UNLOCKING POWER:

A Playbook on Grid Enhancing Technologies for State and Regional Regulators and Policymakers

WATT COALITION

Grid Strategies

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Unlocking Power:
What are Grid Enhancing Technologies?

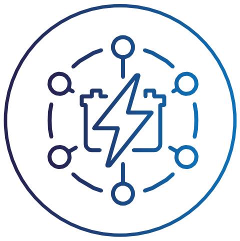
Why Does Our Grid Need New Tools?

Our grid wasn't built in a day, but the way we use and generate electricity is changing rapidly. We must adapt the power network built over 150 years to keep up with growing demand and allow continued access to the lowest-cost energy resources. The U.S. Department of Energy[1] found that we need 57% more transmission capacity by 2035 – it would be too expensive and take too long to build that many new power lines, so the grid needs new technologies to unlock more from the grid we already have.

Three Technologies Can Rapidly and Cheaply Find More Capacity on the Grid

Grid Enhancing Technologies (GETs) are hardware, software, or both that dynamically increase the capacity, efficiency, reliability, and safety of power lines faster and at lower cost than traditional grid infrastructure.

Dynamic Line Ratings (DLR) measure and calculate the true carrying capacity of transmission lines – often finding 20% or more capacity than assumed. This finds room for new power plants or new electricity demand.



Advanced Power Flow Control redirects power to lines with extra capacity, preventing overloads and balancing the use of the grid. In the UK, 48 APFC devices at substations have unlocked capacity for 1.5 gigawatts (GW) of new clean energy.

Topology Optimization is software that finds the best use of grid infrastructure to redistribute power and unlock more capacity. The "grid reconfigurations" identified could save billions of dollars in energy costs every year.

By widely deploying GETs on the grid, America will immediately unlock cost savings and improve reliability and resilience.

1 U.S.Department of Energy, "National Transmission Needs Study," October 2023, https://www.energy.gov/sites/default/files/2023-12/National%20Transmission%20Needs%20Study%20-%20Final_2023.12.1.pdf.

GETs Can Save Money in Three Ways

Delivering lowest-cost energy: Today, insufficient transmission capacity often means that the cheapest energy can't reach cities or industrial sites that need power. GETs could save $4-8 billion per year[2] in energy costs.

Supporting grid expansion and maintenance: While power lines are under construction, or when a power line goes out of service, GETs can increase capacity until the lines are working. This can save millions in energy costs in every instance and can make it easier for utilities to get their work done.

Avoiding unnecessary investments: By optimizing the grid assets, utilities may find they don't need to build new lines. By measuring and controlling the grid, utilities might find that smaller upgrades are sufficient to get needed capacity. Utilities currently spend over $25 billion per year [3]mostly replacing aging assets – GETs give them more information and options to make those investments cost effective.

GETs Improve Reliability and Smooth Change

- **GETs provide access to more power to keep the lights on:** Old, expensive power plants are shutting down across the country. As those plants shut down, GETs find more capacity and manage flows to draw power from other locations.
- **GETs plug in new resources:** New generation used to be integrated in less than two years, but now usually takes almost five years[4] to get approval. Large-scale grid upgrades can delay projects even further. GETs can be deployed in months and double capacity for new generation on the grid.
- **GETs deliver power faster:** As some regions are raising alarms about the need for more generation to meet electricity demand, GETs come online quickly to deliver power from new resources and further distances.

GETs Increase Resilience With Flexibility and Awareness

- **GETs support operator decision-making:** GETs measure capacity, control grid use, and identify options for how power could flow on the grid. The information from GETs allows operators to use infrastructure differently, which can protect the grid and maintain reliability.
- **GETs provide new options for difficult circumstances**: With improved visibility and control from GETs, a utility might redirect power flow from a line in a high fire risk scenario to another circuit with topology optimization or advanced power flow control. Grid operators might avoid rolling blackouts during a cold snap because DLR data allows them to send more power down their lines.

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2 Bruce Tsuchida, Linquan Bai, Jadon Grove, "Building a Better Grid: How Grid-Enhancing Technologies Complement Transmission Buildouts," Brattle Group, April 2023, https://watt-transmission.org/wp-content/uploads/2023/04/Building-a-Better-Grid-How-Grid-Enhancing-Technologies-Complement-Transmission-Buildouts.pdf.

3 Edison Electric Institute, "Resources & Media Industry Data," accessed September 2024, https://www.eei.org/en/resources-and-media/industry-data#:~:text=Transmission%20and%20Distribution,spend%20%2429.1%20billion%20in%202023.

4 Joseph Rand, Nick Manderlink, Will Gorman, Ryan Wiser, Joachim Seel, Julie Mulvaney Kemp, Seongeun Jeong, Fritz Kahrl, "Queued Up: 2024 Edition," Lawrence Berkeley National Laboratory, April 2024, https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_1.pdf.

The Keys to Unlocking GETs: Policy and Regulation

GETs have been commercially available for years, but wide adoption is blocked by:

1. **Institutional inertia:** Utilities and system operators are slow to change their practices and adopt new approaches.
2. **Incentives:** Investor-owned utilities are not rewarded for reducing energy or transmission costs – their business models are based on building new infrastructure, so they do not have teams working on operational efficiency.

Policymakers at all levels of government can adjust utility expectations, requirements, and incentives to drive grid modernization and unlock the power and value behind GETs. Proven policy strategies include:

1. Push utilities and system operators to modernize grid planning and operation, as FERC Order Nos. 881, 2023, and 1920 have done.
2. Require GETs where they'll pay for themselves, as the PJM Interconnection proposed.[5]
3. Incentivize utilities to find high-value GETs deployments, like the UK and Australia[6] have done.

5 WATT Coalition, "Grid Enhancing Technologies Could Unlock More Reliability, Affordable, Clean Energy in PJM," February 2024, https://watt-transmission.org/grid-enhancing-technologies-could-unlock-more-reliable-affordable-clean-energy-in-pjm/.

6 Comments of the WATT Coalition, Inquiry on Improvements to Electric Transmission Incentives Policy, Docket PL19-3-000, June 2019, https://watt-transmission.org/wp-content/uploads/2019/06/watt-noi-comments-with-brattle-grid-strategies-paper.pdf (watt-transmission.org).

