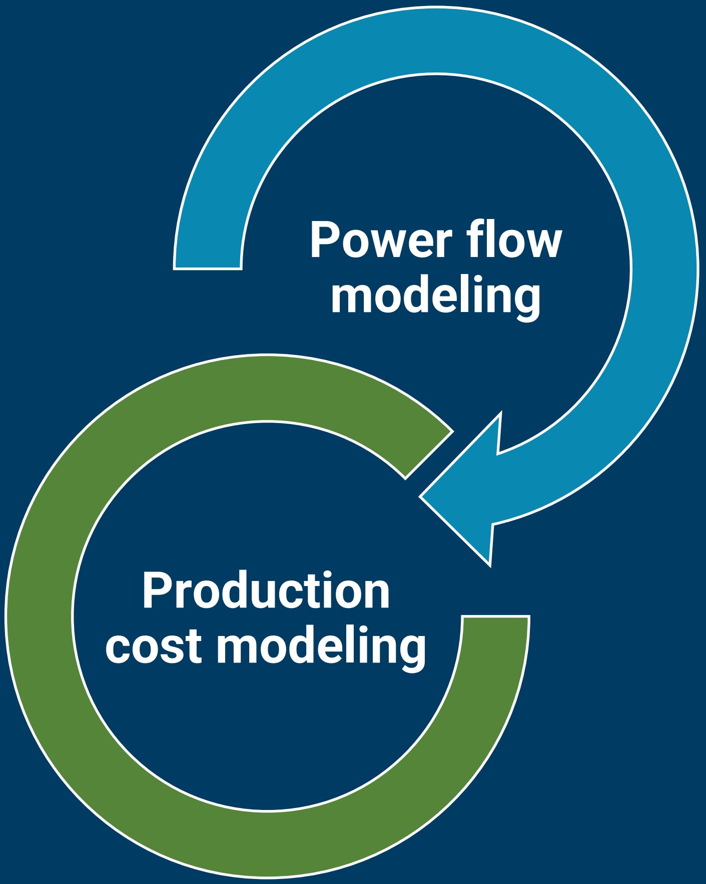
Scope

3 types of GETs:
Dynamic Line Ratings (DLR)
Power Flow Controls (PFCs)
Topology Optimization (TO)

5 PJM states:
Pennsylvania, Ohio, Illinois, Indiana, and Virginia

3 future years:
2026, 2028, and 2030

3 grid conditions:
Summer peak, winter, and light-load



All queued generation and GETs were incorporated into a power flow model + contingency analysis to assess **thermal** overload violations

Cost and emissions benefits from queued projects that, with GETs, could feasibly be operable in PJM by 2026 were quantified

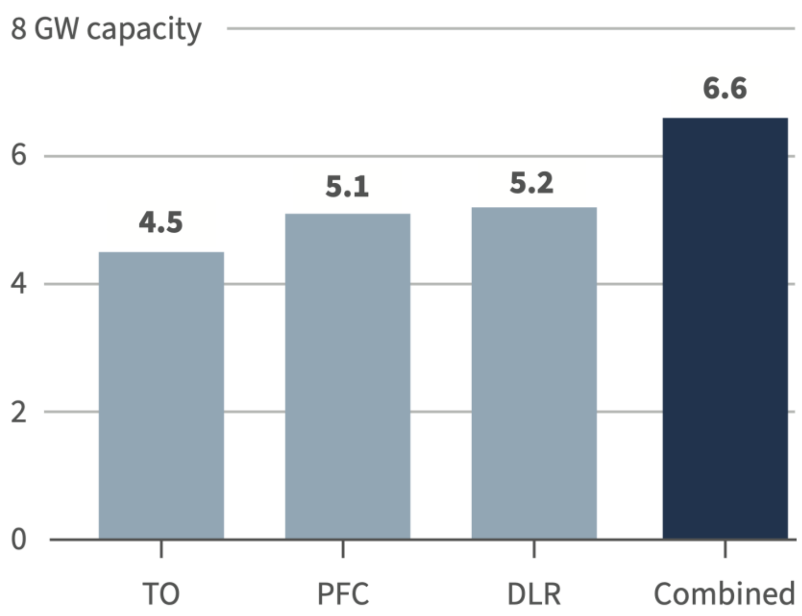
Each GET was incorporated into the power flow modeling with a unique method informed by deep-dive analysis

Our modeling	A 10% uprate to represent DLR was applied to all overloads during summer peak	A python script provided by the vendor was utilized to place and select the number of PFCs in the study	TO was given credit for overloads arising from P1, P2, P4, and P7 NERC contingencies
Deep-dive analysis	A deep-dive analysis of DLR throughout the year at multiple locations revealed an average 17% uprate in summer conditions	Each device is modeled in PSSE with a dynamic reactance that adjusts the line's overall impedance; PFCs are only applicable in meshed grids	A deep-dive analysis of overload cases revealed TO is best-suited to address the above contingency conditions in meshed grids

We designed this to be a replicable approach that could help grid operators and utilities incorporate GETs into their own grid planning models.

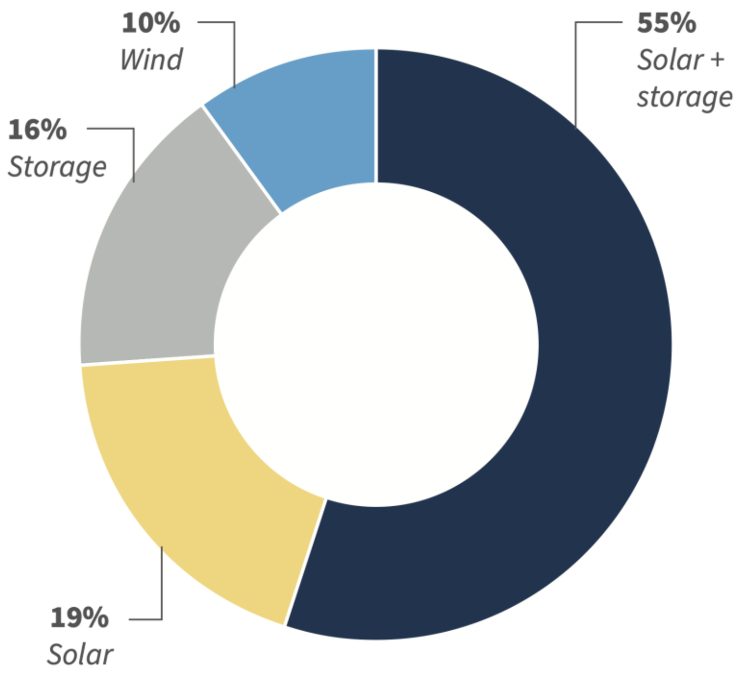
Just 95 GETs could enable 6.6 GW of new clean resources to come online by 2027

