Grid Enhancing Technologies

Introduction to Technologies that Complement Transmission

"POP UP" FORUM ON GRID ENHANCING TECHNOLOGIES

SPONSORED BY THE MASSACHUSETTS EXECUTIVE OFFICE OF
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FEDERAL AND REGIONAL ENERGY AFFAIRS

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Brattle

Grid Enhancing Technologies - 1/2

Grid Enhancing Technologies (GETs) can help reduce transmission congestion.

- GETs can be installed quickly and cost-effectively to help maximize the capability of the existing transmission system.
  - GETs can provide both temporal and permanent solutions.
  - They can also be removed quickly without jeopardizing existing assets.
- GETs can help both the short- and long-run challenges:
  - Reduce out-of-merit dispatch (including those associated with transmission outages).
  - Increase interconnection capacity availability for new resources.
- There are various types of GETs. Examples include:
  - **Topology Optimization**: Automatically finds reconfiguration to re-route flow around congested or overloaded facilities while meeting reliability criteria.
  - **Dynamic Line Ratings (DLR):** Improves thermal ratings used based on actual weather conditions including, at a minimum, ambient temperature and wind, in conjunction with real-time monitoring of resulting line behavior.
  - **Advanced Power Flow Control**: Injects voltage in series with a facility to increase or decrease effective reactance, thereby pushing power off overloaded facilities or pulling power on to under-utilized facilities.

Grid Enhancing Technologies - 2/2

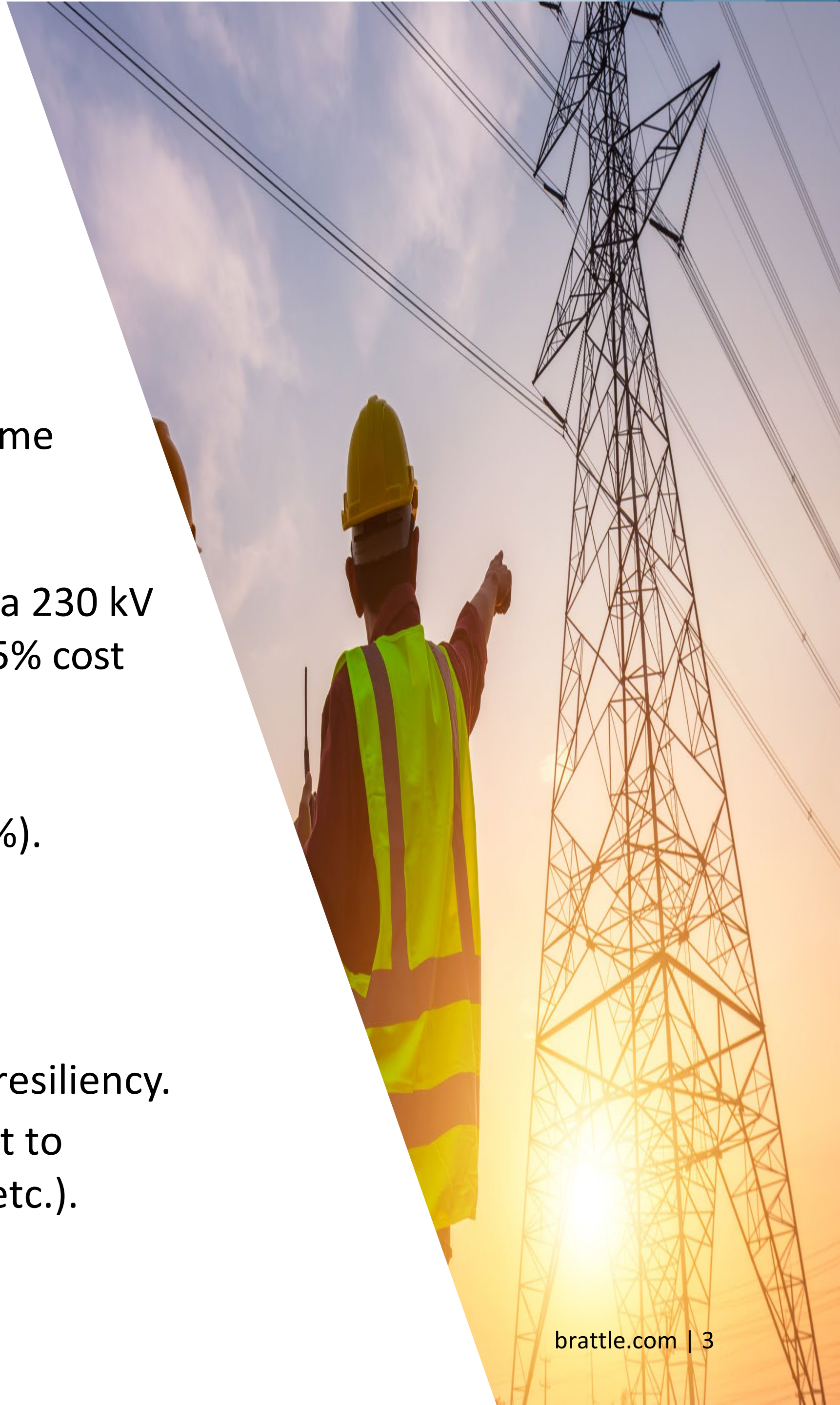
GETs *complement transmission investments*.

