Grid Enhancing Technologies

April 1, 2026
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The WATT Coalition est. 2017 in Washington DC

Advocates for policy that supports the wide deployment of Grid Enhancing Technologies (GETs) to accelerate the lower energy costs and enable economic growth.

- Dynamic Line Ratings
- Advanced Power Flow Control
- Transmission Topology Optimization

Generation owners/developers, investors, and utility members.

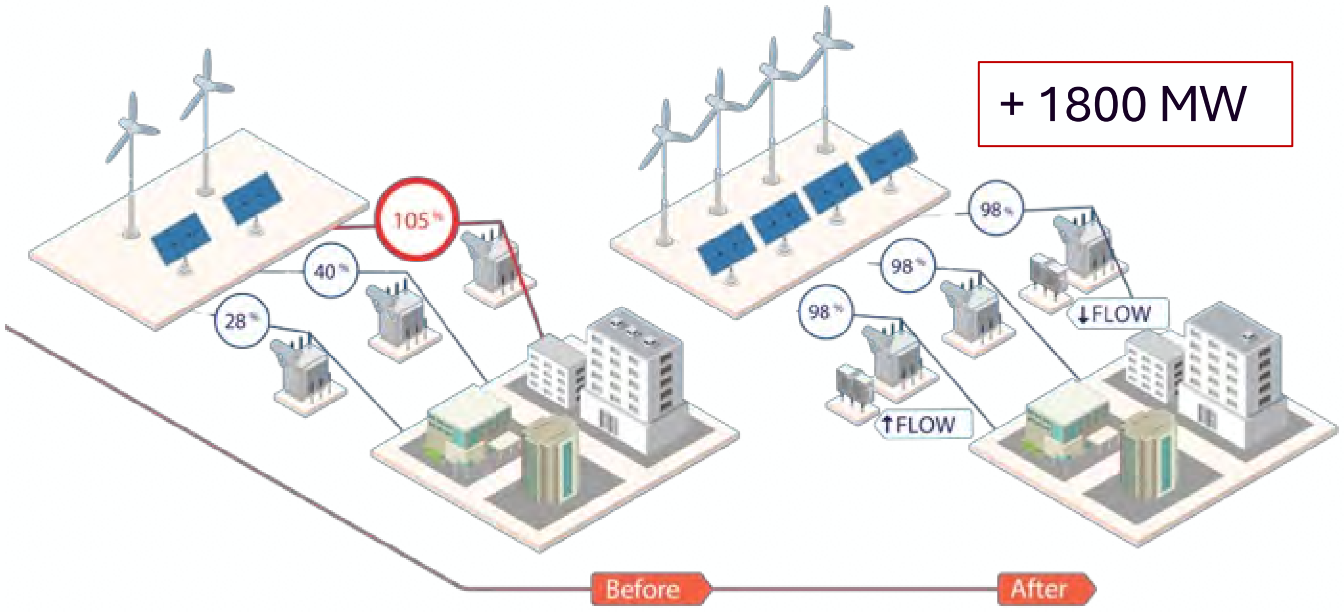
Ampacimon
SOLSYSTEMS
vermont electric power company VELCO
LINEVISION
LINDSEY
newgrid
SMARTWIRES REIMAGINE THE GRID
Heimdall Power
prisma photonics
EDF power solutions
ENGIE
HASI
Invenergy

Agenda

- What are Grid Enhancing Technologies?
  - Advanced Power Flow Control
  - Dynamic Line Ratings
  - Transmission Topology Optimization
- GETs Policy
- Looking ahead

Advanced Power Flow Control

Hardware and software used to reroute electricity from overloaded transmission lines to underutilized transmission corridors by adjusting circuit impedance



185 MW of capacity in New York

Project found capacity for new generation, despite radial grid.

APFC offered advantages over legacy solutions, such as lower cost and smaller footprint

DOE-funded deployment in Vermont

Protects a PST and increases capacity between VT and NY

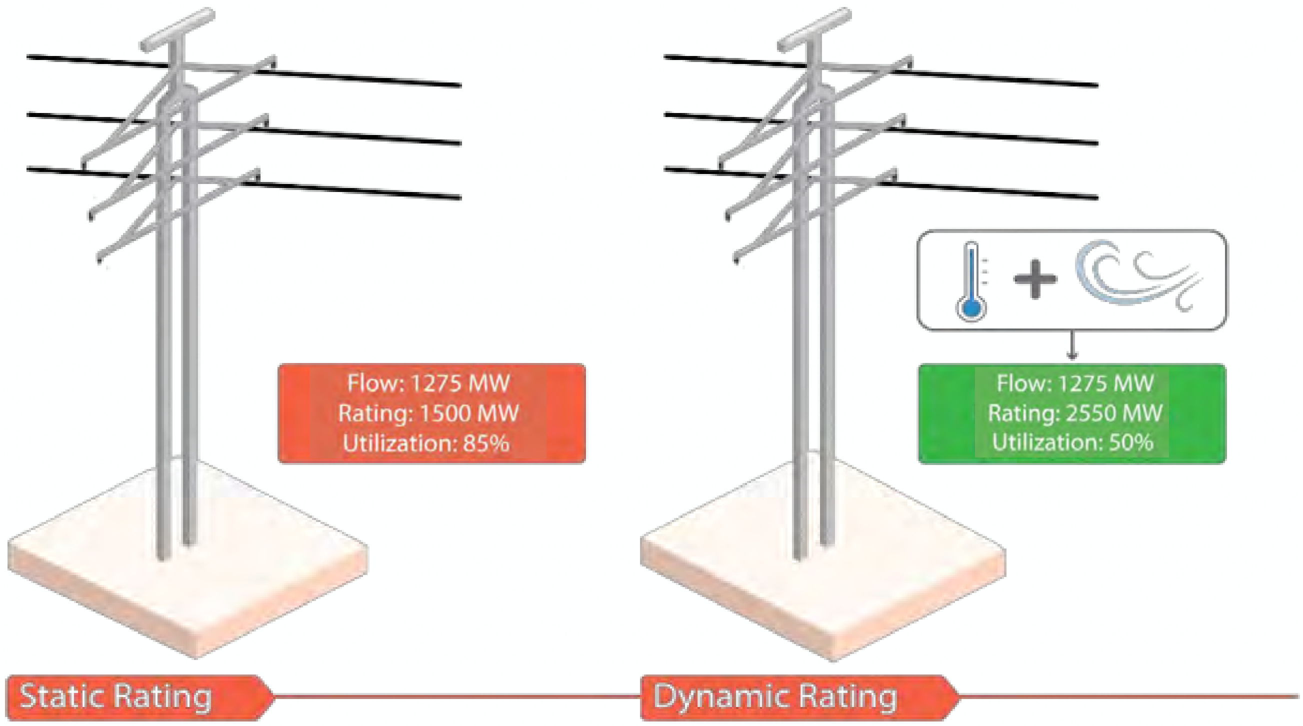
Case study examples

PG&E finds 100MW+ of capacity
Load growth and reliability applications

Georgia Power deploys 21+ modules
Another deployment planned for 2028

Dynamic Line Ratings

Hardware or software used to calculate the true capacity of transmission lines using real-time and forecasted weather conditions



Results from 2021 deployments across 3 states

DLR exceeded static reference ratings by 9-33% in winter, and 26-36% in summer

DLR exceeded static ratings over 85% of the time

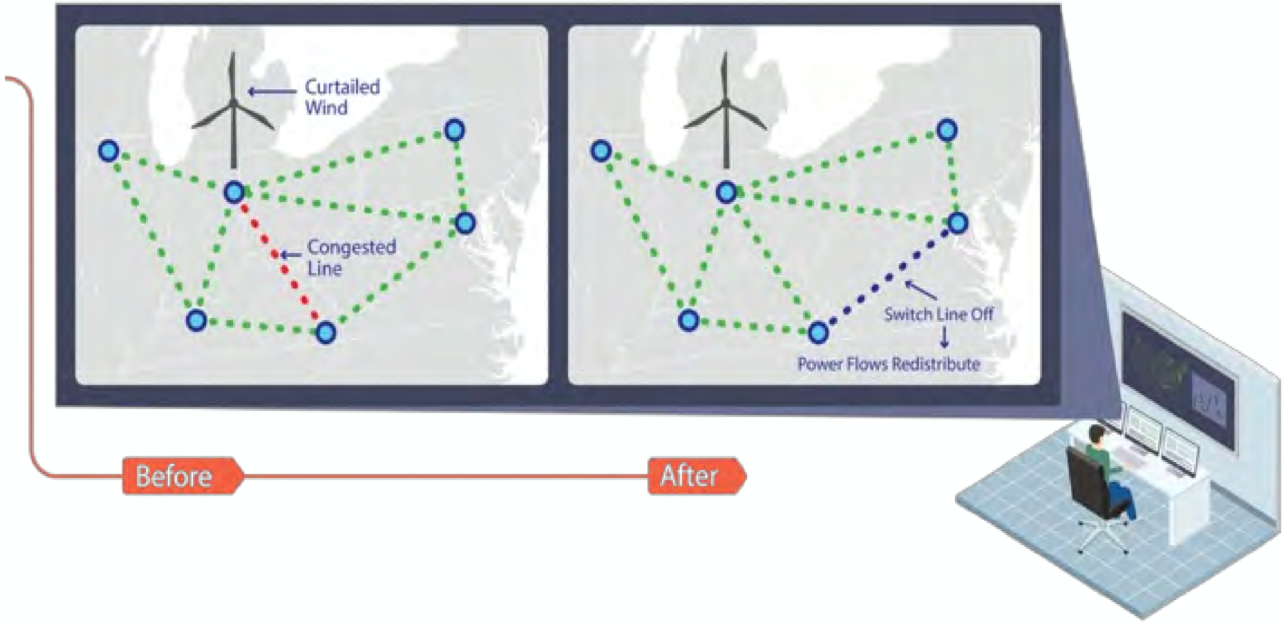
Case study examples

2022 Pennsylvania
Increased line capacity by 25% on average

2012 Belgium
Increased capacity by >20%, 90% of the time.

Transmission Topology Optimization

Technology that identifies reconfigurations of the transmission grid to most efficiently deliver power



Alliant customers saved 49% in congestion costs ($24 million) over 2 years.