Each GET was assessed individually and in combination

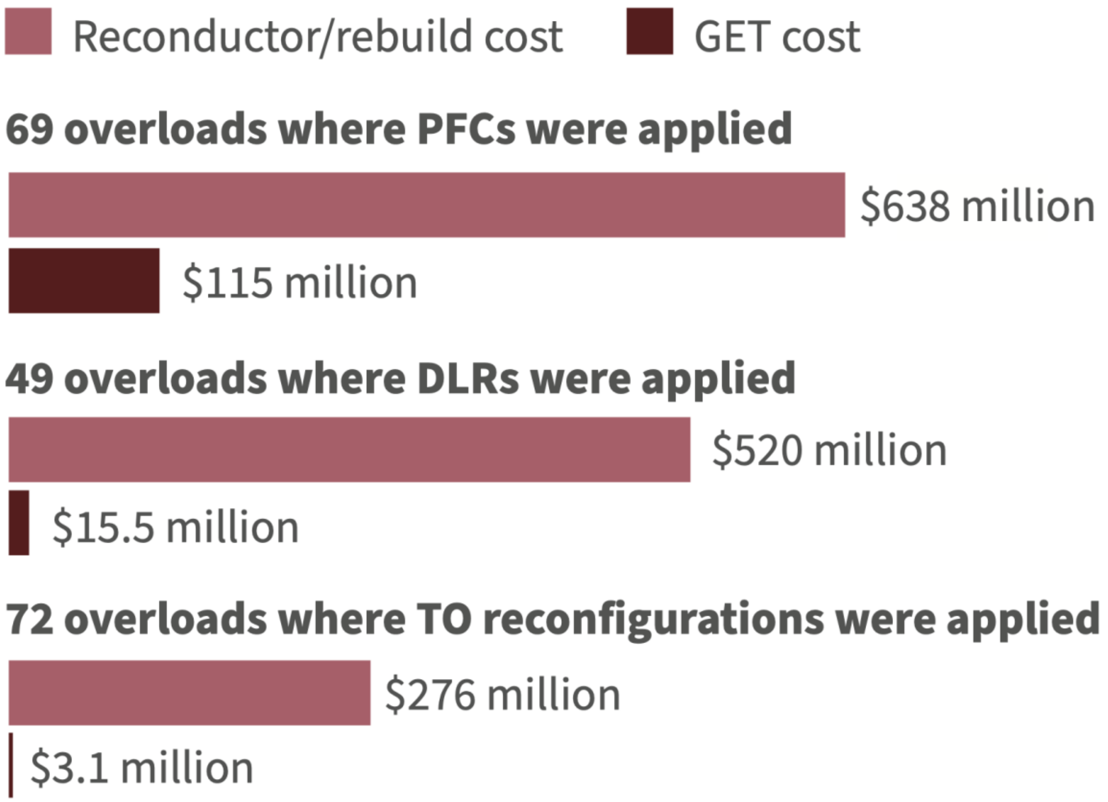


RMI Graphics. Source: Quanta analysis

This amounts to ~5% of all queued generation analyzed



GETs provide dramatic cost savings for developers compared to default network upgrades



RMI Graphic. Source: Quanta analysis

These technologies should be evaluated as a matter of course in grid operator interconnection studies.

Until the regulatory framework is in place to enable that, **developers can request GETs consideration for their projects**, as described in a case study in our report.

GETs drive lower electricity costs for consumers across PJM

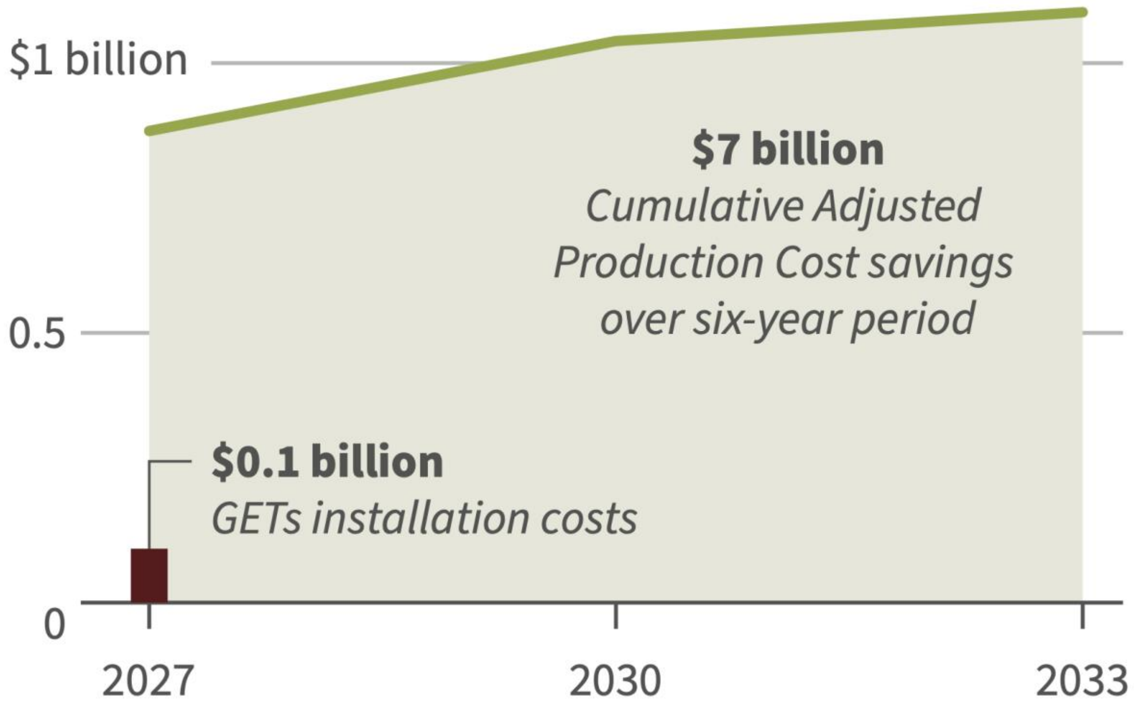
Once online, production cost savings from GETs + new generation can total $1B per year

$$APC = \sum_{Units}^{Base\ Case} \Big[(Fuel\ Costs + Emission\ Costs + Variable\ O\&M) + \begin{pmatrix} PJM\ Purchase \times PJM\ Load\ Weighted\ LMP \\ -PJM\ Sale \times PJM\ Gen\ Weighted\ LMP \end{pmatrix} \Big]$$

These savings are driven by both:

- Lower operating expenses of the new renewable resources displacing fossil-fuel generation, and
- Existing renewable generation benefitting from reduced congestion due to GETs

Carbon emissions are reduced **3.5% in 2027**, avoiding 12 million tons of CO_2e



RMI Graphic. Source: Quanta analysis

These fast-to-deploy, flexible transmission tools can accelerate interconnection and deliver substantial savings

GETs are applicable in a planning paradigm

- Some GETs are viewed today as only operational tools; this fails to recognize their full potential

GETs can be modeled and deployed reliably

- Quanta and GETs vendors pressure-tested GETs application to ensure no adverse impacts elsewhere in the system while respecting all reliability criteria

GETs are complementary transmission solutions

- GETs can work well in combination (particularly DLR, which can be effectively paired with PFCs or TO) and serve as bridge solutions to longer-term transmission upgrades or as part of a broader transmission project

We hope to work with transmission owners and utilities to leverage this analysis as a capacity-building tool, as well as support new regulations or policies that promote uptake of GETs

Clean Repowering in Transmission Interconnection

Clean repowering – deploying clean energy using existing fossil plants' interconnections – can accelerate interconnection

Regional interconnection rules include 2 cases that allow for a more streamlined process

2 key **IRA incentives** improve the economics

Surplus interconnection service: adding new generation at the site of an *existing* plant, that would continue operating

Energy community tax credit bonuses: +10% on ITC or PTC

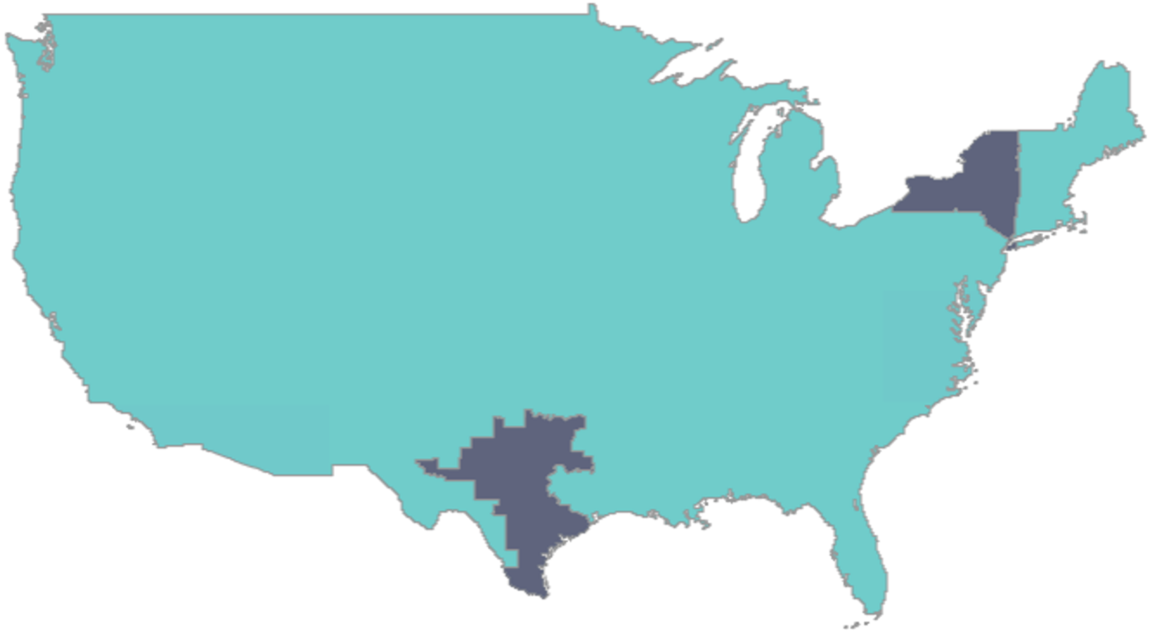
Generator replacement: adding new generation at the site of a *retiring* unit or plant