- Increase benefit to cost ratio of new projects (e.g., use GETs on the underlying lower voltage system in parallel to adding a new high voltage path).
  - Remedy cases when new transmission projects results in unanticipated congestion.
- Provide a “bridge” between today and when the permanent solution (e.g., new transmission line) is put into service.
  - GETs can be removed once the permanent solution is in place.
- Reduce impact of transmission outages (which may be associated with interconnecting a new transmission project) and other short-term/temporal events.
- Smooth out the lumpiness of transmission investments.
  - This also helps smooth out “rate shocks” associated with larger lumpy investments.
- Reduce risks associated with uncertainty. Examples include:
  - Rate increase risk (e.g., anticipated load growth does not realize and the cost is spread among a smaller number of customers leading to higher customer rates, or the utility under-collects its revenue requirements.)
  - System and equipment risk (e.g., the equipment is no longer needed at the installed location).

Potential Benefits of GETs

Various studies indicate significant benefit potential at relatively low cost.

- Regional benefits of GETs are in the tens to hundreds of million dollars.
  - PJM study indicates over $100 million in production cost savings a year in real-time markets.
  - Pacific Gas and Electric Company's review of Distributed Series Reactors (DSRs) indicated installing approximately 2,000 DSR to mitigate thermal overloading of a 230 kV line at an estimated cost of approximately $33 million would lead to almost a 75% cost savings compared to reconductoring.
- GETs reduce congestion and help integrate renewables.
  - European studies indicate DLR's contribution to reduced wind curtailment (~15%).
  - Quick implementation helps with the fast clean energy transition pace.
  - Enables more generation interconnection.
- Other benefits
  - Increased operational awareness, while providing redundancy and helping with resiliency.
  - Relatively lower cost investments help cash-stranded utilities that need to invest to accommodate load growth (which could be triggered further by electrification, etc.).



Transmission and Transfer Capabilities

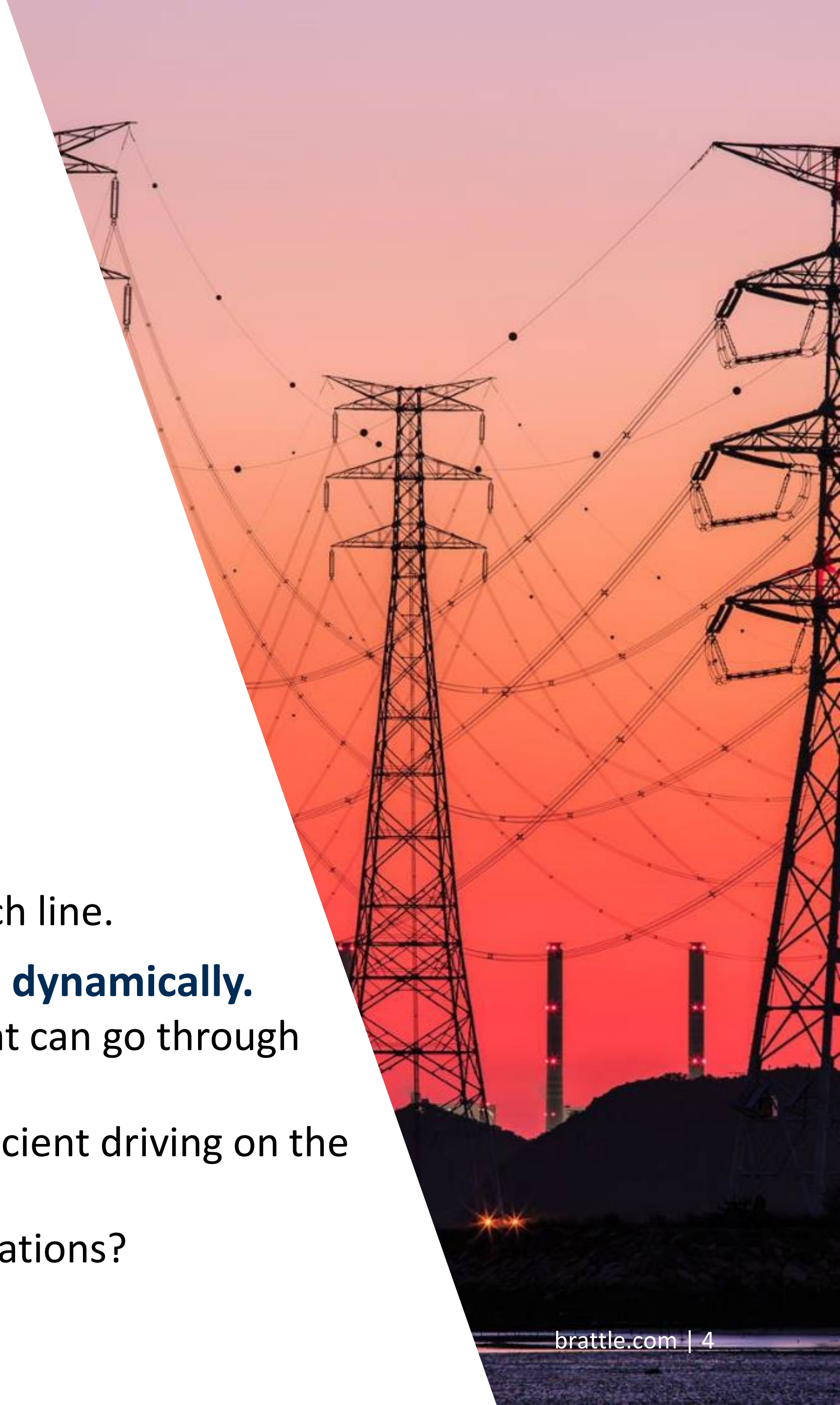
Transfer capabilities are largely defined by two factors: the physical capacity of individual lines and network topology.*

