Technology Council Meeting Agenda

April 27, 2022 @ 3:00 PM ET

I.	Antitrust Guidelines	K. Malaika Walton, Membership and Programs Director
II.	Welcome & Introduction	Aurora Edington, Policy Director Kerrick Johnson, Chief Innovation and Communications Officer, VELCO and GridWise Alliance Board Member
III.	Grid Enhancing Technologies 101: Focus on Resilience	Pablo Ruiz, Co-Founder, Chief Executive Officer and Chief Technology Officer, NewGrid Ted Bloch-Rubin, Director of Business Development, Americas, Smart Wires Inc. Hilary Pearson, Senior Director Governmental & Regulatory Affairs, LineVision
IV.	Discussion / Q&A	Moderated by Aurora Edington

GridWise Alliance
Antitrust Compliance Program Guidelines

It is the policy of the GridWise Alliance to comply fully with the antitrust laws. The Sherman Act and other applicable antitrust laws are intended to promote vigorous and fair competition and to combat various restraints of trade.

Each person who participates in GridWise Alliance activities has a responsibility to his/her employers and to the GridWise Alliance to avoid any improper conduct from an antitrust standpoint. The following guidelines will assist in meeting this responsibility:

1. GridWise Alliance meetings and discussions generally cover topics related to the generation, transmission and distribution of electricity. Should related discussions ever have any potential for competitive impact, all due care shall be taken to avoid such discussion between competitors.

2. In view of antitrust considerations and to avoid any possible restraints on competition, the following legally sensitive subjects must be avoided during any discussion between competitors:

    (a) Future marketing plans of individual competitors should not be discussed between competitors;

    (b) Any complaints or business plans relating to specific customers, specific suppliers, specific geographic markets or specific products, should not be discussed between competitors;

    (c) Purchasing plans or bidding plans of companies in competition should not be discussed (except privately between two parties with a vertical commercial relationship such as supplier and customer); and

    (d) Current and future price information and pricing plans, bidding plans, refund or rebate plans, discount plans, credit plans, specific product costs, profit margin information and terms of sale should not be discussed between competitors. All of the above are elements of competition.

3. Any question regarding the legality of a discussion topic or business practice should be brought to the attention of the GridWise Alliance legal counsel or a company’s individual legal counsel for advice.

SMART WIRES

REIMAGINE THE GRID

Building the Future Grid Together

Flexible and efficient solutions for a reliable, affordable and clean power system

2022 | Ted Bloch-Rubin

Agenda

1. Smart Wires Overview
2. System Resilience Applications
3. Questions

A challenging time for utilities

Rapidly Changing Generation

Need to integrate intermittent resources

Shifting Consumption Patterns

Driven by customer-sited generation, electric vehicles, etc.

Increasing Storm Frequency & Strength

Limited system recovery flexibility

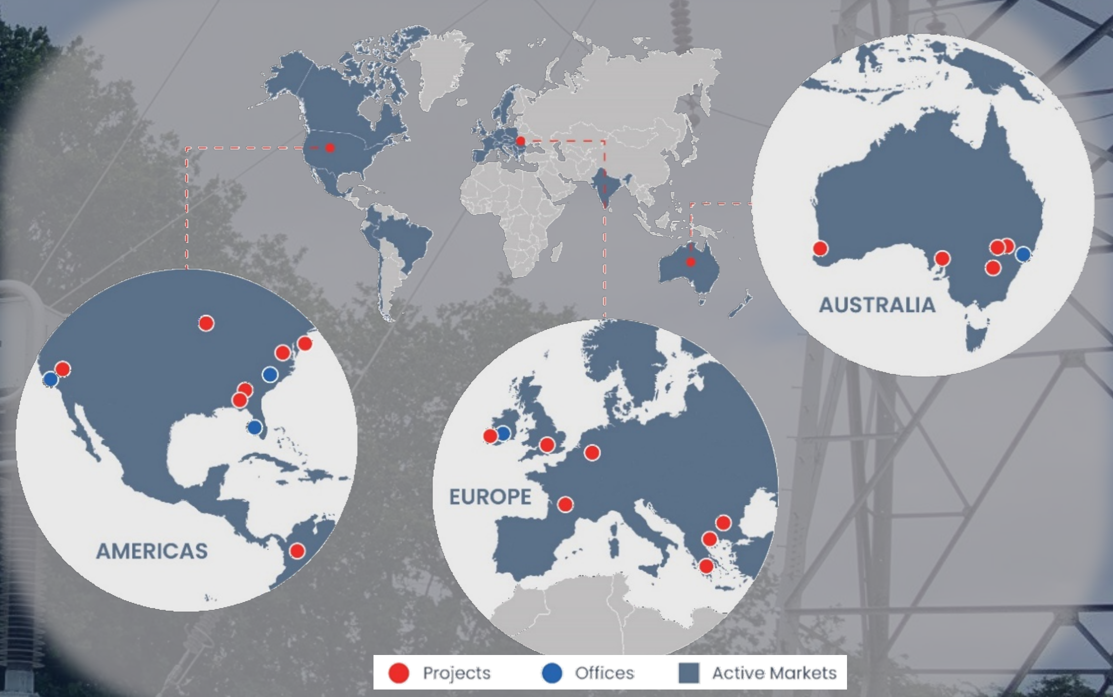
Global Policy & Action

- GHG emission reduction targets
- Electrification of transportation, heating, industry
- Desire to avoid negative financial impact for consumers

Political Shift has caught up to Renewable Economics

- Bipartisan support for jobs and economic recovery
- Savvy firms will utilize all available tools to make the most of this opportunity

Smart Wires develops and implements technologies that advance the delivery of electricity around the world



Maximizing the grid's transfer capacity to accelerate affordable, clean energy

AMERICAS

- Central Hudson (A Fortis Company) – People. Power. Possibilities.
- Minnesota Power – An ALLETE Company
- Southern Company
- Duke Energy
- LA DWP – Los Angeles Department of Water & Power
- nationalgrid
- epm
- TVA
- PG&E
- Grupo Energía Bogotá

AUSTRALIA

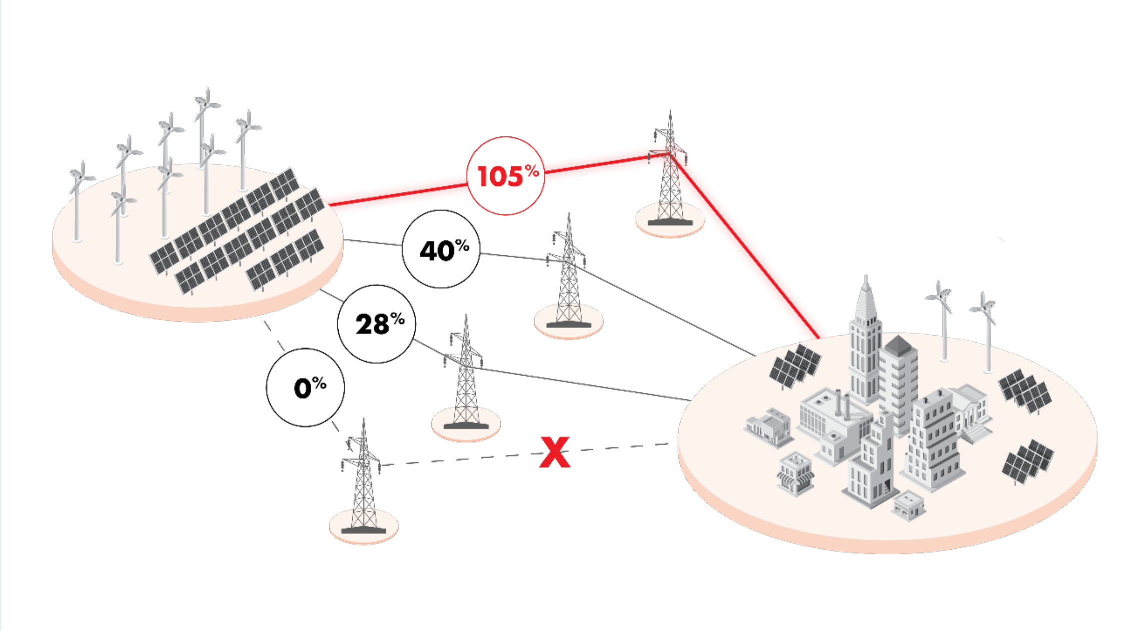
- TransGrid
- AusNet services
- westernpower
- ElectraNet

EUROPE

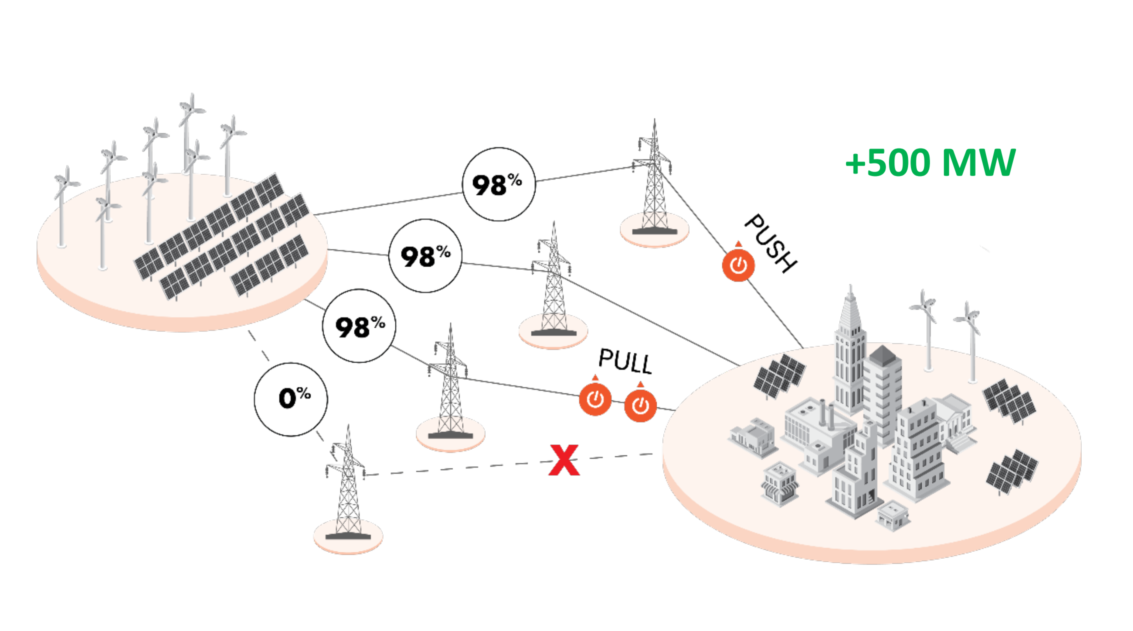
- nationalgrid
- UK Power Networks
- amprion
- Rte
- ESO
- ipto
- flexitranstore
- EIRGRID
- FARCROSS

Smart Wires impact – improving the value of the existing grid

Before Smart Wires



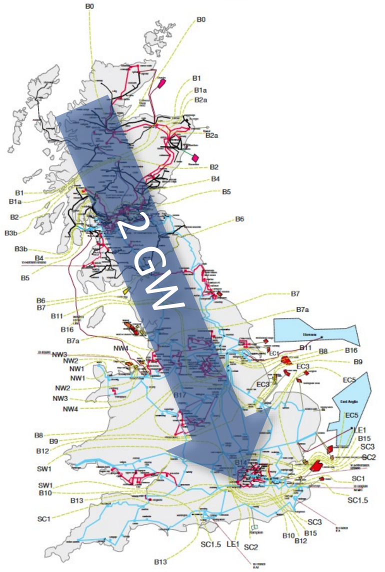
After Smart Wires

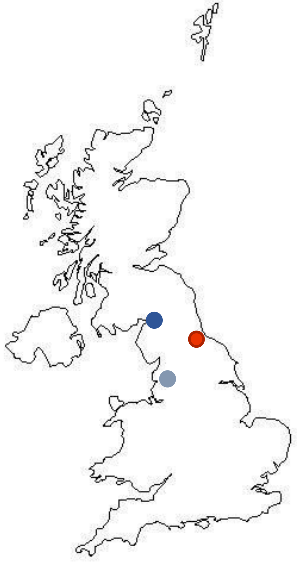


- ✓ Reduced renewables curtailment
- ✓ Reduced complexity and time for interconnection queues
- ✓ Greater utilization of new transmission lines
- ✓ Greater line loading flexibility across challenging scenarios

NGET Project Scale and Details

nationalgrid





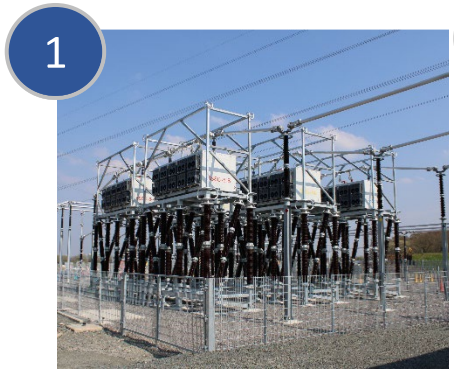
Across 3 boundaries

48 SmartValves < 18 months Manufacturing to commissioning

5 Circuits < 12 months For delivery of expansion

3 Sites £387+ M Savings for UK consumers

In 2022, National Grid is scaling up SmartValve deployments at two sites



SmartValve

Modular Static Synchronous Series Compensator (M-SSSC)

Full Range of Power Flow Control

Injects controllable voltage (leading or lagging) in quadrature with the line current to **pull** power towards or **push** power away from transmission facility

Provides compensation without SSR/SSCI risk

Flexible Deployment Options

Voltage agnostic up to 550 kV

Integrates with existing station communications equipment, SCADA, and EMS

Mobile deployment can be assembled in 4 hours and fully installed and commission within 1 day

Grid Resilience Overview

Definition of resilience (or resiliency), per IEEE Technical Report PES-TR65 and FERC Docket No. AD18-7-000 (Jan. 8, 2018):

"The ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event."