DOE Energy Infrastructure Reinvestment (EIR) Loans: up to $250B

Surplus interconnection service requests are governed by a federal standard (FERC Order 845)

Key Components of FERC Order 845

Priority is given to existing generation owners	No network upgrades allowed
Must not exceed total interconnection service of existing plant	Interconnection rights expire within one year of existing facility retiring



All regions in the United States except for **NYISO** and **ERCOT** follow Order 845 requirements

- **NYISO** received a waiver based on its treatment of existing grid resources
- **ERCOT** is not FERC-jurisdictional and only has a process for adding storage to solar PV resources

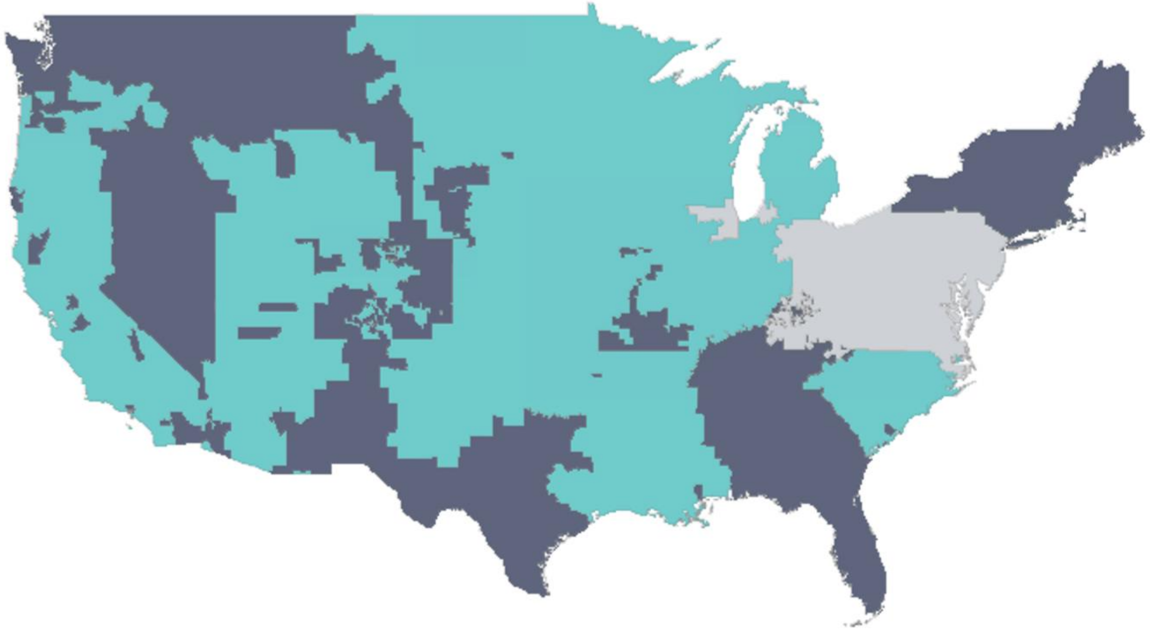
✓ *Has a surplus interconnection process*

✗ *Does not have a surplus interconnection process*

Generator replacement processes that are separate from the queue exist in some regions but not others

- **MISO** set the standard in 2018 with its generator replacement interconnection process
  - Requests must be made at least **one year prior** to retirement and new generation must come online **within three years**
  - Initial process included **restrictions on plant ownership** that have been amended and relaxed over time
- **CAISO** and **ERCOT** have more limited processes that allow for in-kind replacements only
  - CAISO makes an exception for batteries at fossil plants
- **PJM** and **ISO-NE** do not have defined processes, yet
  - **PJM** initiated a stakeholder dialogue to consider the creation of a process in July 2023

Spreading generator replacement processes to new regions can increase the scale of the opportunity

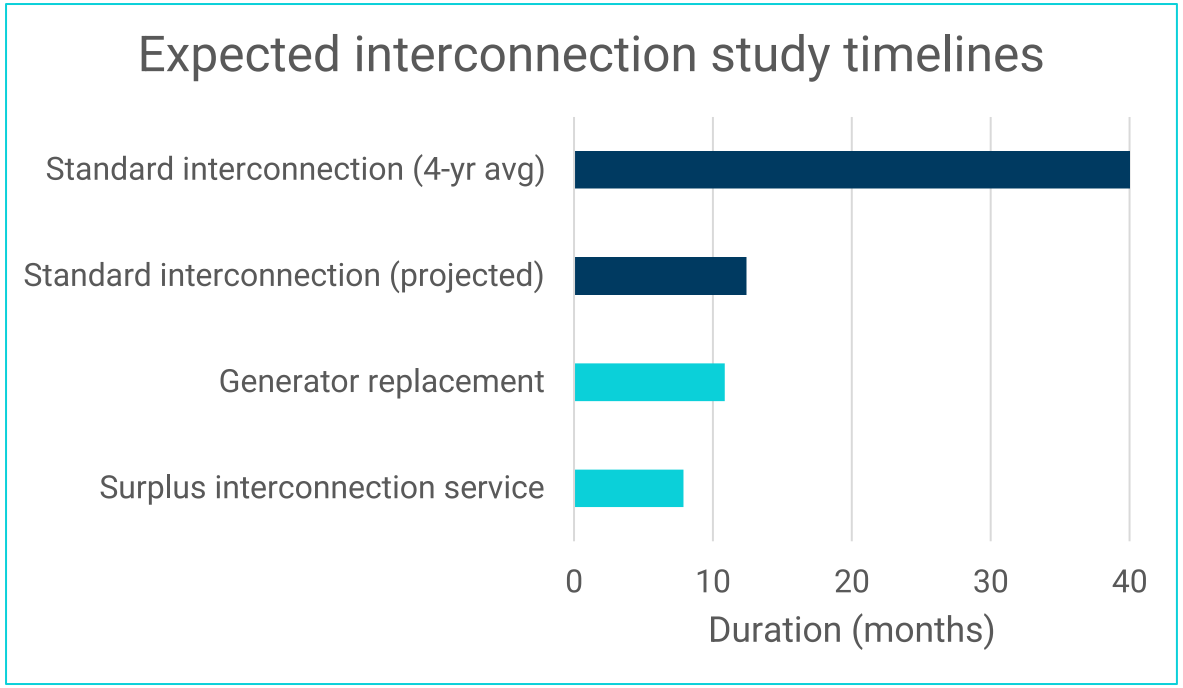


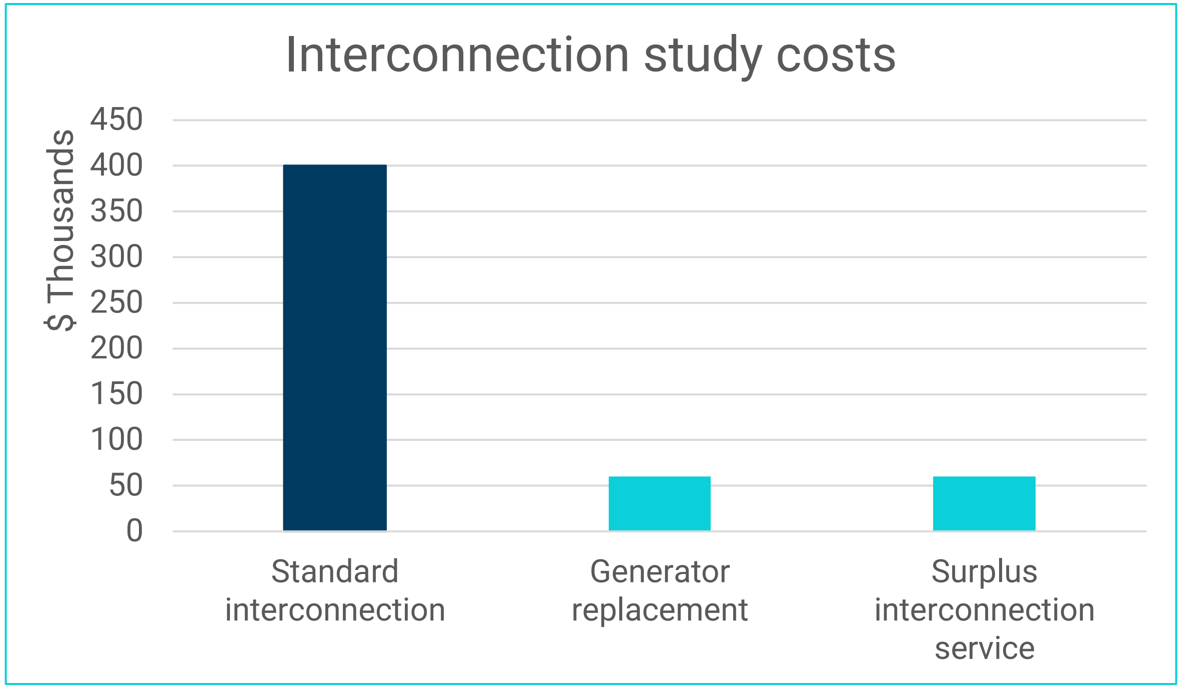
Has a generator replacement process separate from the standard interconnection queue