Select applications in MISO, mostly for outage management, save $113M last year.

Case study examples

ISO-NE and SPP
Used for outage planning

ERCOT and SPP
Replicating MISO's process for congestion mitigation

The Brattle Group 2021: Unlocking the Queue

GETs utilized in this study include:

- **Hardware solutions**: DLR on 56 lines and Advanced Power Flow Control on 8 locations.
- **Software solutions**: 204 unique Topology Optimization reconfigurations, averaging 13 per snapshot.**

Hardware Solutions by Voltage Level	345	230	161	138	115	69	Total
DLR*	10	3	11	22	3	7	56
Advanced Power Flow Control	3	0	4	1	0	0	8

Software Solutions by Voltage Level	345	230	161	138	115	69	Total
Lines	20	10	31	75	4	30	170
Substations	4	0	1	1	0	0	6
Transformers (high voltage terminal)	10	1	4	13	0	0	28

ADDITIONAL RENEWABLES INTEGRATED

State	Base Case			With GETs Case		
	Wind	Solar	Total	Wind	Solar	Total
Kansas	1,710	0	1,710	1,910	0	1,910
Oklahoma	770	100	870	3,200	140	3,340
Total	2,480	100	2,580	5,110	140	5,250,000

X2,000

April Fools!

[Rounded to the nearest 10 MW]

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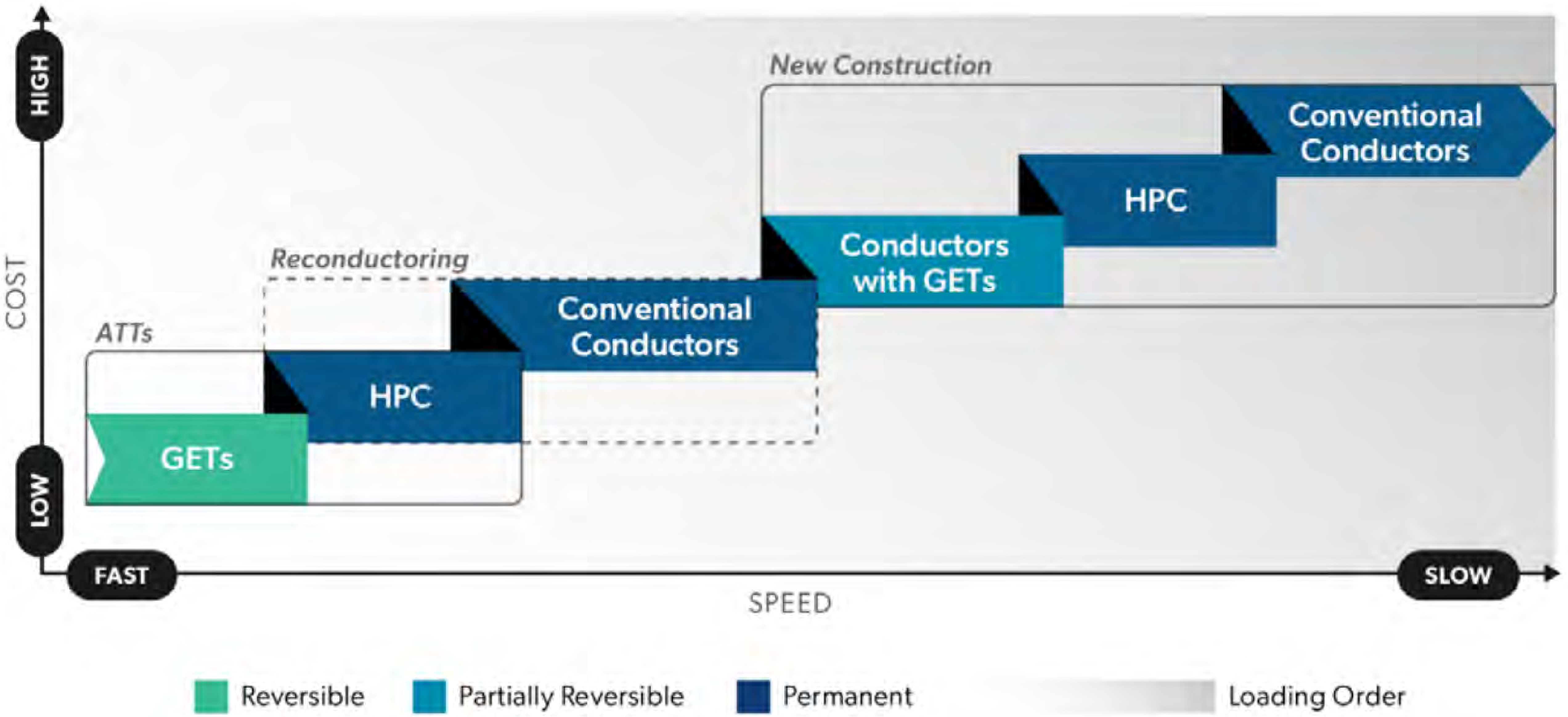
ADDITIONAL RENEWABLES INTEGRATED

State	Base Case			With GETs Case			Delta (GETs - Base)		
	Wind	Solar	Total	Wind	Solar	Total	Wind	Solar	Total
Kansas	1,710	0	1,710	1,910	0	1,910	200	0	200
Oklahoma	770	100	870	3,200	140	3,340	2,430	40	2,470
Total	2,480	100	2,580	5,110	140	5,250	2,630	40	2,670

X2

[Rounded to the nearest 10 MW]

Brattle Transmission Loading Order



Policy context

Federal Money

$1.9 BILLION in federal matching grants

Speed to Power through Accelerated Reconductoring and other Key Advanced Transmission Technology Upgrades (SPARK)

SPARK is for GETs + High Performance Conductors *ONLY*

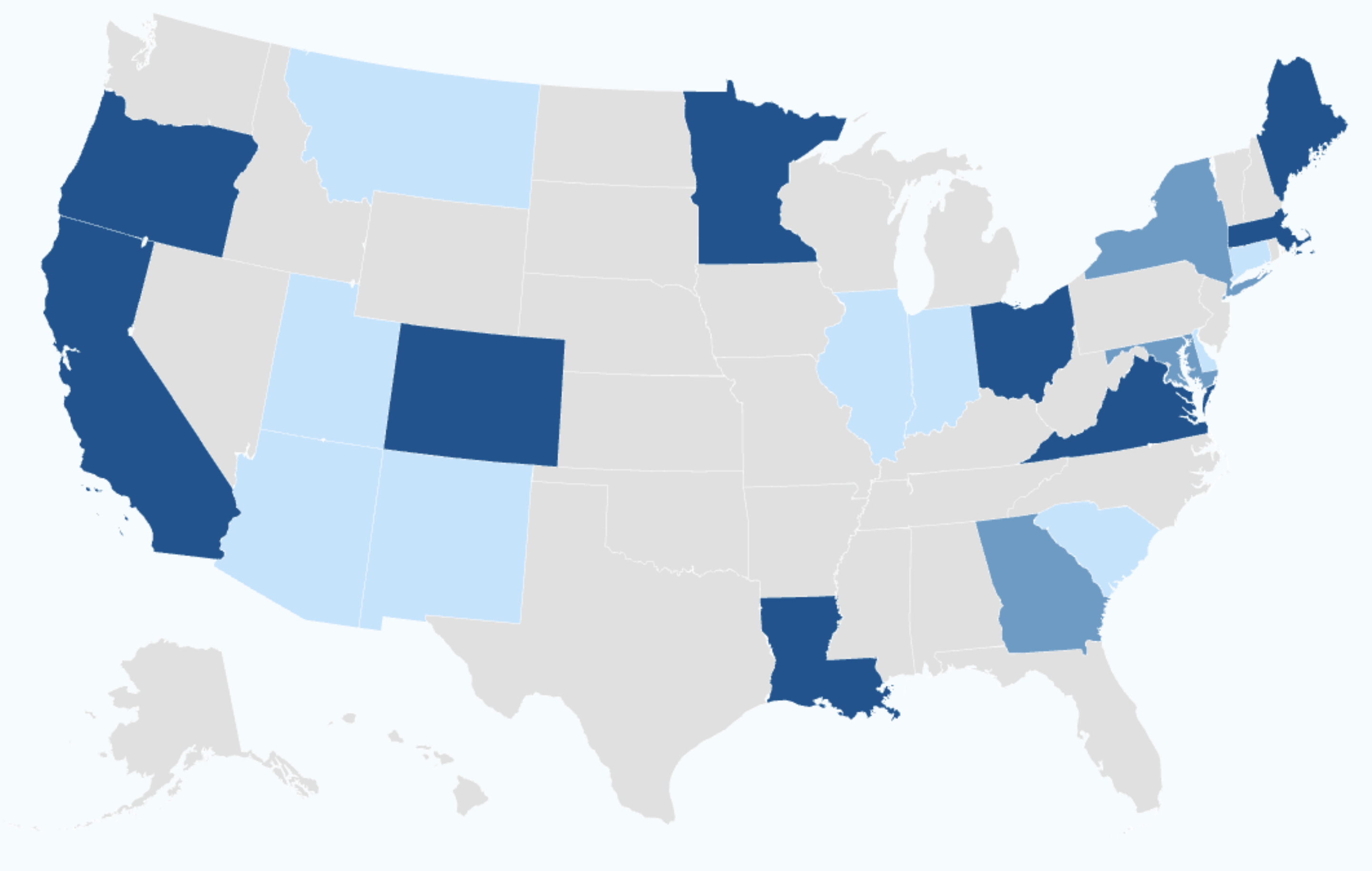
for capacity, reliability, affordability

(4-page concept papers due tomorrow)

Federal policies

Organization	Federal action	ATTs impact	Date
FERC	FPA 219(b)3	**FERC must incentivize transmission technologies**	2005
	Order No. 679	**Utilities can propose rate incentives**	Jul 2006
	Order No. 881	**RTOs prepare to accept DLR**	Dec 2021
	Order No. 2023	**APFC, TTO and HPCs in generator interconnection**	Jul 2023
	Order No. 1920	**ATTs in transmission planning**	May 2024
	DLR ANOPR	**DLR for highly congested lines**	Jun 2024

18 states that have passed ATTs laws, and implementation is underway!