Unlocking the Grid:
Key Benefits of Grid Enhancing Technologies

Cost Savings
Grid constraints cost the U.S. billions of dollars every year and delay low-cost generation – GETs pay for themselves in less than a year.

Fast Upgrades
Traditional transmission upgrades take years to build – GETs can be deployed in months.

Flexibility and Awareness
GETs give operators new tools for managing reliability by measuring and unlocking the grid’s dynamic capabilities.

This resource describes how GETs unlock these benefits through integration across utility processes for generation, transmission planning, and grid operations.

Grid Enhancing Technologies

Dynamic Line Ratings (DLR) measure and calculate the true carrying capacity of transmission lines.

Advanced Power Flow Control (APFC) redirects power from overloaded to underutilized circuits

Topology Optimization is software that finds ideal grid configurations to avoid constraints.

Examples of System and Customer Benefits From Grid Enhancing Technologies

1

More affordable infrastructure:
GETs can increase the value of existing transmission infrastructure and upgrades.

DLR increase transmission capacity:

- **Massachusetts**:[7] DLR deployment created an average increase of 47% in line capacity.
- **New York**:[8] DLR found up to 60% more capacity.
- **Pennsylvania**:[9] Duquesne Light Company found an average of 25% more capacity on transmission lines.
- **Midwest**:[10] Xcel's Minnesota, Wisconsin, and Colorado territory demonstrated increased capacity available 85% of the time.

GETs save money for customers by reducing grid congestion and generator curtailment:

- **Australia**:[11] APFC technology is expected to deliver net benefits of up to $180 million to electricity customers by allowing an additional 170 megawatts (MW) of power to be transferred into New South Wales.
- **England**:[12] APFC technology is estimated to save more than $500 million by avoiding curtailment costs through an effort by National Grid Electricity Transmission to use APFC on five 275 kilovolt (kV) lines and 400 circuits.
- **Pennsylvania**:[13] PPL Electric Utilities deployed DLR to avoid over $20 million in annual grid congestion costs.
- **United States**:[14] Topology optimization studies in four U.S. electricity markets (PJM, MISO, SPP and ERCOT) show reduced congestion costs by 25-50% and reduced renewables curtailment by 50%.

7 K. Engel, J. Marmillo, M. Amini, H. Elyas, and B. Enayati, "An Empirical Analysis of the Operational Efficiencies and Risks Associated with Static, Ambient Adjusted, and Dynamic Line Rating Methodologies," LineVision Inc., National Grid USA, July 2021, https://cigre-usnc.org/wp-content/uploads/2021/11/An-Empirical-Analysis-of-the-Operational-Efficiencies-and-Risks-Associated-with-Line-Rating-Methodologies.pdf.

8 New York Power Authority, "NYPA Installs Sensors to Better Predict Weather Patterns to Improve Transmission," June 2021, YouTube video, 2:13 https://www.youtube.com/watch?v=_GTzg_BV03Q&t=6s.

9 LineVision, "Duquesne Light Company Further Enhances Transmission Capacity, Reliability with Grid-Enhancing Technology," September 2022, https://www.linevisioninc.com/news/duquesne-light-company-further-enhances-transmission-capacity-reliability-with-grid-enhancing-technology.

10 LineVision, "Xcel Energy Installs LineVision's V3 Transmission Line Monitoring System in Colorado, Minnesota and Wisconsin to Increase Grid Capacity and Safety," February 2021, https://www.linevisioninc.com/news/xcel-energy-installs-linevisions-v3-transmission-line-monitoring-system-in-colorado-minnesota-and-wisconsin-to-increase-grid-capacity-and-safety.

11 SmartWires, "Transgrid: VNI Upgrade," accessed October 2024, https://www.smartwires.com/2023/05/05/transgrid-project-page/.

12 National Grid, "Working smarter to get to next zero," May 2021, https://www.nationalgrid.com/stories/journey-to-net-zero-stories/working-smarter-get-net-zero.

13 PJM Inside Lines, "Dynamic Line Rating Activated by PPL Electric Utilities," October 2022, https://insidelines.pjm.com/dynamic-line-rating-activated-by-ppl-electric-utilities/.

14 See "Building a Better Grid: How Grid-Enhancing Technologies Complement Transmission Buildouts."

2

Cleaner energy through faster and cheaper generator interconnection: GETs can lower costs and shorten timelines for new generation.

- **Faster generator interconnection:** At the system level, GETs can double the capacity for new generation on existing infrastructure, per a study of the Kansas and Oklahoma systems and interconnection queues done by the Brattle Group.[15]
- **Reduce interconnection costs**: RMI[16] found that GETs could enable interconnection for 6 GW of renewable energy, saving around $500 million over traditional upgrades. Anecdotally, developers report interconnection costs of $50-400 million for 1-3% projected line overloads, which would likely be resolved by DLR at a fraction of the cost.
- **Shorten study and construction timelines**: New lines and other traditional upgrades can take years to design and deploy, while GETs can be operational within months. PJM's 2024 phase one interconnection study reported upgrade timelines longer than 3 years[17] for many projects.
- **Serve as a bridge while projects wait for traditional upgrades**: GETs can provide additional provisional transmission service for projects awaiting traditional upgrades.
- **Decrease queue withdrawals**: High upgrade costs lead to projects dropping out of the queue, requiring restudies and increasing uncertainty around interconnection costs. By including GETs in interconnection studies, more projects should move through the queue more smoothly.

3

Cost-effective, reliable and flexible transmission planning: GETs can defer upgrades or provide bridge service while large infrastructure is built.

GETs increase value of future investments: The Brattle Group found that GETs increased utilization[18] of existing and planned 345kV lines in Kansas and Oklahoma by 15-22%.

GETs can defer upgrades or provide bridge service while large infrastructure is built:

- **Texas**:[19] AEP installed real-time line ratings on a congested 138 kV transmission line to avoid a $20 million upgrade that would have quickly become a stranded asset as new lines were built to serve increased wind generation.

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15 Bruce Tsuchida, Stephanie Ross, Adam Bigelow, "Unlocking the Queue with Grid-Enhancing Technologies," The Brattle Group, February 2021, https://watt-transmission.org/unlocking-the-queue/.