Separate generator replacement process pending

Does not have a separate generator replacement process

Both "fast-track" processes significantly reduce interconnection study timelines and costs





Data sourced from MISO; timelines and costs are comparable across regions

Electric utilities can utilize EIR low interest debt to pull forward reinvestment in clean energy

Traditional Financing: Reinvestment in 2031

1GW existing asset
$400M unrecovered balance

Plant balance paid off through rates (6.6% ROR)

New Solar + Storage in 2031

Outcomes

	2025	*30-year NPV*
Utility Earnings:	$15M	$430.1M
Ratepayer Costs:	$224M	$1.8B

Accelerated Reinvestment with EIR in 2025

1GW existing asset
$400M unrecovered balance

EIR refinances unrecovered balance over 30 years

New Solar + Storage partially financed w/EIR debt

Outcomes

	2025	*30-year NPV*
Utility Earnings:	$67.1M	$488.6M
Ratepayer Costs:	$80.8M	$1.8B

Clean repowering is a 250 GW "no-regrets" option, as it can reduce system costs by an NPV of $21 B over a 30-year planning horizon while adding resources to improve reliability

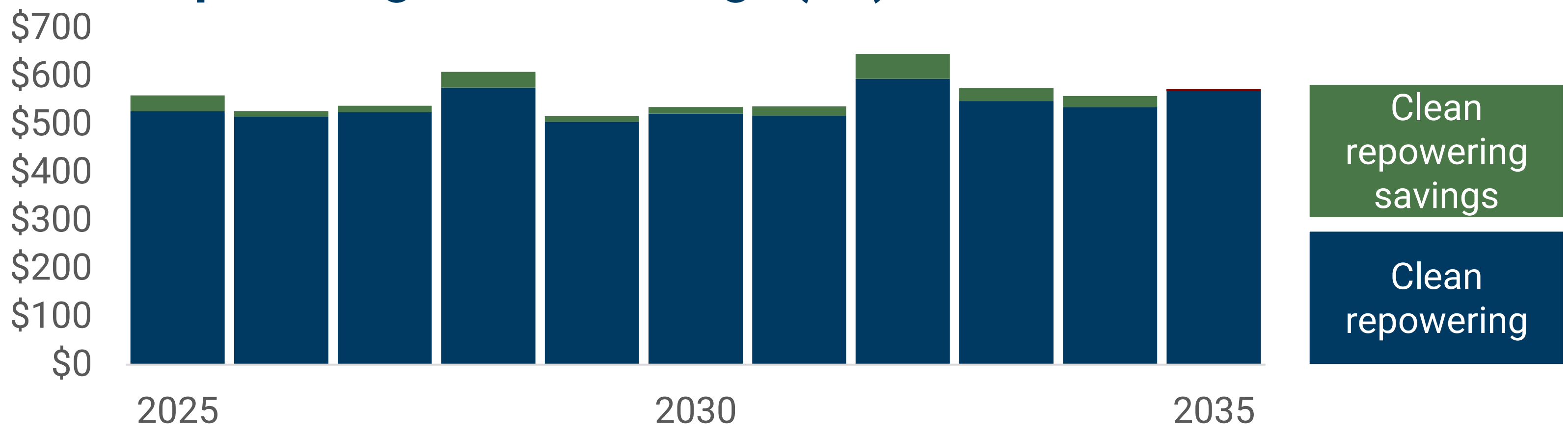
Affordability

- Avoids high costs of fossil fuel use and new transmission build
- Reduces interconnection process costs

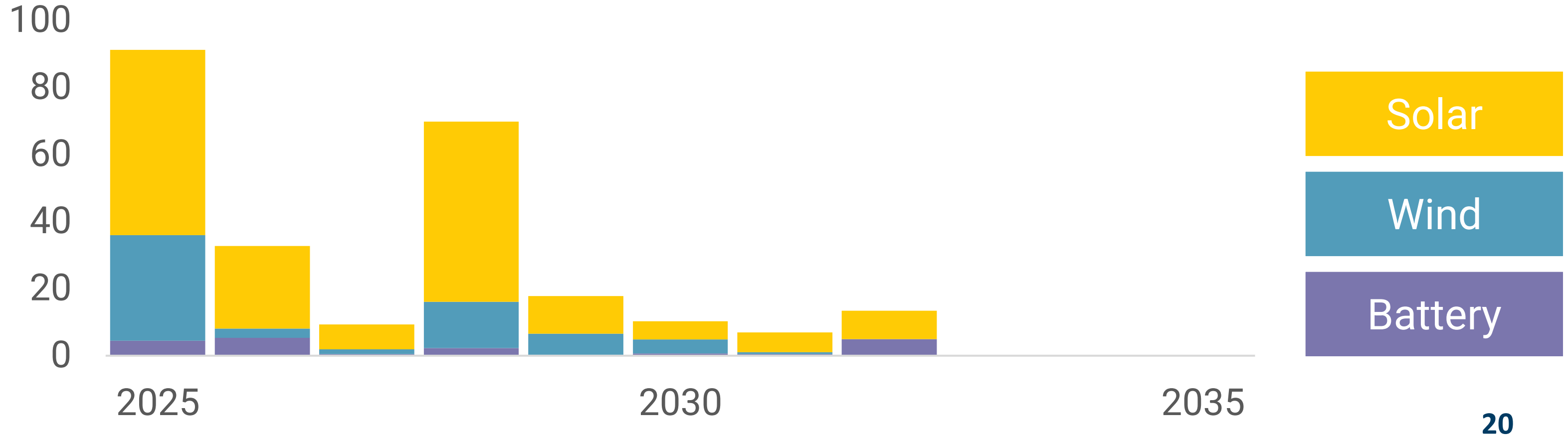
Reliability

- Minimizes grid impacts of new generation + retirements
- Faster interconnection can help mitigate near-term reliability risks

Clean repowering annual savings ($B)



Clean repowering annual deployment (GW)