- Passed ATTs laws, and has started implementation
- Has not yet passed ATTs laws, but has taken action on ATTs
- Passed ATTs laws, and has not yet started implementation

WATT COALITION

Summary:

Policymakers are looking for progress

What is holding progress back?

- Utility missing tools, experience and having to prioritize initiatives
- Incentives and responsibilities don’t focus on grid efficiency
- Communicating benefits & costs to stakeholders

Looking ahead

Easy wins

- Make sure your modeling vendors include GETs as an option
    - “My modeling software never captures grid congestion” is wearing thin as an excuse!

- Share data with vendors to identify high-value projects (there’s still time to get federal cheese!)

- Call Julia if you want a robust load growth/generator interconnection/cost savings/reliability improvement study done with someone else’s money (but your system)! 541-908-5792

Checklist – are you ready for grid modernization?

- Train field personnel on installation and maintenance of ATTs
- Build internal modeling expertise for HPCs, DLR, APFC, and TTO
- Train operators on new data streams and operational procedures
- Update EMS systems to accept DLR
- Incorporate GETs in outage mitigation workflow
- Pre-study topology reconfigurations to enable faster restoration after events.

RTO, Utility, Contractor Tutorials

- Covering DLR, APFC, TTO and HPCs
- Covering planning, operations, and IT (some training all together, some in breakout groups)
- Presented by vendors, modelers, utility contractors, potentially EPRI/ESIG/SEPA/National Labs
- Will include modeling best practices, strategies for on compliance with Orders 881, 1920 and 2023

Fall 2026

2 half days

In person at RTOs or universities

Thank you! jselker@gridstragiesllc.com

GETs can decrease congestion costs by up to 50%, at relatively low cost.

HPCs can double transmission capacity at approximately half the cost of building a new line.

GETs can increase the utilization of high-voltage 345kV lines by 15-22%.

HPCs reduce energy losses by at least 20% for Composite / Carbon Core Conductors, and up to 80% for superconductors

GETs can increase the power transfer capacity of existing transmission lines by 20%+ on average.

HPCs such as Composite / Carbon Core Conductors double transmission capacity, while superconductors can quintuple capacity.

GETs can double the capacity of new generation integrated into the existing transmission grid in months.

HPCs can use existing rights-of-ways, reducing permitting and construction times.

GETs can give operators new tools to manage reliability by unlocking the grid's dynamic capabilities.

HPCs can decrease wildfire risk by reducing line sagging compared to traditional conductors.

GETs can defer the need for construction of new transmission infrastructure.

HPCs can expand transmission capacity using existing rights-of-way.

Appendix

Topology Optimization Examples

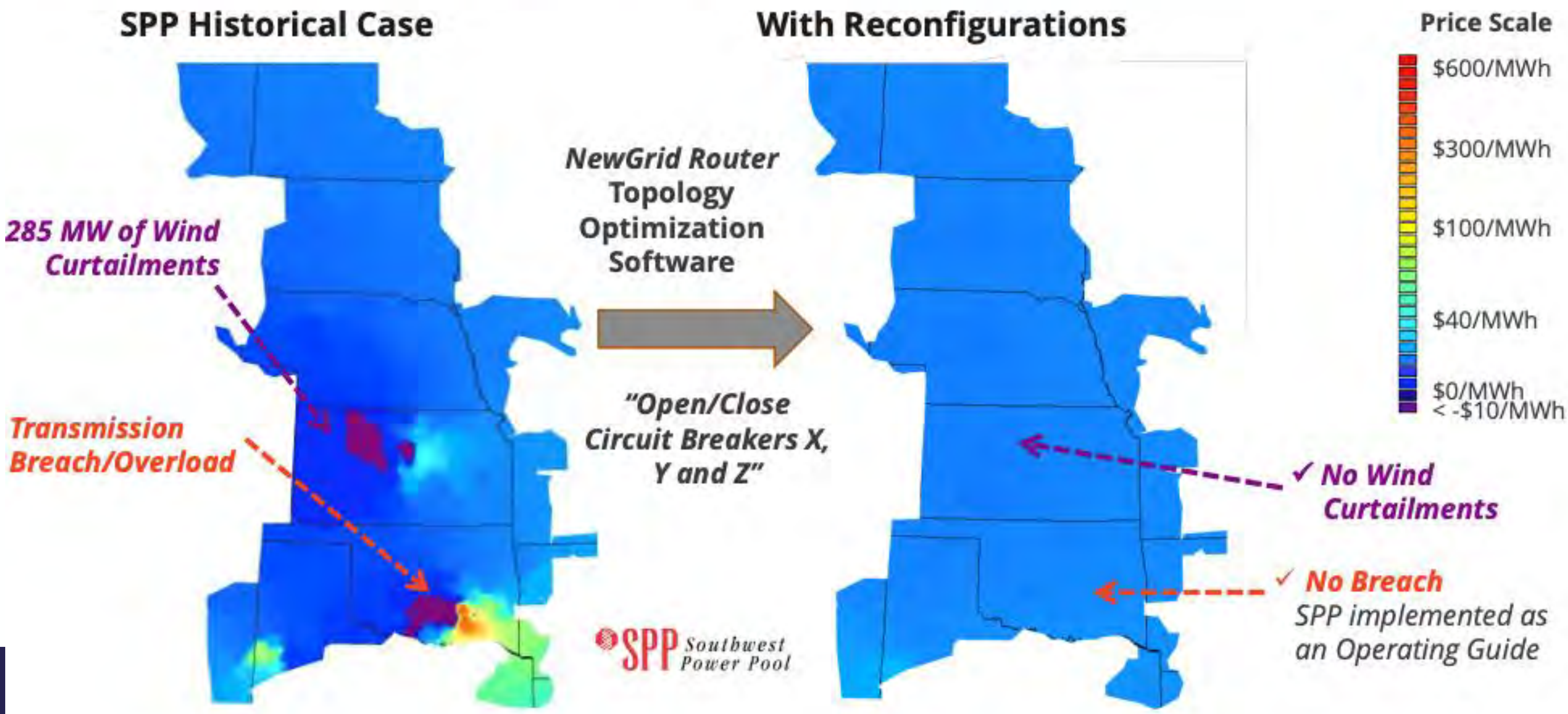
Presented at FERC and MISO

Case study from New Grid Inc.:
FERC Tech. Conf. on Increasing Market and Planning Efficiency through Improved Software (Docket No. AD10-12-013)
Washington, DC, June 23, 2022

SPP Case Study

Congestion Reduction using Reconfigurations

Reconfigurations identified by topology optimization can be a powerful complement to market redispatch for congestion management, materially reducing costs, improving reliability and mitigating curtailments

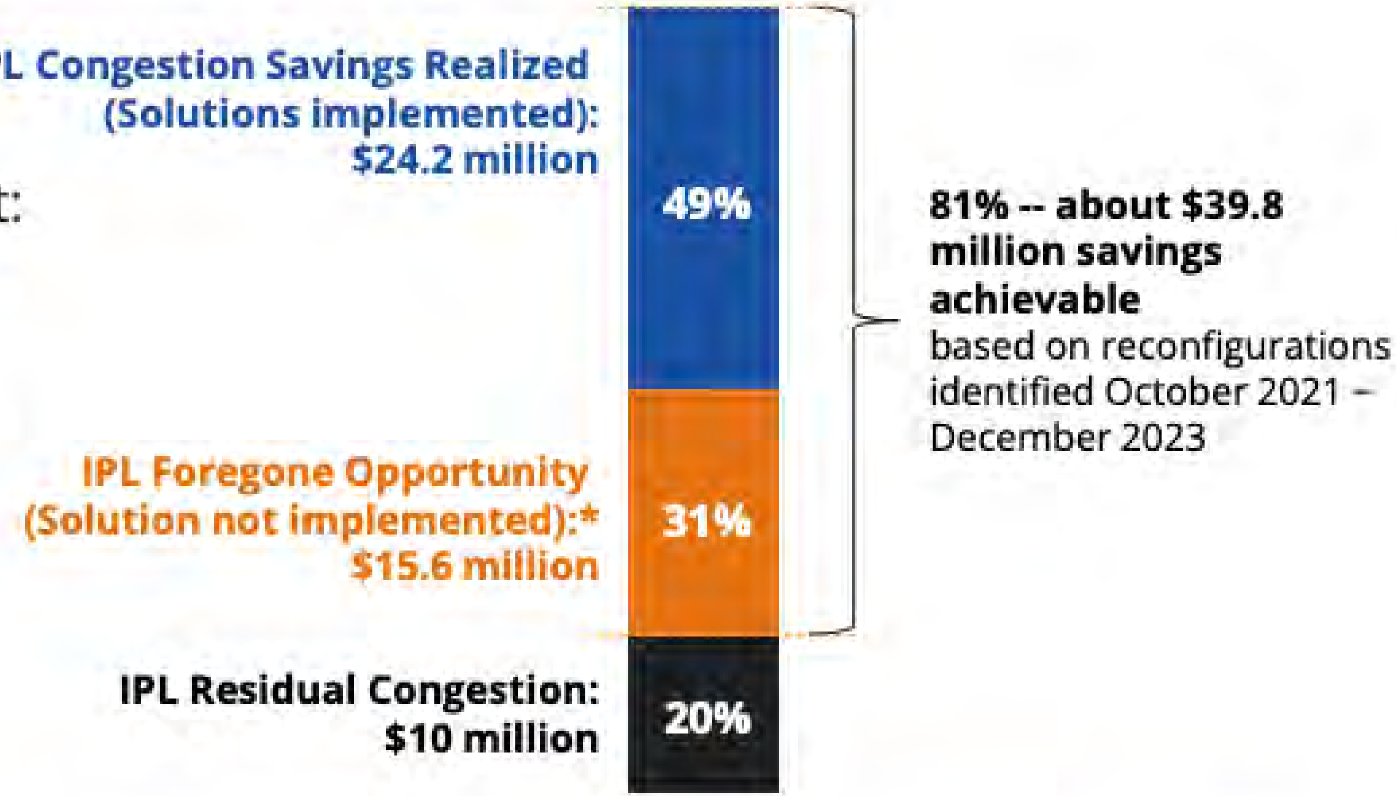


Case study from: https://newgridinc.com/our-solutions/

OVER 80% ACHIEVABLE CONGESTION COST SAVINGS

Alliant Energy

- Alliant Energy and NewGrid pilot:
  - Identify and analyze regionally beneficial reconfigurations
  - Request their implementation
  - Evaluate congestion cost mitigation for Alliant's customers.
- Looking for low-hanging fruit
  - Simple & robust solutions



How to replicate across MISO, increase the potential savings and deliver them?