16 Katie Siegner, Sarah Toth, Chaz Teplin, and Katie Mulvaney, "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue," RMI, February 2024, https://rmi.org/insight/analyzing-gets-as-a-tool-for-increasing-interconnection-throughput-from-pjms-queue?submitted=1#thank-you.

17 PJM, "New Service Requests System Impact Study Executive Summary Report Transition Cycle #1 Phase I," May 2021, https://www.pjm.com/pub/planning/project-queues/Cluster-Reports/TC1/TC1_PH1_Executive_Summary.htm#exec-sum-intro.

18 See "Building a Better Grid: How Grid-Enhancing Technologies Complement Transmission Buildouts."

19 Sandy Aivaliotis, "Dynamic Line Ratings for Optimal and Reliable Power Flow," The Valley Group, June 2010, https://cms.ferc.gov/sites/default/files/2020-05/20100623162026-Aivaliotis%2C%2520The%2520Valley%2520Group%25206-24-10.pdf.

- **Pennsylvania**:[20] PPL Electric Utilities deployed DLR for less than $1 million, compared to $20 million for reconductoring and $40-60 million for rebuilding transmission. DLR would also be operational in less than 1 year with no outages, compared to 2 to 3 years with extended outages for reconductoring, and 3 to 5 years with extended outages for rebuilding transmission.
- **New York**:[21] A DLR project upstate will avoid the need to rebuild 26 miles of transmission lines. With an estimated cost of $3.2 million, the project budget is less than the average cost of rebuilding just a single mile of a 115 kV line in the area.

4

Increase grid reliability and resilience: GETs can mitigate outages and improve both visibility and flexibility across the grid.

- **Colombia**:[22] Mitigating an outage with APFC saved more than $70 million over a 3.5-year outage period. Avoiding redispatch saved an estimated $20.5+ million a year, while the annual costs of APFC devices were only an estimated $1.5-4 million.
- **Minnesota**:[23] MISO implemented a reconfiguration solution to mitigate costs from a major transmission outage, saving ~$40 million over a nine-month period by successfully and reliably increasing throughput by up to 56% in the area.
- **Northeast U.S.**:[24] ISO-NE was able to avoid significant congestion costs during the 2018 "Bomb Cyclone" by leveraging DLR to increase their transmission line ratings to allow more power to flow.

Note: For further reading, please reference the collection of WATT Coalition member case studies for Dynamic Line Ratings, Advanced Power Flow Control and Topology Optimization from around the world. A map of these GET deployments can be found here.

20 See "Building a Better Grid: How Grid-Enhancing Technologies Complement Transmission Buildouts."

21 Id.

22 Id.

23 Id.

24 Id.

Unlock Power Line by Line: Dynamic Line Ratings

Dynamic Line Ratings Are a Grid Enhancing Technology (GET)

Dynamic Line Ratings offer:

Cost Savings
Grid constraints cost the U.S. billions of dollars every year and delay low-cost generation – GETs pay for themselves in less than a year.

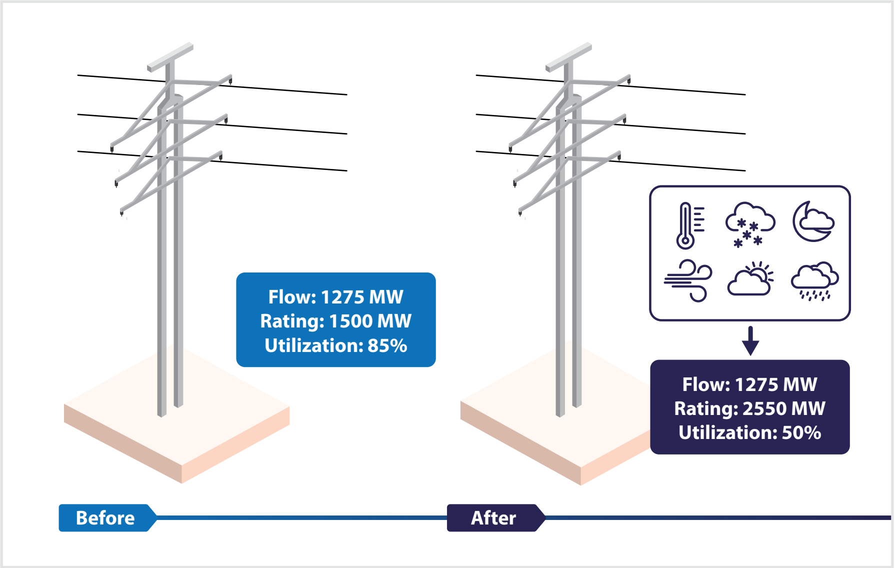
Fast Upgrades
Traditional transmission upgrades take years to build – GETs can be deployed in months.

Flexibility and Awareness
GETs give operators new tools for managing reliability by measuring and unlocking the grid's dynamic capabilities.

Why Do Line Ratings Matter?

As power flows through transmission lines, electric resistance in the metal heats the line in proportion to the energy. If too much power flows through a line, the metal heats, expands, and sags, damaging the infrastructure and risking fires and power outages. For many power lines, this is the limiting factor in how much energy can be transferred over a circuit. However, wind, cloud cover, or other weather factors can cool the line, allowing much more power to flow safely. The same material on a windy ridgeline will have much more carrying capacity than a line in a still, forested valley.

Using sensors, software, or both, **Dynamic Line Rating (DLR)** measures environmental factors or line behavior to forecast and calculate the true transmission capacity. Today's line ratings often assume a wind speed of 2 feet per second (barely a breeze), but the average wind speed across most of the U.S. is over 10 feet per second at the height of transmission lines. With DLR, almost all lines will see at least 10% more capacity 90% of the time, and the average increase in capacity can be 30-50% with favorable climate and geography.



DLR also prevents lines from becoming overloaded. The August 2003 Northeast Blackout was partially caused by high temperatures and low wind overheating a transmission line. Utilities should know the true capacity of a transmission line to ensure safe operations.

