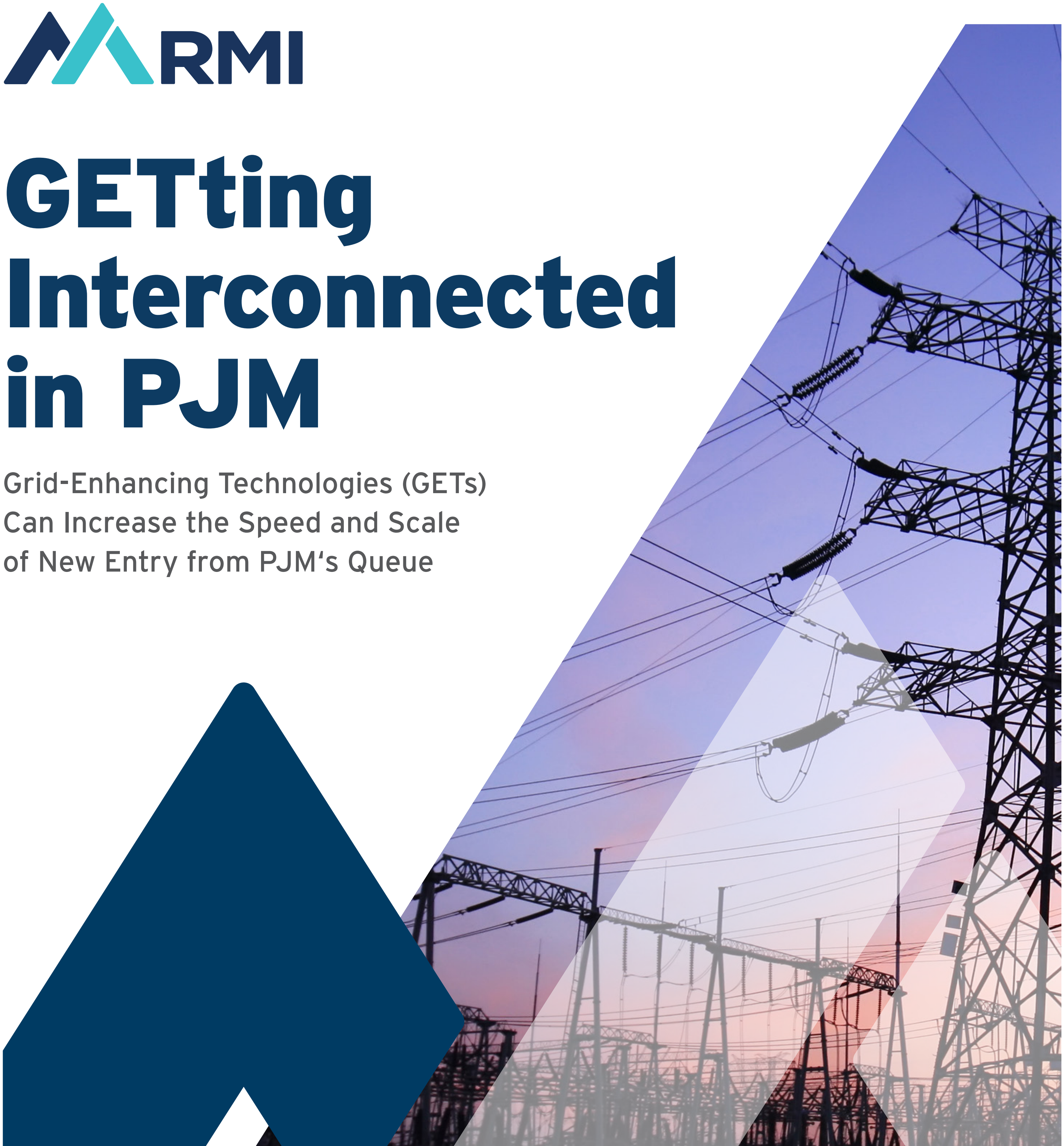
GETting Interconnected in PJM

Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue



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About RMI

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and nongovernmental organizations to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

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Executive Summary

The US power sector continues to see surging levels of new clean generation and storage projects in development, as well as rapidly rising demand for electricity to power new end uses, industrial electrification, and economic growth. There is no shortage of interest in developing and accessing the increasingly low-cost, carbon-free generation that characterizes the vast majority of projects seeking connection to the grid today. There is, however, a shortage of grid capacity to accommodate this expansion of both generation and load. While enhanced transmission planning and build-out is the long-term solution to addressing our capacity-constrained electric grid, there are near-term tools at our disposal to ensure we are getting the most out of the grid we have.

In this analysis, we assess the potential for grid-enhancing technologies (GETs) to facilitate the cost-effective, timely interconnection of new generation across five states within the PJM region: Illinois, Indiana, Ohio, Pennsylvania, and Virginia. Working with regional power flow cases and PJM's interconnection study criteria, we analyzed the viability of GETs as network upgrades for queued projects in those five states. Additionally, we ran a PJM-wide economic dispatch model to evaluate the impacts of these technologies and the queued generation they enable to interconnect.

GETs are hardware and software solutions that are deployed within the existing transmission system, helping increase the capacity, flexibility, and efficiency of the current grid. These transmission tools — dynamic line ratings (DLRs), advanced power flow controls (PFCs), and topology optimization (TO) — are becoming more widely studied and deployed in the United States as well as internationally; however, they are not yet routinely considered in planning paradigms such as grid operators' interconnection studies. Because they are cheaper and quicker to install than other types of transmission upgrades, such as reconductoring or rebuilding lines, GETs have tremendous potential to expedite the integration of new resources onto the grid.

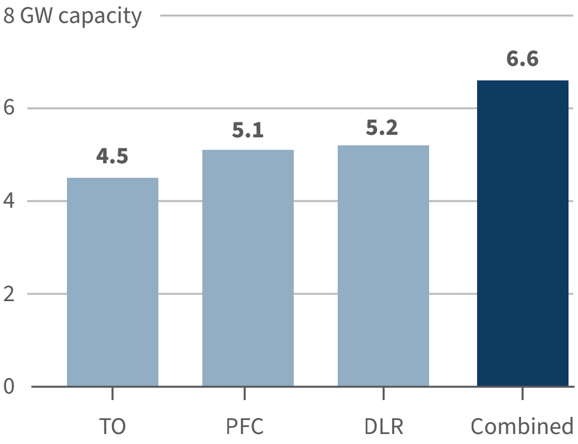
Our analysis results reveal that GETs support higher levels of new resource integration and deliver large economic benefits. We find that deploying GETs as network upgrades would allow over 6 gigawatts (GW) of new capacity from the existing PJM queue to come on line within the next three years (see Exhibit ES1) at significant savings for both project developers (see Exhibit ES2) and consumers (see Exhibit ES3).

Key Finding 1: GETs could facilitate cost-effective interconnection of 6.6 GW of new solar, wind, and storage projects by 2027

Evaluating and deploying GETs as network upgrades would allow for faster and cheaper integration of large volumes of new generation, delivering savings while also supporting grid reliability. This analysis assessed the ability of GETs to address the grid issues or overloads caused by projects in PJM's interconnection queue through Transition Cycle 1 for the five-state footprint in scope.

Exhibit ES1

Capacity of queued generation (in GW) enabled to interconnect by each GET, as well as GETs in combination



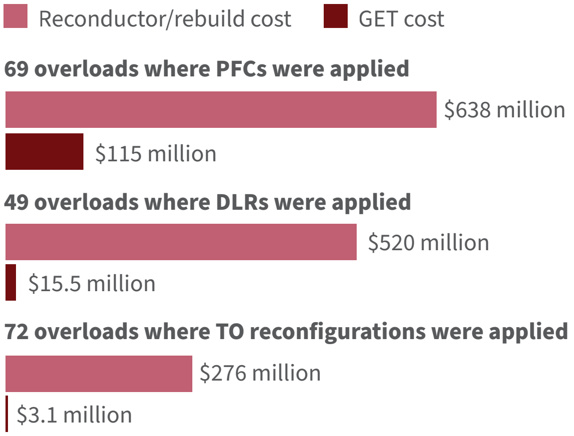
Note: The 6.6 GW finding is derived from the Combined GETs case.
RMI Graphic. Source: Quanta analysis

Key Finding 2: GETs are significantly cheaper than the default network upgrades that interconnection customers might face

GETs are dramatically less expensive than most network upgrades required for interconnection, saving both time and costs for project developers. Compared with standard network upgrades, such as reconductoring or rebuilding a line, GETs deployment costs ranged from $272 million to $523 million less across the study footprint (see Exhibit ES2). These savings could be the difference that allows a developer to move forward with a project instead of dropping out of the queue.