- Physical capacity of individual overhead lines:
  - Primarily defined by the maximum operating temperature to:
    - Maintain minimum electrical clearances (line sagging, etc.).
    - Limit annealing of conductor aluminum.
    - Limit aging of connectors/hardware.
  - Increased power flow warms the line (resistive heating).
  - Ambient conditions also impact line temperature.
- Network topology:
  - Key factor defining the distribution of power flows—i.e., how much flows on each line.

Traditional thinking treated transmission as if it is fixed and cannot be operated dynamically.

- Transmission has a fixed capacity, much like roads do (e.g., the number of cars that can go through at any given time).
- Advancements in maps and GPS technology have allowed for easier and more efficient driving on the same roads.
- Are there similar technologies that allow for such innovation in transmission operations?

* Actual operating limits are more often defined by contingencies, rather than by the normal rating of a single line.



Further Reading

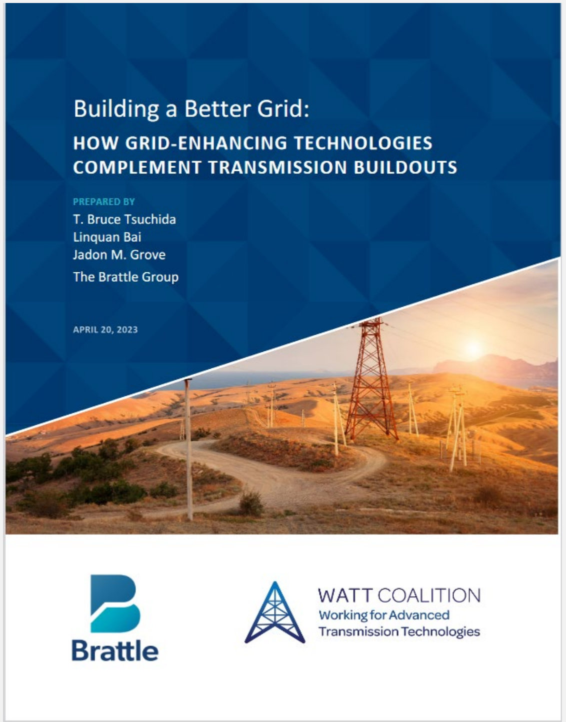
More examples of GETs and their ***economic benefits***:

Available at:
https://elibrary.ferc.gov/eLibrary/filedownload?fileid=15283553

How GETs can help ***integrate more renewables***:

Available at:
https://watt-transmission.org/wp-content/uploads/2021/02/Brattle__Unlocking-the-Queue-with-Grid-Enhancing-Technologies__Final-Report_Public-Version.pdf90.pdf

How GETs are ***complementary to transmission*** expansion:



Available at:
https://watt-transmission.org/wp-content/uploads/2023/04/WATT-Coalition-Draft-National-Transmission-Needs-Study-Comments.pdf

Dynamic Line Ratings - 1/3

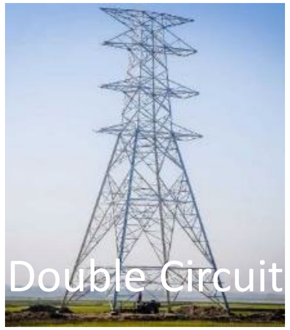
- Historical practice was largely based on Static Line Ratings (SLR).
  - Maximum operating temperature for a given line is pre-determined.
  - Uses conservative assumptions, such as low wind, high temperature, high solar irradiance etc., to accommodate most conditions.
  - It is similar to setting the speed limit for highways based on a snowy road conditions.

- Dynamic Line Ratings (DLR) adjust this limit based on ambient conditions.
  - There are commonalities between SLR and DLR
    - Both use conservative assumptions.
    - The maximum allowable temperature is likely the same.
  - And there are difference between SLR and DLR.
    - DLR requires line-specific data (real-time measurements).
    - SLR that applies uniform weather conditions to all lines is generally lower than DLR that applies line-specific conditions.
    - DLR is variable and therefore requires a forecast for operations planning. Accumulation of real-time DLR data can be used for future calibration.

