Transmission Topology Optimization Case Studies in SPP and ERCOT

Market Efficiency Improvements and Reliability and Resilience Enhancements

Presented by

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FERC Tech. Conf. on Increasing Day-Ahead and Real-Time Market Efficiency and Enhancing Resilience through Improved Software (Docket No. AD10-12-011)

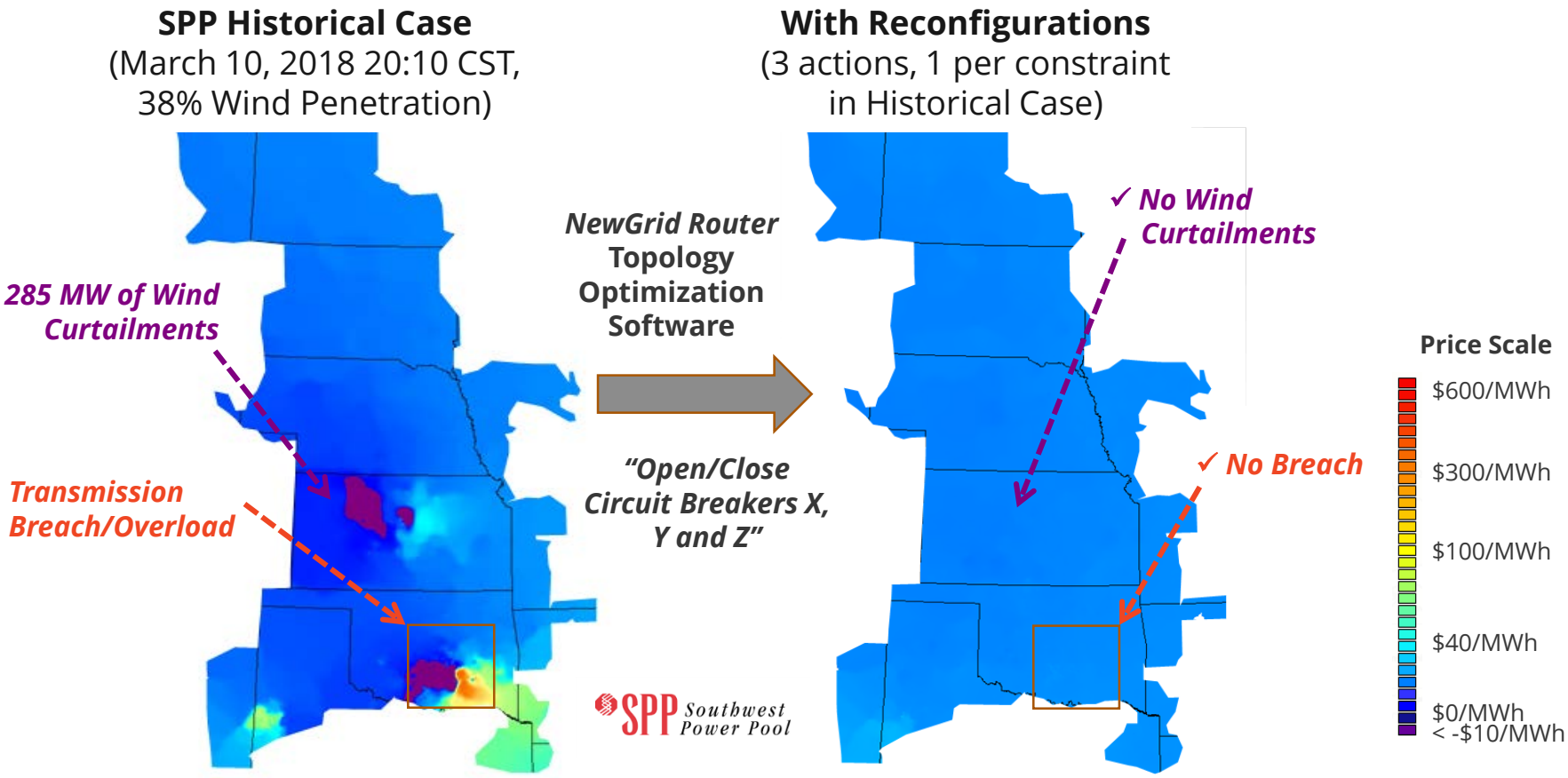
Washington, DC, June 24, 2020

Agenda

- Topology Optimization Technology
  - *Finds reconfiguration options to route around congested/overloaded facilities*
- Reconfigurations: Implementation and Practice
  - *Reconfigurations are applied by switching existing circuit breakers*
- Reliability Criteria and Optimization Scope
  - *Reconfigurations meet operator-specified N-1 and other reliability criteria*
- Applications and Impacts
  - *Reconfigurations adapt the grid to best address system conditions, providing significant resilience, reliability and economic benefits*
- Case Study 1: ERCOT Operations Planning:
  - *Use to validate and select most effective plans, reduce post-contingency load shed actions*
- Case Study 2: SPP Pilot in Operations
  - *Evaluated reconfigurations for 100 flowgates using real-time models, found and validated simple solutions for 55 of them, implemented reconfigurations for some of them*
- Concluding Remarks
- References

Topology Optimization

Topology optimization software technology (developed with DOE ARPA-E support), automatically finds reconfigurations to route flow around congested elements ("Waze for the transmission grid")



Case Study: Overload and Congestion Relief

Found single-action reconfiguration options that fully relieve overloads and congestion on a critical, frequent SPP constraint.