FERC Resiliency Order 2018:

- Ensuring resiliency requires:
  - Determining which risks (events) to the grid to protect against
  - Identifying the steps, if any, needed to ensure those risks are addressed
- Examples of high-impact, low frequency disruptive events
  - Fuel supply interruptions
  - Extreme weather events

SmartValve Grid Resilience Applications

SmartValve can be implemented as a preventative grid hardening measure, or as a corrective response measure before, during, or after a resilience challenge (ex. adverse weather causing a line outage)

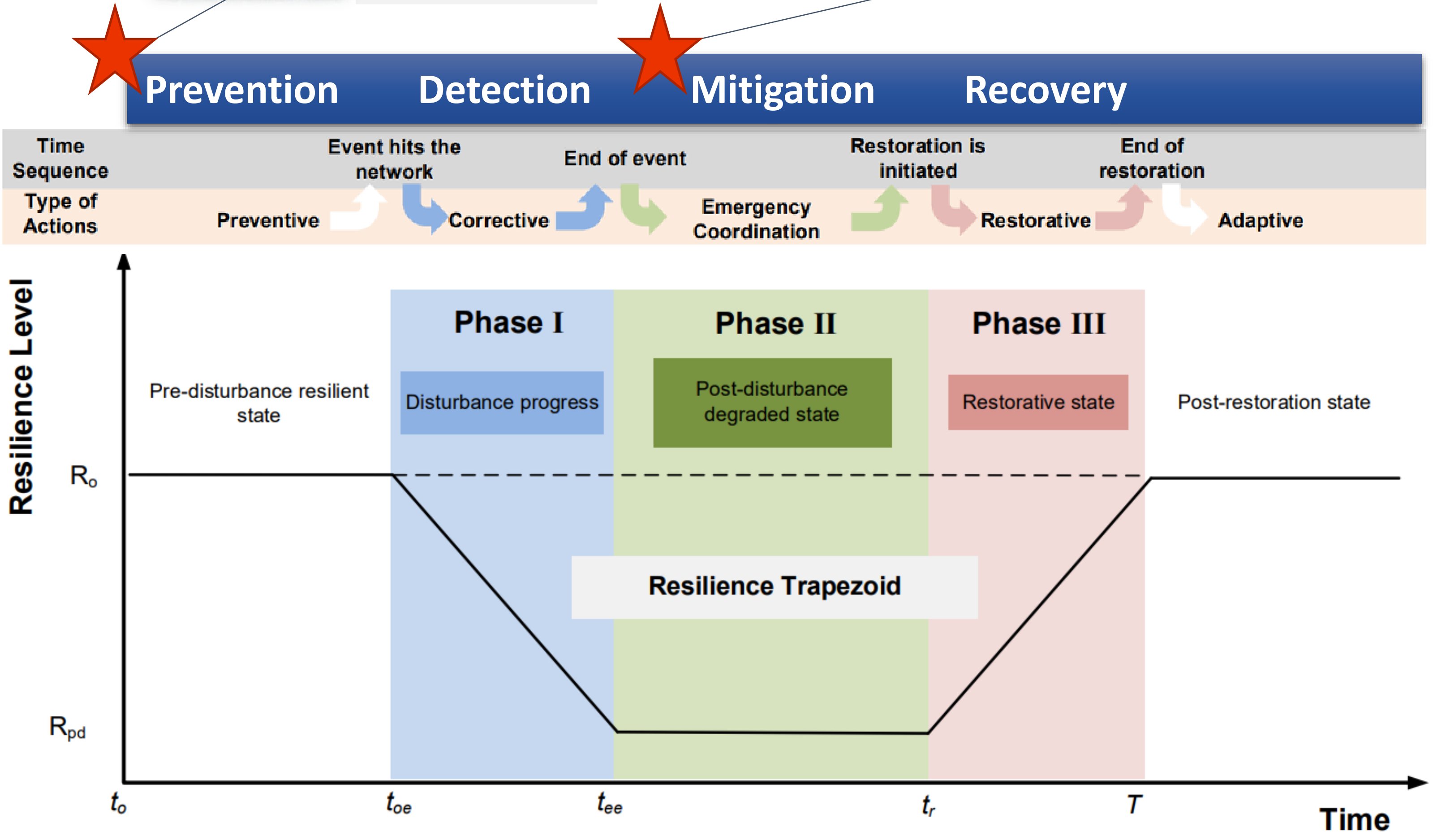
Grid hardening – preventative solution
Deployment of SmartValve technology at multiple locations to resolve congestion and provide granular control of power flows across the grid to improve grid resilience and operational flexibility.

Response – corrective solution
Fleet of SmartValves can be rapidly installed with mobile deployment at pre-determined locations before a forecasted event, or during or shortly after an unexpected event to act as a short-term or bridge solution to enable optimal system recovery measures.

Extreme Event Timeline

Install SmartValve to increase resilience level pre-event

Deploy Mobile SmartValve to temporarily increase resilience level until long-term fixes are implemented.



Source: The Definition and Quantification of Resilience, Technical Report IEEE PES-TR65

Integration with Event Recovery Timeline

Before outage

Identify Critical Customers
100% of the load for critical customers is critical load

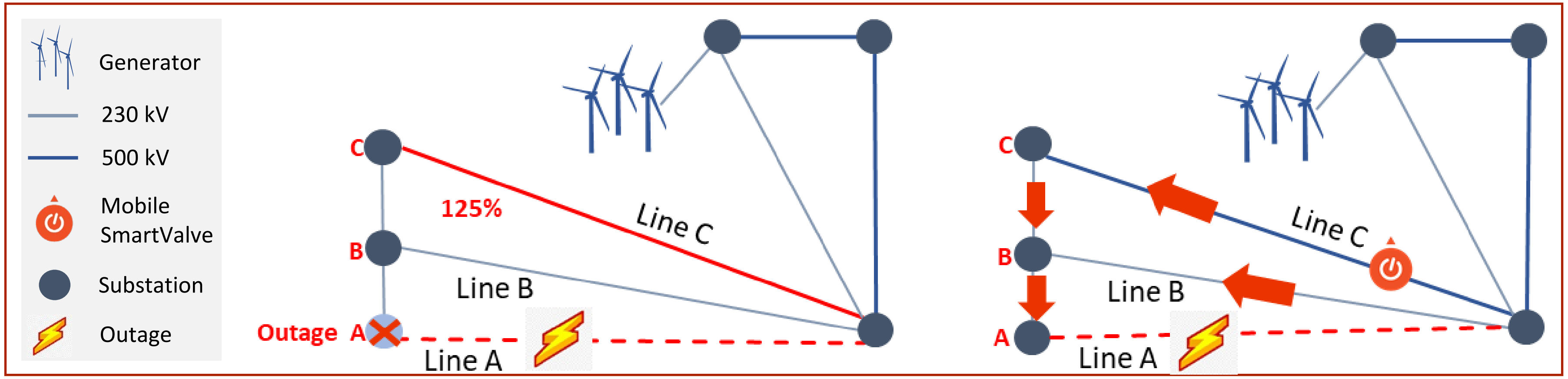
Identify Vulnerable Assets and Conduct Mobile SmartValve Deployment Planning
- Transmission lines serving critical load
- Substations with rapid connection capability

Immediately after outage

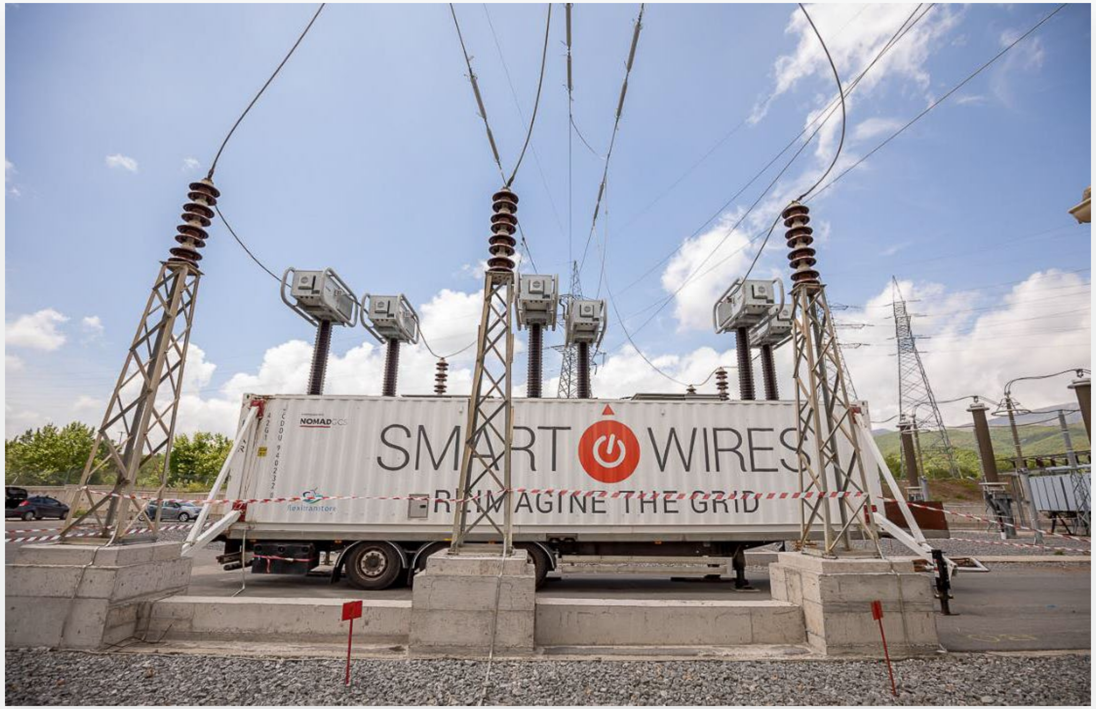
Prioritize Critical Customers and Prioritize Critical Load for Non-critical customers
- Dispatch existing SmartValve deployments to minimize load loss
- Confirm appropriate locations to deploy additional mobile SmartValve units

During power restoration

Restore Power Based on the Load Priority
- Dispatch crews to prep relevant sites for mobile SmartValve units
- Deploy mobile SmartValve units to site and install/ commission (4-8 hours)



Resolving congestion in South-Eastern Europe using mobile deployment



Collaborative project with IPTO (Greece) and ESO (Bulgaria) to enhance and accelerate the integration of renewables in South-Eastern Europe

- **Flexible, re-deployable, voltage agnostic solution** – redeployed from 150 kV in Greece to 110 kV in Bulgaria.
- **Resolve short-term needs** – deployed in Greece to maintain grid resiliency and provide network capacity while new line under construction
- **Quick to install** – install completed in 5 days and required outage time of less than 24 hours
- **Renewable integration** – reduces network congestion to unlock more capacity for renewables and improves cross border flows.
- **Operational flexibility -** delivers faster, lower cost and better way to plan and operate power systems

Smart Wires Analytics for Grid Resiliency

- Advanced software and modeling services to develop detailed grid resiliency programs and mitigation strategies.
- Identifying of vulnerable bulk electric system facilities including substations and protection systems.
- Quantitative and Qualitative assessment of the risks associated with substation vulnerability classifications
- Detailed modelling of gas-electric interdependencies and simulation of extreme events or scenarios.
- Probabilistic risk assessments to quantify the impact of aging infrastructure on system resiliency.
- Identifying potential mitigations of component risks and protection strategies through deployment of SmartValve technology

Questions?