Dynamic Line Ratings - 2/3

Solutions considered for PPL* to relieve congestion on the Harwood to Susquehanna 230 kV path.

- Annual congestion cost for 2025 estimated to be $14.5 million.



	Reconductoring	Double-Circuit	Dynamic Line Rating
Time to Implement	2 – 3 Years	3 – 5 Years	Months
Downtime	Extended Outages	Extended Outages	No Outages
Cost	$0.5 million per mile	$2 - 3 million per mile	< $1 million
Est. Capacity Benefit	+ 34%	+ 106%	+10 – 30%

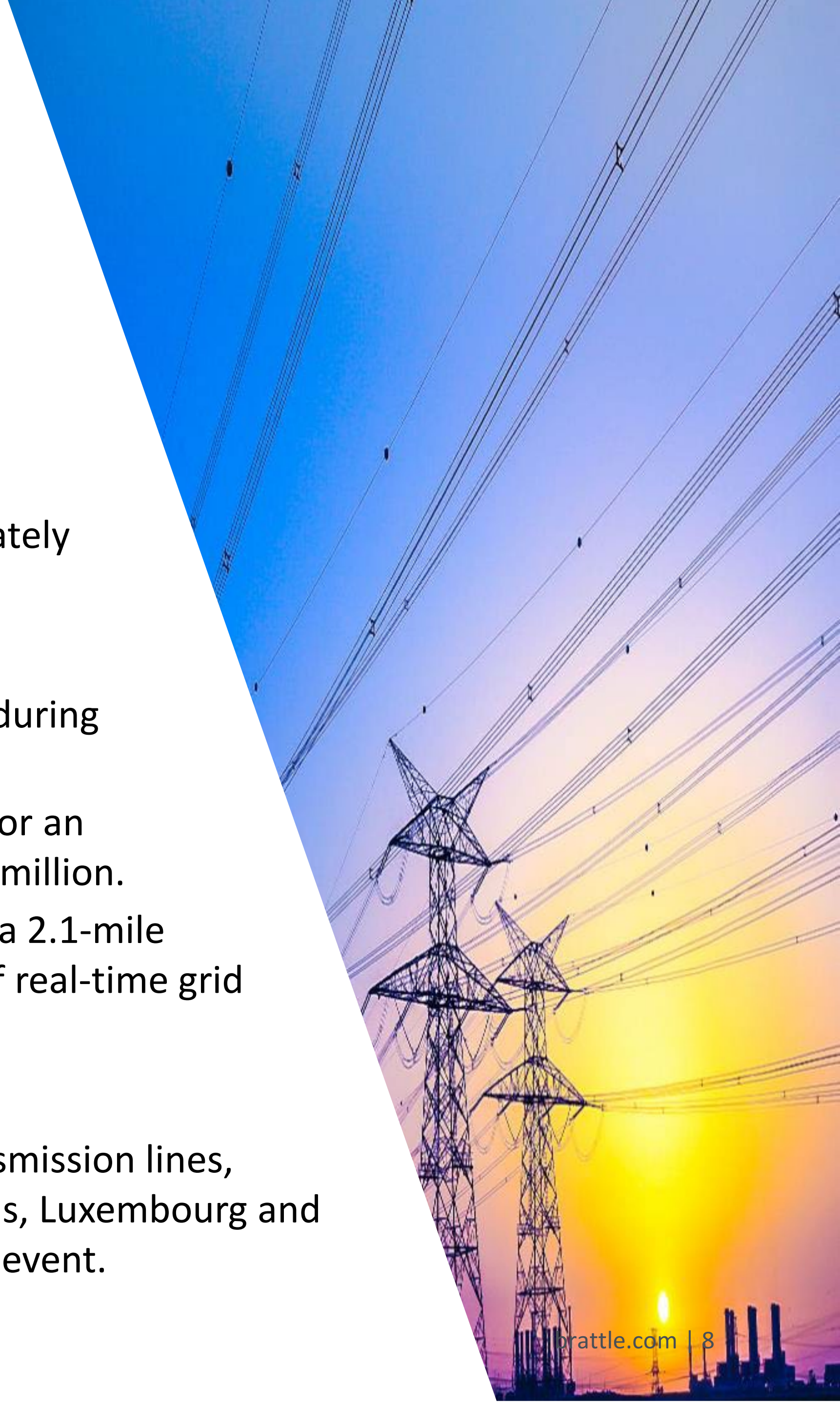
Selected Solution

- How much additional capacity do I need and when?
- How much risk is there in the investment? Is it reversible?
- How much regulatory hurdles are there to go through?