Price Scale

$600/MWh

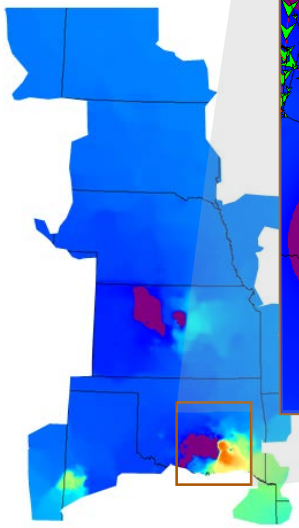
$300/MWh

$100/MWh

$40/MWh

$0/MWh

< -$10/MWh

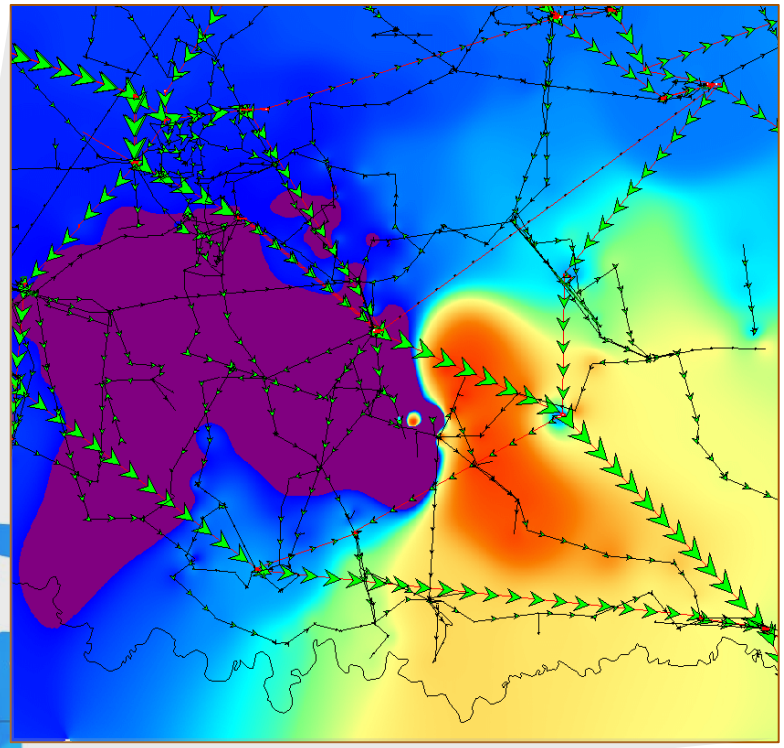


Historical Case

Breached constraint

Shadow price: **$984/MWh**

Third most congested constraint in SPP in 2018*

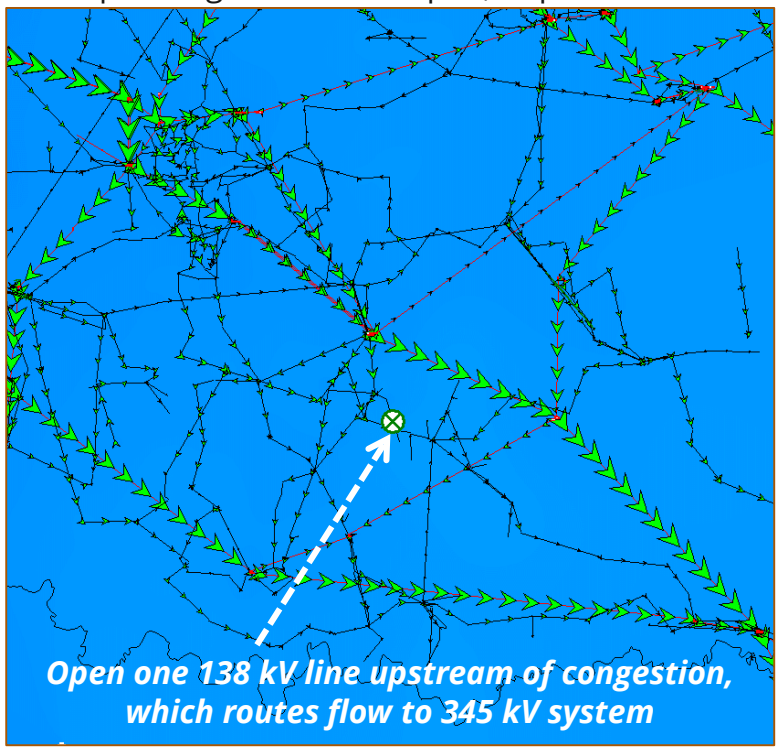


With Reconfiguration

No breach, full congestion relief

Over 25% flow reduction

Operating Guide developed, implemented



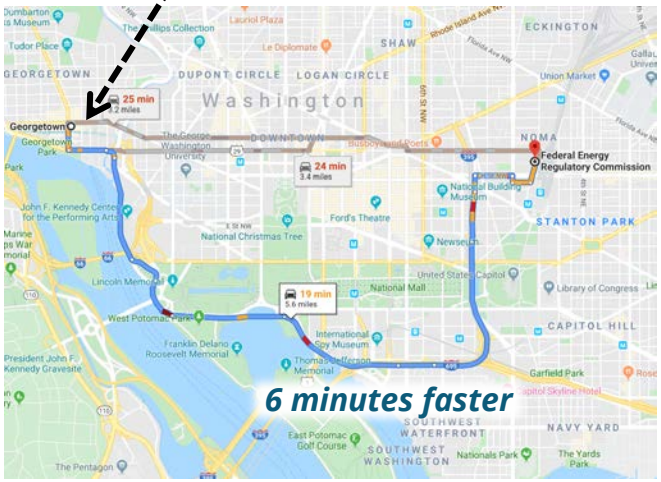
SPP Real Time Market, March 10, 2018, 20:10 CST

* SPP State of the Market 2018, Figure 5-5

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
- Feasibility assessment:
  - *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*
  - *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
  - *Low cost*: usually $10-$100 per switching cycle**



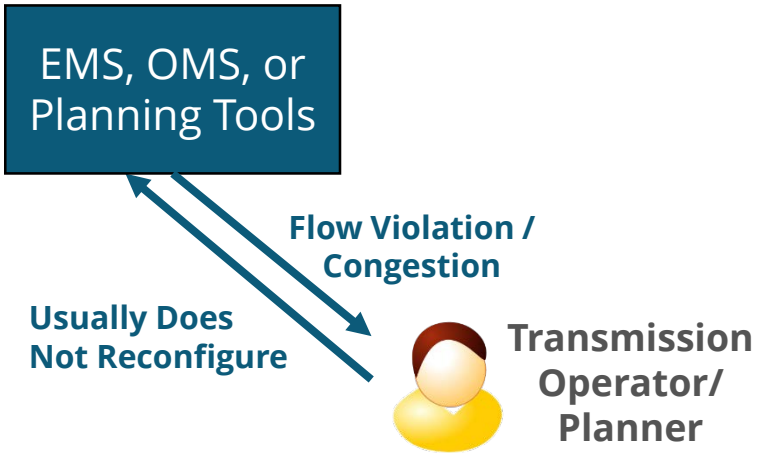