Ted Bloch-Rubin
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Chair, WATT Coalition
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Transmission Topology Optimization

Pablo A. Ruiz, PhD

Grid Enhancing Technologies 101: Focus on Resilience

GridWise Alliance Technology Council

April 27, 2022

newgrid

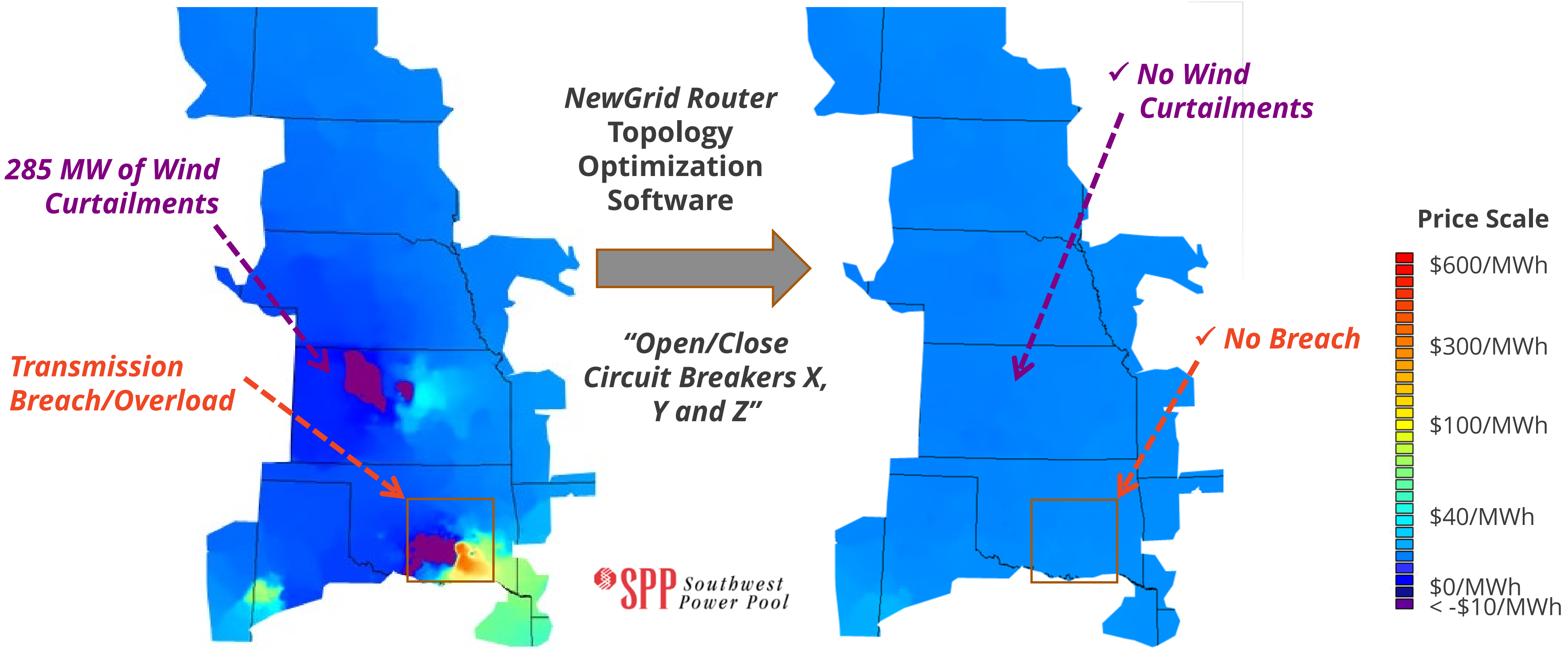
Less risk. More power.

Topology Optimization

Topology optimization software technology automatically finds reconfigurations to reroute flow around congested elements ("Waze for the transmission grid")

SPP Historical Case
(March 10, 2018 20:10 CST,
38% Wind Penetration)

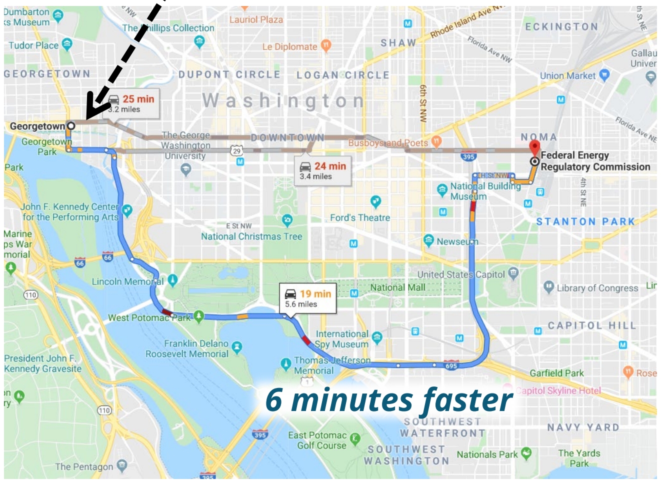
With Reconfigurations
(3 actions, 1 per constraint
in Historical Case)



Reconfiguration Implementation

Topology optimization is analogous to Waze: "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
- **Reconfigurations are implementable today!**
  - *Switching infrastructure is already in place:*
    - Most breakers are controlled remotely over SCADA by the TO
    - Phone call between TO and RTO to coordinate operations
  - *Circuit breakers are capable of high duty cycles & extremely reliable*
    - Two designs: 2k or 10k switching cycles per maintenance overhaul
    - Some breakers are switched very frequently today, e.g., those connecting generating units with daily start and stop
    - Failure occurs less than once in 20,000 switching cycles*
  - *Low cost*: usually $10-$100 per switching cycle**



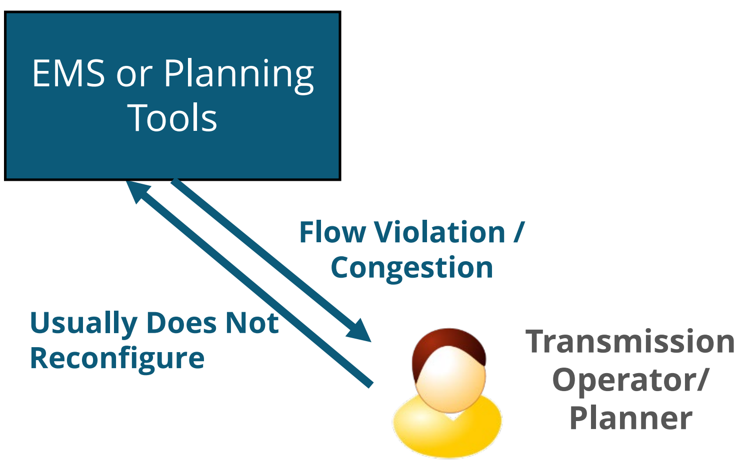
* For single-pressure SF6 breakers. Based on a CIGRE survey of 281,090 breaker-years with responses from 82 utilities from 26 countries, source: A. Janssen, D. Makareinis and C.-E. Sölver, "International surveys on circuit-breaker reliability data for substation and system studies," *IEEE Transactions on Power Delivery*, v. 29, n. 2, April 2014, pp. 808-814

** All-in cost of maintenance overhauls for single-pressure SF6 breakers rated 72.5-362 kV.

Reconfiguration Practice

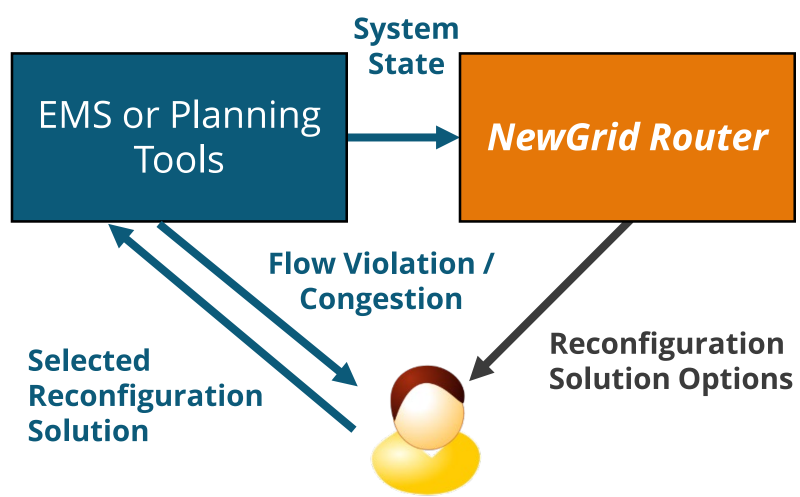
Traditional Practice

- Reconfigurations identified based on staff experience
  - Time-consuming process
  - Depends on expert operators
- Already employed to a limited extent, on an ad-hoc basis
  - Operating Guides
  - Remedial Action Plans
- Solutions are blunt instruments, they are not developed for current system conditions
- Transmission grid flexibility underutilized



With Topology Optimization

- ✓ Software finds reconfiguration solution *options*
  - Fast search time: 10 s – 2 min
  - Enables all operators to optimize the grid
- ✓ Enables broad application of reconfigurations in different processes
- ✓ Know when to restore/close open assets
- ✓ Analyzes current system conditions, continue to optimize as conditions change
- ✓ Take full advantage of grid flexibility



Applications

Topology optimization can support business processes across many scales. It is particularly effective as an operations support tool.

Real-time

- **Adapt to emergency system conditions**, increasing grid resilience
- Relieve N-1 flow violations
- Minimize RUC and manual unit starts for constraint management

Intra-Day

- Unlock capacity from export-constrained areas
- **Minimize congestion costs** in the real-time market
- Reduce renewables curtailments

Day-ahead

- Pre-position the system topology to match expected conditions
- Minimize congestion costs in the day-ahead market
- Support **outage scheduling and coordination** (enable conflicting tickets)

Weeks Ahead

- Mitigate the expected congestion impacts of outages
- **Develop Op. Guides** for extreme events that minimize load shedding
- Adjust underlying system topology when new projects are energized

Long-Term

- Optimize transmission expansion portfolio
- Maximize the benefit-to-cost ratio of new projects

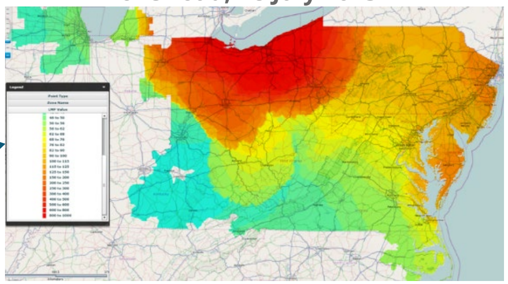
Proven Real-World Results

Adapting the grid configuration to best address system conditions provides reliability and economic benefits:

Improve Grid Resilience and Reliability

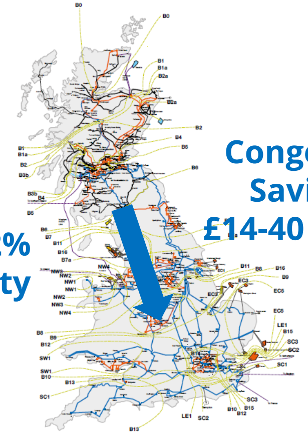
- **Full overload relief with outage conditions, extreme weather events** (MISO, PJM, SPP)
- Avoid load shedding under critical contingencies (ERCOT, SPP)
- Reduce frequency of intervals with constraint violations by 75% (SPP)

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



Increase Transfer Capability

- *Large interface constraints*: **+3 to 12% capability** (Great Britain)
- *Single-element constraints*: average flow relief over 20% (SPP, ERCOT)



+ 3 to 12% Capability

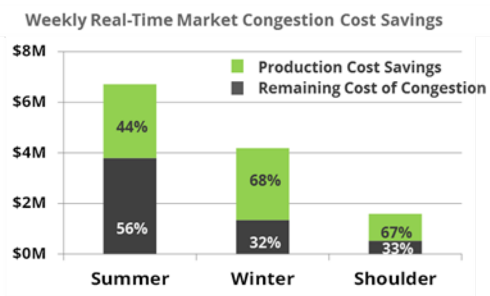
Congestion Savings: £14-40 million

Reduce Congestion Costs

Real Time market congestion 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)



Case Study 1: MISO North

Congestion Relief during Polar Vortex 2014

During the Polar Vortex event of 2014, Brattle supported a utility in the upper Midwest to mitigate congestion and overloads under those critical conditions.