Calculating line ratings: The Institute of Electrical and Electronics Engineers has a standard formula (IEEE Std 738-2023) for calculating how much power a transmission line can carry. There are four different approaches for calculating that rating:

MOST BASIC → MOST ACCURATE

Static	Seasonal	Ambient Adjusted	Dynamic
The utility can put in one set of assumptions for how fast the line is heated by the power flowing through it, and how fast the heat is spread to the air. These assumptions are applied to every line and do not change.	The utility can change assumptions based on the expected temperature or wind in different seasons, for instance increasing capacity when the line is cooled faster in winter. When a season changes, the rating on all lines will change at the same time in the same manner.	The utility can use weather forecasts to input the forecast temperature on the line. In other words, the expected hottest day in summer won't limit the line capacity. Each line will have its rating based on local temperature.	Sensors and software integrate multiple factors heating and cooling the line: temperature, wind speed and direction, cloud cover, precipitation, and others. This leads to highly accurate forecasted and real-time ratings for each line.

Economic Benefits of Accurate Line Ratings

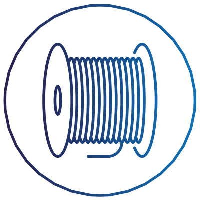
Grid Constraints are Expensive

DLR can address transmission constraints that cost ratepayers and generators over $20 billion per year across the country. The first market-integrated deployment of DLR in the U.S. by PPL Electric Utilities[25] in Pennsylvania reduced congestion by over $60 million year-over-year on a single line. The alternative upgrade, rebuilding the line, would have cost $50 million and required an extended outage. For that price, DLR could be installed 200 times over.

In Europe, DLR has been widely deployed since 2008. In 2017, the extra capacity from DLR in Belgium saved 500,000 euros in redispatch costs in a single day. The ENTSO-E Technopedia[26] describes other DLR deployments and their impacts in Europe.

Grid Enhancing Technologies are the Fastest Tools to Increase Transmission Capacity

PPL Electric Utilities chose to deploy DLR because they were able to achieve needed capacity increases in one year, at low cost, and without coordinating a transmission outage (which alone can take more than a year).



	Reconductor	Rebuild	Dynamic Line Rating
Time to Implement	2-3 Years	3-5 Years	~1 Year
Downtime	Extended Outages	Extended Outages	No Outages
Cost	$0.5 M per mile	$2-3 M per mile	<$1 M
Est. Capacity Benefit	+ 34%	+ 106%	+ 10-30%

25 See "Dynamic Line Rating Activated by PPLElectric Utilities."

26 ENTSO-E, "Dynamic Line Rating," accessed September 2024, https://www.entsoe.eu/Technopedia/techsheets/dynamic-line-rating-dlr.

Accelerating Dynamic Line Ratings Adoption

In the U.S., DLR adoption is slow largely because transmission owners have a cost-of-service business model – improving asset utilization yields minimal profit compared to the returns from large new infrastructure. The Federal Energy Regulatory Commission (FERC) is working on policies to increase the use of DLR. In Order No. 881, FERC required that the operators of regional power markets be capable of accepting DLR by July 2025. FERC opened a notice of inquiry in spring 2022,[27] which received comments suggesting potential congestion-based thresholds for DLR requirement. PJM, the largest market in the U.S., proposed[28] that thermally-limited lines with high and persisting congestion be required to install DLR.

In June 2024, FERC issued an Advanced Notice of Proposed Rulemaking (ANOPR)[29] to require the deployment of DLR in certain scenarios, which lays out the policy options they could pursue in a final rule. The ANOPR covers non-RTO regions as well, where congestion costs are not transparently reported. Final comments on the ANOPR will be submitted in late November 2024. The Commission could then proceed to a Notice of Proposed Rulemaking, with further comments, before issuing a final rule.

Utilities would have to comply with a DLR rule from FERC no sooner than 2026, and likely even later. In the interim, state regulators can encourage or require individual utilities to install DLR and grid operators facing challenges meeting the generation needs of new and existing customers could adopt their own DLR requirements, similar to PJM's recommendations, as a low-cost, quick-turnaround solution.

Other Resources

- WATT Coalition studies, summaries, and comments to regulators[30] - the WATT Coalition is the trade association for Grid Enhancing Technologies – Dynamic Line Ratings, Advanced Power Flow Control, and Topology Optimization.
- Canary Media article on Dynamic Line Ratings[31] (July 2022)
- Idaho National Laboratory Guide to Case Studies of Grid Enhancing Technologies[32] (October 2022)

27 Implementation of Dynamic Line Ratings, Docket No. AD22-5-000, 178 FERC ¶ 61,110 (2022), available at: https://www.ferc.gov/news-events/news/ferc-opens-inquiry-use-dynamic-line-ratings-promote-grid-efficiency.

28 Motion for Leave to Comment and Comments of PJM Interconnection, L.L.C, Implementation of Dynamic Line Ratings, Docket AD22-5-000, May 2022, https://www.pjm.com/-/media/documents/ferc/filings/2022/20220509-ad22-5-000.ashx.

29 Implementation of Dynamic Line Ratings, Docket No. RM24-6-000, 187 FERC ¶ 61,201 (2024), available at: https://www.ferc.gov/media/e-1-rm24-6-000.

30 Watt Coalition, "Resources," access October 2024, https://watt-transmission.org/resources-2/.

31 Jeff St. John, "How to move more power with the transmission lines we already have," Canary Media, July 2022, https://www.canarymedia.com/articles/transmission/how-to-move-more-power-with-the-transmission-lines-we-already-have.

32 Idaho National Laboratory, "A Guide to Case Studies of Grid Enhancing Technologies," October 2022, https://inl.gov/content/uploads/2023/03/A-Guide-to-Case-Studies-for-Grid-Enhancing-Technologies.pdf.