Exhibit ES2

Comparison of the typical network upgrade costs that would have been used to address an overload versus the cost of the GETs alternatives



RMI Graphic. Source: Quanta analysis

Key Finding 3: GETs and the new generation they enable could yield $1 billion annually in production cost savings

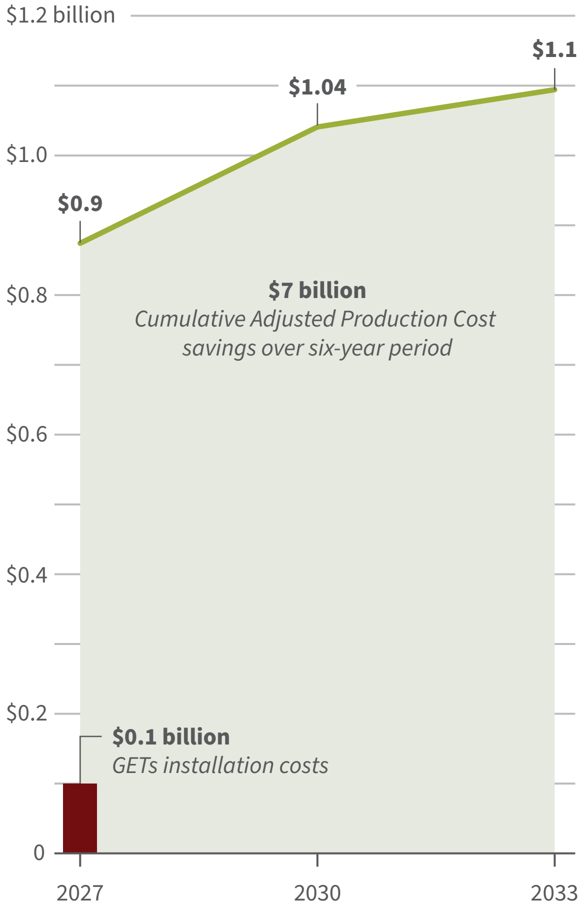
Consumers also benefit from GETs upgrades because they allow more cost-effective generation to come on line more quickly. In our production cost modeling analysis, we find that GETs-enabled new generators and reduced congestion would reduce energy production costs by just under $1 billion in 2027, ramping up to over $1 billion in savings per year by 2030 (see Exhibit ES3).

Recommendations

These findings make a compelling case for more widespread deployment of GETs in PJM, where today there are only a handful of pilots and proposed projects. PJM and its stakeholders have an opportunity to spur broader uptake of these technologies by leveraging the growing proof points, modeling tools, and changing regulatory landscape that are driving GETs adoption. Most notably, Federal Energy Regulatory Commission (FERC) Order 2023 mandates consideration of alternative transmission technologies (including some GETs) in the interconnection study process. To further realize the potential of GETs, we recommend that:

Exhibit ES3

Annual adjusted production cost savings from 2027–33, driven by GETs and the new generation enabled to interconnect



RMI Graphic. Source: Quanta analysis

- PJM should institute robust evaluation of GETs across its interconnection and transmission planning practices and ensure its staff has the requisite training and modeling tools.
- Transmission owners should build their internal capacity on GETs through studies and deployments.
- Developers should propose and support GETs evaluation as network upgrades for their interconnection projects wherever applicable.
- State regulators should provide oversight and guidance to spur GETs adoption by their jurisdictional utilities.
- FERC should take additional steps to provide a comprehensive national regulatory framework that supports GETs adoption.

By utilizing GETs to their full potential, we can economically and efficiently upgrade today's grid while also planning for the system expansion we will need to meet the growing demands of the energy transition.

Introduction

Transmission constraints and interconnection delays are slowing the integration of cost-effective, carbon-free power onto the grid

The development of increasingly low-cost wind, solar, and storage projects is proliferating. In 2023, the United States added 16 GW of utility-scale solar, 4 GW of wind, and 6 GW of storage to the grid, a 44% increase in renewable and storage capacity additions from the previous year.[1] Powered by the Inflation Reduction Act and surging demand for cheap, clean energy from policymakers, corporations, and consumers, annual additions of wind and solar will double in the next two to five years (between 2025 and 2028) according to BloombergNEF projections.[2]

However, new generators still face significant obstacles slowing their interconnection to the grid. Projects must join interconnection queues before coming on line and be studied by grid operators to ensure they will not adversely impact grid reliability. If adverse impacts are identified, new projects are required to pay for any transmission upgrades necessary to support their reliable integration. Today's transmission system is nearing capacity, resulting in rising congestion costs nationwide.[3] Large numbers of new interconnection requests, combined with an already congested transmission system, have resulted in an interconnection study process that has become difficult and time-consuming.

Lawrence Berkeley National Laboratory (LBNL) estimates that the amount of new zero-carbon generation capacity active in interconnection queues (1,260 GW of generation and 680 GW of storage as of Q4 2022) exceeds the capacity of the current US electricity system.[4] LBNL also finds that timelines for connecting to the grid are slowing and costs are rising.[5] Interconnection wait times have doubled since the early 2000s, and network upgrade costs have also increased significantly, more than doubling in several regions.

Delayed integration of new clean energy has serious implications for the grid, the economy, and the climate.

- **Grid operators fear interconnection of new generation will not keep pace with retirements, posing a looming threat to resource adequacy.** In 2023, Western Electricity Coordinating Council (WECC), Midcontinent Independent System Operator (MISO), and PJM publicly expressed concerns that the addition of new generation resources will not keep pace with planned retirements of thermal resources.[6] There is more than enough generation in interconnection queues, including firm, variable and storage solutions, to fill the gap; however, the slow pace and rising costs of the interconnection process pose a barrier to new entry that must be overcome to alleviate this risk.

- **Slow clean electricity deployment stifles economic development.** A low-cost, low-carbon electric grid is increasingly foundational to local economies. Previous RMI research projected that, by 2030, rural communities could see $11 billion annually in revenues from the wind and solar projects expected to be built this decade.[7] The longer these projects sit in queues, the longer communities have to wait for the capital investments and jobs that will accompany them: a recent report from the American Council on Renewable Energy estimates that the PJM region could have realized an additional $17 billion in capital investment over the next four years (through 2027) if PJM had proactively planned more transmission capacity to enable higher interconnection rates.[8] Additionally, improved interconnection rates and access to clean electricity for large load customers will support major economic development opportunities for the surrounding areas.

- **Climate targets demand expedited clean electricity deployment.** States, corporations, and the federal government have set increasingly ambitious clean energy and climate policies that are dependent on bringing clean energy onto the grid at unprecedented scale and speed. But interconnection delays threaten those goals. The Natural Resources Defense Council's spring 2023 *Waiting Game* report found that PJM may narrowly be able to interconnect sufficient renewable energy to meet the renewable portfolio standards of states in the region.[9] However, the analysis did not account for corporate clean energy goals, nor the prospect of any additional or increased targets being set by states in the coming years, indicating more work is needed to ensure interconnection does not pose a barrier to realizing the full suite of clean energy goals in the region.

FERC Order 2023, released in July 2023, institutionalizes important reforms to interconnection processes that will help alleviate some of the challenges present today.[10] These reforms include the use of a cluster study approach to consolidate the volume of studies, accountability mechanisms like withdrawal penalties for developers and fines on grid operators for missing study deadlines, and a requirement to evaluate alternative transmission technologies. Although the FERC order represents progress, several root causes of today's interconnection issues remain unaddressed, and more action is needed to ensure new carbon-free resources can connect to the grid at a pace consistent with reliability, economic, and policy imperatives.[11]

GETs offer a near-term solution to expedite the deployment of new resources

GETs have the potential to bring new generation resources on line faster and at lower cost in the near term, while regional transmission organizations (RTOs) and transmission providers enact broader, systemic changes to interconnection and transmission planning. GETs are hardware and software tools that increase the capacity, efficiency, and flexibility of the existing transmission system. They can perform functions such as rerouting power flows to avoid congested lines and providing data on real-time conditions that could enable more power to flow through a line when conditions allow — thus increasing our ability to best utilize the transmission infrastructure we already have. In this analysis, we considered three GETs: advanced PFCs, DLRs, and TO.

GETs are gaining recognition for their potential role in making better use of the existing transmission system and providing operators greater situational awareness and control over the grid. A 2021 Brattle study found that GETs deployment could roughly double renewable energy integration in Kansas and Oklahoma.[12] More recently, national media outlets including National Public Radio and The Hill described GETs as no-regrets solutions to some of the grid challenges the United States is experiencing today.[13] In its Order 2023 on interconnection, FERC requires transmission providers to evaluate alternative transmission technologies, including some GETs (PFCs), in the interconnection study process for feasibility of deployment as well as cost and time savings relative to traditional network upgrades.

Despite GETS' benefits and their utilization in European countries for decades, deployment has been limited in the United States.[14] Many utilities still lack familiarity and experience with these technologies, creating a learning curve barrier that must be surmounted. Additionally, in many jurisdictions, there are misaligned incentives for such low-cost investments, presenting a need for regulation to require or incentivize greater consideration of GETs.[15] FERC Order 2023 is a step in the right direction to encourage

GETs adoption, but utilities, grid operators, and regulators must continue to build the knowledge and support structures necessary to foster faster deployment.

This study evaluates the potential for GETs to facilitate more rapid, cost-effective interconnection in PJM

With its 160 GW peak and average 90 GW load, PJM is the largest wholesale electricity market in the world and has tremendous potential to advance reliable, cost-effective decarbonization through its market and grid-planning processes. Wind and solar generation contributed less than 5% of PJM generation over the last year, significantly less renewable generation than most other regions, due in part to PJM's acute interconnection challenges.[16] PJM's queue has become so severely backlogged that, as part of a 2022 interconnection reform package, the RTO instituted a pause on new interconnection applications until 2026. PJM said this delay was necessary to give staff time to implement the new process and work to clear the existing queue. As of the end of 2022, PJM had the second largest queue volume of the RTOs (behind only MISO), and the longest queue wait times of any region from 2018 to 2022.[17] Implementation of the 2022 reforms is now underway, a promising step in the right direction for increasing interconnection throughput.