- Severe transmission congestion affected the upper Midwest:
  - Record-setting high loads in MISO North due to extreme cold weather
  - Substantial number of unplanned generation outages due to cold weather
  - Extended 230 kV planned transmission outages

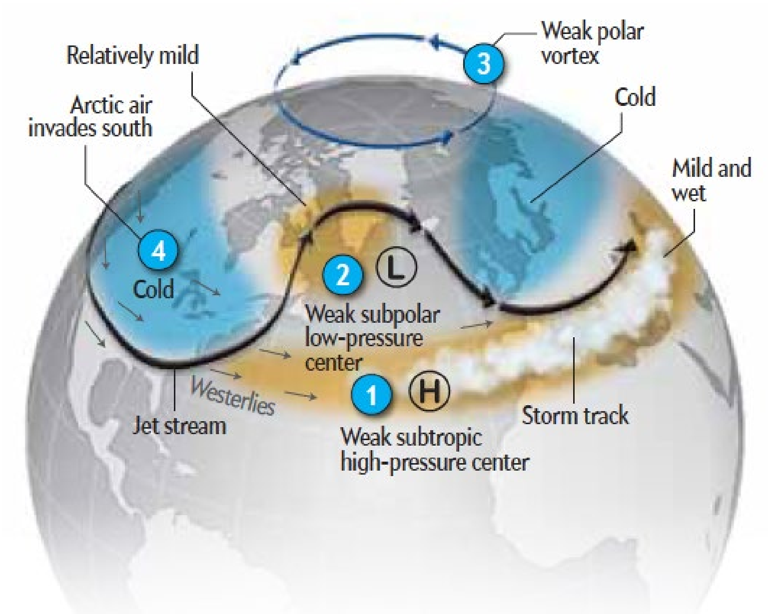


Figure Source: http://blogs.scientificamerican.com

- The cost of electricity to customers in the area increased by over $15 million in the first 10 weeks of 2014 due to congestion.
  - Load energy prices in the affected areas at times more than doubled the corresponding generation energy prices.

- Using topology optimization we identified reconfiguration solutions that relieved much of the congestion and overloads. The solutions were implemented after validation by MISO and the transmission owners in the area.

Avoiding Non-Consequential Load Loss

- NERC allows load shedding as part of the *Corrective Action Plan* (CAP) for specified planning events that involve multiple transmission outages which would otherwise result in NERC TPL-001-4 violations.*

- SPP identified three severe multiple-contingency events whose CAPs rely on load shedding (re-dispatch is ineffective):
  - *P6 Event*: multiple contingency – two overlapping single contingencies.
  - *P7 Event*: multiple contingency – loss of a common structure.
  - *Extreme Event*: loss of a transmission corridor, of an entire substation or power plant, or of multiple elements due to a regional event.

* NERC Standard TPL-001-4 — Transmission System Planning Performance Requirements.

Case Study 2: SPP Long-Term Planning

Avoiding Non-Consequential Load Loss

We found corrective reconfigurations that:

- Fully relieve the violations *without load shedding,* and
- Do not cause other violations.

Case Study Type	Flow on Violated Branch Initial [% of Rating]	With Solution [% of Rating]	Avoided Load Loss [MW]	No. of Actions	No. of New Constraints >95% flow	>100% flow	<0.9 pu volt	Radialized Load [MW]
P6 Event	129%	86%	243	2	1	0	0	65
P7 Event	107%	94%	55	2	0	0	0	0
Extreme Event	113%	97%	151	1	0	0	0	0

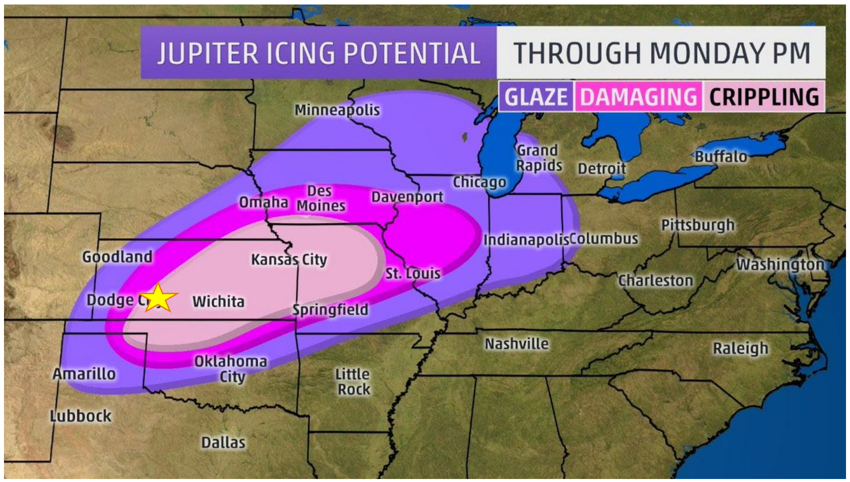
* NERC Standard TPL-001-4 — Transmission System Planning Performance Requirements.

Case Study 3: Ice Buildup Mitigation

January 15-16 2017 Winter Storm Jupiter

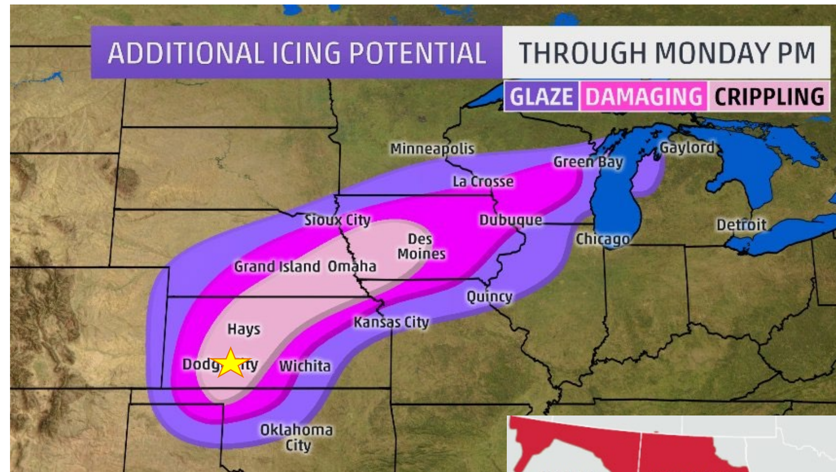
Jupiter caused "crippling" icing in the Dodge City area, leading to multiple transmission outages.

Icing Forecast, January 12, 2017, 2pm



Source: weather.com

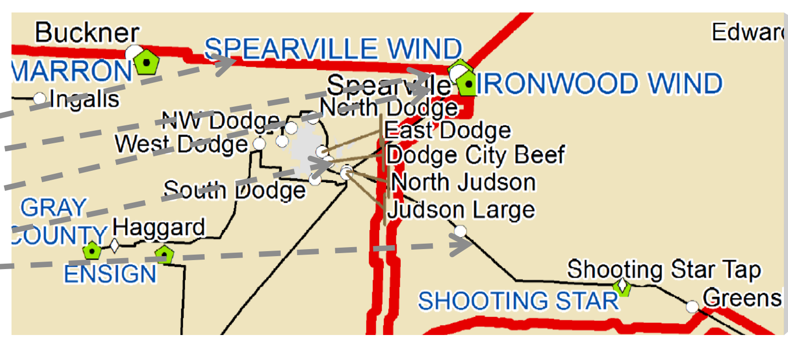
Icing Forecast, January 15, 2017, 2pm



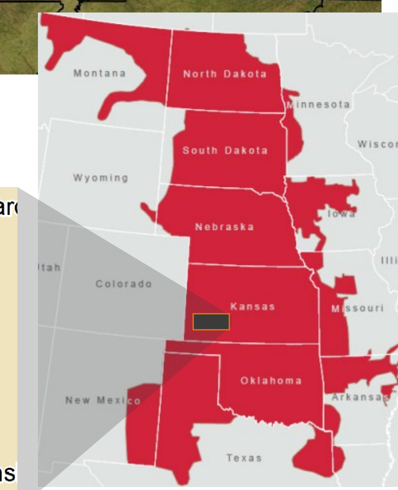
Source: weather.com

Outages Near Dodge City

1. FORD – SHOOTING STAR 115 kV
2. SPEARVILLE 345/115 kV XFMR
3. SPEARVILLE 230/115 kV XFMR
4. N. FT. DODGE – S. DODGE 115 kV
5. BUCKNER – SPEARVILLE 345 kV



Source: Southwest Power Pool

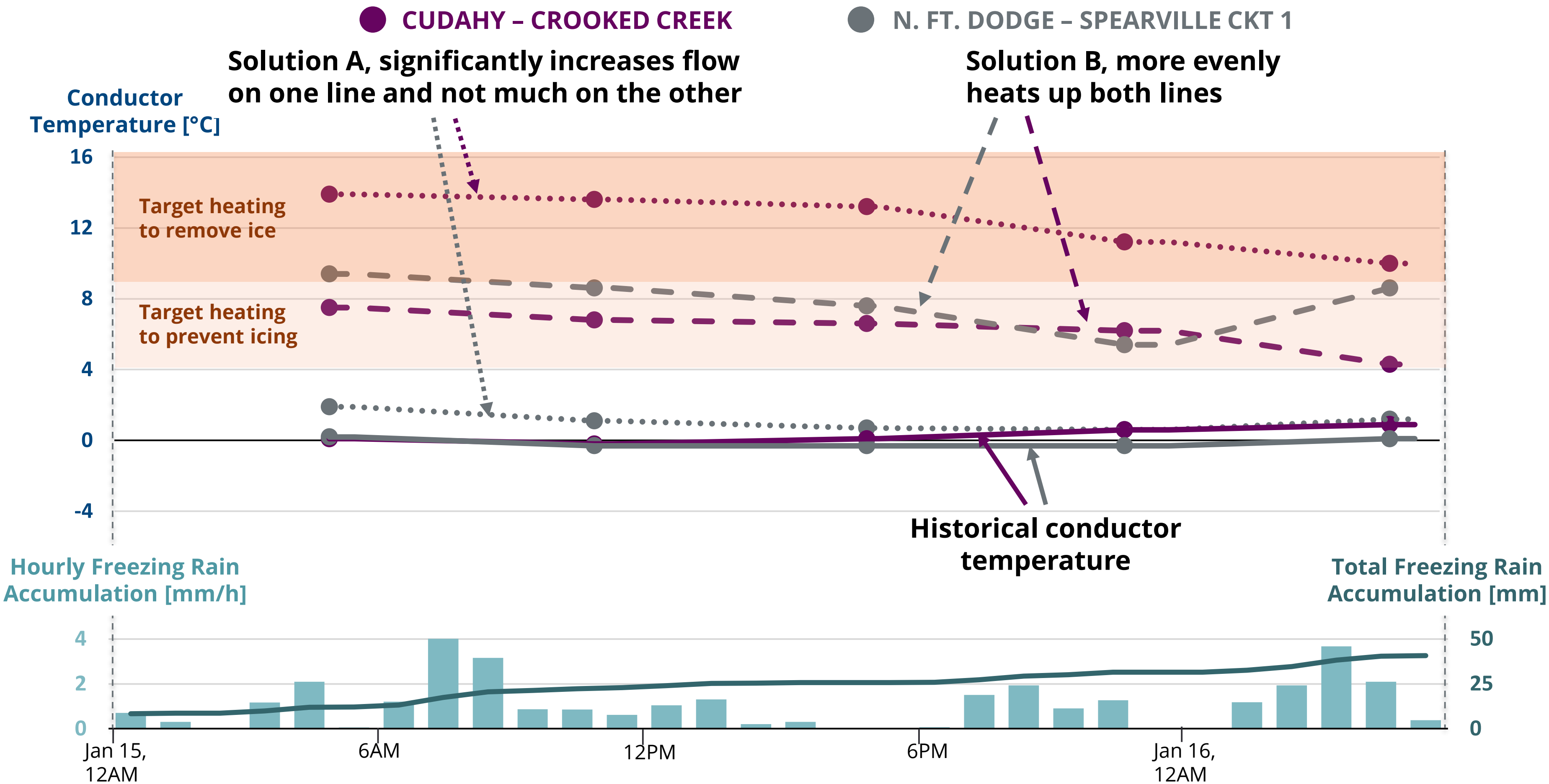


Source: ISO/RTO Council

Case Study 3: Ice Buildup Mitigation

Reconfigurations to Prevent/Remove Ice

Two reconfigurations significantly increase heating on critical lines specified by Sunflower Electric and SPP.



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LESS RISK. MORE POWER.