* PPL is formerly known as Pennsylvania Power & Light

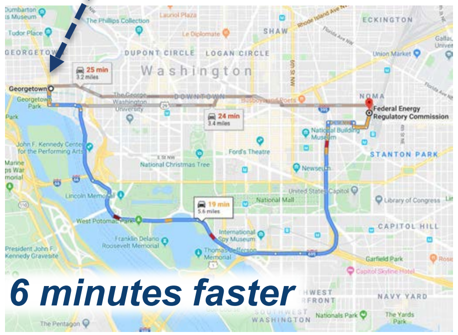
Dynamic Line Ratings - 3/3

- ONCOR DLR Study
  - Indicates DLR transfer capability to be 5% to 25% higher than Static Line Ratings.
  - Estimates 10% increase in ratings could eliminate most congestion.
  - Estimates if one-twentieth of ERCOT transmission lines were outfitted with DLR technologies, annual savings from congestion reductions would amount to approximately $20 million, or 3% reduction in congestion costs.
- Other U.S. examples
  - Entergy confirms an average of 10+% increase in line capacity (DLR applied primarily during off-peak periods).
  - PJM and LineVision study shows net congestion cost savings of $4.2 million annually for an estimated one time DLR installation and implementation costs of approximately $0.5 million.
  - LineVision's study with AEP and Southwest Power Pool ("SPP") demonstrates DLR on a 2.1-mile segment provided opportunities to save approximately $18,000 during just 5 hours of real-time grid congestion.
- Belgian Transmission System Operator Elia
  - Elia with Ampacimon has deployed a utility-wide DLR system with sensors on 30 transmission lines, increasing exchange capacities (additional import of 33 MW) with France, Netherlands, Luxembourg and Germany, leading to about €0.25 million savings during a single four-hour congestion event.



Topology Optimization - 1/3

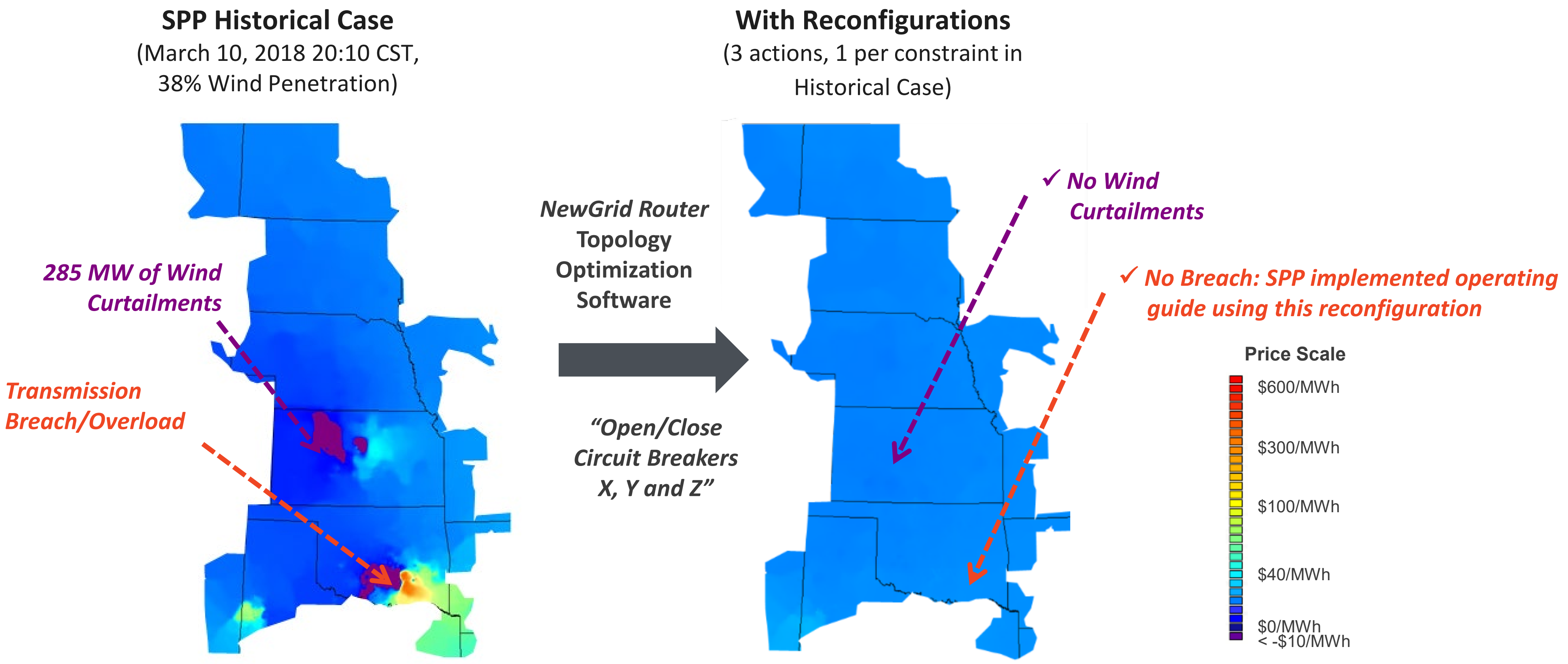
- Topology optimization is analogous to a GPS: “Arrive to destination reliably, with minimum delay even when there are events on the road.”
  - Reconfigurations are implemented by switching circuit breakers open or close.
    - Analogous to temporarily diverting traffic away from congested roads to make traffic smoother.
  - Feasibility assessment.
    - Circuit breakers are capable of high duty cycles and extremely reliable (failure occurs less than once in 20,000 switching cycles*)—some breakers are switched very frequently today, e.g., those connecting generating units with daily start and stop operations.
    - Switching infrastructure is already in place—most breakers are controlled remotely over SCADA (supervisory control and data acquisition system) by the Transmission Owner (phone calls between Transmission Owner and Regional Transmission Operator to coordinate operations).
    - Low cost: usually $10-$100 per switching cycle.