In tandem with these reforms, PJM should prioritize unlocking capacity on its existing transmission system. GETs have a vital role to play in supporting the PJM grid through this decade of significant transition. Although several pilots of GETs have been deployed in the region — such as a DLR pilot in Pennsylvania that the local utility, PPL, estimates is saving $23 million per year in congestion costs[18] — GETs adoption lags far behind the technological potential. Additionally, many of the pilots focus on GETs as operational tools; no study or deployment to date has tested the viability of GETs in a planning paradigm such as the interconnection study process. This comprehensive analysis of GETs as network upgrade alternatives seeks to fill that gap.

The analysis rigorously assesses GETs' ability to reliably address grid issues triggered by interconnecting projects

The scale of the GETs opportunity in PJM is large: gigawatts of additional new generation could be interconnected and billions of dollars in production cost savings could benefit ratepayers. However, to take advantage of GETs, grid operators and utilities will need to adopt new modeling approaches (such as GETs' inclusion in typical power flow studies) and operational changes (such as integration into existing energy management system software). Therefore, an explicit aim of this effort is to support PJM and transmission owners in the region in advancing their evaluation and use of GETs in planning paradigms such as interconnection, as well as longer-term transmission planning. To conduct the analysis, we partnered with Quanta Technology, an independent power sector consulting company with experience working in PJM, to develop a transparent and replicable approach for analyzing GETs in interconnection studies.

Modeling Approach and Lessons Learned

To assess GETs as network upgrade options for projects in PJM's queue, we developed a three-phase methodology (see Exhibit 1) that incorporated the power flow modeling that PJM would use in the interconnection study process and production cost modeling to show the impact of GETs on the regional grid.

Exhibit 1 **Overview of the modeling approach**

1. Set up power flow and contingency analysis (PSSE, TARA)

- Load base power flow cases
- Incorporate all queued projects through Transition Cycle 1
- Eliminate those projects that cause either no or extreme overloads

2. Apply GETs, individually and in combination (PSSE, TARA)

- Conduct deep-dive analyses of each technology in partnership with vendors
- Apply each GET where feasible to remaining overloads
- Apply GETs in combination

3. Conduct production cost modeling (PROMOD)

- Develop scenarios: Business as usual (BAU, based on PJM projections) and GETs + new generation enabled to interconnect
- Compare production cost modeling results to assess impact of GETs on electricity costs, emissions, etc.

Note: for more information see the Detailed Methodology in the Appendix, available for download as a separate PDF on the report website.

RMI Graphic. Source: Quanta analysis

Step 1: Quanta prepared a power flow model that included queued generation to identify grid constraints in future years. Generation that caused either no overloads or extreme overloads was excluded from subsequent analyses.

Quanta set up a power flow model in PSSE that simulates the grid in five states for a set of future years and grid conditions. The intention of this step, which replicates the feasibility study portion of the PJM generator interconnection process, is to reveal the transmission system impacts associated with the addition of the projects in the interconnection queue. Model inputs included all generation currently installed on the system, planned transmission upgrades, load growth, etc., and projects in PJM's interconnection queue through Transition Cycle 1.

The power flow model then simulated a set of NERC-defined contingencies to test queued projects against challenging potential grid conditions and ensure their deliverability to load. Any adverse impacts triggered by a project, such as transmission line overloads or other constraints that could arise, must be mitigated either by curtailing the generator or by network upgrades to bolster the transmission system's capacity to integrate the new generation. In practice, the interconnecting generator can either choose to pay the allotted network upgrade costs or drop out of the queue if the costs are prohibitive. Queue completion levels in PJM have historically averaged 20%–25% but have dropped to as low as 5% recently.[19]

Analysis scope

- **States:** Illinois, Indiana, Ohio, Pennsylvania, Virginia
- **Future years:** 2026, 2028, 2030
- **Grid conditions:** Summer, winter, light load

Running the power flow base case resulted in numerous overloads and constraints, given the large volume of projects currently in PJM's interconnection queue. After this initial power flow analysis, Quanta removed queued generators from consideration in the model if they required more than 90% curtailment to prevent reliability problems, because this high level of curtailment indicated that the grid impacts in that area were particularly severe. This served as a proxy for filtering out projects that would likely not be viable and drop out of the queue due to high network upgrade costs. For more information on the setup and assumptions underpinning the base case, see the Appendix, which is available for download on the report website.

Step 2: Quanta assessed whether GETs could resolve the overloads triggered by the remaining queued generation.

With the smaller subset of remaining queued generation, Quanta assessed which transmission overloads were good candidates for resolution with GETs. This required understanding the technology-specific capabilities and the grid conditions they were well suited to resolve, as well as developing an approach for integrating each GET into the power flow model.[i] Below and in Exhibit 5 (page 16), we summarize the capabilities and use cases for each GET:

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[i] For clarity, the GETs applications and results reported here reflect the most limiting power flow case studied, which was the summer 2026 peak.

Dynamic Line Ratings (see Exhibit 2):

- **Capabilities:** DLR systems use a variety of sensors and data sources to calculate the safe operating capacity of a transmission line in real time. These data sources can include but are not limited to wind speed, ambient temperature, solar irradiance, and conductor sag. DLR systems use this data to calculate the current-carrying capacity of the conductor, taking into account all of the factors that can affect its ability to dissipate heat. This allows utilities to safely increase the amount of power that can be transmitted over existing lines. DLR is best suited to address modest overloads (~10%) on thermally limited lines.

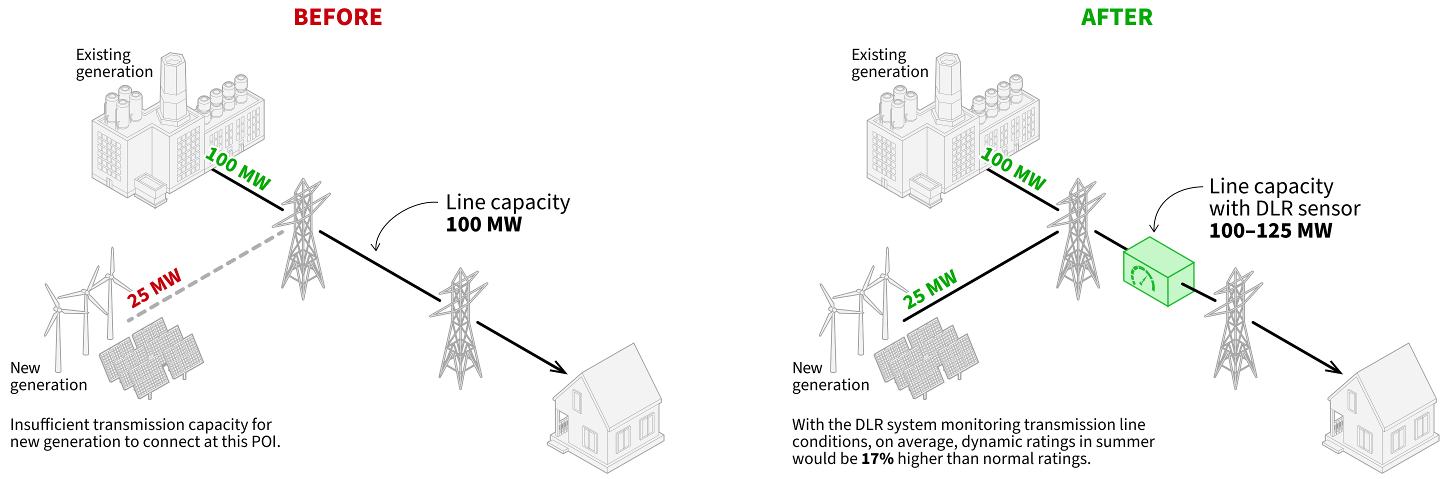
- **Enabling Grid Conditions:** Windy areas will deliver the highest transmission line capacity increases because wind's cooling effect allows for more power to flow through a line.

- **Modeling Approach:** A deep-dive analysis conducted in partnership with a DLR vendor revealed high potential for DLR application across the five-state footprint of the analysis, with improvements to transmission capacity up to 30% in certain cases. On average, the summer rating could be 17% higher than the static rating. Based on this initial screen, Quanta simulated the addition of DLR sensors to the model by applying a conservative average of a 10% uprate from the static rating to all overloaded lines in geographies with wind speeds of more than 3 feet per second. This served to remove the overload in those cases, which would enable new resources in that location to come on line with less curtailment and/or network upgrades. Notably, because this increased line rating cannot be guaranteed for every hour of the year due to the uncertainty inherent in weather conditions, there would likely still be periods when the new generators would have to be curtailed due to lower wind speeds. That raises implications for the level of interconnection service (energy only versus capacity) these resources can attain, depending on market participation requirements; if full deliverability was desired, DLR could be paired with other GETs or grid upgrades.

- **Impact on Interconnecting Generation:** Individually, DLR was applied to 49 overloads across the study footprint, which could facilitate the integration of 5.2 GW of new interconnecting generation.