Impacts calculated ex-post based on analyses of state estimator cases published by MISO and of historical market data.

* Solution not implemented includes the impacts of all solutions found, requested and that were not declined on a technical basis, as well as solutions not requested due to the lack of an established request process (prior to July 2023).

Case study from: https://newgridinc.com/our-solutions/

OVERLOAD EVENT RISK CAN BE REDUCED BY 90%

Alliant Energy

- Alliant Energy and NewGrid pilot:
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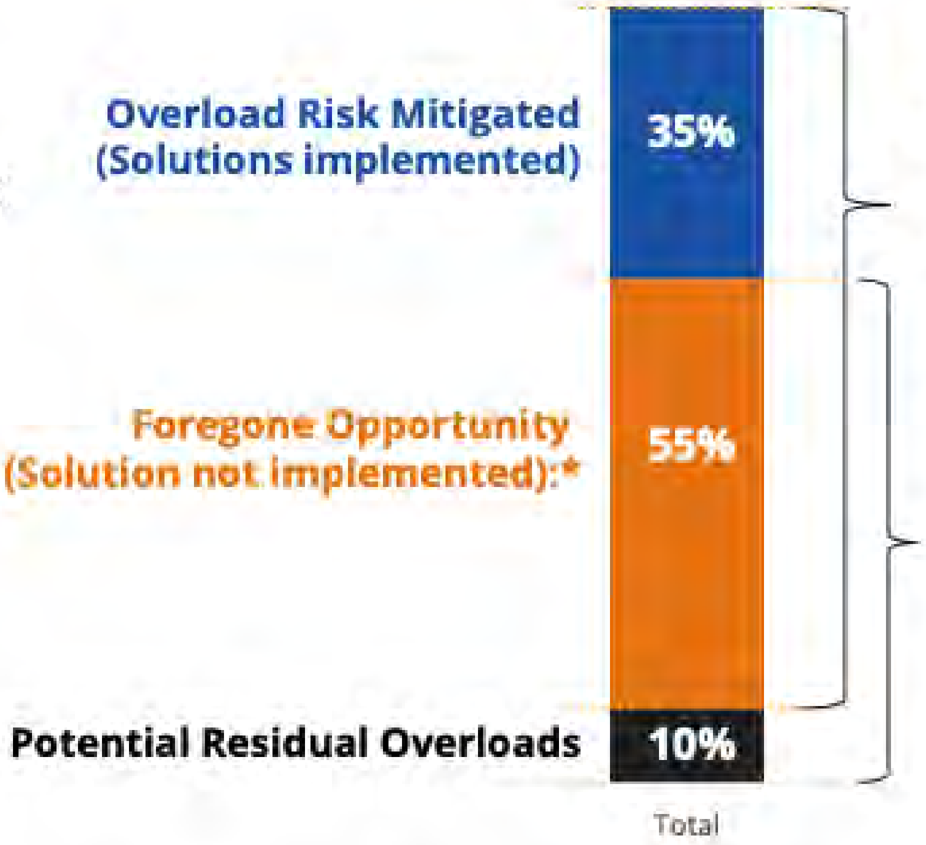


90% reduction in overload event risk – 614 constraint-hours w/ reconfiguration request process in MISO based on reconfigurations identified in January - August 2023

Realized overloads: 444 constraint-hours

Impacts calculated ex-post based on analyses of state estimator cases published by MISO and of historical market data.

* Solution not implemented includes the impacts of all solutions found, requested and that were not declined on a technical basis, as well as solutions not requested due to the lack of an established request process (prior to July 2023).

DLR Case Study from Great River Energy

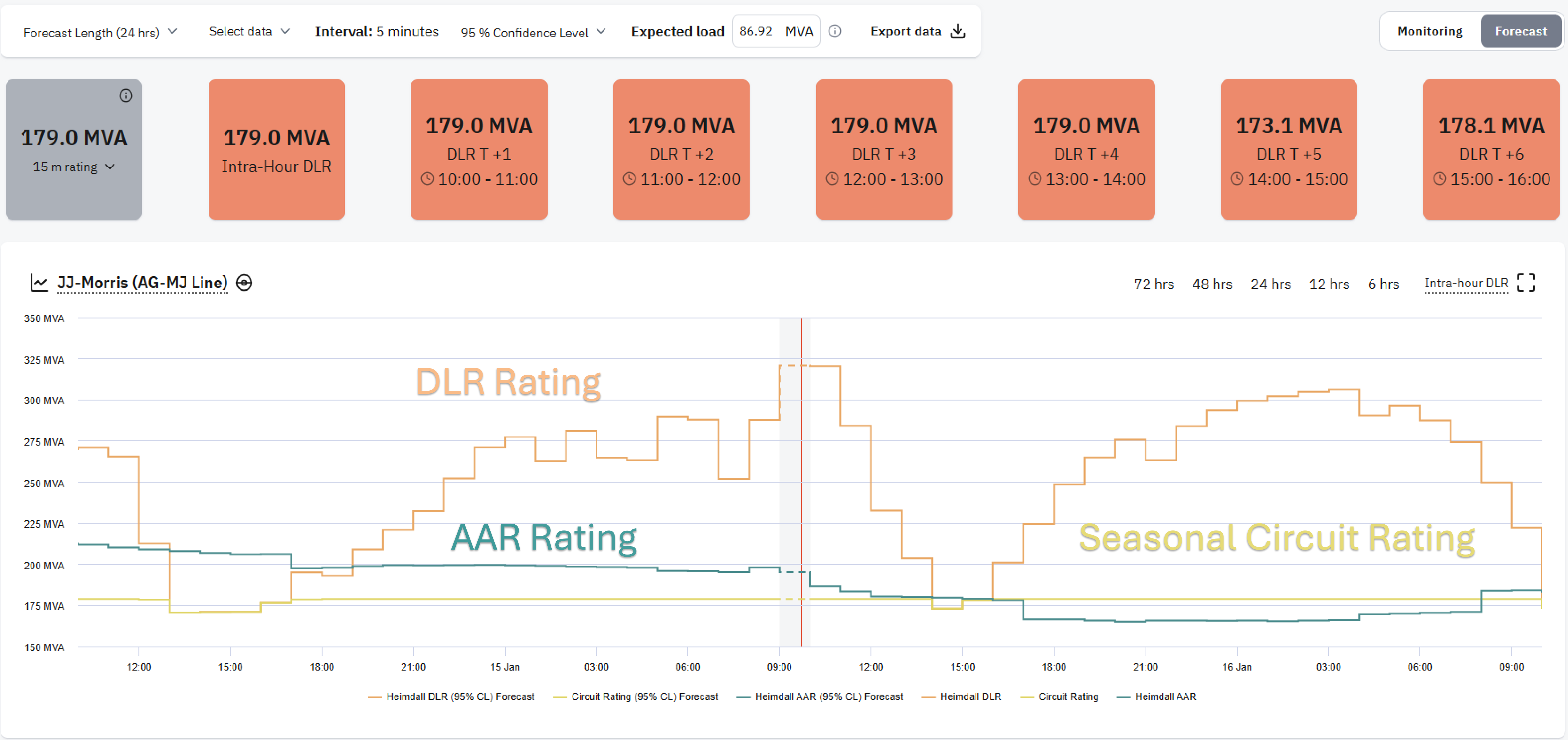
Presented at APPA 2025

Installation locations

Transmission line
Pleasant Valley – Austin
Benton – Mud Lake – Riverton
Inman - Rush Lake – Schuster
Bunker-Blaine-Linwood-Rush City
Johnson Junction – Morris (pilot)