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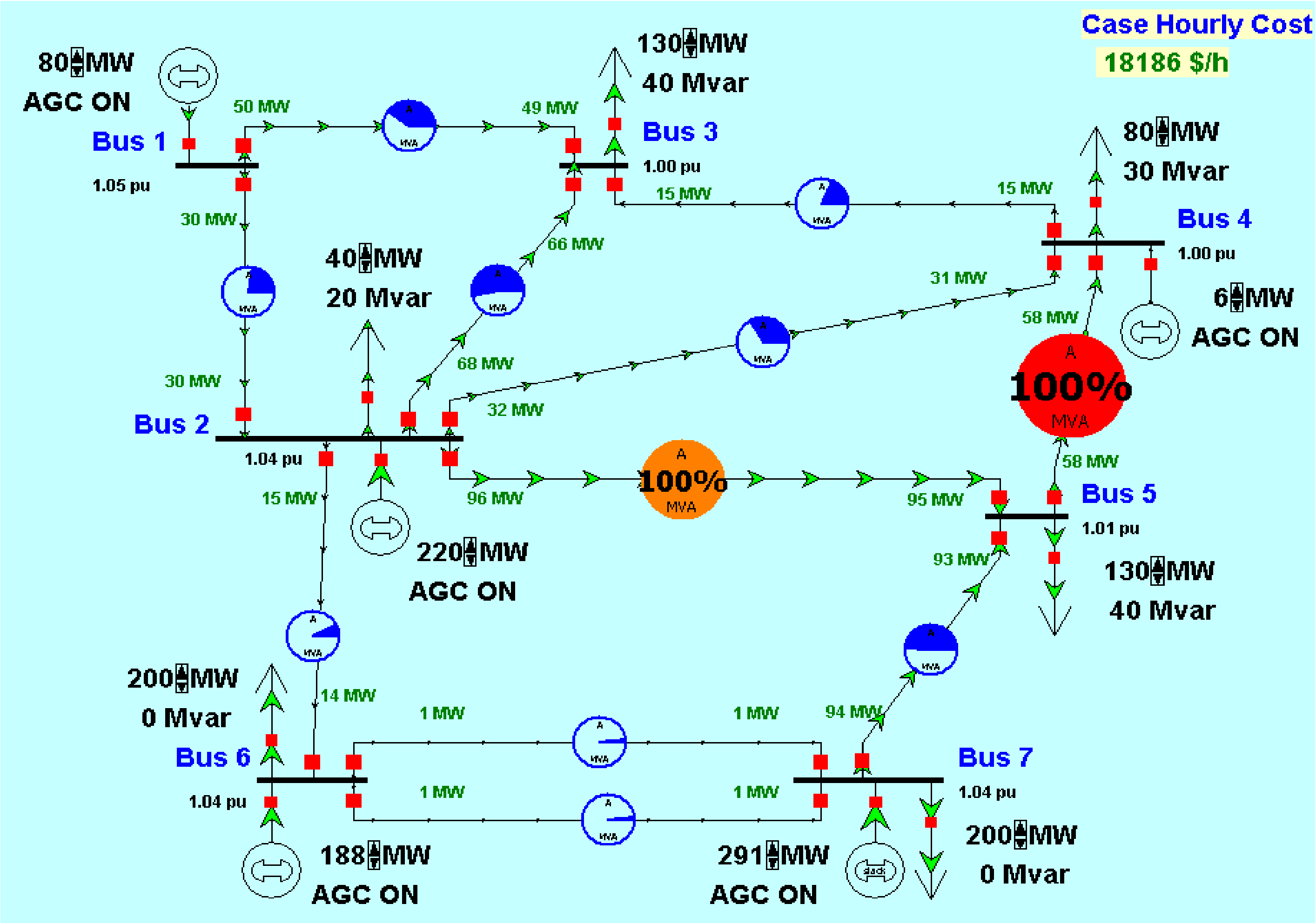
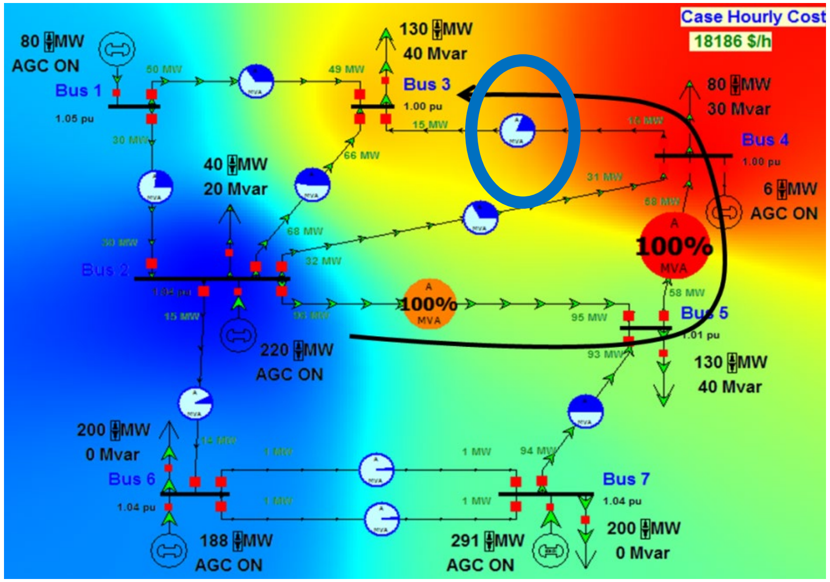
Illustrative Example

7-bus Example: All Lines Closed

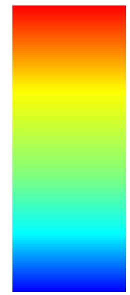


7-bus Example Results: Before and After

Before: all lines Closed



$40/MWh

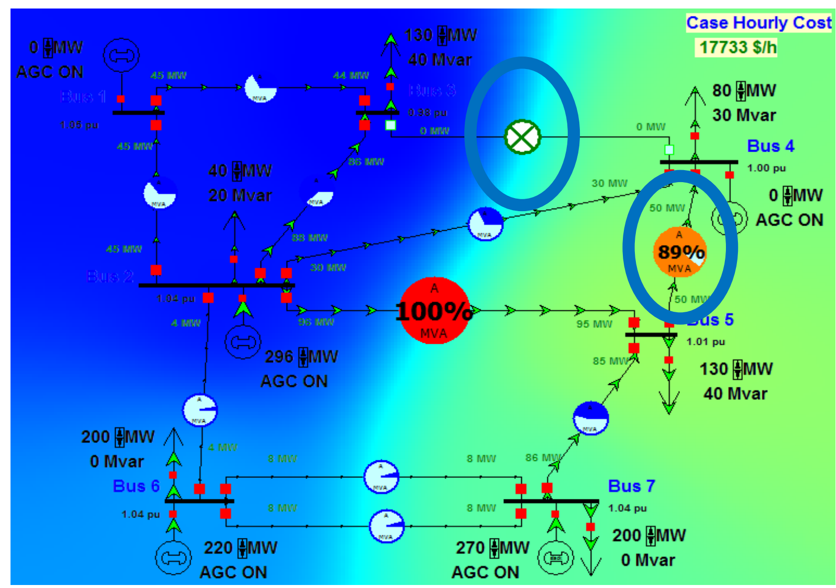


$15/MWh

Hourly Cost	
All lines Closed:	$18,186
Line 3-4 Opened:	$17,733
Savings:	$453

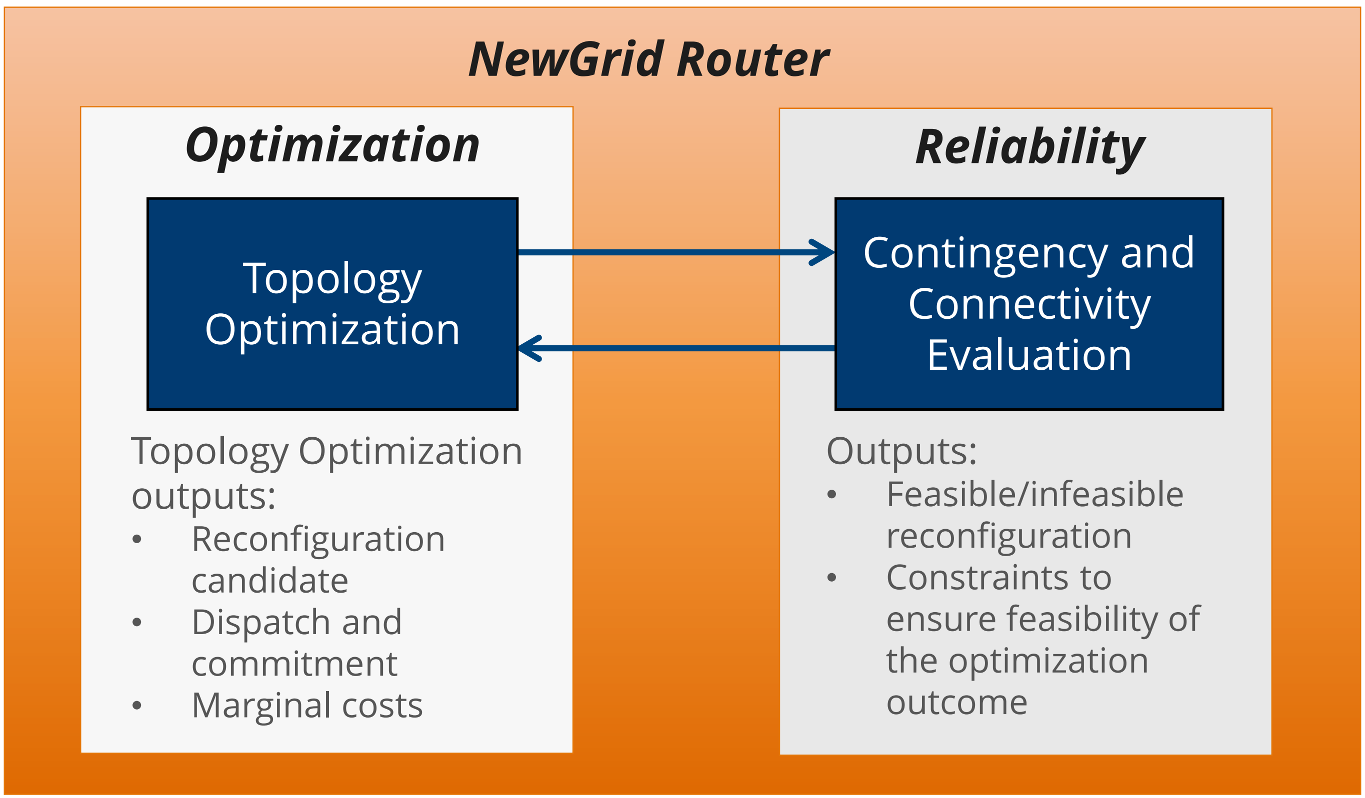
Generation	All lines closed	Line 3-4 open
Bus 1	80 MW	0 MW
Bus 2	220 MW	296 MW
Bus 4	6 MW	0 MW
Bus 6	188 MW	220 MW
Bus 7	291 MW	270 MW
Total	785 MW	786 MW

After: line 3-4 Opened



Reconfigurations Meet Reliability Criteria

The reconfigurations are feasible under all specified contingencies (e.g., do not introduce new problems, and are consistent with mitigating the ongoing risks in operations) and do not radialize load beyond a user-specified value. They can be validated for transient and/or voltage stability performance as needed using existing software tools.



A Path For Technology Implementation

Incremental implementation stages provide increasing resilience benefits.

I. **Market Participants** (MP) use technology to identify solutions, request evaluation and implementation to RTOs (RCs in non-RTO regions) and TOs
   - Simplest first step for ratepayers to capture the low-hanging fruit in congestion mitigation right away
   - The burden to find the solutions is on market participants
   - RTOs, RCs and TOs need not deploy topology optimization software, they already have the required software to evaluate requests (similar to outage requests)
   - Least effort required from RTO, RC and TO staff (reconfiguration request evaluation is similar to outage request evaluation)

II. RTO, RC and TO staff uses the technology in **operations planning** applications
   - Off-line advisory tool deployed at RTOs to support outage coordination and Op. Guide development.
   - Minimal integration with EMS or other tools – transfer data through power flow case files

III. RTO and RC staff uses the technology for **real-time operations support**
   - Software integrated with RTO and RC EMS
   - Online advisory tool, provides reconfiguration options to shift engineers for their consideration

IV. RTO uses the technology as part of **market clearing**
   - Software integrated with RTO MMS for day-ahead and real-time market clearing
   - Software integrated with RTO FTR (or similar) market clearing engine
   - Pre-approved reconfigurations from the previous processes (I – III) are provided as inputs to market clearing engines

Appendix

References (I/II)

[1] P. A. Ruiz and X. Li, "Transmission Topology Optimization to Efficiently Mitigate Congestion & Overloads," at *FERC Tech Conf on Increasing Market Efficiency through Improved Software*, Docket AD10-12-012, Washington, DC, June 2021. [Online]

[2] R. MacLaren, P. A. Ruiz and J. Caspary, "New Constraint Management Techniques for Meshed Transmission and Active Distribution Networks," CIGRE UK Technical Webinar, Dec 2020. [Online] https://drive.google.com/file/d/1Hz4cwnUXdpAUW-1COGCqrW4AuhMtRR8u/view?usp=sharing

[3] T. B. Tsuchida and R. Gramlich, "Improving transmission operation with advanced technologies: a review of deployment experience and analysis of incentives," White Paper, June 2019. [Online] https://www.brattle.com/news-and-knowledge/publications/improving-transmission-operation-with-advanced-technologies-a-review-of-deployment-experience-and-analysis-of-incentives