Exhibit 2

Stylized example of how DLRs can be applied to enable new generator interconnection



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

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

Note: Not to scale.
RMI Graphic. Source: RMI

Power Flow Controls (see Exhibit 3):

- **Capabilities:** PFCs can be used to redirect power away from congested lines and toward lines with more capacity. Advanced PFCs utilizing power electronics do this by injecting voltage in series with line current to vary the reactance on the line. This causes power to be “pushed” or “pulled” onto adjacent facilities with available capacity. In an interconnection context, PFCs can solve thermal overloads or voltage stability issues arising from N-0 or N-1 contingencies.[ii]

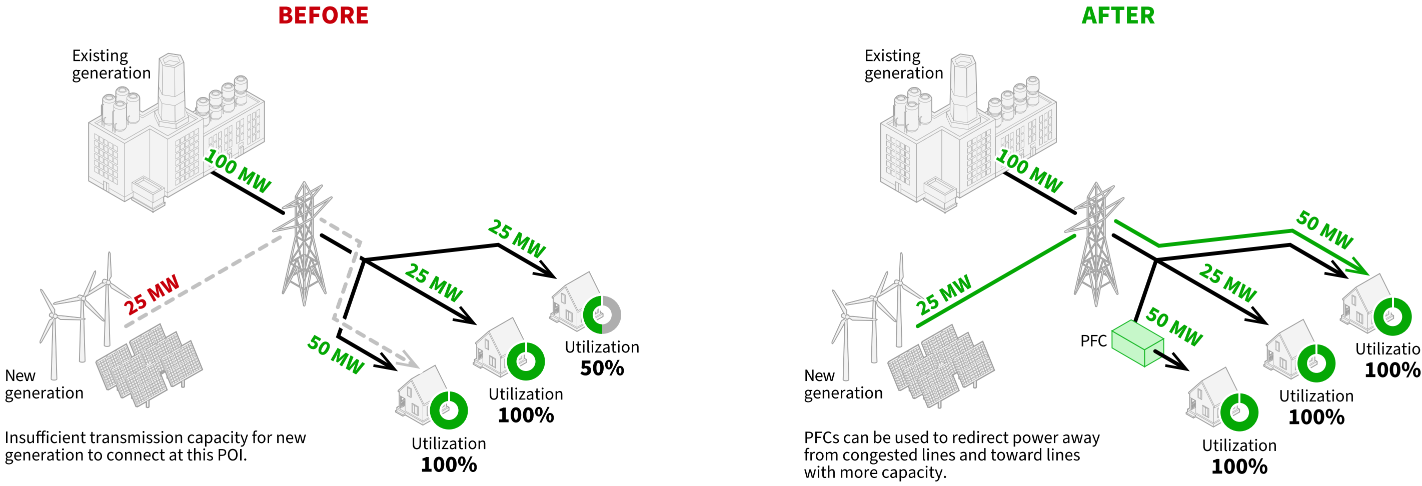
- **Enabling Grid Conditions:** PFCs can be utilized to address thermal overloads only when there are multiple paths for the power to flow through (a “meshed” system). If the lines are radial, there is only a single path for power to flow through, and PFCs cannot be used to redirect the power (though they are still effective for providing voltage support). PFCs are best suited for use on transmission lines below 550 kilovolts (kV).

- **Modeling Approach:** To model the deployment of PFCs, Quanta used a Python script developed by a PFC vendor that integrated with the PSSE power flow software. Looking at grid constraints in places where the grid topology is meshed, the modeler can opt to apply PFCs to particular lines. Rerunning the power flow model with the Python script reveals how much the constraint or overload could be reduced and provides a check on the number of PFC devices applied to ensure the application is rightsized.

- **Impact on Interconnecting Generation:** Individually, 69 PFCs were applied across the study footprint, which could facilitate the firm delivery of 5.1 GW of new interconnecting generation.

Exhibit 3

Stylized example of how PFCs can be applied to enable new generator interconnection



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.

Note: Not to scale.
RMI Graphic. Source: RMI

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ii In NERC Reliability Standard TPL-001-4, system contingencies (that grid operators must assess) are “the unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch or other electrical element.” An N-0 contingency scenario examines the bulk electric system as is, with all facilities in service; an N-1 contingency scenario examines the system with the loss of a single component, and so on.

Topology Optimization (see Exhibit 4)

- **Capabilities:** TO software identifies transmission system reconfigurations that can relieve constraints on lines by rerouting power flow around those constraints. TO leverages parallel paths with available capacity, or modifies conditions at the substation to change the effects of potentially problematic contingency events. The reconfigurations are implemented by opening or closing circuit breakers. The software presets the change, so that during the contingency or challenging grid conditions, the rerouting would occur automatically, with no need for further operator intervention.

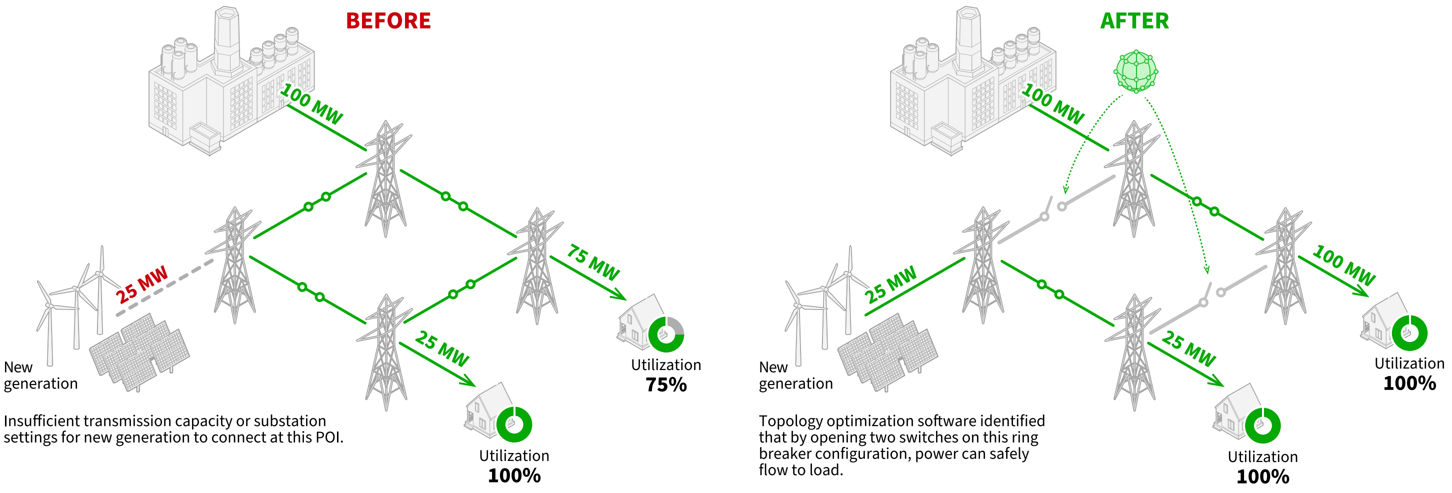
- **Enabling Grid Conditions:** TO, like PFCs, can be applied only to meshed grid configurations. Although TO software generally has broad applicability, including for real-time operations support, in an interconnection context, our analysis indicated the software was most likely to be able to solve constraints that arise from P1, P2, P4, and P7 contingency conditions.[iii]

- **Modeling Approach:** Because TO is a software solution that leverages existing facilities, for this analysis we subcontracted with a software provider to identify reconfigurations for an initial set of 10 diverse constraints. Based on its screening criteria, the provider was able to find solutions for five of the 10 constraints. It ran contingency analyses to ensure each reconfiguration would solve the problem while not creating any new overloads. Quanta then extrapolated these results to similar constraints in other locations to model the potential of TO across the footprint of the analysis.

- **Impact on Interconnecting Generation:** Individually, TO was applied to address 70 constraints across the footprint under analysis, which would facilitate the integration of 4.5 GW of new interconnecting generation.

Exhibit 4

Stylized example of how TO can be applied to enable new generator interconnection



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.

Note: Not to scale.
RMI Graphic. Source: RMI

[iii] In NERC Reliability Standard TPL-001-4, planning events, defined in the context of system contingencies, are categorized as P0 through P7.

Combined Applications of GETs

- **Capabilities:** Because of the different types of technologies and use cases represented by the three GETs under study, they can complement each other and be deployed in concert in some instances to deliver a more comprehensive solution to grid challenges.

- **Enabling Grid Conditions:** Depending on the combination of GETs used, the enabling grid conditions particular to each would need to be present (e.g., in order to utilize PFCs or TO, the local grid system must have a meshed, not radial, topology).

- **Modeling Approach:** As a first step, Quanta applied DLR to the transmission system in accordance with the modeling approach outlined above to obtain the best estimates of available transmission capacity. Then, PFCs or TO can be applied to fully address constraints where the system is meshed and there is available headroom on nearby lines.

- **Impact on Interconnecting Generation:** In combination, GETs were applied to address 95 constraints across the footprint under analysis, which would facilitate the integration of 6.6 GW of new interconnecting generation.