*For single-pressure SF6 breakers. Based on a CIGRE survey of 281,090 breaker-years with responses from 82 utilities from 26 countries, source: A. Janssen, D. Makareinisand C.-E. Sölver, "International surveys on circuit-breaker reliability data for substation and system studies," IEEE Transactions on Power Delivery, v. 29, n. 2, April 2014, pp. 808-814
**All-in cost of maintenance overhauls for single-pressure SF6 breakersrated 72.5-362 kV.
Road closure picture from https://www.islandecho.co.uk/plea-motorists-heed-road

Topology Optimization - 2/3

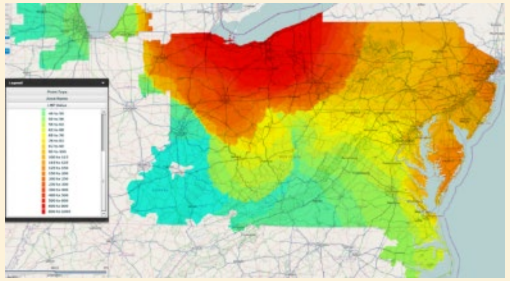
Topology Optimization software technology automatically finds reconfigurations to route flow around congested or overloaded elements -- "Waze (GPS app) for the transmission grid".



Topology Optimization - 3/3

Topology optimization is analogous to GPS: "Arrive to destination reliably, with minimum delay even when there are events on the road."

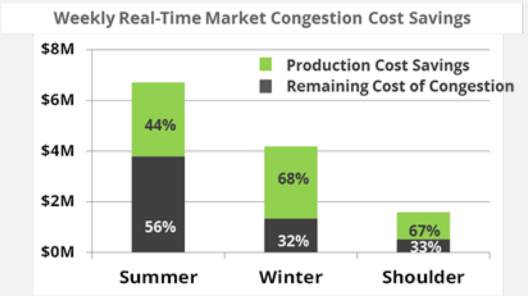
PJM RT prices w/critical transformer overload, 18 July 2013



Improve Grid Resilience and Reliability

- **Full overload relief with outage conditions, extreme weather events** (MISO, PJM, SPP)
- Avoid load shedding under critical contingencies (ERCOT, SPP)
- Reduce frequency of intervals with constraint violations by 75% (SPP)

Reduce Production Costs

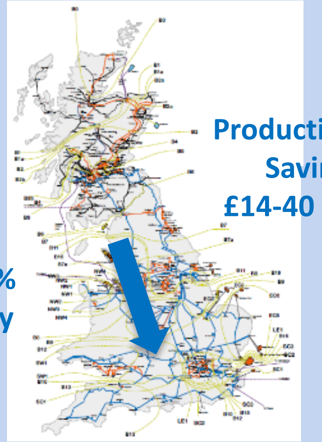


Real Time market production cost savings:
- **$100+ million/year savings** (PJM)
- $18-44 million/year (SPP)
- £14-40 million/year (Great Britain)

Day Ahead savings: $145 million/year (PJM)

Increase Transfer Capability

- *Large interface constraints*: **+4 to 12% capability** (Great Britain)
- *Single-element constraints*: average flow relief over 20% (SPP, ERCOT)