[4] P. A. Ruiz and J. Caspary, Transmission Topology Optimization – A Software Solution for Improving Congestion Management," ESIG Webinar, June 2019, [Online] https://www.esig.energy/event/webinar-transmission-topology-optimization-a-software-solution-for-improving-congestion-management/

[5] P. A. Ruiz and K. Dial, "Transmission topology optimization: SPP Pilot and Study, and Thoughts on Implementation," presented at *SPP Operating Reliability Working Group Meeting*, Feb 2020. [Online] https://spp.org/Documents/61418/ORWG%20Meeting%20Materials%2002-06-20.zip

[6] P. A. Ruiz and N. Steffan, "Transmission topology optimization: operations and market applications and case studies," presented at *ERCOT Demand Side Working Group Meeting*, Austin, TX, Nov 2017. [Online] http://ercot.com/content/wcm/key_documents_lists/127739/PRuiz_ERCOT_DSWG_FINAL.pdf

[7] National Grid Electricity Transmission Network Innovation Allowance Annual Summary 2016/2017, Jul 2017, page 14. [Online]https://www.nationalgrid.com/sites/default/files/documents/National%20Grid%20Electricity%20Transmission%20NIA%20Annual%20Summary%202016-17.pdf

[8] National Grid, Network Innovation Allowance Closedown Report, Transmission Network Topology Optimisation, project NIA_NGET0169, Jul 2017. [Online] http://www.smarternetworks.org/project/nia_nget0169/documents

[9] P. A. Ruiz, "Transmission topology optimization software: operations and market applications and case studies," presented at *SPP Technology Expo*, Little Rock, AR, Nov 2016. [Online] https://www.spp.org/Documents/45058/Tech Expo 11 14 16 Agenda & 20Presentations.zip

Appendix

References (II/II)

[10] P. A. Ruiz *et al*, "Transmission topology optimization: simulation of impacts in PJM day-ahead markets," at *FERC Tech Conf on Increasing Market Efficiency through Improved Software*, Docket AD10-12-007, Washington, DC, June 2016. [Online] https://www.ferc.gov/CalendarFiles/20160629114654-2%20-%20PRuiz%20FERCTechConf%2028Jun2016_FINAL_2.pdf

[11] P. A. Ruiz, E. A. Goldis, A. M. Rudkevich, M. C. Caramanis, C. R. Philbrick, and J. M. Foster, "Security-constrained transmission topology control MILP formulation using sensitivity factors," *IEEE Trans on Power Systems*, vol. 32, no. 2, Mar 2017, pp. 1597 – 1605.

[12] E. Goldis, P. A. Ruiz, M. C. Caramanis, X. Li, C. R. Philbrick, A. Rudkevich, "Shift factor-based SCOPF topology control MIP formulations with substation configurations," *IEEE Trans. on Power Systems*, vol. 32, no. 2, Mar 2017, pp. 1179 – 1190.

[13] P. Ruiz *et al*, "Topology Control Algorithms (TCA) – Simulations in PJM Day Ahead Market and Outage Coordination," at *FERC Tech Conf Increasing Market Efficiency through Improved Software*, Docket AD10-12-006, Washington, DC, June 2015. [Online] https://www.ferc.gov/CalendarFiles/20150623084820-W2-A-%201%20-%20RUIZ%20-%20PRuiz%20TCA%20FERC%20Tech%20Conference%202015%20FINAL.pdf

[14] E. A. Goldis, X. Li, M. C. Caramanis, A. M. Rudkevich, P. A. Ruiz, "AC-Based Topology Control Algorithms (TCA) – A PJM Historical Data Case Study," in *Proc. 48th Hawaii Int. Conf. System Science*, January 2015.

[15] P. A. Ruiz, X. Li, and B. Tsuchida, "Transmission Topology Control – Curtailment Reduction through System Reconfiguration," at *Utility Variable-Generation Integration Group Fall Technical Workshop*, San Antonio, TX, Oct 2014.

[16] P. A. Ruiz *et al*, "Transmission Topology Control for System Efficiency: Simulations on PJM Real Time Markets," presented at *2013 IEEE PES General Meeting*, Vancouver, Canada, July 2013.

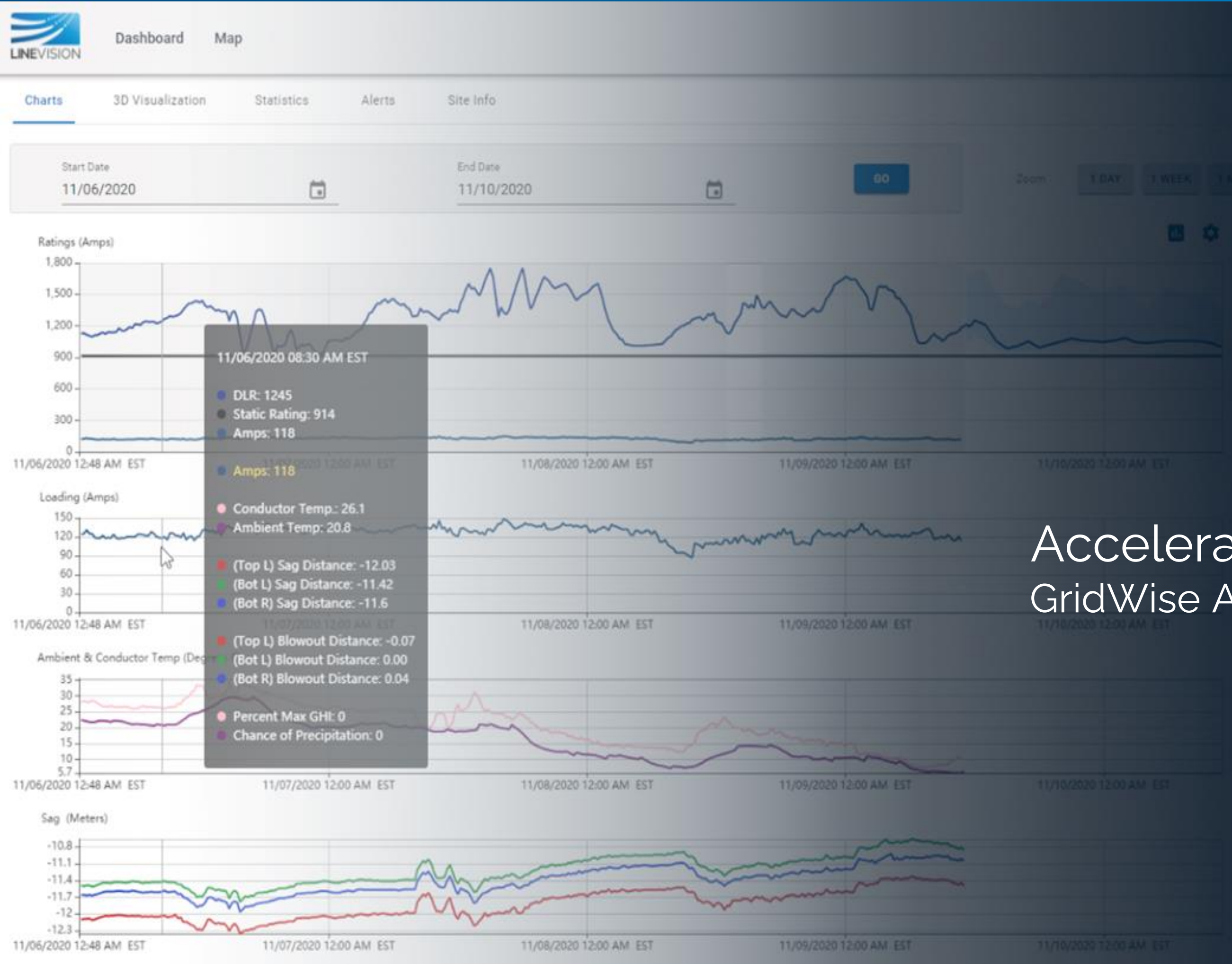
[17] P. A. Ruiz, J. M. Foster, A. Rudkevich and M. C. Caramanis, "Tractable transmission topology control using sensitivity analysis," *IEEE Transactions on Power Systems*, vol. 27, no. 3, Aug 2012, pp. 1550 – 1559.

[18] P. A. Ruiz, J. M. Foster, A. Rudkevich and M. C. Caramanis, "On fast transmission topology control heuristics," in *Proc. 2011 IEEE Power and Energy Soc. Gen. Meeting*, Detroit, MI, July 2011.

[19] R. O'Neill, R. Baldick, U. Helman, M. Rothkopf, and W. Stewart, "Dispatchable transmission in RTO markets," *IEEE Transactions on Power Systems*, vol. 20, no. 1, pp. 171–179, Feb. 2005.

[20] E. B. Fisher, R. P. O'Neill, and M. C. Ferris, "Optimal transmission switching," *IEEE Transactions on Power Systems*, vol. 23, no. 3, pp. 1346–1355, Aug. 2008.

[21] K. W. Hedman, R. P. O'Neill, E. B. Fisher, and S. S. Oren, "Optimal transmission switching with contingency analysis," *IEEE Transactions on Power Systems*, vol. 23, no. 3, pp. 1577–1586, Aug. 2009.



LineVision

Accelerating the Net Zero Grid

GridWise Alliance Technology Council

April 2022

Advanced Monitoring Addresses Numerous Challenges

Grid Expansion

100% growth in grid capacity required by 2035

Intensifying Climate Risk

$90B+ in economic losses from Texas' 2021 storm

Aging & Failing Infrastructure

50% of lines are at or near the end of useful life

Interconnection Backlog

1000 GW of interconnection projects stuck in the queue

LineVision V3 Technologies

Non-Contact LiDAR & EMF Sensors

Patented Technology:

> EMF Power Flow Monitoring
> Non-Contact Conductor Position Monitoring

Scanning LiDAR:

> Continuously measures conductor position
> Secure cloud analytics power advanced insights

Removing Barriers to Adoption

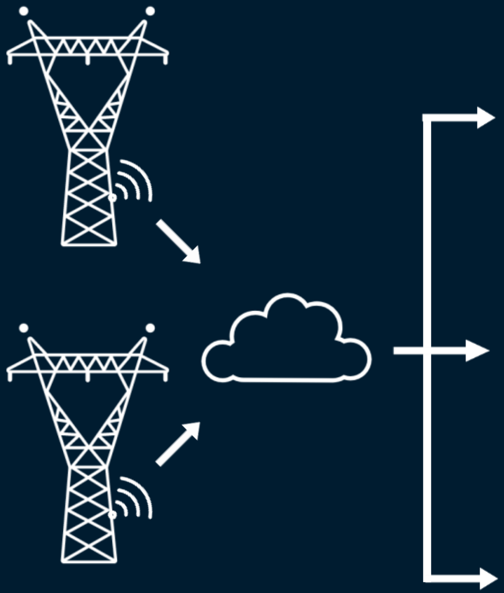
Simplified Installations

> No outages
> No live-line work

Industry Best Accuracy & Analytics

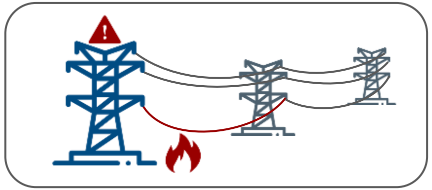
> Data on ALL conductor phases
> Any tower, any voltage, any conductor
> IEEE & CIGRE standards based

One Platform - Multiple Value Solutions
Various Resilience Applications



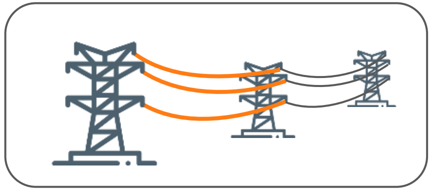
LineAware

Situational Awareness
Inform operators with clearances and horizontal motion data, triggering alerts on exceedances.



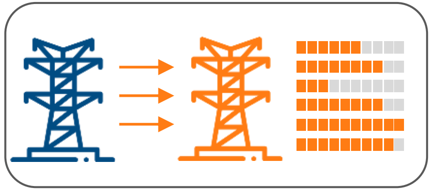
LineRate

Advanced Line Ratings
Increase capacity on lines with Dynamic Line Ratings (DLR) and Ambient Adjusted Ratings (AAR+).



LineHealth

Asset Health Monitoring
Improve maintenance strategies by creating a digital twin to determine conductor health.



FERC Order No. 881
On Managing Transmission Line Ratings

Order No. 881 Requires:

> Transmission providers **implement ambient adjusted ratings** on the transmission lines over which they provide transmission service that are impacted by air temperatures.

> Transmission providers to use uniquely determined emergency ratings for contingency analysis in the operations horizon and in post-contingency simulations of constraints.