Unlock Power by Reshaping the Grid: Topology Optimization

Topology Optimization is a Grid Enhancing Technology (GET)

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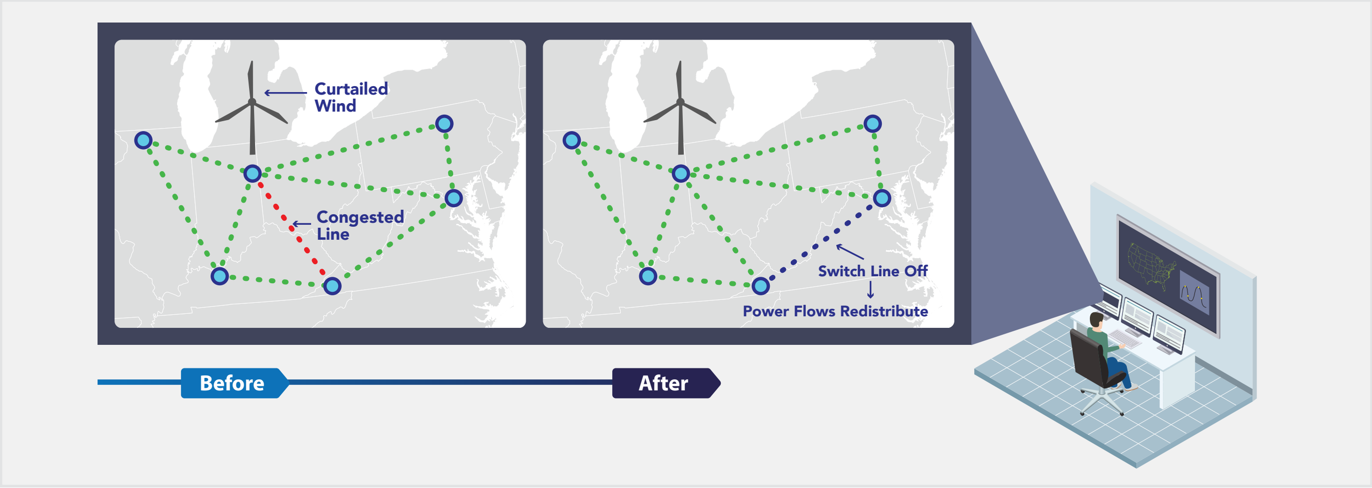
Traditional transmission upgrades take years to build – GETs can be deployed in months.

Flexibility and Awareness
GETs give operators new tools for managing reliability by measuring and unlocking the grid's dynamic capabilities.

What is Topology Optimization Software?

Topology Optimization is like the grid's navigation app: when there's too much traffic on one power line, the software can find alternative, reliable routes for the power. The laws of physics are simple, but the electric grid is complicated. Topology Optimization software combines available power sources, where power is needed, and the status of grid infrastructure to evaluate the best use of the network based on available switches to reroute power around bottlenecks. Often, those changes have unintuitive effects and this sophisticated software allows grid operators to identify and test reconfigurations quickly.



Topology Optimization is a Proven Technology

Grid operators manage reconfigurations in the form of scheduled and unplanned line outages on a daily basis. Sometimes grid operators develop "Remedial Action Plans" and "Operating Guides" that include reconfigurations to address specific scenarios. However, operators and planners usually don't systematically look at reconfigurations to reduce system costs because it has been too time-consuming and difficult. Topology Optimization software allows grid operators to quickly and automatically identify reliable and cost-effective reconfigurations.

In 2011, the U.S. Department of Energy's Advanced Research Projects Agency funded the development of Topology Optimization software. Since then, the Electric Reliability Council of Texas (ERCOT),[33] the New England Independent System Operator,[34] and the Southwest Power Pool (SPP)[35] have all implemented the software for select reliability applications. In the Midcontinent Independent System Operator (MISO) footprint, grid users are allowed to propose reconfigurations that show net system benefits.[36] These reconfigurations usually lead to better delivery of low-cost renewable power, supporting climate goals.

Topology Optimization Saves Money

- Across the PJM Interconnection, Topology Optimization could reduce congestion costs by 30-50%.[37] This potentially represents over $1 billion in yearly wholesale power savings.
- One reconfiguration saved more than $1 million per week[38] in MISO, and reduced wind curtailment by 86%. Topology Optimization in Alliant Energy's service area in Iowa reduced grid congestion costs borne by customers by 49%,[39] saving them $24 million in wholesale power costs over two years.
- In almost half the high-wind hours,[40] a transmission constraint in Evergy's territory in Kansas and Missouri was blocking power delivery. Topology Optimization identified a reconfiguration that eliminated the constraint. With full deployment, Topology Optimization could reduce congestion costs by about 85% for Evergy customers.

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33 1. Pablo Ruiz, Jay Caspary, Luke Butler, "Transmission Topology Optimization Case Studies in SPP and ERCOT," NewGrid and The Brattle Group, Southwest Power Pool, and ERCOT, prepared for Technical Conference on Increasing Day-Ahead and Real-Time Market Efficiency and Enhancing Resilience through Improved Software, Docket No. AD10-12-011, June 2020, https://www.ferc.gov/sites/default/files/2020-06/W3-1_Ruiz_et_al.pdf.

34 Massachusetts Clean Energy Center, "Grid Modernization and Infrastructure Planning," accessed September 2024, https://www.masscec.com/grid-modernization-and-infrastructure-planning.

35 See "Transmission Topology Optimization Case Studies in SPP and ERCOT."

36 WATT Coalition, "MISO Grid Optimization Process Will Reduce Congestion Costs, Improve Reliability and Renewable Delivery," July 2023, https://watt-transmission.org/miso-grid-optimization-process-will-reduce-congestion-costs-improve-reliability-and-renewable-delivery/.

37 Pablo Ruiz et al, "Transmission Topology Optimization Simulation Impacts in PJM Day-Ahead Markets," NewGrid, prepared for Technical Conference on Increasing Market Efficiency Through Improved Software, Docket No. AD10-12-007, June 2016, https://cms.ferc.gov/sites/default/files/2020-05/20160629114654-2%2520-%2520PRuiz%2520FERCTechConf%252028Jun2016_FINAL_2.pdf.

38 Pablo Ruiz, Mitch Myhre, "Congestion Mitigation with Transmission Reconfigurations," NewGrid, Alliant Energy, March 2024, https://newgridinc.com/wp-content/uploads/2024/03/NewGrid_Congestion-Mitigation-with-Reconfigurations_OMS-MWG-TWG_20240311_FINAL_website.pdf.

39 Id.

40 Pablo Ruiz and Derek Brown, "Reliable and Efficient Congestion Mitigation Using Transmission Reconfigurations," NewGrid and Evergy, presentation, October 2022, https://www.spp.org/Documents/67968/SAG%20Meeting%20Materials%2020221007.zip.

- Two constraints in SPP cost $25 million per year[41] and affected market outcomes in 16% of hours. Reconfigurations resolved the constraints.