Production Cost Savings: £14-40 million

+ 4 to 12% Capability

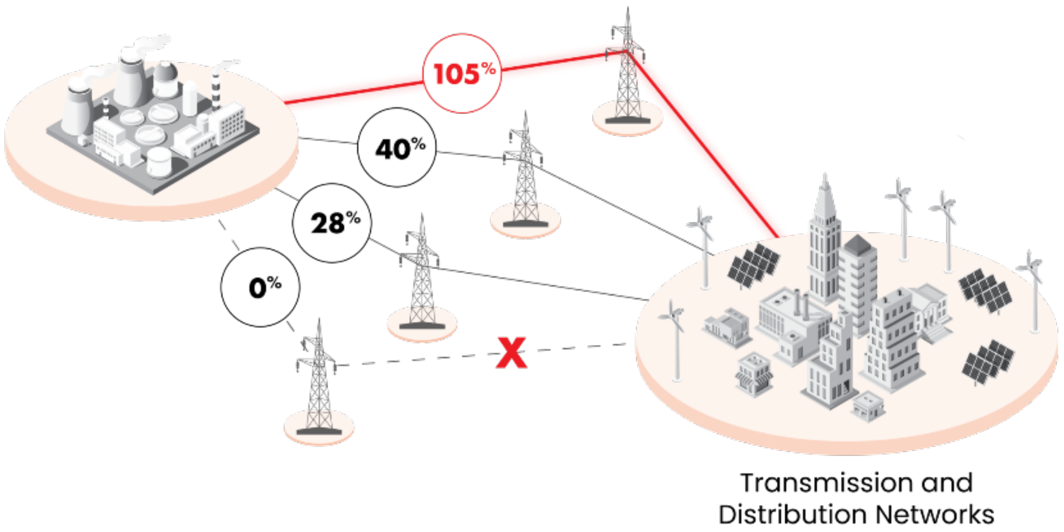
GETS EXAMPLES

Advanced Flow Control - 1/3

- Phase Shifters/Phase Angle Regulators (PARs) and Flexible Alternating Current Transmission Systems (FACTS) devices help the operator control flow through a given path.
  - PARs are widely accepted in the industry.
    - The largest drawback is the cost—for example, a recently-installed PAR between Michigan and Ontario has an annual carrying cost of over $10 million.
  - FACTS devices are power-electronic-based static devices that allow for flexible and dynamic control of flow on transmission lines or the voltage of the system.
    - Some FACTS devices (e.g., series capacitors) alter the reactance of a line to control the flow (i.e., increasing the reactance will push away flows while decreasing the reactance will pull in more flow to the line).
    - FACTs devices typically cost significantly less than PARs, can be manufactured and installed in a shorter time, are scalable, and in many cases, are available in mobile form that can be easily deployed while providing flexible layout options.

Advanced Power Flow Control - 2/3

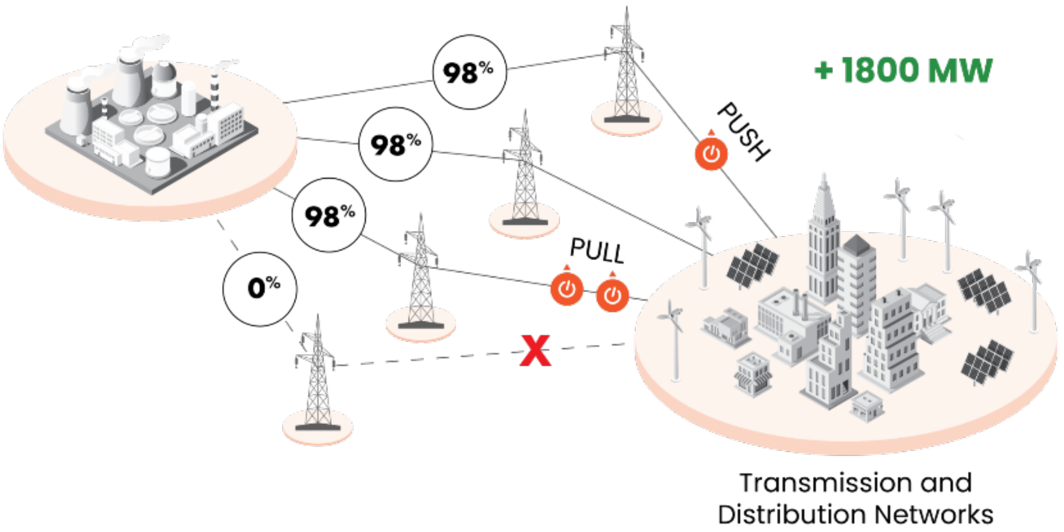
Before FACTS Device*



Traditional solutions include:

1. Redispatch generation
2. Reconductor constraining element
3. Install PSTs/Series Capacitor/Series Reactor
4. Construct a new parallel circuit