Compliance Timeline Obligations:

> Transmission providers must submit compliance filings within 120 days of the effective date of the rule (March 14th)

> All requirements in this rule must be implemented no more than three years from the compliance filing due date.

Additional Considerations:

> This rule applies to all transmission providers under FERC regardless of the status of participation in an RTO/ISO market.

> RTOs and ISOs are required to implement the systems and procedures necessary to allow electronically updated transmission line ratings least hourly.

> FERC will continue to explore the implementation of Dynamic Line Ratings in a new docket AD22-5-000.

LineAware – Situational Awareness

Real-time field verified line information and alerts on conductor motion allows operators and risk managers to protect asset health, system reliability and public safety.

LineAware Output:

> Each phase conductor sag

> Each phase conductor blowout

> Line loading, current

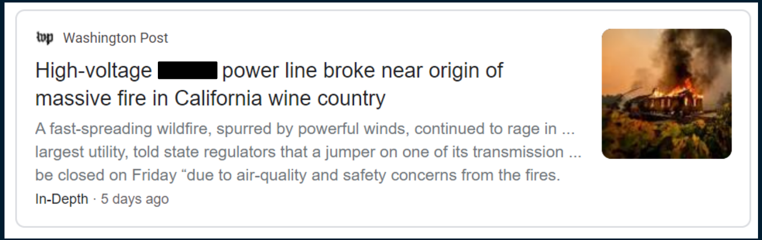
> Icing & galloping detection

> Anomalous conductor motion alerts

> Local ambient weather conditions

LineAware – Safety in Operations

Stay out of the headlines…


Washington Post

High-voltage [redacted] power line broke near origin of massive fire in California wine country

A fast-spreading wildfire, spurred by powerful winds, continued to rage in ... largest utility, told state regulators that a jumper on one of its transmission ... be closed on Friday "due to air-quality and safety concerns from the fires.

In-Depth · 5 days ago

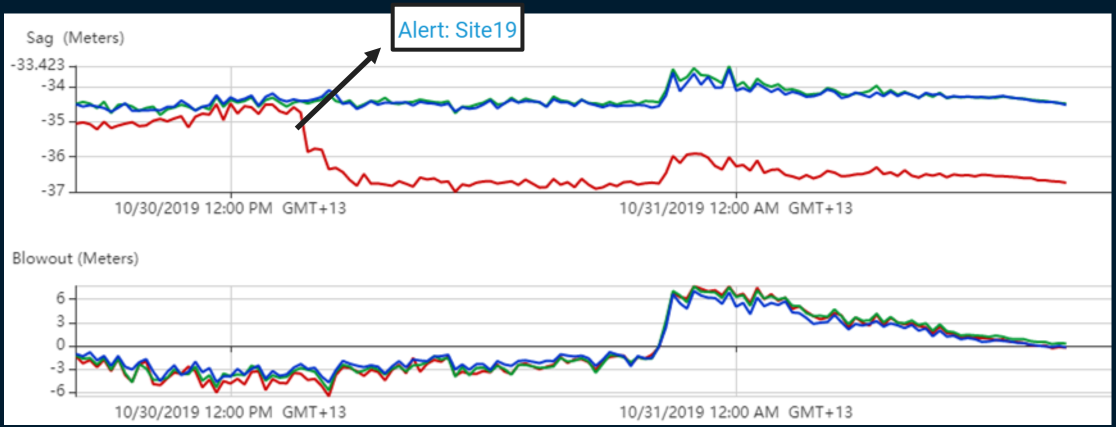

Reuters

California utility [redacted] stock tumbles as wildfire spreads

California utility [redacted] stock tumbles as wildfire spreads ... a damaged high-voltage transmission tower owned by [redacted], which is California's ...

2 days ago

Anomaly detection alerts…



Continuously monitor the position of conductors to confirm they are within safe operating limits.

Prevent damage and fires caused by excessive conductor sag and blowout.

Use verified monitor data in Risk Management Strategies for reporting when called upon.

LineRate - Dynamic Line Ratings

Increase the ratings on existing lines with up to 40% additional capacity.

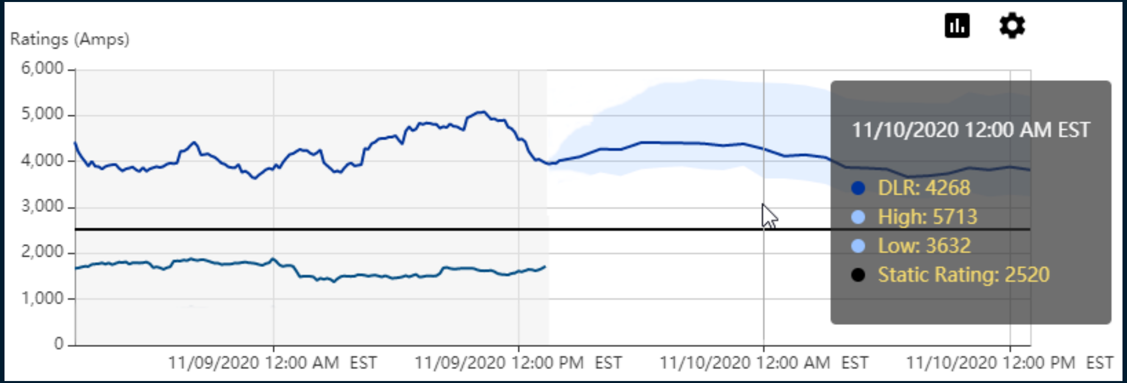
LineRate Output:

> Dynamic Line Rating

> Conductor temperature

> Forecasted line ratings, hourly, up to 240 hours (10 days) out

> Customizable short term and long term emergency ratings



Forecasted line ratings are:

> Customized for the monitored line segment

> Tuned/trained by LineVision real-time monitoring data

> Delivered with Exceedance Probabilities

Integrate real-time and forecasted DLR with system operations with automated data transfers.

LineRate - AAR+

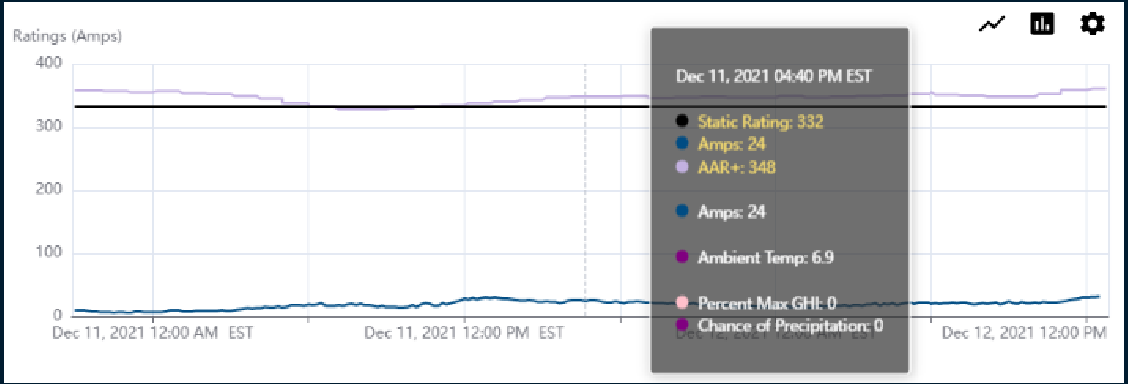
FERC Order 881 Compliant Ambient Adjusted Ratings

LineRate AAR+ Output:

> Ambient Adjusted Ratings

> Forecasted +10 day ratings

> Updated hourly



Reliability and safety ensured:

> Field sensor verified

> Statistically limiting section identified and monitored

> Prevents overestimating capacity

Integrate real-time and forecasted AAR+ with system operations with automated data transfers.

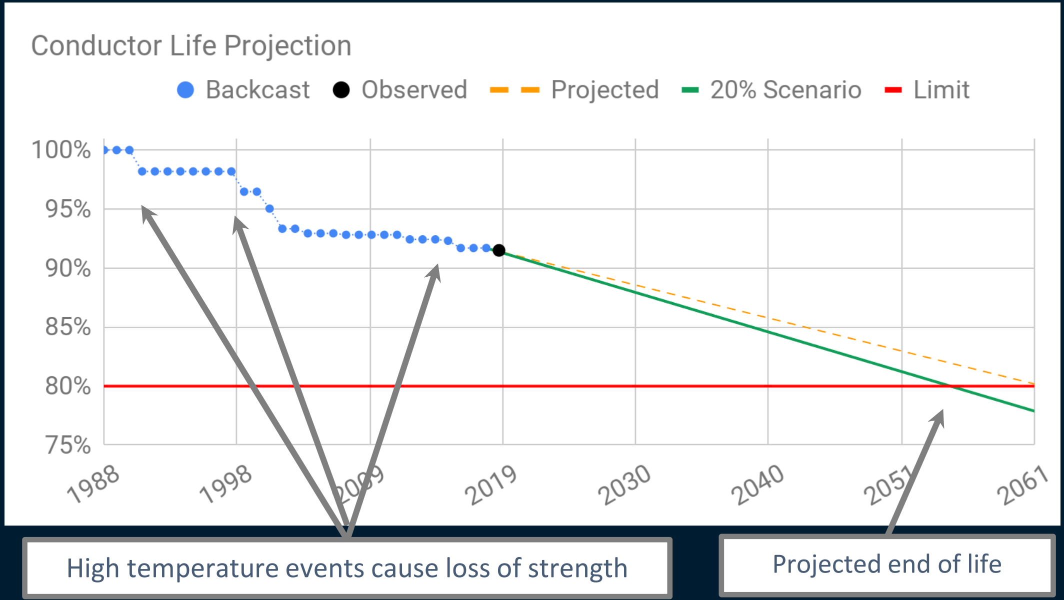
LineHealth – Conductor Asset Health

Create a conductor digital twin and prioritize the repair and replacement of lines that are most critical based on the module's estimation of remaining conductor life.

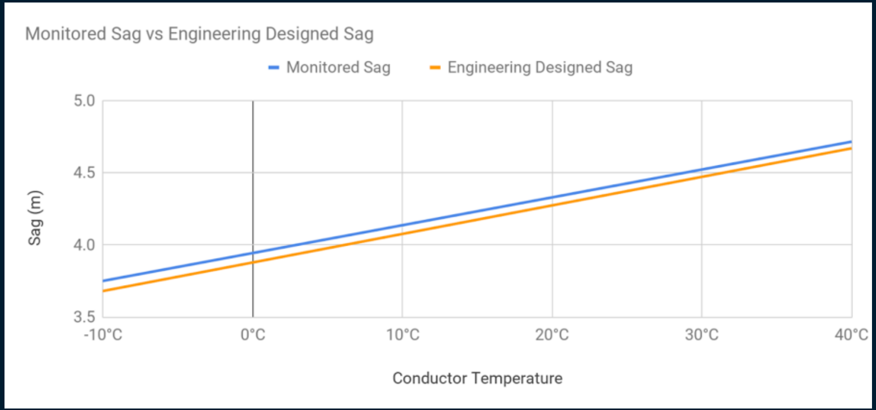
Inputs: Historical SCADA & weather data, engineering designs, V3 sensor measurements

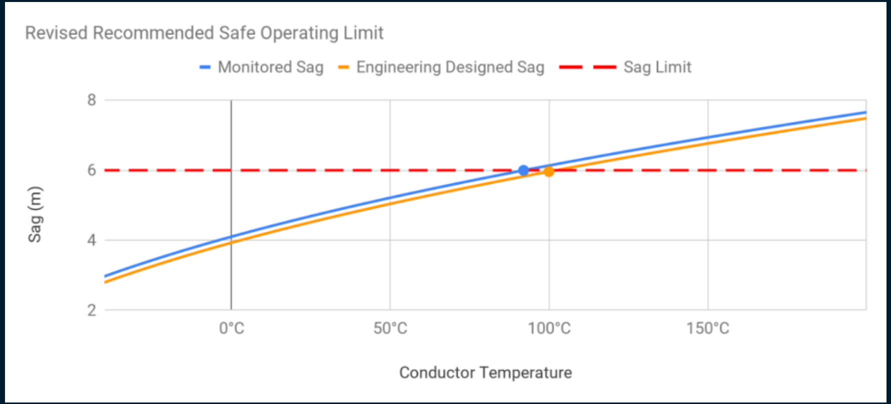
LineHealth Output:

- Loss of strength from historical annealing analysis
- Conductor end of life projection
- Phase by phase observed sag distributions
- Observed sag/temperature relationship curves
- Conductor elongation analysis
- Projected safe maximum operating temperature
- Rated breaking strength evaluation & aeolian vibration risk
- Average conductor temperature for the monitored stringing section



LineHealth –Anomalous Events & Conductor Analysis





Ice Detection
Based on a comparison of *observed* vs *expected* conductor temperature & clearance.

Galloping Detection
Based upon optically observed galloping phenomenon.

Shield / Ground Wire – motion is also able to detected.