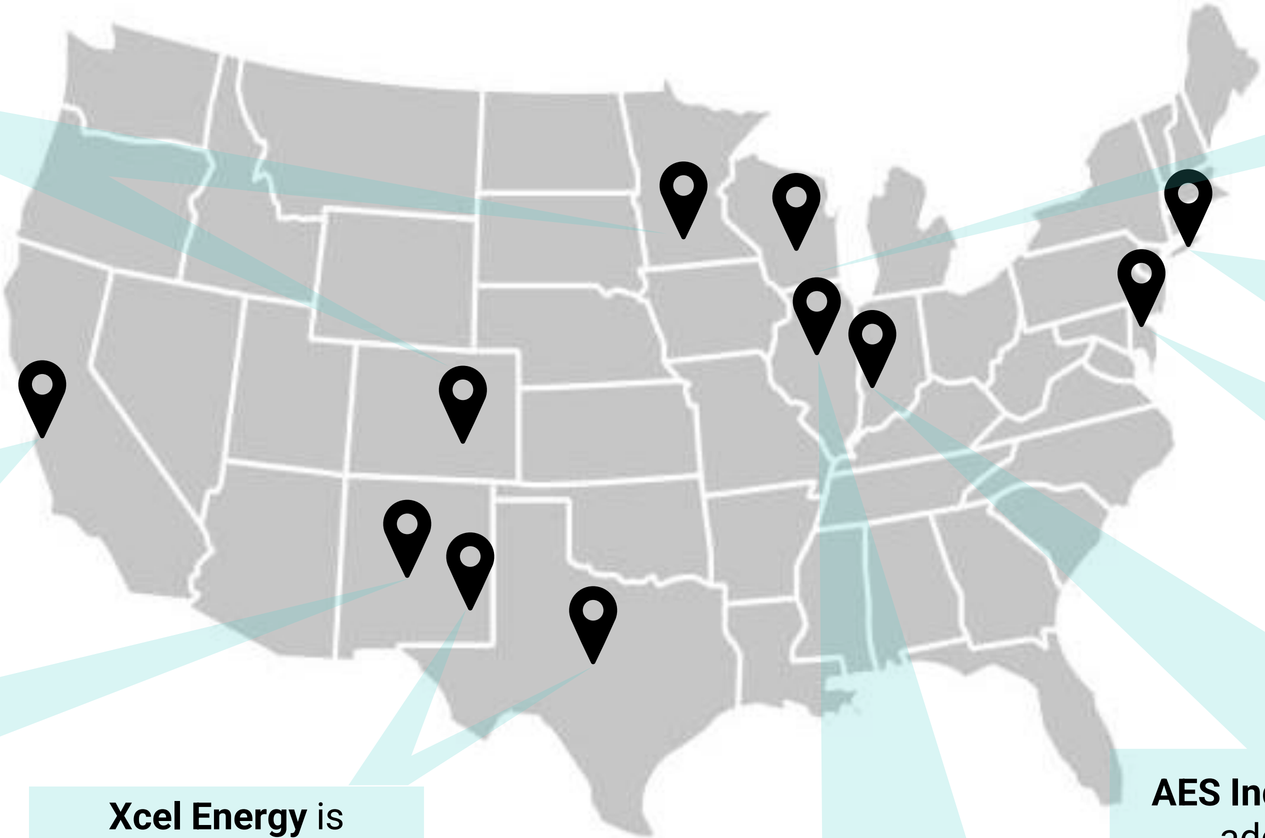


Plans for clean repowering projects are in development nationwide, and growing

Xcel Energy plans to replace coal plants in **Minnesota** and **Colorado** with solar and long-duration iron-air storage

Vistra replaced its **Moss Landing** natural gas plant with 750 MW of 4-hr battery storage

PNM is prioritizing storage resources that "leverage existing interconnections" in its latest RFP



Xcel Energy is adding solar to 2 of its oldest natural gas units in **New Mexico** and **Texas**

Vistra is retiring its **Joppa** and **Edwards** coal plants and replacing them with battery storage

Alliant Energy received a grant from the DOE Office of Clean Energy Demonstrations to pilot a **compressed CO_2 energy storage** project at its Columbia Energy Center

Several offshore wind projects along the East Coast are looking to use surplus or retiring fossil plant interconnections to connect to the grid

Elevate Renewables is deploying storage at existing natural gas generation facilities and currently has a pipeline of 5 GW across 25 locations in the Mid-Atlantic

AES Indiana is adding 200 MW of storage (in addition to natural gas) to its retiring **Petersburg** coal-fired power station

With the IRA, the time is now to look at uneconomic or underutilized generation and consider clean repowering

Takeaways

- Clean repowering can support **faster interconnection** of clean energy resources and minimize costly transmission network upgrades (for both the developer and system as a whole)
- IRA incentives make this **even more economic** for asset owners to pursue — but some, like the EIR, are time-limited
- Maximizing this opportunity will ensure we make the **best use of the existing grid** and minimize reliability risks associated with retiring generation

Calls to action

Build new clean generation at existing generation sites where possible

Evaluate IRPs and generation asset decisions accounting for economic and interconnection realities

Ensure interconnection rules for such projects are just and reasonable, and extend throughout the United States

In our future work on interconnection we hope to focus on the dynamic reliability implications of this work

- **In both our GETs and Clean Repowering work, we were limited in scope to only steady-state thermal analyses**
  - While impacts to voltage and stability are also important, the dynamic analyses required were prohibitive in the large-scale contexts for each of these works
- **In future work we hope to analyze whether advanced or grid-forming inverters can expedite interconnection and support reliability on a dynamic assessment basis – *please reach out to get involved in this with us!***

Thank you

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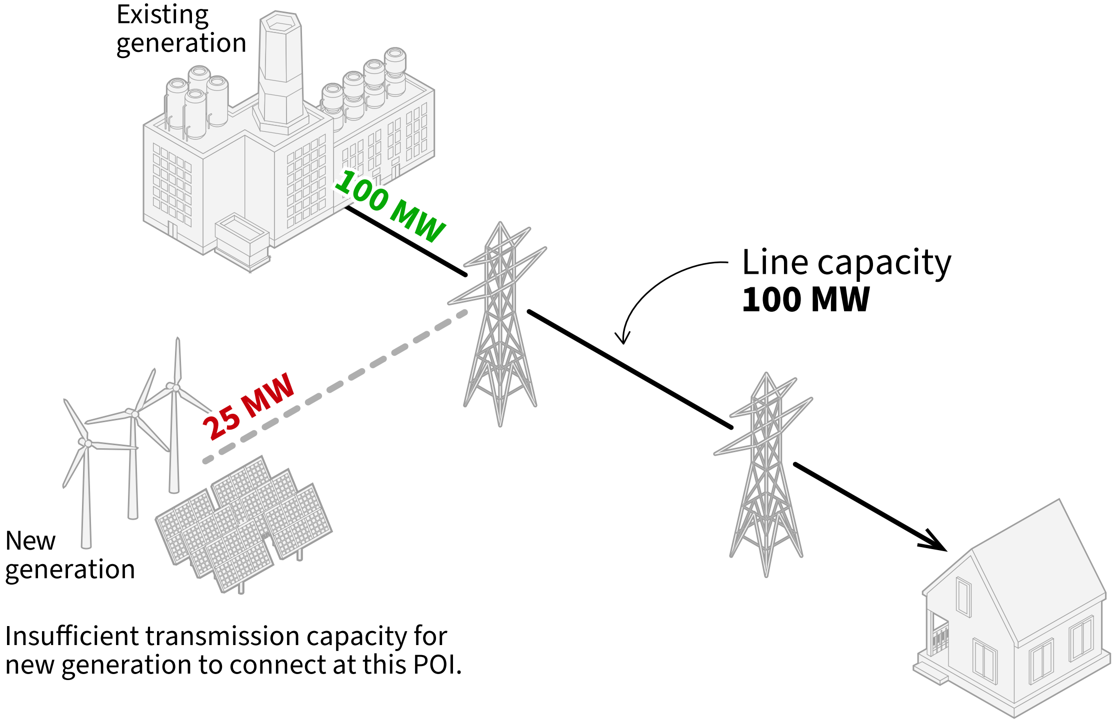
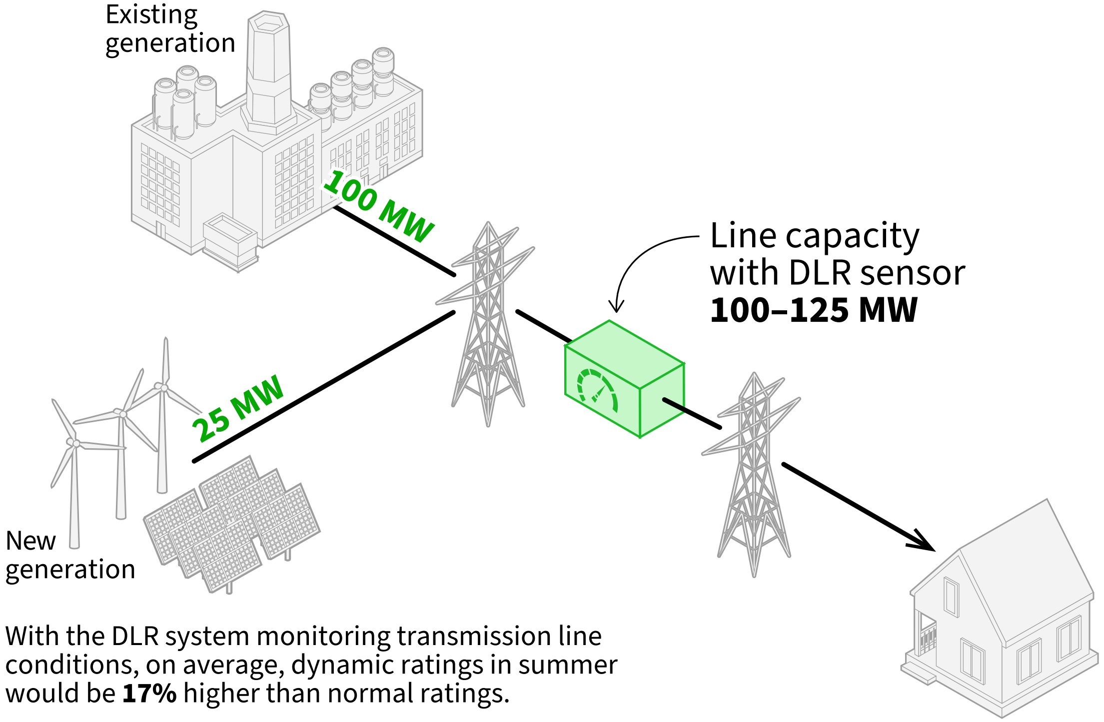
DLR is best suited to address modest overloads on thermally limited lines in windy areas

BEFORE



Insufficient transmission capacity for new generation to connect at this POI.