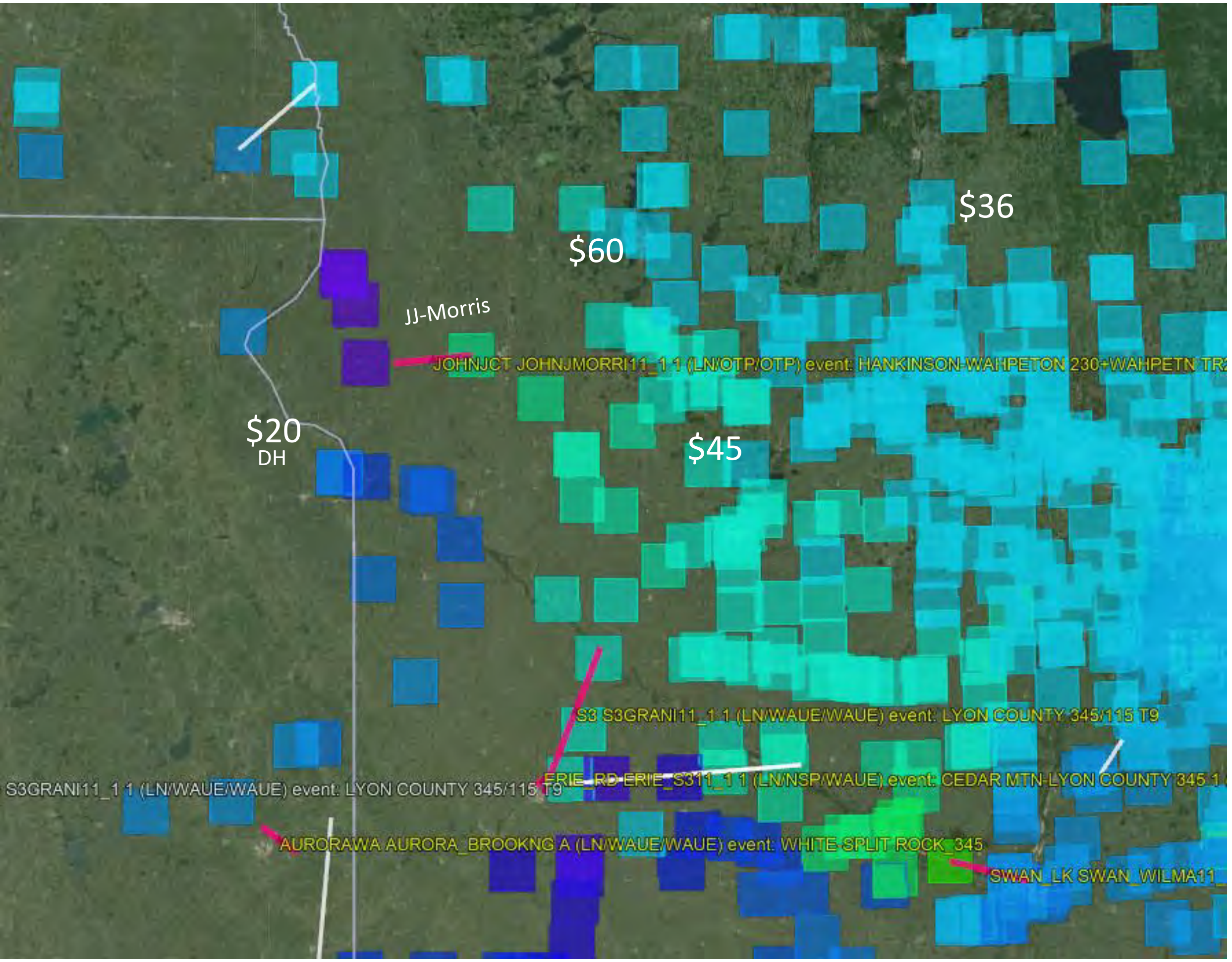
One congestion event per line estimated cost to GRE: $3.157M

Example Results

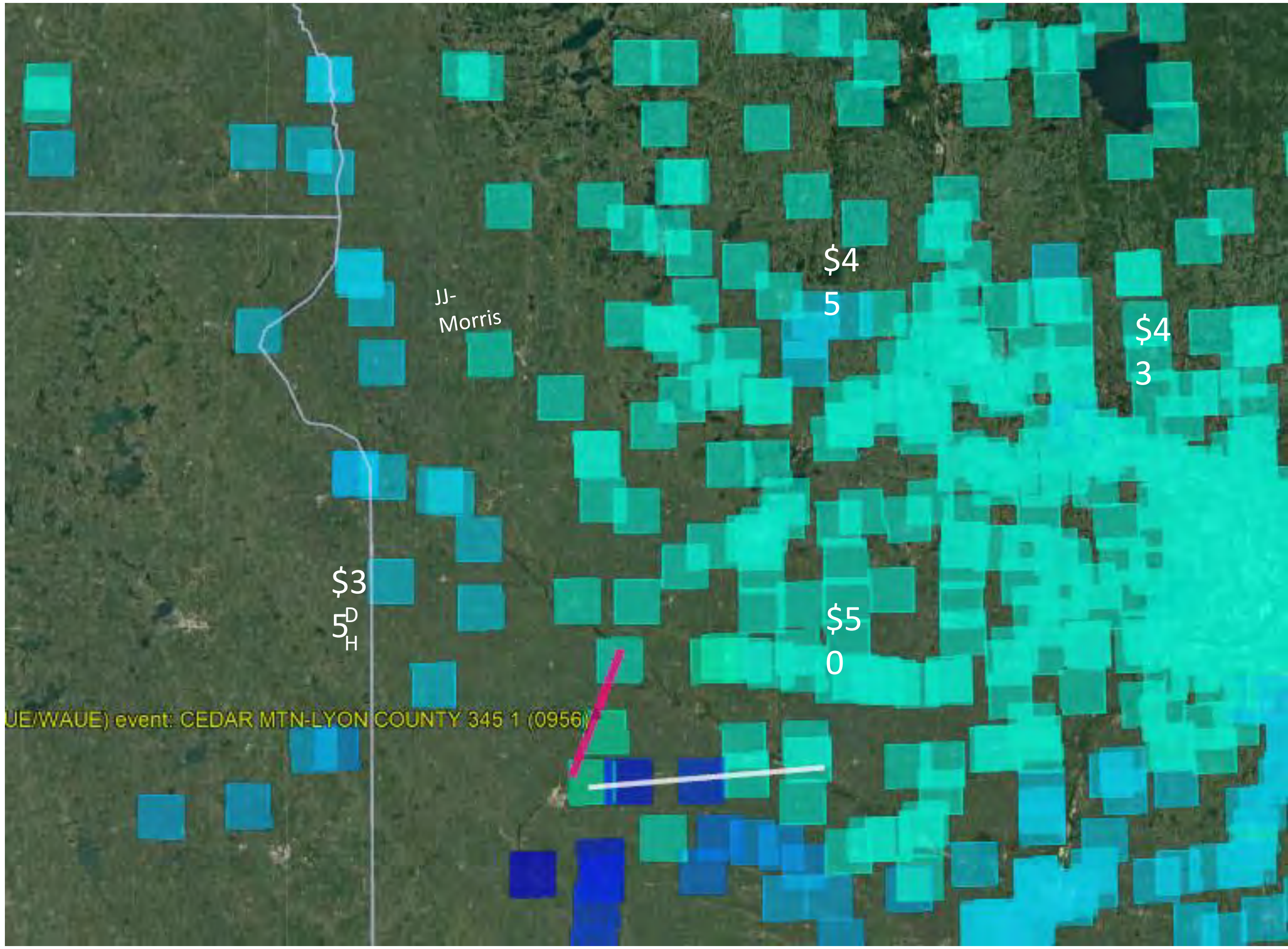


Constraint Event July 2024 <u>Friday 3 pm</u>

Day-ahead market (binding)



Real-time market (not binding)



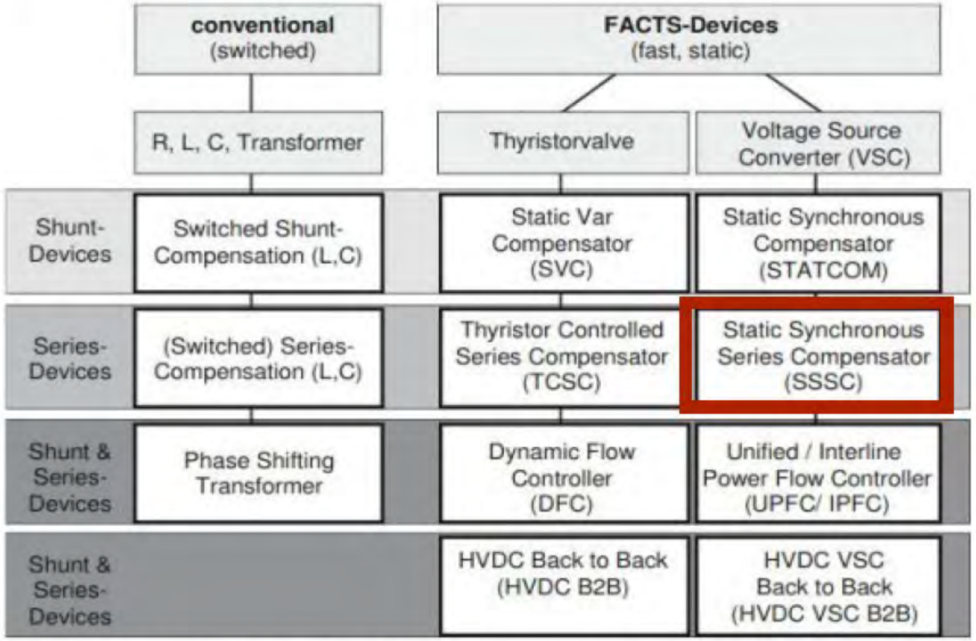
APFC Details

Flexible AC Transmission Systems (FACTS)

FACTS devices improve the security and flexibility of the existing transmission system

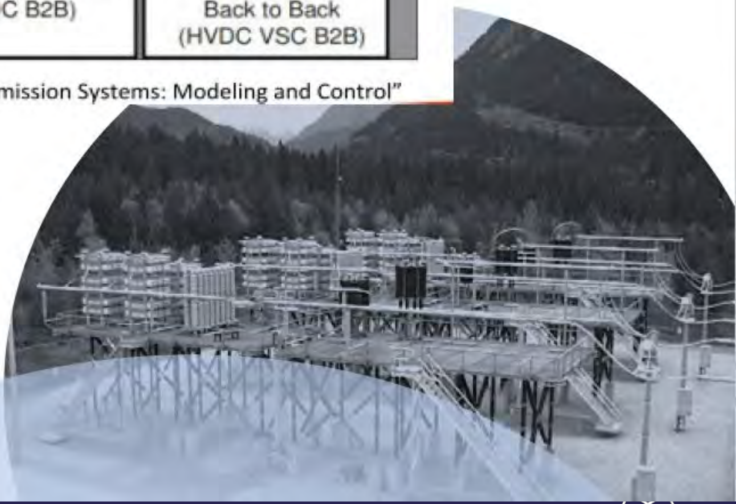
FACTS devices are typically categorized as either:

1. **Shunt-connected devices**
   1. Typically used for voltage regulation and reactive power compensation
   2. Examples: Static Var Compensator (SVC), and STATCOM
2. **Series-connected devices**
   1. Typically used for power flow control & dynamic series compensation
   2. Examples: Thyristor Controlled Series Compensator (TCSC), and Static Series Synchronous Compensator (SSSC) first employed in 1990's by AEP and NYPA

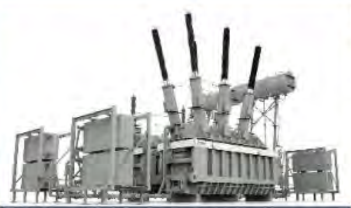


X-P Zhang, C Rehtanz, and B Pal, "Flexible AC Transmission Systems: Modeling and Control"

Traditional FACTS: Systems with custom-made components, such as Coupling Transformer, Capacitors, MOVs, Thyristors or IGBTs, Cooling Systems, Control and Protection (dedicated control building).