Exhibit 5 **Summary of how GETs can be integrated in modeling and operations**

Technology	How it can be integrated in models and planning	How it was modeled and applied in this analysis	How it can be integrated into operations
Dynamic line ratings	Vendors have developed a replicable approach to assessing DLR potential based on historical weather data, which can be applied to new interconnection studies for specific deployments	Quanta extrapolated from an in-depth assessment of line capacity increases for a subset of the region and applied a conservative 10% uprate to overloaded transmission lines where DLR was a viable solution	DLR software and data integrate into existing energy management systems; data is available usually within three months of installation
Power flow control	Vendors have developed a script that integrates into existing power flow modeling software; eventually this could become a native plug-in	Quanta utilized the vendor-provided Python script to apply PFCs to all overloads they were suited to address	Vendors provide two-day operator training, and PFC software integrates into existing energy management systems
Topology optimization	Evaluation of this software solution requires analysis at the substation level, as well as licensing or contracting with a provider	The deep-dive analysis performed by the vendor informed a decision to apply reconfigurations to all overloads triggered by P1, P2, P4, and P7 contingencies	Simple reconfigurations can be run in existing energy management systems; more complex reconfigurations may require addition of a simple script provided by a vendor

RMI Graphic. Source: RMI

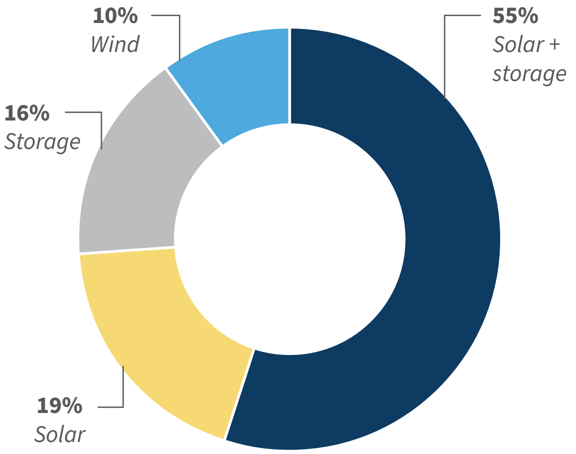
Step 3: Quanta evaluated the impact of GETs and the increased generation capacity they enable via production cost modeling.

To determine the economic impact of GETs on an annual basis, Quanta conducted hourly production cost modeling in PROMOD for two scenarios: a business as usual (BAU) case, and that same case with the addition of GETs and the 6.6 GW of new generation enabled by GETs deployment (GETs case). This new generation included 3.6 GW of solar + storage capacity, 1.2 GW of solar capacity, 1.1 GW of stand-alone storage capacity, and 0.7 GW of wind capacity (see Exhibit 6).

To simulate the effect of the GETs in the production cost model, the constraints they addressed were eliminated over the modeling period for that scenario. This modeling was conducted across three future years — 2027, 2030, and 2033.

Exhibit 6

Breakdown of GETs-enabled new generation capacity by resource type



RMI Graphic. Source: Quanta analysis

Based on the production cost model results, Quanta calculated and compared the PJM-formulated adjusted production cost (a measure of wholesale electricity costs in the energy market, which do not include other costs such as those from capacity or ancillary service markets), CO_2 emissions, and sulfur dioxide (SO_2) emissions.[20] Due to the lower cost of operating renewable energy generators as well as broad congestion relief enabled by GETs, the higher amount of renewables dispatched in the second scenario resulted in lower system-wide costs and emissions while maintaining reliability.

Lessons Learned for Future GETs Modeling Efforts

Conducting this analysis yielded lessons learned that could be applied to future GETs modeling efforts by grid operators and transmission owners. These are summarized below:

- GETs can be modeled individually or in combination; the specific approach depends on the grid conditions, the issues being addressed, and the compatibility of the different technologies. DLR, for example, is highly compatible for complementary use along with PFCs and TO. Augmenting DLR with controllable technologies can also help provide more comprehensive solutions that meet firm deliverability criteria.

- The more that GETs are integrated into different models and planning paradigms, the more opportunity there is to employ standardization and common approaches, which can help lower the study burden of incorporating these technologies into the grid.

- GETs are flexible and easily scalable tools, which can be used to address immediate grid constraints quickly as well as provide more headroom or additional capacity on the system. Because of their cost-effectiveness and the scale of benefits they enable, GETs also make financial sense as interim solutions in cases where rebuilding or adding new transmission is being pursued in parallel.

- Each technology has its own capabilities and limitations that dictate where potential applications would best be explored; these should be understood as a prerequisite to studying and modeling GETs for a particular deployment or use case.
    - As an example, there are unique deliverability implications for DLR and, in some cases, TO. Because DLR is a weather-dependent technology, there cannot be 100% certainty that weather conditions will be favorable for increased line ratings, and thus delivering a particular resource's capacity to load, during all 8,760 hours of the year. Even if a resource utilizing DLR could transmit its full capacity 95% or even 99% of the time, it still would not qualify as a capacity resource, and therefore would have to elect energy-only interconnection service. Similarly, in some but not all cases, the TO reconfiguration identified might briefly trip the interconnecting resource in question offline, preventing it from being deliverable in the minutes to hours necessary to alleviate the contingency. This should not preclude these tools from evaluation in the network upgrade solution set. Rather, in the near term, consideration should be given to the supplemental transmission solutions or generator dispatch behavior that might be required. And in the long term, the rules and criteria for interconnection and network upgrades should be revisited to ensure they appropriately balance reliability, cost-effectiveness, and flexibility.
- Different study approaches can be used to suit different analytical purposes:
    - For a planned deployment targeting a specific interconnection request, an in-depth study can determine the extent to which the GET would alleviate a particular grid constraint. This study would include pressure testing the GET solution to ensure it holds up under various contingencies and does not create new problems on other parts of the transmission system. GETs vendors and a growing number of experienced analysts, such as Quanta, have conducted such studies and can be a resource called in for support if needed.
    - For an assessment of GETs' potential across a specific geography or transmission system, a more probabilistic study approach could be used. For example, leveraging understanding of each technology's primary use cases and a deep-dive analysis on part of the system, modelers could extrapolate applications of GETs to the rest of the system. This approximation can provide an indication of GETs' value-add to the system and help make the case for further study and deployment. That was the approach taken in this study.

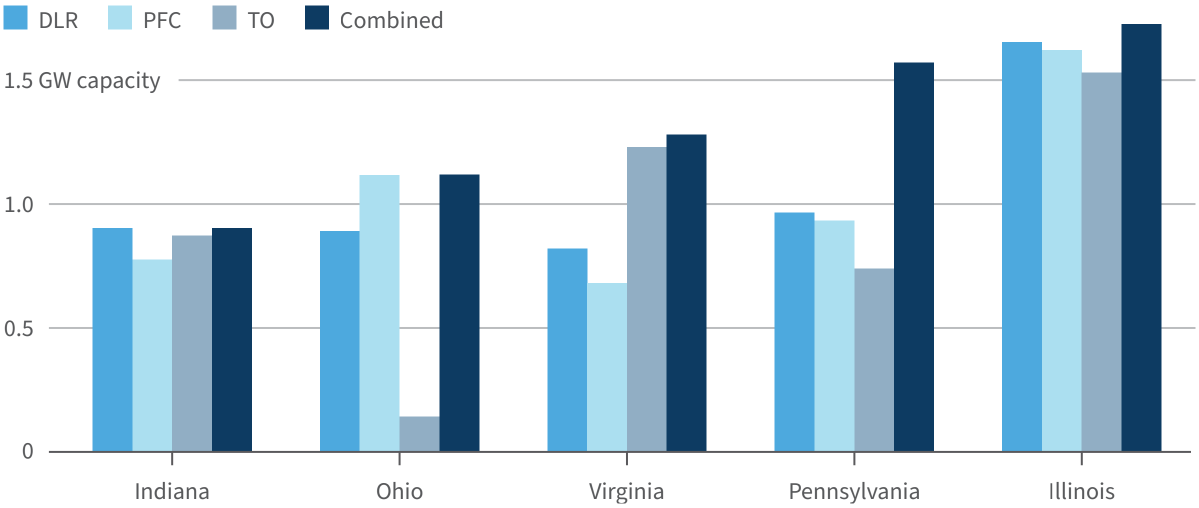
Findings

In the five states studied, GETs could enable 6.6 GW of queued solar, wind, and storage generation to connect to the grid more quickly, and at dramatically lower cost

Our analysis revealed that GETs can facilitate the interconnection of 6.6 GW of new wind, solar, and storage generation across Illinois, Indiana, Ohio, Pennsylvania, and Virginia that otherwise might have required prohibitively high-cost or time-consuming network upgrades. For comparison, in these five states, just over 2 GW connected to PJM's grid in 2023.[iv] To understand GETs' full potential and complementarity, Quanta ran power flow models with each GET individually as well as with the GETs in combination. When combining technologies, Quanta added DLRs first, then PFCs and TO.[v]

Exhibit 7 shows the new generation capacity enabled by each GET individually and in combination, broken out by state. In some places, such as Pennsylvania, combining GETs brings a large advantage, while in others, such as Illinois, GETs are primarily substitutes, rather than complements. This highlights the need for site-specific study and analysis of these technologies, because their applications and use cases depend on the specific grid conditions in a particular geography.