Topology Optimization Supports Reliability

- During Winter Storm Elliot (December 23-24, 2022) SPP used two transmission reconfigurations to release 845 MW[42] of transmission-constrained generation – delivering 14 gigawatt-hours of power at critical times. Two other reconfigurations could have released an additional 600 MW, but were not implemented.
- An important 345 kV transmission line was out of service over 7 months in MISO in 2021 as the line was being upgraded. A reconfiguration allowed 56% more power[43] throughput during the outage, mitigating congestion costs and risk.
- SPP used Topology Optimization to address reliability risks that could have led to customers losing power.[44]

Other Resources

- See more examples of Topology Optimization.[45]
- WATT Coalition studies, summaries, and comments to regulators[46] - the WATT Coalition is the trade association for Grid Enhancing Technologies – Dynamic Line Ratings, Advanced Power Flow Control, and Topology Optimization.

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41 Southwest Power Pool Market Monitoring Unit, "State of the Market 2019," May 2020 https://www.spp.org/documents/62150/2019%20annual%20state%20of%20the%20market%20report.pdf.

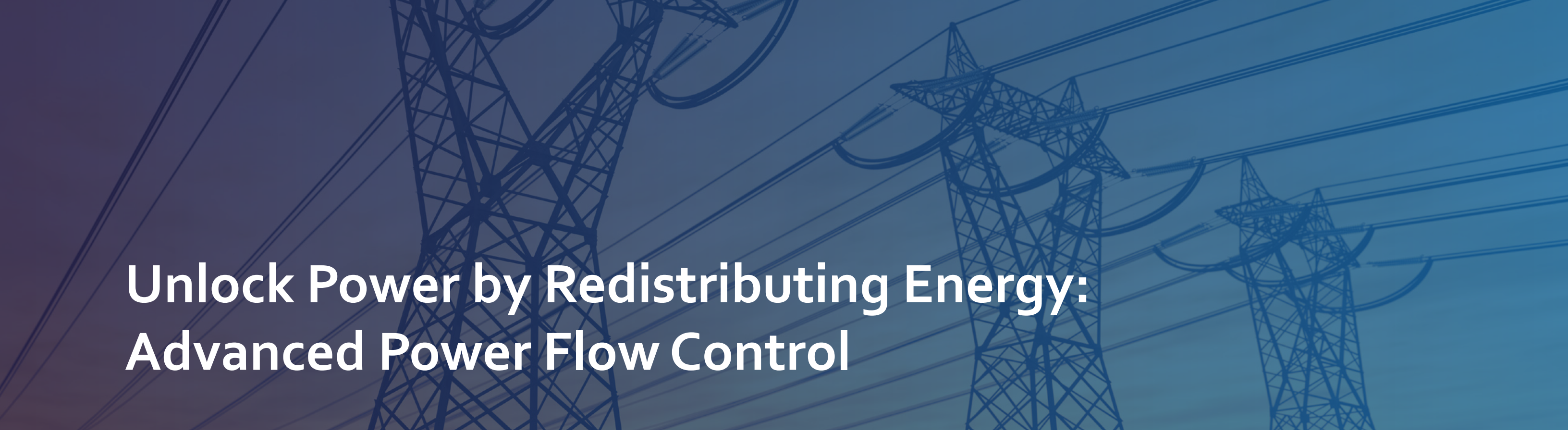
42 Pablo Ruiz and German Lorenzon, "Topology Optimization for Least-Cost and Reliable Congestion Mitigation," NewGrid and The Brattle Group, prepared for FERC Technical Conference on Increasing Market and Planning Efficiency through Improved Software, Docket AD10-12-014, June 2023, https://www.ferc.gov/media/pablo-ruiz-newgrid-somerville-ma.

43 Pablo Ruiz, Paola Caro Ochoa, Mitchell Myhre, Rodica Donaldson, Xiaoguang Li, "Congestion and Overload Mitigation with Transmission Reconfigurations Experience in MISO and SPP," NewGrid and the Brattle Group, Alliant Energy, EDF Renewables, prepared for FERC Technical Conference on Increasing Market and Planning Efficiency through Improved Software (Docket No. AD10-12-013 Increasing Market and Planning Efficiency through Improved Software, Docket No. AD10-12-013, June 2022, https://www.ferc.gov/media/congestion-and-overload-mitigation-using-optimal-transmission-reconfigurations-experience.

44 Pablo A. Ruiz, Doug Bowman, Kathryn Dial, Xiao Li, Ryan Schoppe, Zachary Sharp, Jason Terhune, Bruce Tsuchida, "Transmission Topology Optimization," NewGrid, The Brattle Group, Southwest Power Pool, prepared for FERC Technical Conference on Increasing Market and Planning Efficiency and Enhancing Resilience through Improved Software, Docket No. AD10-12-009, https://www.ferc.gov/sites/default/files/2020-08/T4-2_Ruiz.pdf.

45 NewGrid, "Topology Optimization Case Studies,"May 2024, https://newgridinc.com/wp-content/uploads/2024/05/topology-optimization-case-studies.pdf.

46 See "Resources."



Unlock Power by Redistributing Energy: Advanced Power Flow Control

Advanced Power Flow Control is a Grid Enhancing Technology (GET)

Advanced Power Flow Control offers:

Cost Savings
Grid constraints cost the U.S. billions of dollars every year and delay low-cost generation – GETs pay for themselves in less than a year.

Fast Upgrades
Traditional transmission upgrades take years to build – GETs can be deployed in months.

Flexibility and Awareness
GETs give operators new tools for managing reliability by measuring and unlocking the grid's dynamic capabilities.

How Does Power Flow Across The Grid?

The grid is a meshed network, with lines crisscrossing the country, loading and unloading power at substations. Power flows along the path of least resistance through this network, with generation and demand creating a push-and-pull effect.