Power flow control (PFC) technologies

						SmartValve
	Fixed Solutions		Dynamic Solutions			
						
	Series Reactor	**Fixed Series Capacitor (FSC)**	**Phase Shifting Transformer (PST)**	**Thyristor Controlled Series Capacitor (TCSC)**	**Unified Power Flow Controller (UPFC)**	**Modular Static Synchronous Series Compensator (M-SSSC)**
Method of creating the injected voltage	Line current flows through an inductor	Line current flows through a capacitor	Harvest voltage from two phases and inject into the other phase, repeat for the other phases	Line current flows through a parallel combination of an inductor and capacitor, with the net effect (which can vary from capacitive to inductive) determined by the percentage of time the power electronic switches allow current to flow through the inductor	Harvest energy, store as DC and inject using power electronics in both shunt and series	Harvest energy, store as DC and inject in series using power electronics
Year first deployed	~1920	1928	1956	1991	1998	2016
Manufacturers	Coil Innovation | GE Hilkar | Nokian | Trench	Siemens Energy | GE Hitachi Energy | NR Electric	Siemens Energy | ABB | GE BTW | CG Power | JSHP SGB-SMIT | Tamini	Hitachi Energy Siemens Energy	NR Electric Siemens Energy (considering entry)	Smart Wires NR Electric (NR considering entry, no commercial projects)

M-SSSC advantages over competing PFC technologies

	SmartValve			
Application	Modular Static Synchronous Series Compensator (M-SSSC)	Phase Shifting Transformer (PST)	Thyristor Controlled Series Capacitor (TCSC)	Unified Power Flow Controller (UPFC)
Power flow control	●	●	●	●
Transient stability	●	●	●	●
Power Oscillation Damping	●	○	●	●
Speed of Response	●	○	◐	●
Space requirements	●	○	○	○
Controllability	●	○	◐	●
Installation flexibility	●	○	○	○
Delivery timeframe	<1 year	5 to 7 years	2 to 3 years	Unknown

SmartValve (M-SSSC) Operating Range

- The SmartValve **injects a voltage in quadrature with the line current such that it is capacitive (- Ωs) or inductive (+ Ωs)**. However, unlike physical capacitors or inductors, the injected voltage is **independent of the line current**.
- The curve shows the range of injected reactance as a function of the line current. The outer orange boundary is when the SmartValve is injecting the full output voltage
- The operating limits of each group depend on the type and number of devices installed.

For a certain line current, the maximum equivalent reactance is equal to:

$$X_{effective}^{max} = \frac{V_{injected}}{I_{min\ line}}$$

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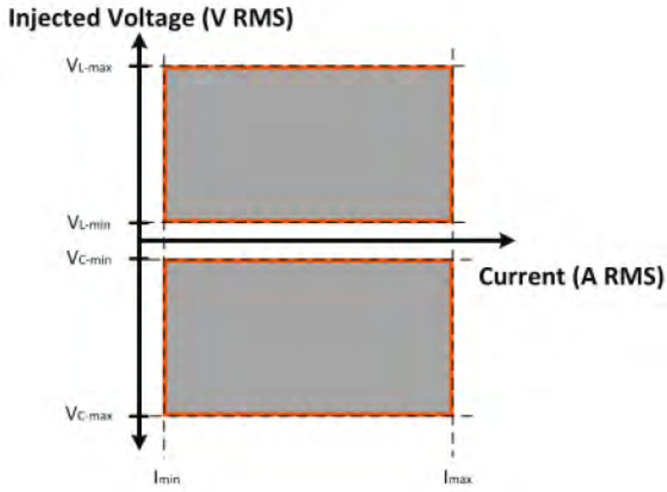
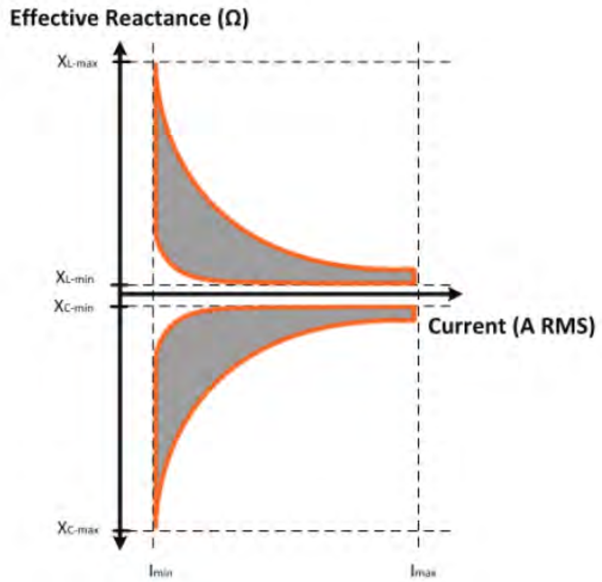
$$X_{effective} = \frac{V_{injected}^{max}}{I_{line}}$$





General Guidelines for Planners

To enable an efficient evaluation of potential APFC solutions, we suggest focusing on the following use cases:

- **Near-Term (<5 years) NERC Violations:** Reducing overloads on circuits where SmartValve can operate as a dynamic series reactor, wherein:
  - Alternative solutions (new line or rebuild) exceed cost thresholds due to circuit length:
    - Line ≥20 miles (rebuild scenario, assuming $300k/Mile) or ≥10 miles (new-build scenario, assuming $600k/Mile)
    - High community, routing, or terrain constraints
  - Series reactor is not feasible due to:
    - Short-circuit level impacts, Transient Recovery Voltage (TRV) concerns
- **Maximizing Utilization of New Transmission:** Parallel transmission paths where SmartValve can shift flows toward higher-rated circuits (Usually the higher voltage lines in the path), ex:
  - New 345+ kV transmission line, Line ≥ 50 miles, 2 or more lower-voltage parallel circuits
- **Improving Line Voltage Stability:** On long transmission lines that would normally require series capacitors, SmartValve can provide stability benefits without contributing to sub-synchronous resonance, ex:
  - New or existing 345+ kV, Line ≥ 100 miles, 500 MW or more inverter-based resources connected radially (after N-1) to transmission line
- **Managing Inter-regional Flows (PST Alternative & PST Life Extension):** SmartValve acts as a dynamic reactance controller, providing power flow control at lower cost and faster deployment than a PST
  - PST experiencing excessive annual tap changes, nearing 40-year asset lifetime, or logistically challenging to transport replacement

GETs studies

The Brattle Group 2021: Unlocking the Queue

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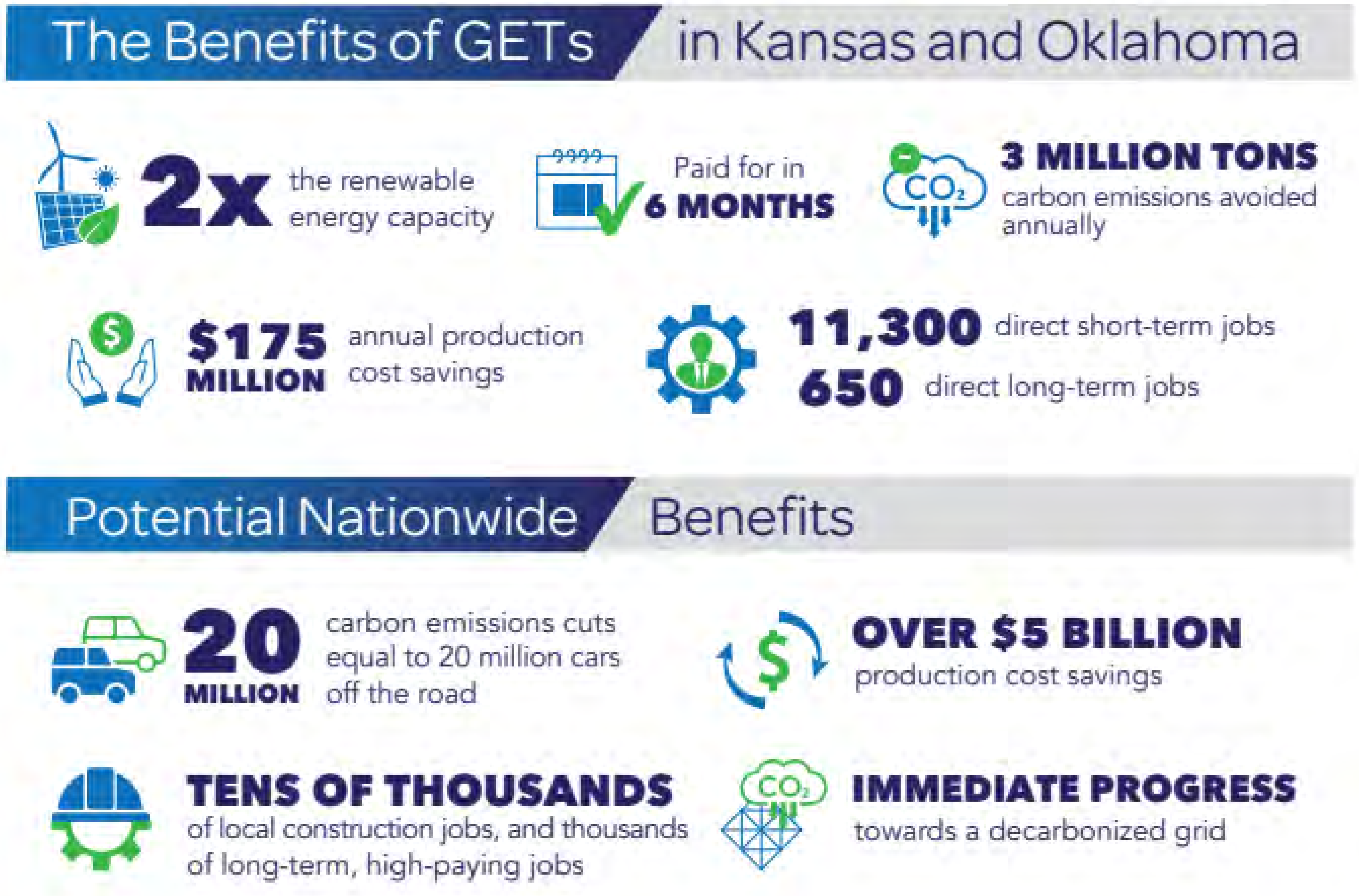
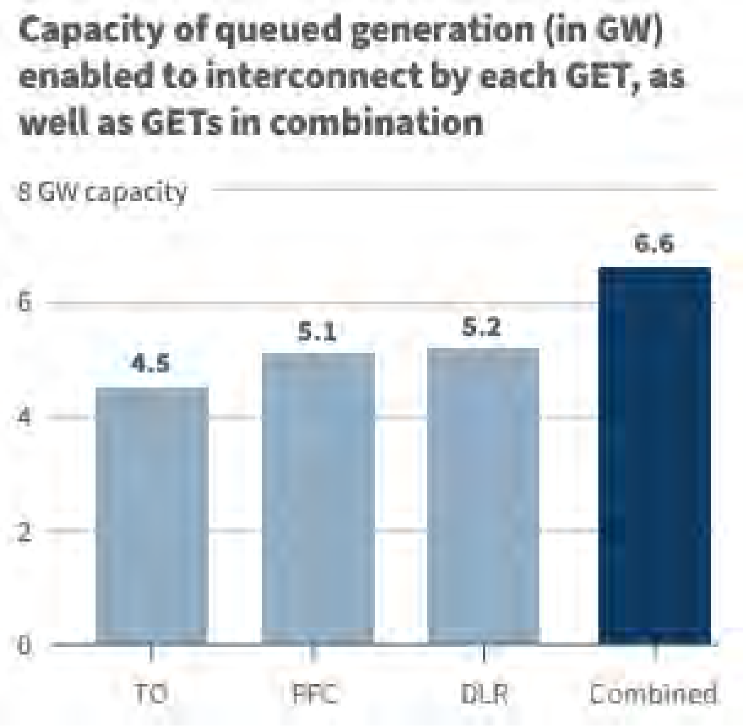
X2