Exhibit 7 **Queued generation capacity (in GW) enabled to interconnect by each GET, as well as GETs in combination, for five PJM states in 2026**



RMI Graphic. Source: Quanta analysis

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iv State-by-state breakdown of wind, solar, and storage additions in the first 11 months of 2023: Illinois, 990 megawatts (MW); Ohio, 423 MW; Pennsylvania, 327 MW; Virginia, 268 MW; Indiana, 0 MW. This data is just for the PJM footprint of these states, several of which, such as Indiana, are primarily in MISO.

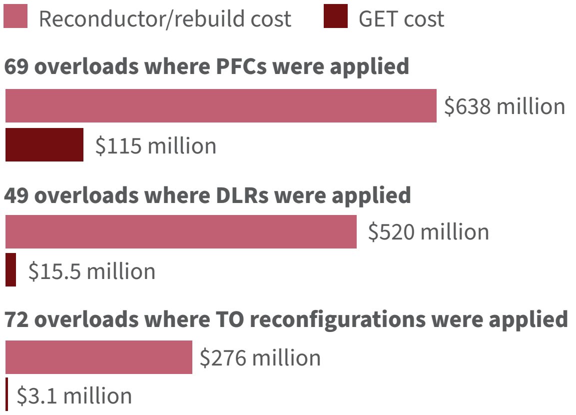
v Because in some cases multiple GETs could have been used to address the same constraint, the combined scenario reflects a lower level of GETs deployments compared with adding up each of the individual GETs scenarios.

Across the study footprint, GETs could save project developers hundreds of millions of dollars in interconnection costs compared with the default network upgrades

GETs enable interconnection at dramatically lower cost than standard network upgrades. Network upgrade costs have increased significantly in recent years — in PJM and elsewhere — as less and less hosting capacity is available on regional grids and more expensive upgrades are required.[21] Transmission owners are now commonly identifying reconductoring or rebuilding affected transmission lines as upgrades to address overloads triggered by interconnecting projects. As shown in Exhibit 8, GETs costs range from $272 to $523 million less than these types of network upgrades. In addition to the cost savings, GETs significantly reduce the time required to connect new generation. Reconductoring or rebuilding lines can take up to three years or more, while transmission owners can deploy GETs in months.

Exhibit 8

Comparison of the typical network upgrade costs that would have been used to address an overload versus the cost of the GETs alternatives



Note: These results are derived from the power flow scenarios in which each technology was applied individually throughout the study footprint. For TO, costs were estimated by applying a one-time analysis consultant fee to each project where a reconfiguration solution was identified (under the current participant-funded upgrade paradigm, this would be paid by the project developer). In many cases, the reconfiguration solutions identified used preexisting substation equipment, so no additional capital expenditure costs would be required. In other cases, the costs to implement more complex reconfigurations were assessed and included.

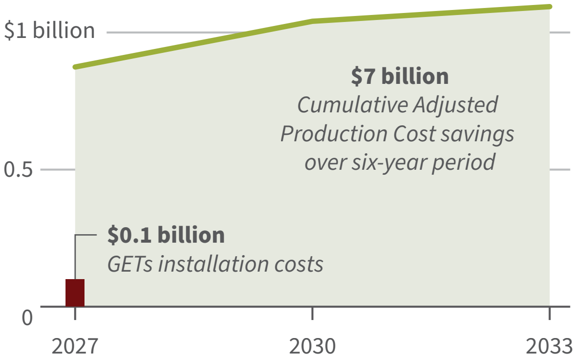
RMI Graphic. Source: Quanta analysis

Together, GETs and the new generation they enable yield $1 billion annually in production cost savings

Production cost modeling results reveal significant savings that would flow to electricity consumers in the PJM region. GETs and the wind, solar, and storage enabled to interconnect reduced production costs by $0.9 billion in 2027, $1.04 billion in 2030, and $1.1 billion in 2033 (see Exhibit 9).[vi] This is driven by the lower operating expenses of the new renewable and storage resources, as well as the broader congestion relief that GETs provide, unlocking additional lower-cost generation on PJM's grid.

Exhibit 9

Annual adjusted production cost savings resulting from GETs and the new generation they enable



RMI Graphic. Source: Quanta analysis

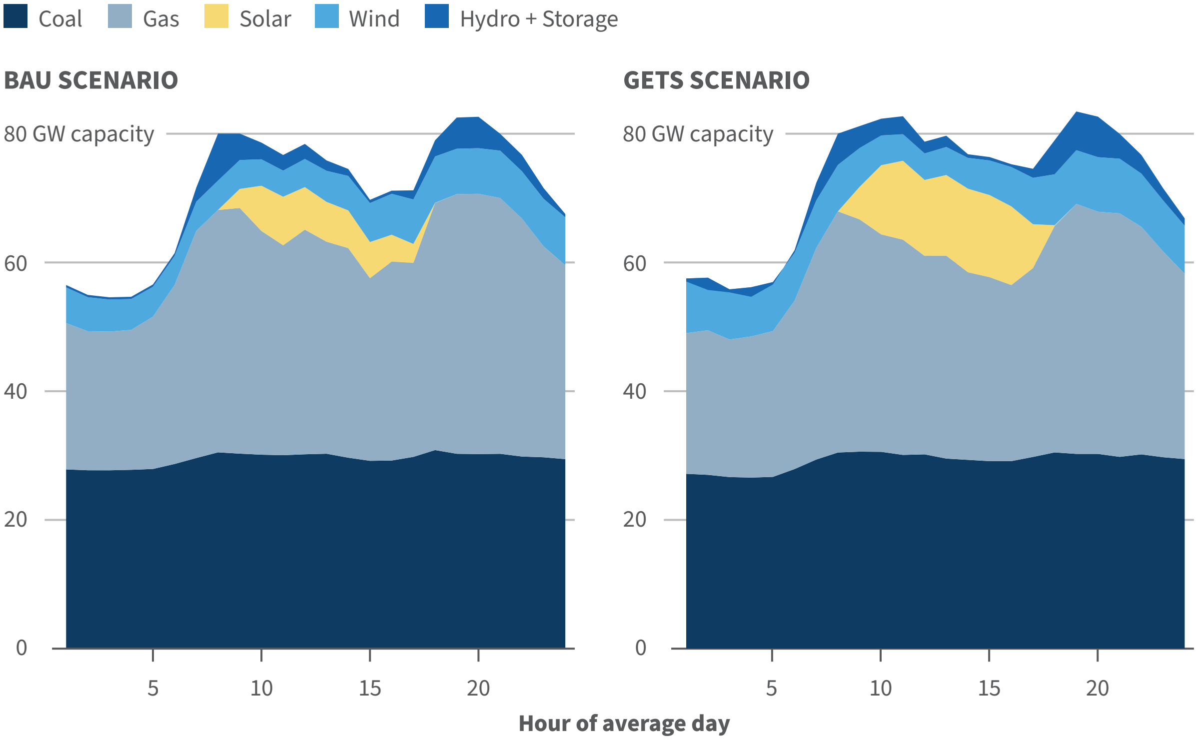
[vi] This additional capacity is just in the five-state footprint in scope for this analysis; applying GETs across the PJM footprint would unlock additional generation and enable even greater savings. Actual production cost savings will vary depending on the total capacity of renewable generation interconnected to PJM's system before 2027.

The production cost savings delivered by GETs are an order of magnitude greater than the GETs deployment costs ($0.1 billion), making a clear financial case for GETs' regular consideration as interconnection network upgrades. Even factoring in the capital costs of the new generation, estimated at $11.4 billion,[vii] the benefits delivered by the energy savings would exceed the up-front costs in just over 10 years — a relatively quick payback period for these 30-year assets.

Exhibit 10 shows the changes in economic dispatch between the BAU scenario and the GETs scenario: coal and gas resources are dispatched less in the GETs scenario, supplanted by the addition of cheaper solar and wind; additionally, storage resources discharge when energy costs are high and charge when costs are lower, further reducing overall energy costs. What is more, while not captured in the production cost modeling, these new resources would likely participate in PJM's ancillary service and capacity markets, which could yield even greater consumer cost reductions.

The addition of this new carbon-free generation to PJM's grid would reduce carbon emissions 3.5% (12 million tons) in 2027, 2.9% in 2030, and 2.6% in 2033 (see the Appendix, which is available for separate download on the report website, for more information).

Exhibit 10 **Average hourly capacity output of coal, gas, solar, wind, and pumped hydropower and storage resources over a 24-hour period in 2027, for both BAU and GETs scenarios**



RMI Graphic. Source: Quanta analysis

[vii] This is based on NREL's 2023 Annual Technology Baseline (ATB) for each technology. Capacity and ancillary service market savings would likely reduce payback times considerably. Note that the project developers would bear the economic risk of these projects while customers would benefit from reduced energy market prices.

Case Study: PJM Approves PFCs as Network Upgrades for an Illinois Wind Project

Although PJM does not yet include GETs routinely in interconnection study processes, developers and utilities can propose GETs for consideration in particular instances. As a case study, we summarize the approval of PFCs as network upgrades for a recent wind project uprate in PJM.

In 2018, a developer submitted a request to PJM to expand its wind project, located in north-central Illinois in ComEd territory, by just over 100 megawatts (MW). At the feasibility study phase of the interconnection process, PJM concluded that the 100 MW addition would require roughly $100 million of system upgrades, some of which might be shared with other projects in prior queue positions.[viii, 22] The upgrades included reconductoring, new lines, and sag mitigation, with construction timelines estimated at up to three years. These proposed network upgrades threatened the financial viability of adding the 100 MW of wind.