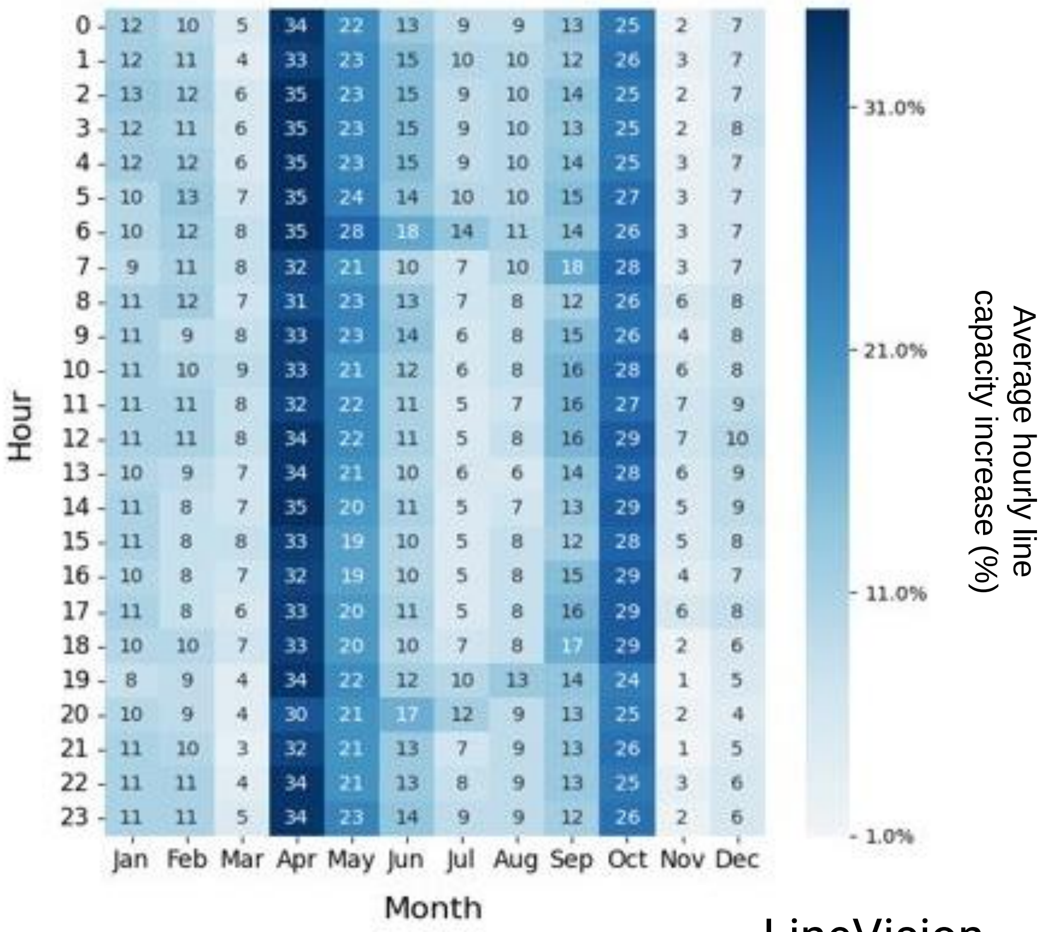
AFTER



With the DLR system monitoring transmission line conditions, on average, dynamic ratings in summer would be **17%** higher than normal ratings.

Deep-dive analysis of DLR

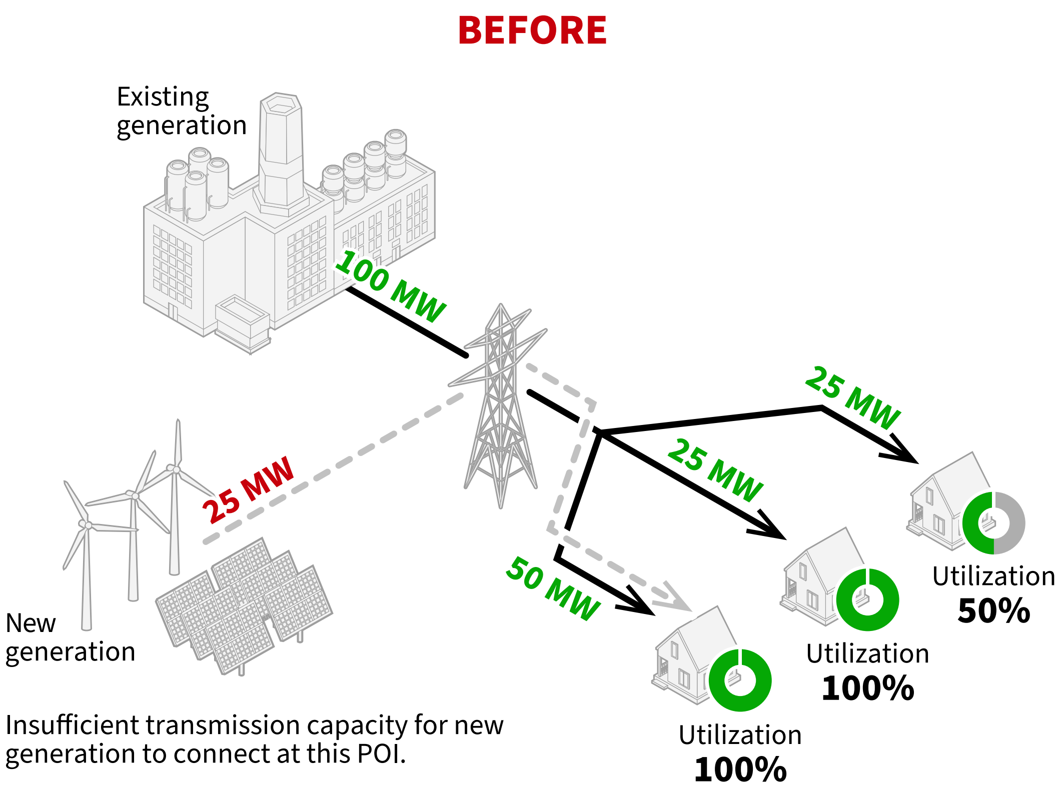
- Evaluation of DLR potential for one line:
  - LineVision calculated the static rating assuming a 3 ft/sec wind speed (w/ sensitivity analysis)
  - LineVision calculated the dynamic rating given wind speed, temperature, and irradiance data
  - Compared to the static rating, the average percent capacity increase of the dynamic rating is shown in the heatmap to the right
- This deep-dive analysis was conducted on 11 monitored facilities, and revealed an average summer line capacity increase of 17%