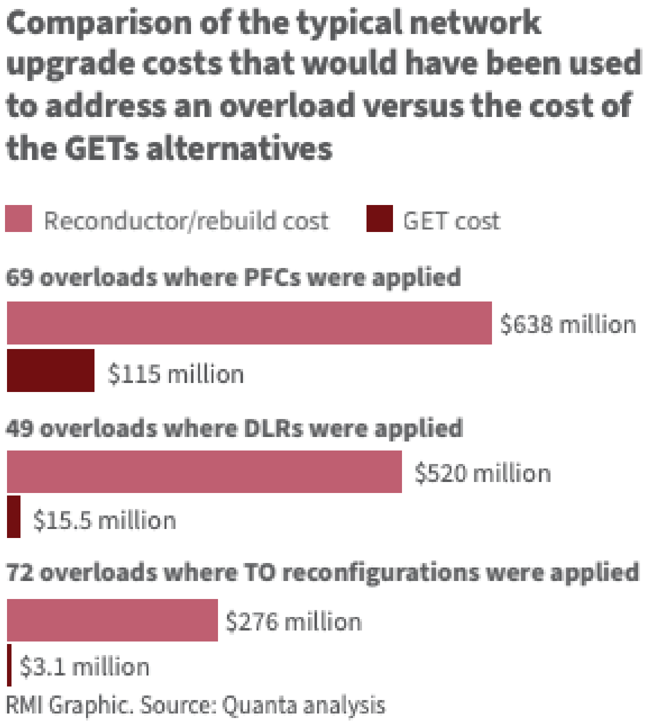
[Rounded to the nearest 10 MW]

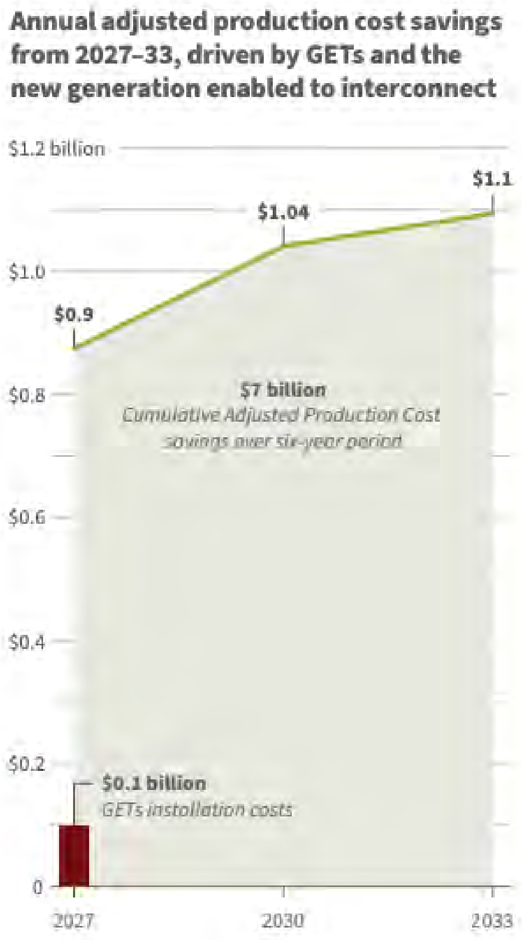
The Brattle Group 2021: Unlocking the Queue



Quanta/RMI 2024: GETting Interconnected in PJM







GETs policy

FERC Order No. 2023 requires *some* Alternative Transmission Technologies for *evaluation* in generator interconnection

Require evaluation:

- static synchronous compensators
- static VAR compensators
- **advanced power flow control devices**
- **transmission switching**
- synchronous condensers
- voltage source converters
- advanced conductors
- tower lifting

Optional

- **Dynamic Line Ratings**
- Storage as Transmission

Advanced Transmission Technologies and Order 1920

<table>
<tr><th>Benefits</th><th>DLR</th><th>APFC</th><th>TTO</th></tr>
<tr><td>1. Avoided or deferred reliability transmission facilities and aging infrastructure replacement</td><td colspan="3">✓</td></tr>
<tr><td>2. Reduced loss of load probability or reduced planning reserve margin</td><td colspan="3">✓</td></tr>
<tr><td>3. Production cost savings</td><td colspan="3">✓</td></tr>
<tr><td>4. Reduced transmission energy losses</td><td colspan="3">✓</td></tr>
<tr><td>5. Reduced congestion due to transmission outages</td><td colspan="3">✓</td></tr>
<tr><td>6. Mitigation of extreme weather events and unexpected system conditions</td><td colspan="3">✓</td></tr>
<tr><td>7. Capacity cost benefits from reduced peak energy losses.</td><td colspan="3">✓</td></tr>
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All regions are seeing progress, but piecemeal

ISO/RTO	ISO-NE	Uses TTO software to support their transmission outage coordination process; Is adding a position to evaluate ATTs for asset condition projects
	MISO	Allows grid users to propose TTO reconfigurations
	PJM	Accepts DLR into both real-time and day-ahead market operations
	SPP	Will allow grid users to propose TTO reconfigurations
	ERCOT	Will allow grid users to propose TTO reconfigurations
	CAISO	Calls out ATTs in transmission plan, with utilities each doing studies per 2024 legislation
Non - ISO/RTO	Southeast	Southern Company has APFC, DLR and HPC projects announced; originates GETs projects from planning, real-time operations, and maintenance teams
	Southwest	Limited HPC adoption
	Northwest	PSE, BPA, PGE beginning DLR deployments; PacifiCorp and NV Energy deploying HPCs

Proposed GETs Solutions for Interconnection

For wind generation facilities in the Eastern Interconnection

Dynamic Line Ratings Could Avoid 100 Miles of Line Rebuild

Problem: Thermal line overloads in summer high-wind case.

TO solution: rebuilding more than 100 miles of 115kV lines. Interconnection study assumed wind at 2 meters per second to calculate the line ratings.

Developer solution: DLR could likely increase the line capacity by up to 30% in the conditions that triggered the overload.

TO response: Would not consider DLR.

Photo from Heimdall Power

Dynamic Line Ratings Could Avoid $50 Million Line Rebuild

Problem: 3% modeled thermal overload in high-wind scenarios in summer and winter.

TO solution: $50 million line rebuild

Developer solution: DLR

TO response: Would not consider DLR.

Photo from LineVision

A 1% Line Overload Could Cost $400 Million

Problem: 1% thermal overload in high-wind scenarios

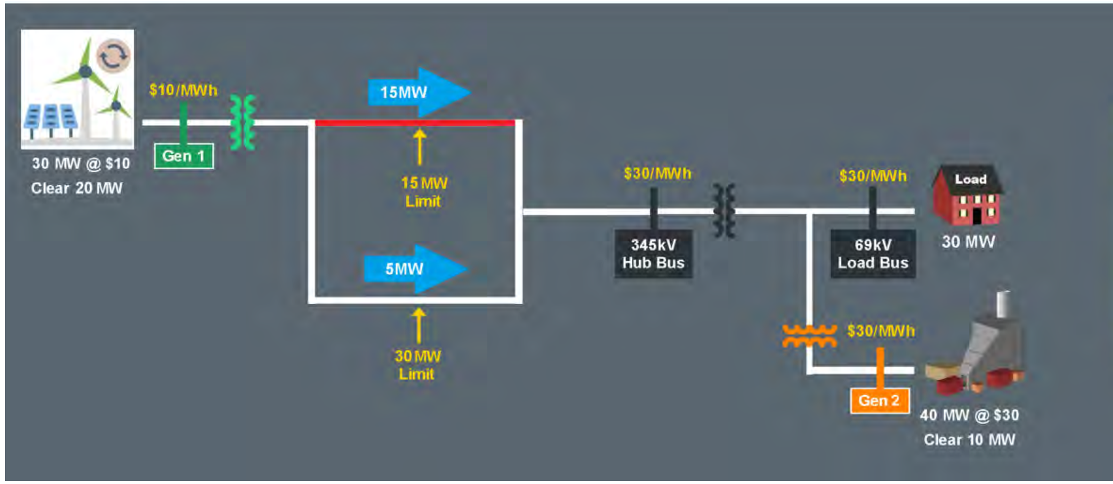
TO solution: $400 million upgrade between RTO seams.