To find a way forward for its project, the developer requested that PJM evaluate Smart Wires' PFC devices, SmartValves, in lieu of the originally identified network upgrades. The upgrades in question were intended to address a stability issue on a long gen-tie line, the Dixon-McGirr 138 kV line, onto which multiple wind and solar projects in the same area feed and which then connects to the load center in Chicago. The developer's proposal noted that SmartValves, which inject either capacitive or inductive voltage in series with the line, could help manage the line loading from the growing number of inverter-based resources, with minimal risk of subsynchronous control interactions. This would serve to shorten the electrical distance the power must flow, minimizing voltage loss that contributes to stability issues.

In evaluating this alternative network upgrade proposal, PJM conducted a thorough, two-year study to ensure the deployment would not adversely affect other parts of the network, while ComEd assessed how the SmartValves would fit into its local grid topography. PJM approved the SmartValves solution, and the project received a draft interconnection service agreement in summer 2023.[23] Based on the terms of that agreement, deploying PFCs would cut costs for interconnecting the new wind capacity to $12 million (nearly an order of magnitude lower) and cut the installation time in half, compared with the network upgrades originally identified (see Exhibit 11, next page). Additionally, because SmartValves are modular tools, their deployment could also be quickly and easily scaled for future generator interconnections in the region.

[viii] At that time, the policy for network upgrade cost allocation was "first to cause", meaning the wind project would have been responsible for the full share of the cost; however, PJM has since moved to cluster processing, where network upgrade costs would be shared by projects in the same study cluster.

Exhibit 11 Interconnecting project information

Project Capacity (Uprate)	105.9 MW
Capacity Interconnection Rights Requested	21.2 MW
Location	ComEd service territory, north-central Illinois
Interconnection Problem *(Network Impacts Triggered by Project)*	Reliability criteria violations due to system stability constraints on long gen-tie line connecting multiple renewables projects to load center
PJM Proposed Network Upgrades	A package of 12 network upgrades was identified in the facilities study, including reconductoring, sag mitigation, and new lines
Developer Proposed Alternative	Set of SmartValves (PFCs) to be installed on the 138 kV Dixon-McGirr line
Outcome	**PJM and ComEd studied and accepted the SmartValves solution**

Initial network upgrade

Upgrade cost: $100 million

Timeline: 3 years

GETs upgrade

Upgrade cost: $12 million

Timeline: 12–15 months

RMI Graphic. Source: RMI

Recommendations

This study shows that GETs can improve interconnection efficiency and meaningfully reduce electricity costs. PJM and electricity industry stakeholders can address structural barriers to the use of GETs by employing the following recommendations.

PJM should institute robust evaluation of GETs across its interconnection and transmission planning practices

As the regional grid operator, PJM can enshrine study and evaluation of GETs in both its interconnection study and transmission planning practices. To date, PJM has taken a hands-off approach, leaving GETs consideration to the discretion of transmission-owning utilities. PJM should do more to build its own and its members' familiarity with GETs, including helping develop and standardize interconnection modeling tools that include GETs capabilities. Ultimately, PJM should proactively and fully evaluate GETs in all economic planning evaluations, accounting for a variety of scenarios and value streams. GETs should be considered as both alternative transmission solutions and interim solutions that could help mitigate congestion during asset maintenance or replacement, or when new transmission lines are approved but are not yet in service. In preparing for compliance with FERC Order 2023 and its directives to consider certain GETs in the interconnection study process, PJM can:

- **Require interconnection studies to consider GETs.** As part of its Order 2023 compliance filing, PJM should be ambitious in its interpretation of the alternative transmission technologies that warrant consideration in interconnection studies. PJM can explicitly include the full spectrum of possible transmission solutions — including all GETs, advanced conductors, etc. — in its interconnection study process. This would help ensure identified network upgrades are as streamlined and cost-effective as possible.

- **Utilize analysts and consultants with GETs modeling experience** both to incorporate consideration of GETs into studies in the near term, and to support internal capacity building.

- **Build familiarity with GETs.** PJM should leverage this analysis and the ongoing work of its Applied Innovation team to build familiarity with GETs capabilities among its own staff. PJM should develop in-house trainings for interconnection study engineers and other positions where improved understanding would ensure GETs are evaluated as a matter of course.

- **Require GETs-capable power system planning software.** PJM should require its software providers to rapidly augment their tools so they include native hardware models of relevant GETs (e.g., advanced PFCs) in steady-state, dynamic, and electromagnetic transient domains, or switch to new software providers with GETs capabilities. More broadly, PJM should maintain up-to-date software and models for all new technologies it might be evaluating or deploying as the RTO builds and operates the grid of the future.

- **Ensure Energy-only Resource Interconnection Service (ERIS) is a viable option for new generators.** Even in cases where GETs do not meet the full deliverability criteria required for Network Resource

Interconnection Service (NRIS), they could be applicable tools for ERIS resources. ERIS interconnection is generally more rapid and low cost than NRIS, due to the less stringent standards for these resources, which face higher curtailment risk as a result. Given the production cost and emissions benefits associated with more rapid interconnection of carbon-free generation, PJM should make every effort to accommodate this option.

Transmission owners should prioritize deploying their first GETs projects, build confidence in GETs technologies, and institute the systems needed for routine deployment

Transmission owners have a crucial role in meeting the need for grid modernization, driven by a rapidly changing generation mix and increasing load growth. As shown in this study, transmission owners can cost-effectively deploy GETs to relieve congestion, interconnect new generation more quickly, and serve as a bridge to the longer-lead-time transmission expansion projects they might have underway. To build confidence in GETs, transmission owners can:

- **Deploy an inaugural GETs project.** While GETs are proven technologies, each utility's initial deployment is a learning experience. A first deployment offers both rapid learning by doing and a proof point for GETs benefits, making subsequent deployments more straightforward.

- **Partner with experienced analysts and peer companies** that have conducted GETs pilots or deployments. As an example, the Energy Systems Integration Group (ESIG) recently launched a GETs User Group that provides a forum for utilities to share learnings.[24] Transmission owners with and without GETs experience should participate in this user group.

- **Integrate any needed software or functionality into the operating platform** and modeling tools used to monitor their system, to keep pace with the changing capabilities of grid technologies.

- **Regularly evaluate the potential for GETs** to be deployed on their systems as solutions to a variety of transmission needs, including interconnection as well as other drivers of additional transmission capacity needs. Transmission owners should also provide public reports on these evaluations as well as deployments to allow industry stakeholders to see and gain trust in these technologies.

Developers should propose GETs for needed network upgrades as part of their interconnection requests

Developers are at the vanguard in understanding GETs and their capabilities, so they are well positioned to help make the case for their expeditious integration into the studies and modeling tools of utilities and grid operators. To save time and money in interconnecting their projects, developers can:

- Propose GETs as an alternative network upgrade to be evaluated by grid operators during the interconnection study process.

- Conduct their own modeling and analysis of GETs as network upgrade options, if necessary, to vet grid operator studies — particularly where GETs were not considered.

State regulators should provide oversight of utility practices and any necessary guidance to maximize the potential for GETs adoption to reduce ratepayer bills

GETs are well-established, consumer-friendly transmission solutions; nevertheless, utilities have been slow to adopt them. Utilities may be both risk-averse and disinclined to use modular, low-cost solutions inconsistent with prevailing incentives for capital expenditures. This is a natural intervention opportunity for state regulators, who can help ensure their utilities are pursuing transmission planning and build-out responsibly by evaluating and deploying GETs wherever practicable. To the extent their spheres of jurisdiction allow, state regulators can:

- **Advance understanding of GETs** among key energy industry players in their state by opening an investigative proceeding, requiring utilities to conduct a cost-benefit analysis of GETs deployments across their transmission system, or creating a utility-stakeholder working group to fill in needed gaps such as the development of GETs-specific modeling tools for utilities' systems.

- **Require GETs consideration or deployment.** This could take the form of a requirement for GETs evaluation in utilities' regular transmission or resource planning processes, or a standard (similar to state energy efficiency standards) establishing a minimum threshold for GETs deployment in the state, which could be linked to metrics such as transmission line miles or congestion cost/frequency.

- **Incentivize GETs deployments** through a performance incentive mechanism that rewards utilities for installing GETs on their systems, or a shared savings incentive that allows the utility to share in the ratepayer cost savings enabled by GETs.[25]

- **Engage in RTO and FERC proceedings**, independently or through state associations such as the Organization of PJM States Inc. (OPSI) and the National Association of Regulatory Utility Commissioners (NARUC) to push for higher-level regulatory reforms that would support more widespread GETs uptake.

FERC should take additional steps to provide a comprehensive national regulatory framework that supports GETs adoption

GETs align with many of the core principles underpinning FERC's regulation of the electricity sector — principles of open access, for which a workable interconnection process is a prerequisite, as well as ensuring just and reasonable rates. They have also been proven to uphold grid reliability in the growing number of studies and deployments to date.[26] There are several available channels at FERC to build out the regulatory architecture that would help GETs become routinely evaluated and deployed transmission solutions. Building on the inclusion of alternative transmission technologies in Order 2023, FERC can:

- **Finalize a strong transmission planning rulemaking** that includes a requirement to evaluate GETs as possible transmission solutions.
- **Establish a national shared savings incentive** to encourage utility adoption of GETs, drawing from the record of stakeholder comments and the technical conference held in September 2021 on transmission incentives.[27]
- **Advance the Notice of Inquiry on DLR** to a Notice of Proposed Rulemaking that would develop a standardized process for deploying DLR in response to certain criteria.
- **Provide guidance on best practice approaches to GETs capacity building and modeling efforts** by FERC-jurisdictional utilities and grid operators to ensure learning curves keep pace with technological innovation and commercialization of these technologies.