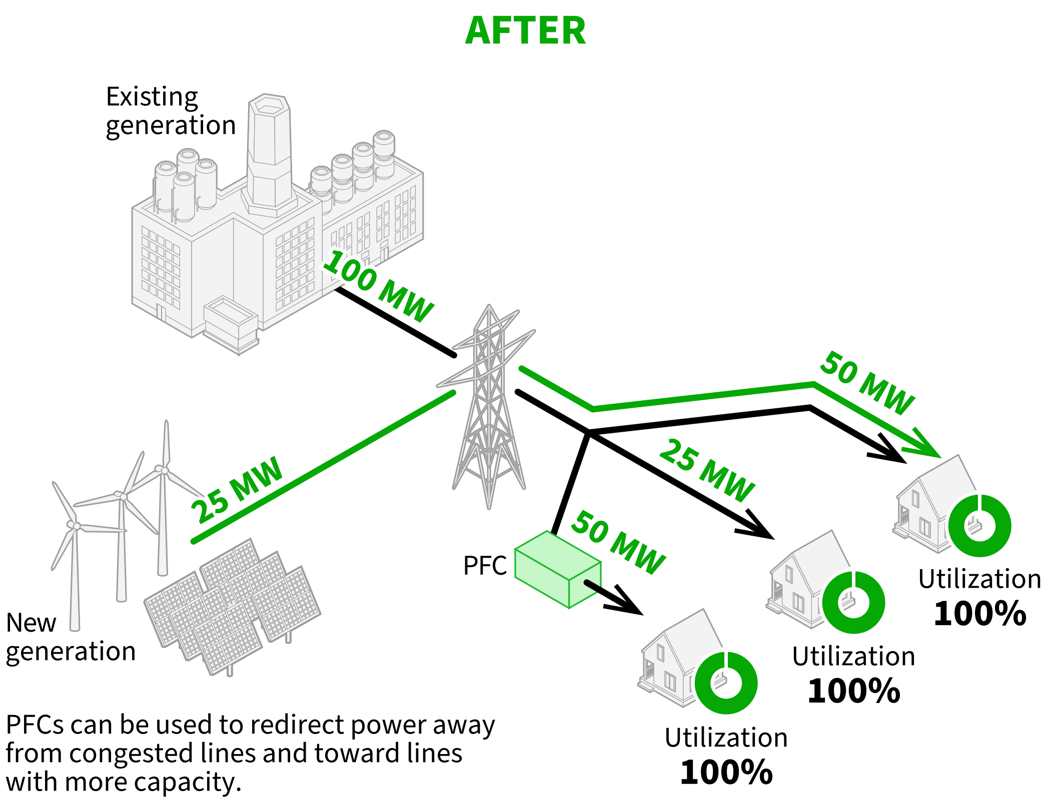
LineVision

Based on these results, Quanta modeled the deployment of DLR across the study footprint by applying a conservative 10% uprate to lines with modest overloads (<110%).

PFCs can be utilized to address thermal overloads only when there are multiple paths for power flow (a “meshed” system)



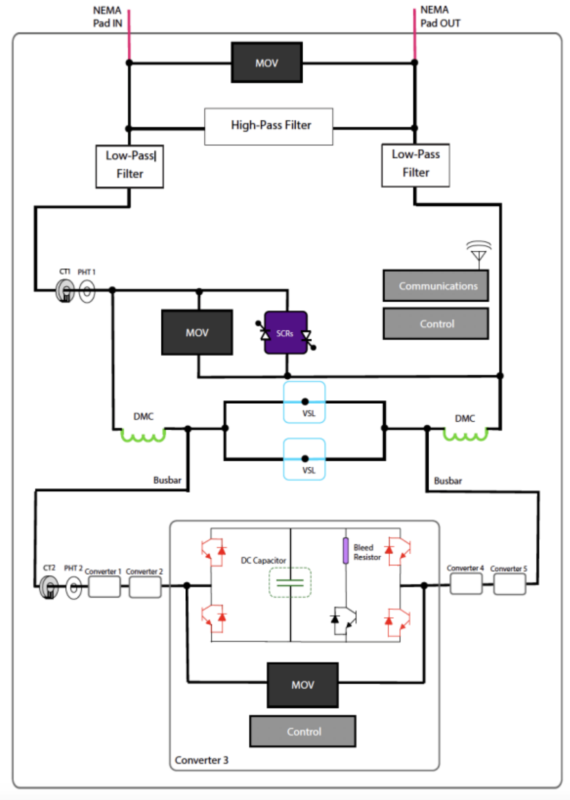
Insufficient transmission capacity for new generation to connect at this POI.

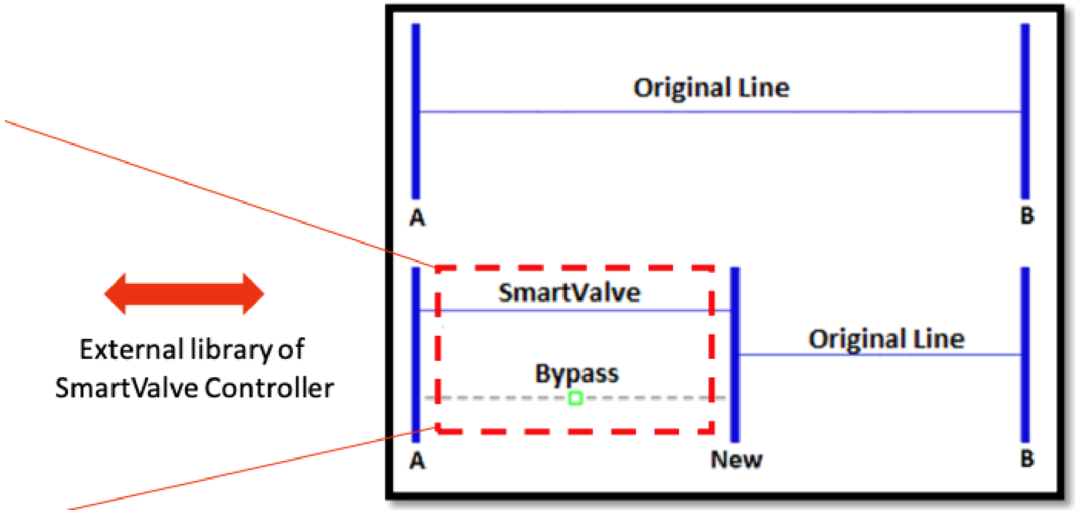


PFCs can be used to redirect power away from congested lines and toward lines with more capacity.

Deep-dive analysis of PFCs

- Applicable only for meshed (not radial) grid topologies
- Each device is modeled in PSSE with a dynamic reactance that adjusts the line's overall impedance
- Since electricity flows down the path of least impedance, PFCs can enable power that previously overloaded the line to be pushed to flow on nearby lower-impedance lines