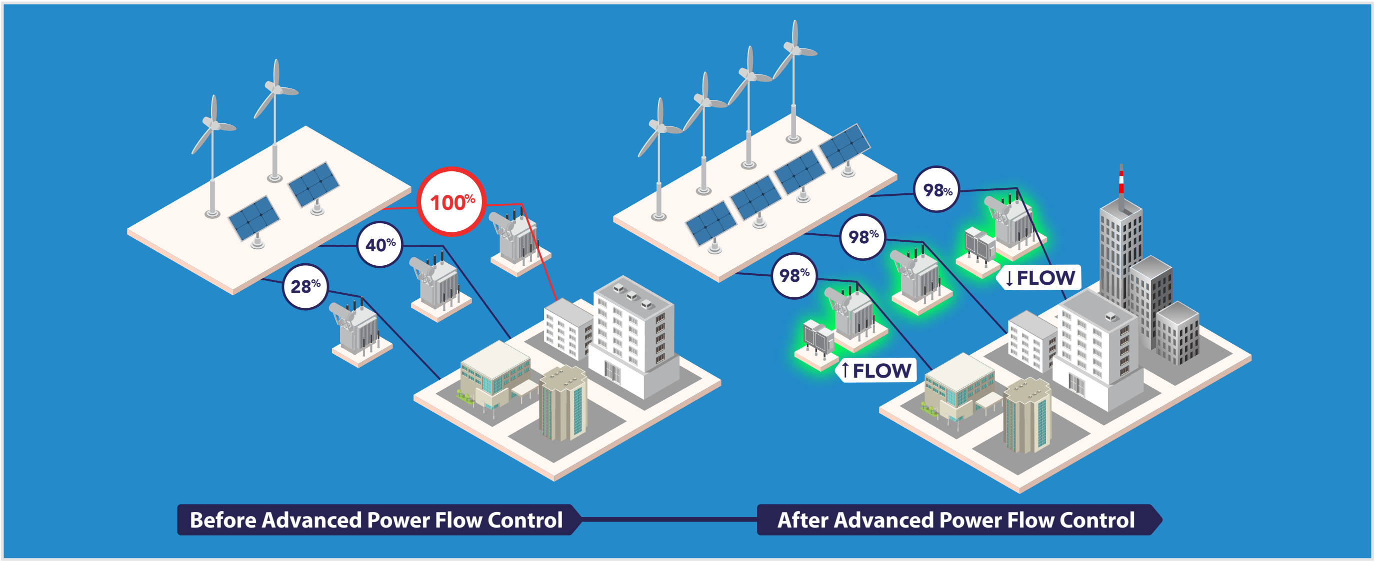
Power flow control technologies have been available for decades, but traditional solutions are large and expensive. **Advanced Power Flow Control** (APFC) devices are smaller, modular, and can be scaled or redeployed as needed. They automatically or manually adjust the impedance, or total resistance, of a power pathway. They are located at substations, where power is spread over multiple circuits. APFC not only unlocks additional capacity, but improves grid stability by controlling voltage. APFC was first commercially deployed in 2016.

Advanced Power Flow Control Saves Money

- Australia:[47] APFC technology is expected to deliver net benefits of up to $180 million to electricity customers by allowing an additional 170 MW of power to be transferred into New South Wales.
- Colombia:[48] Mitigating an outage with APFC saved more than $70 million over a 3.5-year outage period. Avoiding redispatch saved an estimated $20.5+ million a year, while the annual costs of APFC devices were only an estimated $1.5-4 million.

47 See "Transgrid: VNI Upgrade."

48 See "Building a Better Grid: How Grid-Enhancing Technologies Complement Transmission Buildouts."



Advanced Power Flow Control Improves Reliability

- Vermont:[49] Vermont Electric Power Company received a recent grant from the U.S. Department of Energy (DOE) to install APFC to increase transfer capacity across regional borders and increase the useful life of other transmission assets.
- Illinois and Texas:[50] Algonquin Power Fund America, also supported by a DOE grant, will use APFC to improve grid stability and increase renewable energy delivery.

Advanced Power Flow Control Enables Cleaner Power

- Colombia:[51] ISA TRANSELCA deployed APFC across two 220 kV circuits to push power off overloaded lines in outage conditions, unlocking 300 MW of capacity for renewable energy resources to be reliably connected to the grid from 2023 onward. Alternate network options that were evaluated for this project were more costly, took longer to install, were disruptive to communities and didn't provide flexibility to be quickly adapted over time to meet the changing needs of the grid.
- England:[52] National Grid Electricity Transmission is using Smart Wires' APFC on five 275 kV lines and 400 circuits to solve grid congestion and unlock over 2 GW of capacity across multiple boundaries in Northern England. This accelerates the integration of new wind power in Scotland by providing capacity faster than the alternatives considered, and provides a more cost-efficient solution that can deliver over $500 million in savings in avoided curtailment costs.

Other Resources

- WATT Coalition studies, summaries, and comments to regulators[53] - the WATT Coalition is the trade association for Grid Enhancing Technologies – Dynamic Line Ratings, Advanced Power Flow Control, and Topology Optimization.

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49 U.S. Department of Energy Grid Deployment Office, "Fact Sheet: Grid Resilience and Innovation Partnerships Program," October 2023, https://www.energy.gov/sites/default/files/2023-10/DOE-GRIP-Electric-Power-Research-Institute.pdf.

50 Id.

51 SmartWires, "ISA TRANSLECA: Co-Cost Project," accessed September 2024, https://www.smartwires.com/2023/10/24/co-cost-project-resolving-congestion-to-support-reliable-connection-of-renewables-in-la-guajira/.

52 SmartWires, "National Grid: Northern England Projects," accessed September 2024, https://www.smartwires.com/2024/04/02/national-grid-northern-england-projects/.

53 See, "Resources."

Understanding the Benefits of Grid Enhancing Technologies: Resources Demonstrating the System and Consumer Value of GETs

Grid Enhancing Technologies (GETs)

- **Dynamic Line Ratings** (DLR) measure and calculate the true carrying capacity of transmission lines.
- **Advanced Power Flow Control** (APFC) redirects power from overloaded to underutilized circuits.
- **Topology Optimization** is software that finds ideal grid configurations to avoid constraints.

These Benefits of GETs are Illustrated in Research Listed Below:

Cost Savings
Grid constraints cost the U.S. billions of dollars every year and delay low-cost generation – GETs pay for themselves in less than a year.

Fast Upgrades
Traditional transmission upgrades take years to build – GETs can be deployed in months.

Flexibility and Awareness
GETs give operators new tools for managing reliability by measuring and unlocking the grid's dynamic capabilities.