Conclusion

In this analysis, we show that GETs speed up interconnection and reduce costs. The ensuing benefits are significant: new, low-cost generation that drives down electricity costs for consumers, reduces emissions, and supports the growing demand for electricity to power new end uses and spur economic development. FERC Order 2023 provides an important catalyst to further the consideration of alternative transmission technologies in interconnection studies; PJM and other grid operators should build on FERC's order and include GETs as standard network upgrade options for generator (and new load) interconnection. By rightsizing network upgrade costs, grid operators can take a key step toward a smoother interconnection process. More broadly, GETs are a core element of ensuring optimal use of the existing grid while we pursue the grid expansion necessary for an increasingly electrified, decarbonized, and reliable energy system. In the future, all GETs should be routinely evaluated in contexts such as interconnection and transmission planning, whether as stand-alone solutions or part of a least-cost solutions package.

Endnotes

1. Allison Good, "US Generating Capacity Additions Up in 2023, with Solar Providing the Largest Share," 2024, **https://www.capitaliq.spglobal.com/apisv3/spg-webplatform-core/news/article?id=80114087&KeyProductLinkType=12**.

2. Dan McCarthy and Maria Virginia Olano, "The US Climate Law Is Fueling a Factory Frenzy. Here's the Latest Tally," 2023, **https://www.canarymedia.com/articles/clean-energy-manufacturing/the-us-climate-law-is-fueling-a-factory-frenzy-heres-the-latest-tally**.

3. Richard Doying, Michael Goggin, and Abby Sherman, *Transmission Congestion Costs Rise Again in US RTOs*, 2023, **https://gridstrategiesllc.com/wp-content/uploads/2023/07/GS_Transmission-Congestion-Costs-in-the-U.S.-RTOs1.pdf**.

4. LBNL, "Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection," 2023, **https://emp.lbl.gov/queues**.

5. LBNL, "Generator Interconnection Costs to the Transmission System," 2023, **https://emp.lbl.gov/interconnection_costs**.

6. Garrett Hering, "Western US Grid Official Flags 'Real Question' on Energy Transition Pace," 2023, **https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/western-us-grid-official-flags-real-question-on-energy-transition-pace-76615314**; MISO, *Managing Reliability Risk in the MISO Footprint*, 2022, **https://cdn.misoenergy.org/20220616%20Board%20of%20Directors%20Item%2008a%20Reliability%20Imperative625168.pdf**; PJM, *Energy Transition in PJM: Resource Retirements, Replacements & Risks*, 2023, **https://www.pjm.com/-/media/library/reports-notices/special-reports/2023/energy-transition-in-pjm-resource-retirements-replacements-and-risks.ashx**.

7. Katie Siegner, Kevin Brehm, and Mark Dyson, *Seeds of Opportunity: How Rural America Is Reaping Economic Development Benefits from the Growth of Renewables*, 2021, **https://rmi.org/insight/seeds-of-opportunity/**.

8. Noah Strand, *Power Up PJM: Quantifying the Economic Benefits of Renewable Energy Projects Waiting to Connect to the Mid-Atlantic Power Grid*, 2023, **https://acore.org/wp-content/uploads/2023/06/ACORE-Power-Up-PJM-Report.pdf**.

9. Dana Ammann, *Waiting Game: How the Interconnection Queue Threatens Renewable Development in PJM*, 2023, **https://www.nrdc.org/sites/default/files/2023-05/pjm-interconnection-queue-renewable-development-report.pdf**.

10. FERC, Order 2023, 2023, **https://www.ferc.gov/media/e-1-order-2023-rm22-14-000**.

11. "Commissioner Clements Concurrence on Order No. 2023: Improvements to Generator Interconnection Procedures and Agreements," 2023, **https://www.ferc.gov/news-events/news/e-1-commissioner-clements-concurrence-order-no-2023-improvements-generator**; US Department of Energy, "DOE Releases Draft Roadmap to Improve Interconnection of Clean Energy Resources on the Nation's Transmission Grid," 2023, **https://www.energy.gov/eere/articles/doe-releases-draft-roadmap-improve-interconnection-clean-energy-resources-nations**; Claire Wayner, Katie Siegner, Mathias Einberger, Russell Mendell, and Sarah Toth, "Going the Distance on Interconnection Queue Reform," 2023, **https://rmi.org/going-the-distance-on-interconnection-queue-reform**.

12. Brattle, *Unlocking the Queue with Grid-Enhancing Technologies*, 2021, **https://watt-transmission.org/wp-content/uploads/2021/02/Brattle__Unlocking-the-Queue-with-Grid-Enhancing-Technologies__Final-Report_Public-Version.pdf90.pdf**.

13. Julia Simon, "Why Lasers Could Help Make the Electric Grid Greener," 2023, **https://www.npr.org/2023/08/13/1187620367/power-grid-enhancing-technologies-climate-change**; Philip Giudice, "Technologies to Enhance the Power Grid Exist, We Just Need to Deploy Them," 2023, **https://thehill.com/opinion/energy-environment/4171124-technologies-to-enhance-the-power-grid-exist-we-just-need-to-deploy-them/**.

14. David Roberts and Julia Selker, "Getting More Out of the Grid We've Already Built," 2023, **https://www.volts.wtf/p/getting-more-out-of-the-grid-weve**.

15. Kaja Rebane, Katie Siegner, and Sarah Toth, "Cheaper, Cleaner, Faster," 2023, **https://rmi.org/cheaper-cleaner-faster/**.

16. Sustainable FERC Project, "Transforming PJM is the Key to a Clean Energy Grid," 2020, **https://sustainableferc.org/transforming-pjm-is-the-key-to-a-clean-energy-grid/**.

17. LBNL, *Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection as of the End of 2022*, 2023, **https://emp.lbl.gov/sites/default/files/queued_up_2022_04-06-2023.pdf**.

18. Utility Dive, "Unlocking Grid Potential: Paving the Way for Renewable Energy," 2023, **https://www.utilitydive.com/spons/unlocking-grid-potential-paving-the-way-for-renewable-energy/693715/**.

19. Joseph Rand, Ryan H. Wiser, Will Gorman, Dev Millstein, Joachim Seel, Seongun Jeong, and Dana Robson, *Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection as of the End of 2021*, 2021, **https://emp.lbl.gov/publications/queued-characteristics-power-plants-0**.

20. Nicolae Dumitriu, "PJM Market Efficiency Benefits Calculation," 2019, **https://www.pjm.com/-/media/committees-groups/task-forces/mepetf/20190510/20190510-item-02-pjm-market-efficiency-benefits-calculation.ashx**.

21. Joachim Seel, Joe Rand, Will Gorman, Dev Millstein, Ryan Wiser, Will Cotton, Katherine Fisher, Olivia Kuykendall, Ari Weissfeld, and Kevin Porter, *Interconnection Cost Analysis in the PJM Territory*, 2023, **https://eta-publications.lbl.gov/sites/default/files/berkeley_lab_2023.1.12-_pjm_interconnection_costs.pdf**.

22. PJM, *Feasibility Study Report for PJM Generation Interconnection Request Queue Position AD2-134 Shady Oaks*, 2018, **https://www.pjm.com/pub/planning/project-queues/feas_docs/ad2134_fea.pdf**.

23. PJM, AD2-134 Interconnection Service Agreement, 2023, **https://www.pjm.com/pub/planning/project-queues/isa/ad2_134_isa.pdf**.

24. ESIG, "GETs User Group," accessed December 2023, **https://www.esig.energy/gets-user-group**.

25. WATT Coalition and AEE, Comments re: FERC NOPR on Electric Transmission Incentives Policy Under Section 219 of the Federal Power Act, 2020, **https://watt-transmission.org/wp-content/uploads/2020/08/watt-coalition-aee-filing-to-ferc-in-incentives-nopr.pdf**.

26. PJM, Draft Supplemental DLR NOI Comments — AD22-5, 2023, **https://pjm.com/-/media/documents/ferc/filings/2024/20240117-ad22-5-000.ashx**.

27. WATT Coalition, ACPA, AEE, ACORE, NRDC, and Sustainable FERC Project, Post-Technical Conference Comments – AD19-19-000, 2022, **https://acore.org/wp-content/uploads/2022/01/Post-Technical-Conference-Comments-of-Clean-Energy-Parties-on-Electric-Transmission-Incentives-Policy.pdf**

Katie Siegner, Sarah Toth, Chaz Teplin, and Katie Mulvaney, *GETting Interconnected in PJM: Analyzing Grid-Enhancing Technologies (GETs) as a Tool for Increasing Interconnection Throughput from PJM's Queue*, RMI, 2024, **https://rmi.org/insight/analyzing-gets-as-a-tool-for-increasing-interconnection-throughput-from-pjms-queue/**.

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