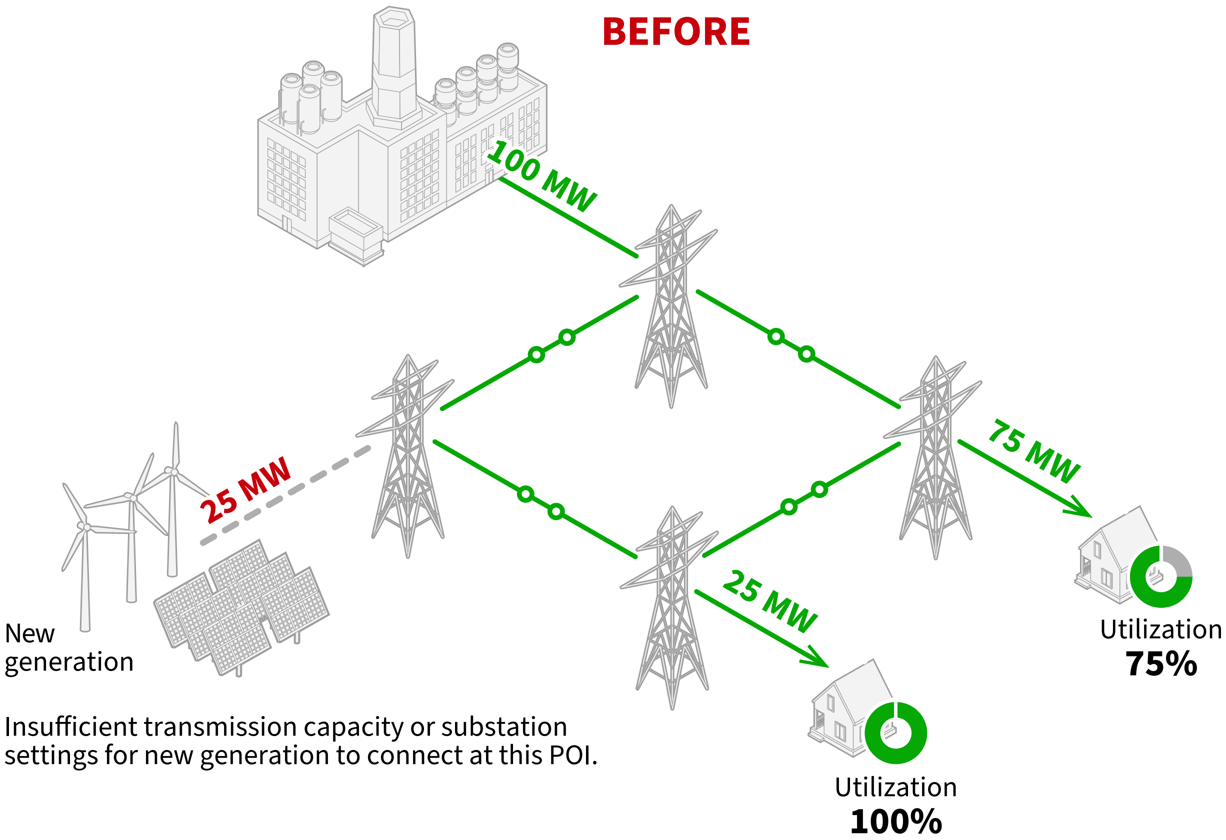




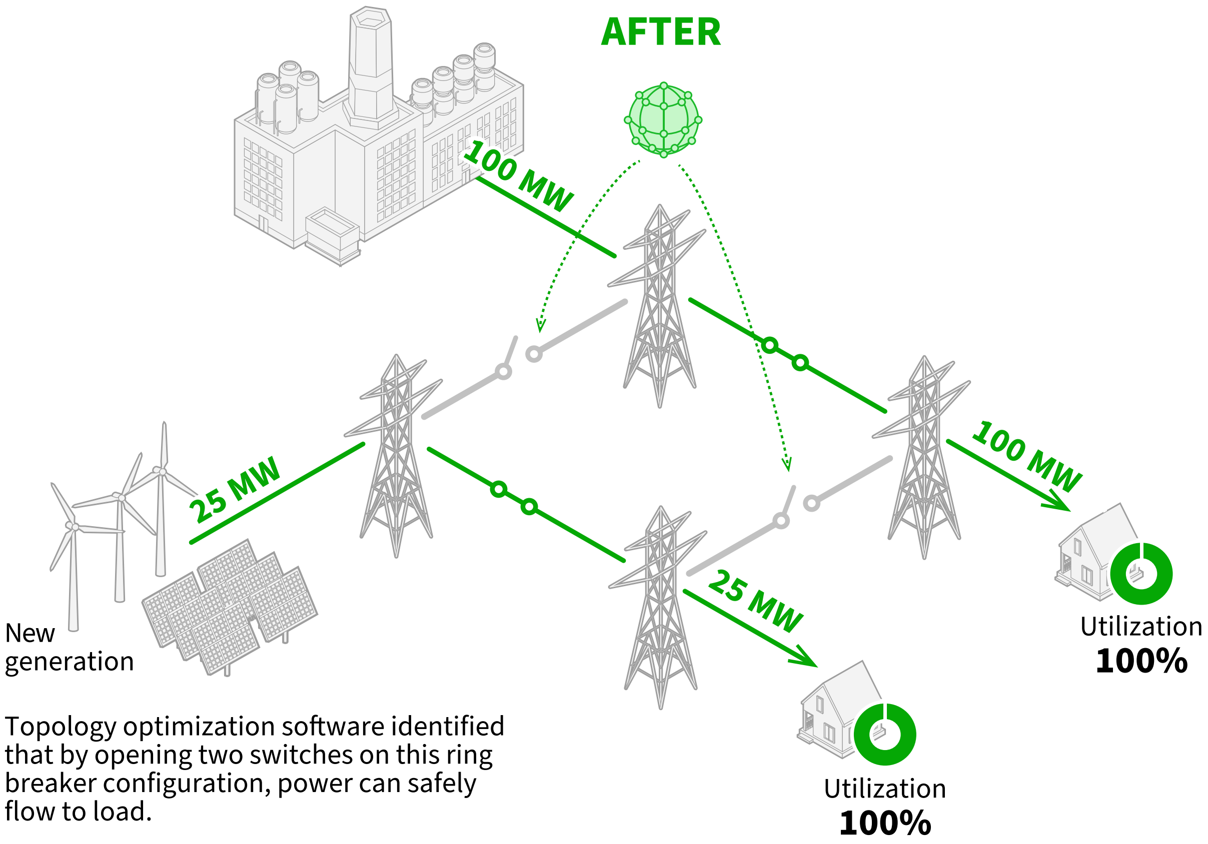
Smart Wires

Quanta utilized Smart Wires' python script which automated the analysis and placement process for PFCs in PSSE to model deployment across the study footprint.

TO can be applied only to meshed grid configurations and is most likely to solve constraints that arise from P1, P2, P4, and P7 contingency conditions



Insufficient transmission capacity or substation settings for new generation to connect at this POI.

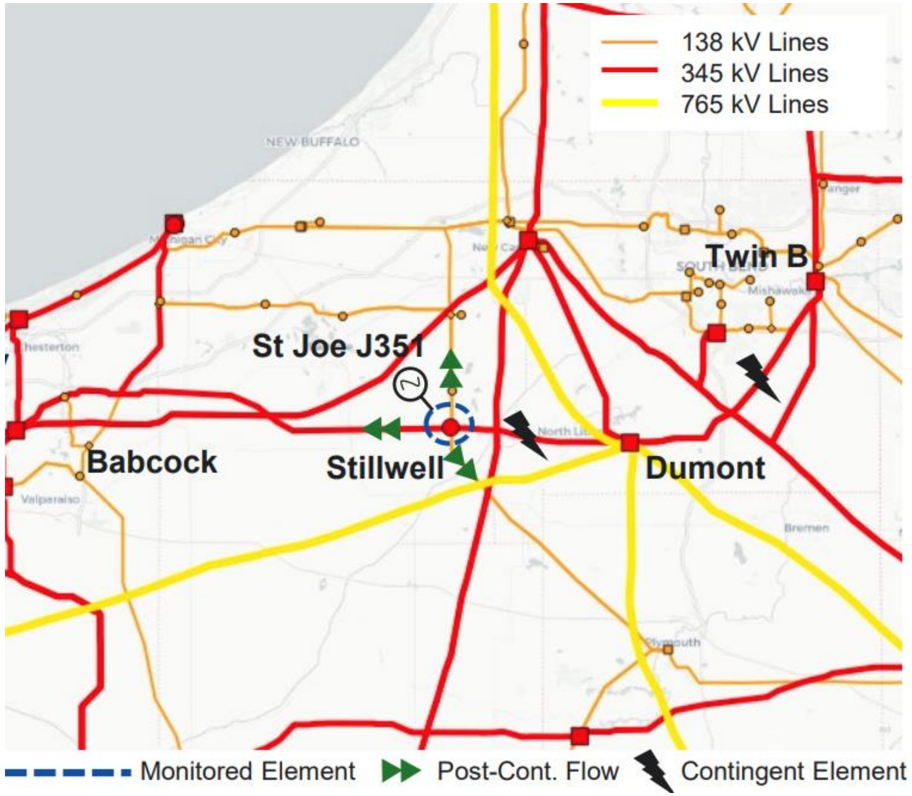


Topology optimization software identified that by opening two switches on this ring breaker configuration, power can safely flow to load.

Deep-dive analysis of TO

Conducted for 10 constraints identified by Quanta; solutions found for 5
Example reconfiguration detailed below:

- Modeling the addition of one queued project (J351) under a P4 multiple contingency (fault plus stuck breaker)
  - Multiple contingency opens both the Dumont-Twin Branch and Dumont-Stillwell lines (these are the "contingent elements", aka they are no longer in service)
  - Post-contingency constraints are over 100% on a 345/138kV transformer at the Stillwell substation
- The reconfiguration – opening two 345kV breakers at the Stillwell substation – does not affect normal operations, but modifies the elements opened under this P4 contingency such that:
  - The outage of the Dumont-Stillwell line also opens the Stillwell transformer; the utilization of other nearby elements increases but does not overload those elements
  - This improves overall system performance by redistributing flows more evenly under this contingency



NewGrid

Based on NewGrid's analysis of possible reconfigurations for the 10 constraints, Quanta applied TO to grid constraints triggered by P1, P2, P4, and P7 contingencies across the study footprint