The Brattle Group: Unlocking the Queue With Grid-Enhancing Technologies[54] (February 2021)

T. Bruce Tsuchida, Stephanie Ross, and Adam Bigelow, The Brattle Group

The Brattle Group investigated the potential for GETs to unlock additional capacity in SPP and interconnect new generation to the grid. They found that GET deployment could:

- **Double the amount of interconnection for wind and solar generation** over the next five years, from 2,580 MW to 5,250 MW.
- **Pay for itself after 6 months of full operation,** saving $175 million in annual production costs, less the initial $90 million one-time installation costs.
- **Create additional positive environmental and economic effects**, by both reducing emissions and creating jobs in the region.

54 See, "Unlocking the Queue with Grid-Enhancing Technologies."

RMI: GETting Interconnected in PJM[55] (February 2024)

Katie Mulvaney, Katie Siegner, Chaz Teplin, Sarah Toth

RMI analysis shows that GETs can increase the speed and scale of new entry from PJM's queue in three key ways:

- **GETs could enable 6 GW of new renewable generation to interconnect by 2027**, across solar, wind, and storage projects.
- **GETs could save $500 million+ in interconnection costs for** the 6 GW of generation studied, as they are cheaper than traditional line upgrades.
- **Generation interconnected with GETs would save over $1 billion every year in wholesale energy costs** by 2030.

Idaho National Laboratory (INL): Assessing the Value of Grid Enhancing Technologies: Modeling, Analysis, and Business Justification[56] (June 2023)

Jake Gentle, Alex Abboud, Megan Culler, Chris Sticht, and Telos Energy - Sean Morash, Andrew Siler, Leonard Kapiloff, Derek Stenclik, Matthew Richwine

INL studied a key offshore wind interconnection point in southeastern Massachusetts, modeled under a 2030 resource mix with over 50% renewable energy.

INL found that Dynamic Line Ratings and Advanced Power Flow Control deployments would:

1. **Pay for themselves** in less than a year.
2. **Support reliability** and reduce production costs.
3. **Reduce renewable curtailment** at the interconnection point by >50%.

The Brattle Group: Building a Better Grid: How Grid-Enhancing Technologies Complement Transmission Buildouts[57] (April 2023)

T. Bruce Tsuchida, Linquan Bai, and Jadon M. Grove, The Brattle Group

Brattle collected case studies of GETs deployment and analyzed modeled impacts in the Southwest Power Pool to assess how GETs support transmission expansion.

- **Before building new lines, GETs can increase transfer capacity on existing infrastructure by up to 40%,** reducing the impact of the constraints in the near term.
- **During construction of new lines, GETs can mitigate construction-related outages** by increasing capacity and rerouting power to minimize costs and disruptions.
- **After new lines are in service, GETs can increase the utilization of a line by 15-22%,** increasing the infrastructure's cost-benefit ratio and supporting efficient planning decisions.

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55 See, "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue."

56 Jake Gentle, Sean Morash, Ken Donohoo, "Assessing the Value of Grid Enhancing Technologies: Modeling, Analysis, and Business Justification," Idaho National Laboratory, Telos Energy, Energy Systems Integration Group, June 2023, https://www.esig.energy/event/webinar-assessing-the-value-of-grid-enhancing-technologies-modeling-analysis-and-business-justification/.

57 See, "Building a Better Grid: How Grid-Enhancing Technologies Complement Transmission Buildouts."

Idaho National Laboratory: A Guide to Case Studies for Grid Enhancing Technologies[58] (October 2022)

INL studied the impact of 28 GET deployments and studies. They found that GET deployments rapidly pay for themselves and save money by:

1. Reducing the cost of transmission infrastructure
2. Reducing transmission congestion and generator curtailment

U.S. Department of Energy: Grid Enhancing Technologies: A Case Study of Ratepayer Impact[59] (February 2022)

The DOE studied DLR and APFC deployments in upstate New York, finding that:

1. **Combined synergies between DLR and APFC drove a 42% reduction in renewable curtailment**, demonstrating complementary value in the two technologies when used together.
2. **GETs paid for themselves in 2 years or less,** only considering the value of enabling lower-cost generation.

According to the **AES Corporation**, which owns utilities and energy generators worldwide, "GETs are under-deployed on the U.S. power grid relative to their established technical capability." Their white paper, **Smarter Use of the Dynamic Grid**[60] describes barriers to deployment: utility and regulator awareness and understanding of the technologies, appropriate incentives and funding, example deployments and guidelines for future deployments.

These resources suggest paths for state leaders to support and expand the use of GETs:

1. A guide to Federal Funding for Advanced Transmission Technologies[61]
2. Recommended Actions for State Regulators to Unlock Transmission Capacity through the Deployment of Advanced Transmission Technologies[62]
3. Best Practices for State Legislation on Advanced Transmission Technologies[63]

For more resources, see the WATT Coalition website: www.watt-transmission.org.

58 See, "A Guide to Case Studies of Grid Enhancing Technologies."

59 U.S. Department of Energy, "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," February 2022, https://www.energy.gov/sites/default/files/2022-04/Grid%20Enhancing%20Technologies%20-%20A%20Case%20Study%20on%20Ratepayer%20Impact%20-%20February%202022%20CLEAN%20as%20of%20032322.pdf.

60 AES Corporation, "Smarter use of the dynamic grid," April 2024, https://www.aes.com/sites/aes.com/files/2024-04/Smarter-Use-of-the-Dynamic-Grid-Whitepaper.pdf.

61 AMP Coalition, WATT Coalition, "Federal Funding for Advanced Transmission Technologies," accessed October 2024, https://watt-transmission.org/wp-content/uploads/2024/08/WATT-and-AMP-Federal-Funding-for-Advanced-Transmission-Technologies.pdf.

62 AMP Coalition, WATT Coalition, "Recommended Actions for State Regulators to Unlock Transmission Capacity through the Deployment of ATTs," accessed October 2024, https://watt-transmission.org/wp-content/uploads/2024/08/WATT-and-AMP-Recommended-Priorities-for-State-Regulators-to-Unlock-Transmission-Capacity.pdf.

63 AMP Coalition, WATT Coalition, "Best Practices for State Legislation on Advanced Transmission Technologies," accessed October 2024, https://watt-transmission.org/wp-content/uploads/2024/08/WATT-and-AMP-Best-Practices-for-State-Legislation-on-ATTs.pdf.