Max Tension Calculated – for icing and galloping.

Conductor Performance Analysis
Expected vs observed sag/temperature behavior for lines can indicate loss of strength and damage.

Operating Limit Recharacterization
A new safe Max Operating Temperature is provided.

Optimize Maintenance
Data validating the need for reconductoring or replacement

Real Time: Icing Detection

Continuously monitor the position of conductors while comparing to the expected position.

Monitor Sag

Observe Conductor Displacement

Build a digital twin to understand the expected conductor sag without ice buildup across different weather conditions

Alert on Risk

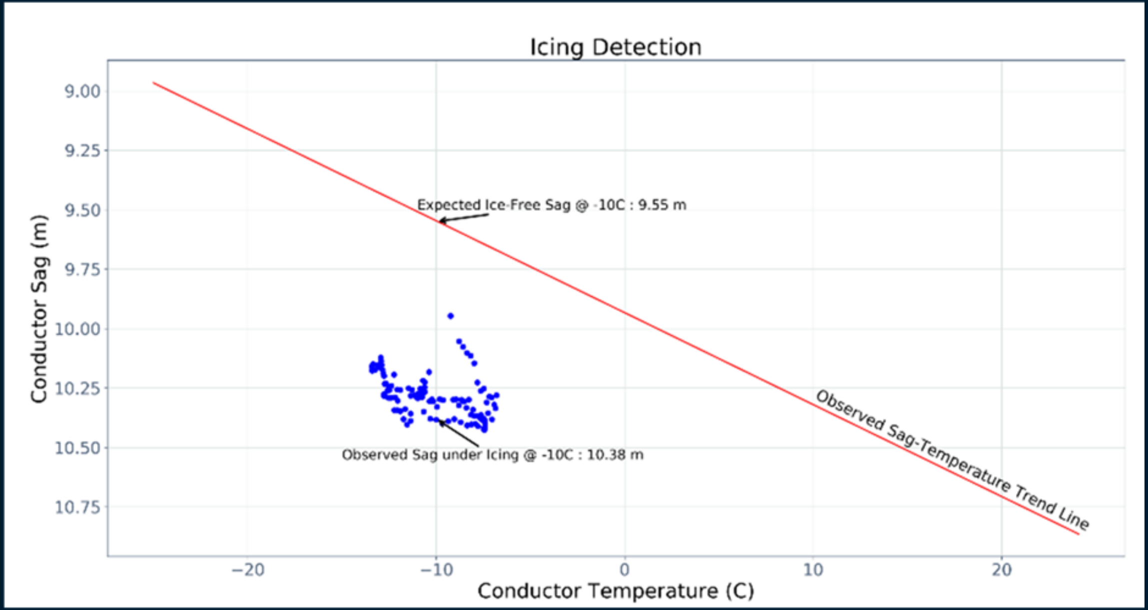
Icing Watch

Alert when conditions may lead to icing such as temperatures below freezing and a nonzero chance of precipitation

Alert on Anomalies

Icing Warning

Alert when observed sag exceeds expected sag, indicating that ice may be causing excess weight on the conductor



Our Approach: Wildfire Risk Mitigation

Continuously monitor the position of conductors to confirm they are within **safe operating limits**.

Monitor Sag/Blowout

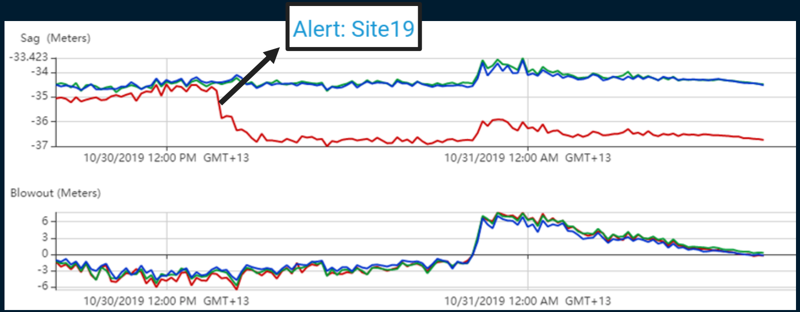
Observe Conductor Displacement
Assess the risk of conductor-slap or contact with nearby vegetation during high wind events

Alert on Anomalies

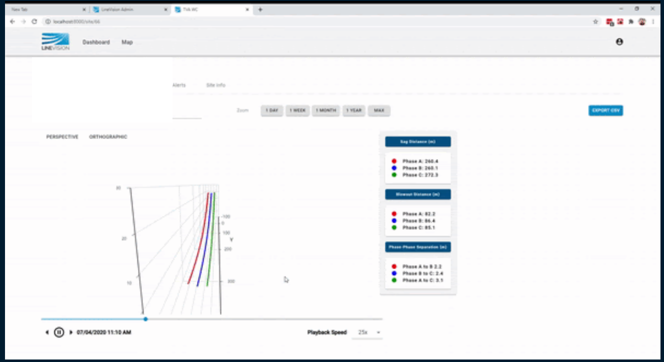
Receive Event Alerts
Conductor in unexpected position, galloping, asynchronous swing, phase-to-phase proximity

Field Verified Information

Documented Data
Keep historical records of horizontal and vertical positions



Customizable Alerts



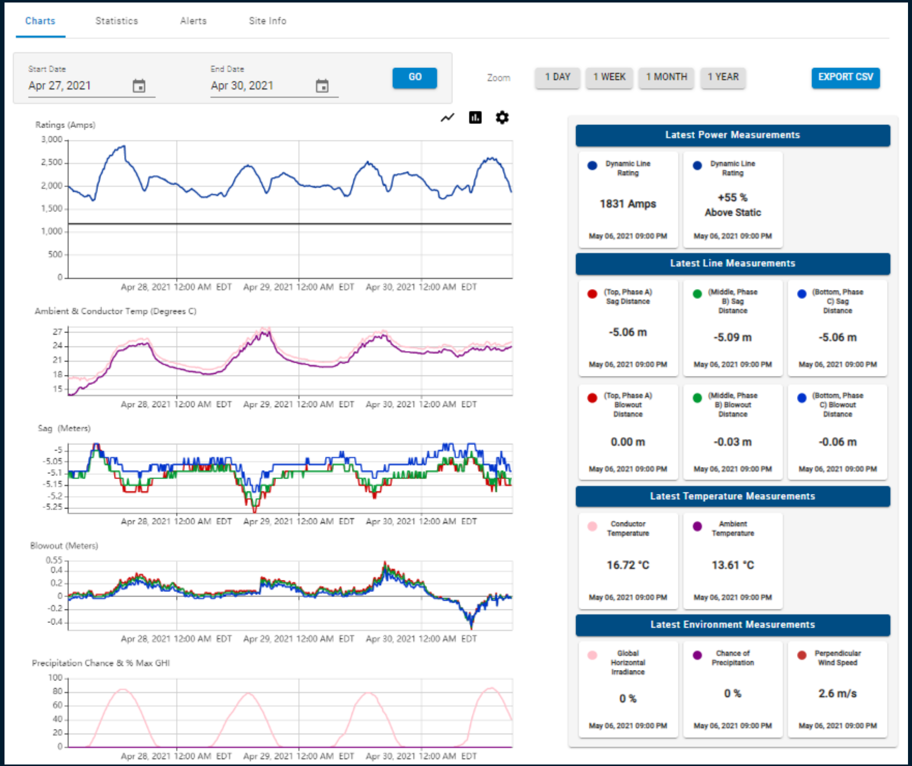
Flexible Installation Configurations

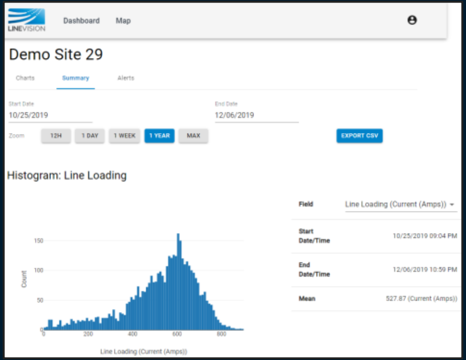
MONOPOLE

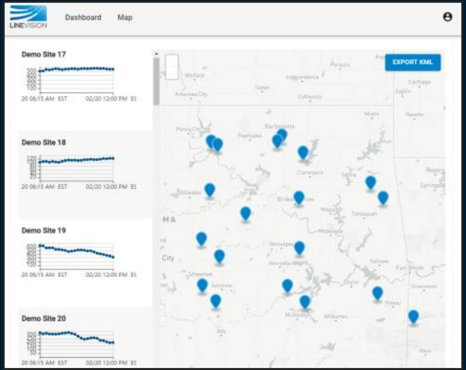
WOOD POLE

LATTICE

Secure Data Portal & Data Feed



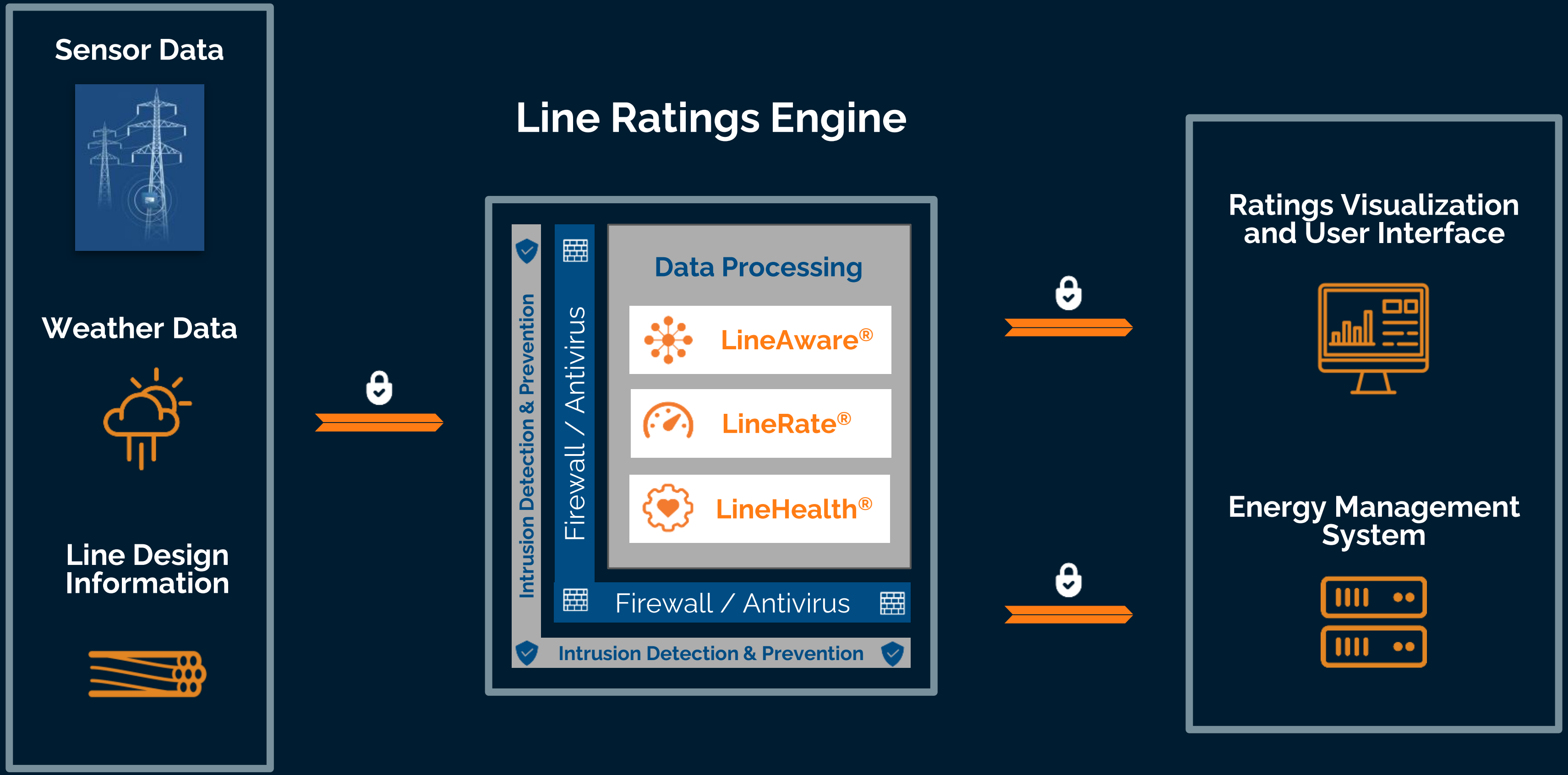




INTERFACE DETAILS:

- Secured via HTTPS
- Client Specific
- Multi-User Access
- Mapping & Statistical Tools
- Configurable Client Alerts
- .CSV Data Download
- API Integration

Advanced Line Ratings Integration



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