After FACTS Device

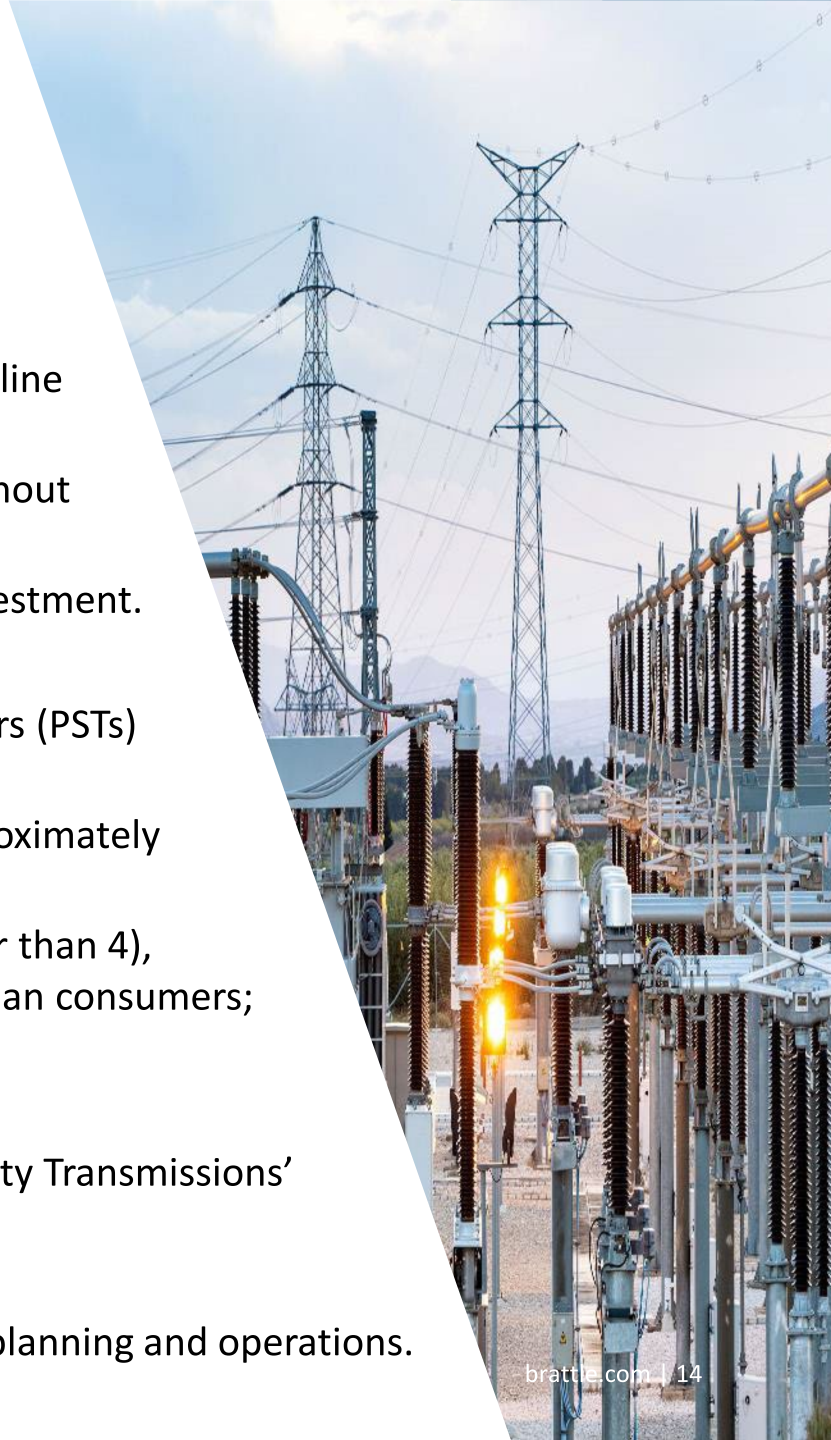


Power can be **PUSHED** and **PULLED** to alternate lines with spare capacity—leading to maximum utilization (typically obtained by a number of small applications on more than one circuit.)

* Illustrative example from Smart Wires, https://www.smartwires.com/smartvalve/

Advanced Power Flow Control - 3/3

- Distribution network operator UK Power Networks
  - Modular FACTS power flow control devices solve critical bottleneck on a 132 kV power line in southeast England.
  - Enabled an additional 95 MW of renewable sources to be connected to the system without building new electrical cabling and substations.
  - Saved customers over £8 million compared with traditional approaches to network investment.
- Quick, flexible solution that enables longer-term transmission investment
  - What if Germany took €400M of planned investment in four Phase Shifting Transformers (PSTs) and invested in modular static synchronous series compensators (m-SSSCs) instead?
  - M-SSSCs can provide the same grid benefits: reduce congestion by 6.8 TWh/year (approximately 17% of national congestion estimated for the study year of 2023).
  - Leveraging the smaller, modular nature, m-SSSCs can be installed in 12 locations (rather than 4), providing far larger benefits: doubles congestion reduction; saves €1.1 B/year for German consumers; provides a 4x larger cost-benefit ratio.
- Unlock large-scale, system-wide power transfers
  - m-SSSCs installed in 5 locations at 275 kV and 400 kV across UK's National Grid Electricity Transmissions' network.
  - These implementations unlock 1.5 GW of transfer capacity in less than on year.
  - These projects showcase the value a flexible, modular and distributed solution to grid planning and operations.



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Mr. T. Bruce Tsuchida is a Principal of The Brattle Group with over thirty years of experience in domestic and international power generation development, utility operation, and power market analysis. He specializes in bridging technology, economics, and regulatory policy, particularly in assessing the impact of new technologies and regulatory changes. This includes analysis of evolving wholesale electric markets and modeling, impact of renewable and other new technologies' on system operations, utility business, and various impacts on valuations of transmission, generation, and distribution assets, deliverability, and contracts. He has evaluated various utility business model options associated with the change in markets (structural changes through deregulation and landscape changes such as increase in renewables). These studies range from large interconnected systems to small island system, often with testimonies and/or affidavits filed for regulatory purposes.

Clarity in the face of complexity

Brattle