Developer solution: DLR

TO response: Would not consider DLR.

Photo from Ampacimon

APFC to Reduce Generation Curtailment and Lower Congestion Costs

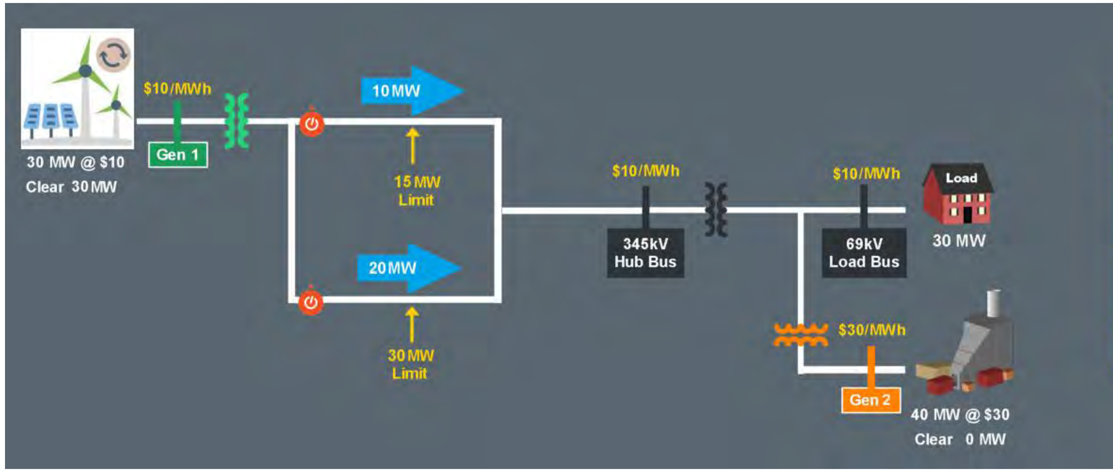


Payments to Sellers

	LMP	MW	
Gen 1	$10	20	$200
Gen 2	$30	10	$300
Total			$500

Charges to Buyers

	LMP	MW	
	$30	30	$900
Total			$900



Payments to Sellers

	LMP	MW	
Gen 1	$10	30	$300
Gen 2	$30	0	
Total			$300

Charges to Buyers

	LMP	MW	
	$10	30	$300
Total			$300

APFC could save $150M in congestion costs

Problem: High congestion costs driven by flow imbalance across lower-rated lines.

TO Solution: Reconductoring to increase thermal capacity.

Developer Solution: Deploy APFC to redistribute power flow and relieve constraints.

TO response: APFC perceived as complex to model and integrate into planning studies.

Photo from Smart Wires

What are Grid Enhancing Technologies and High Performance Conductors?

Grid Enhancing Technologies (GETs)

Dynamic Line Ratings

Hardware or software used to calculate the true capacity of transmission lines using real-time and forecasted weather conditions.

Advanced Power Flow Control

Hardware and software used to reroute electricity from overloaded transmission lines to underutilized lines by adjusting circuit impedance.

Topology Optimization

Software that identifies reconfigurations of the transmission grid to deliver power most efficiently.

High Performance Conductors (HPCs)

High Performance Conductors

Modern conductor technologies which have increased capacity, higher efficiency, and less thermal sag. HPCs include Carbon Fiber and Composite Core Conductors and Superconductors.

*These technologies are collectively known as **Advanced Transmission Technologies (ATTs)**, which can cost-effectively increase the capacity, efficiency, reliability and/or safety of power lines, faster than traditional grid infrastructure and at lower cost or with higher net benefits. New innovations may be added to each of these categories as they are developed in the future.*

High Performance Conductors

Modern conductor technologies that have greater performance characteristics when compared to traditional conductors

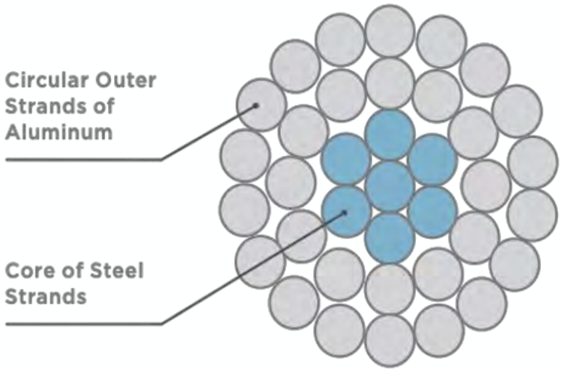
Carbon and composite core (high-temperature low-sag) conductors

These are overhead, bare conductors that use a trapezoid shaped wire of annealed aluminum to carry electrical current and use a carbon fiber or composite core for support, reducing line losses thermal sag, while increasing power-flow capacity.

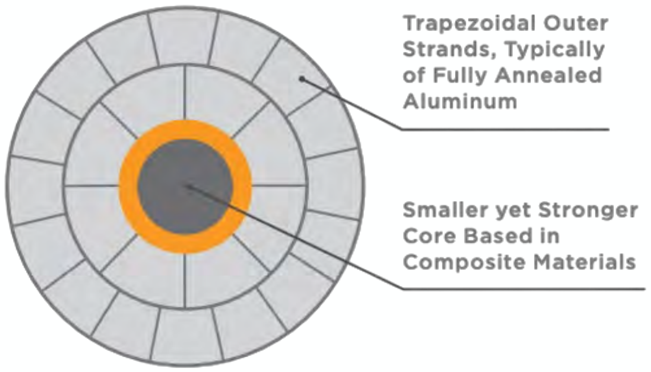
Superconductors

These use a class of metallic compounds that exhibit negligible resistive losses when cooled using liquid nitrogen, enabling very low power losses and very high power-flow capacities.

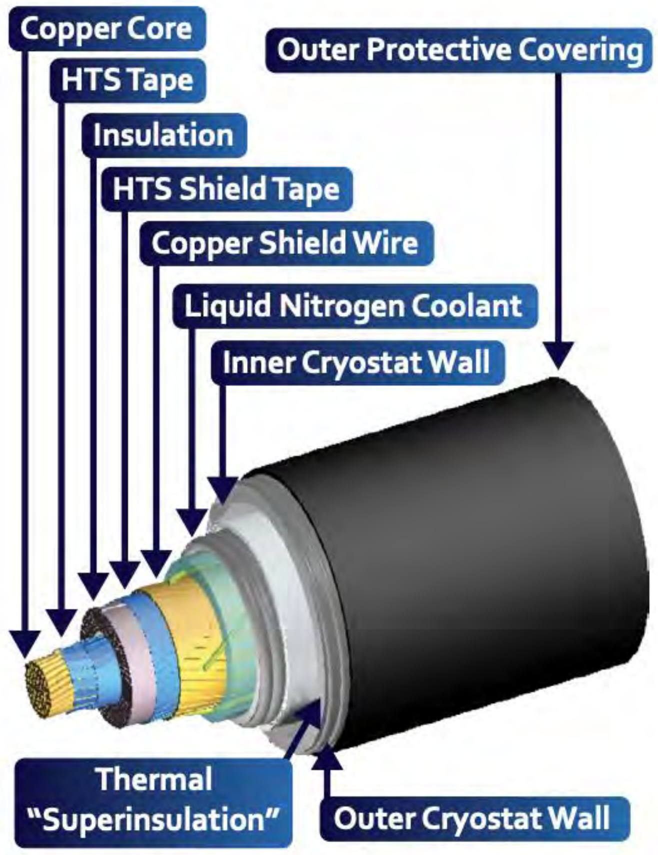
Traditional ACSR conductor



Carbon / Composite Core Conductors



Superconductor cross section



Source: GridLab, Reconductoring Technical Report (April 2024); ACORE, High Performance Conductor Playbook (October 2024)..

ATTs have been commercially available for years, but adoption is blocked

Institutional inertia

The utility industry is historically slow to change and is currently managing digital and resource transformations in parallel. ATT adoption requires technical upgrades and training, as well as a significant cultural shift towards thinking about the grid as a dynamic asset in the case of GETs.

Misaligned incentives

Traditional utility incentives offer a return on capital investment projects; more expensive projects offer more profit. Lower-cost GETs are not part of the business model, because utilities are not directly rewarded for speed or cost-effectiveness in transmission investments, or improving operations.

Cost misunderstanding

Some HPC projects are mischaracterized as ”gold-plating” because they have higher up-front costs than like-for-like replacement. However, the net lifetime benefits of HPCs usually exceed traditional conductors.

Incomplete benefit-cost

Some economic analyses of utility investments focus only on capital costs, and do not capture the holistic benefits of ATTs.

These analyses can overlook the potential savings from modernized technologies, such as improved energy efficiency, avoided costs for increasing transmission capacity, and reduced congestion charges due to operational efficiencies.

Faster new energy: GETs can accelerate the generator interconnection process

Before new generation is installed

While new generation is being installed

After new generation is installed

Serve as a bridge

Provide service while projects wait for traditional upgrades

GETs can provide additional provisional transmission service for projects awaiting traditional upgrades.

Clear the queue

Decrease queue withdrawals

High upgrade costs lead to projects dropping out of the queue, requiring restudies and increasing uncertainty.

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.

Cut costs

Saving money for generators

RMI found that GETs could enable inter-connection for 6GW of renewable energy, saving $600 million compared to traditional upgrades. Anecdotally, developers report interconnection costs of $50-400M for 1-3% projected line overloads, which would likely be resolved by DLR at a fraction of the cost.

Accelerate

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 over 3 years for many projects.

Reduce curtailment

Address operational constraints

GETs can significantly reduce curtailment due to outages or other operational limits. Topology optimization often reduces congestion by 50%, and DLR reduces curtailment, especially during cold and windy conditions.