* For single-pressure SF6 breakers. Based on a CIGRE survey of 281,090 breaker-years with responses from 82 utilities from 26 countries, source: A. Janssen, D. Makareinis and C.-E. Sölver, "International surveys on circuit-breaker reliability data for substation and system studies," *IEEE Transactions 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.
Road closure picture from https://www.islandecho.co.uk/plea-motorists-heed-road-closed-signs/

Decision Support (Advisory) Technology

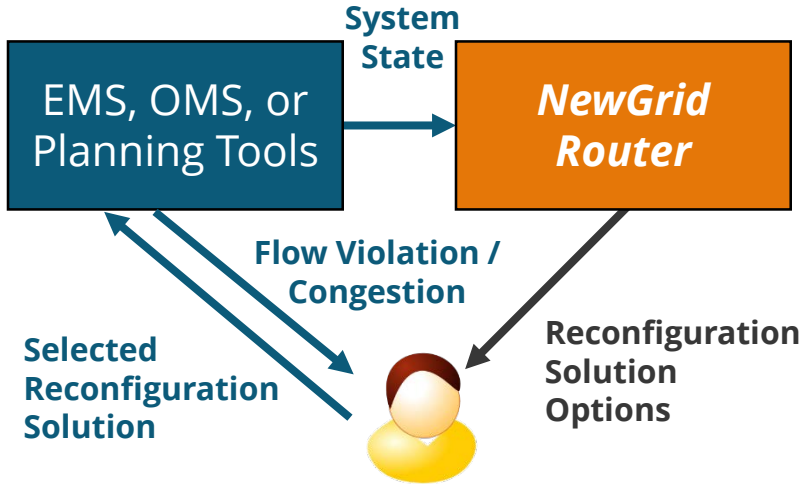
Traditional Practice

- Reconfigurations identified based on staff experience
  - Time-consuming process
  - Depends on expert operators
- Employed to a limited extent, on an ad-hoc basis, mostly for reliability applications
  - PJM Switching Solutions*
  - Operating Guides and RAS
- Solutions are blunt, they are not developed for current system conditions
- Transmission grid flexibility underutilized



With Topology Optimization

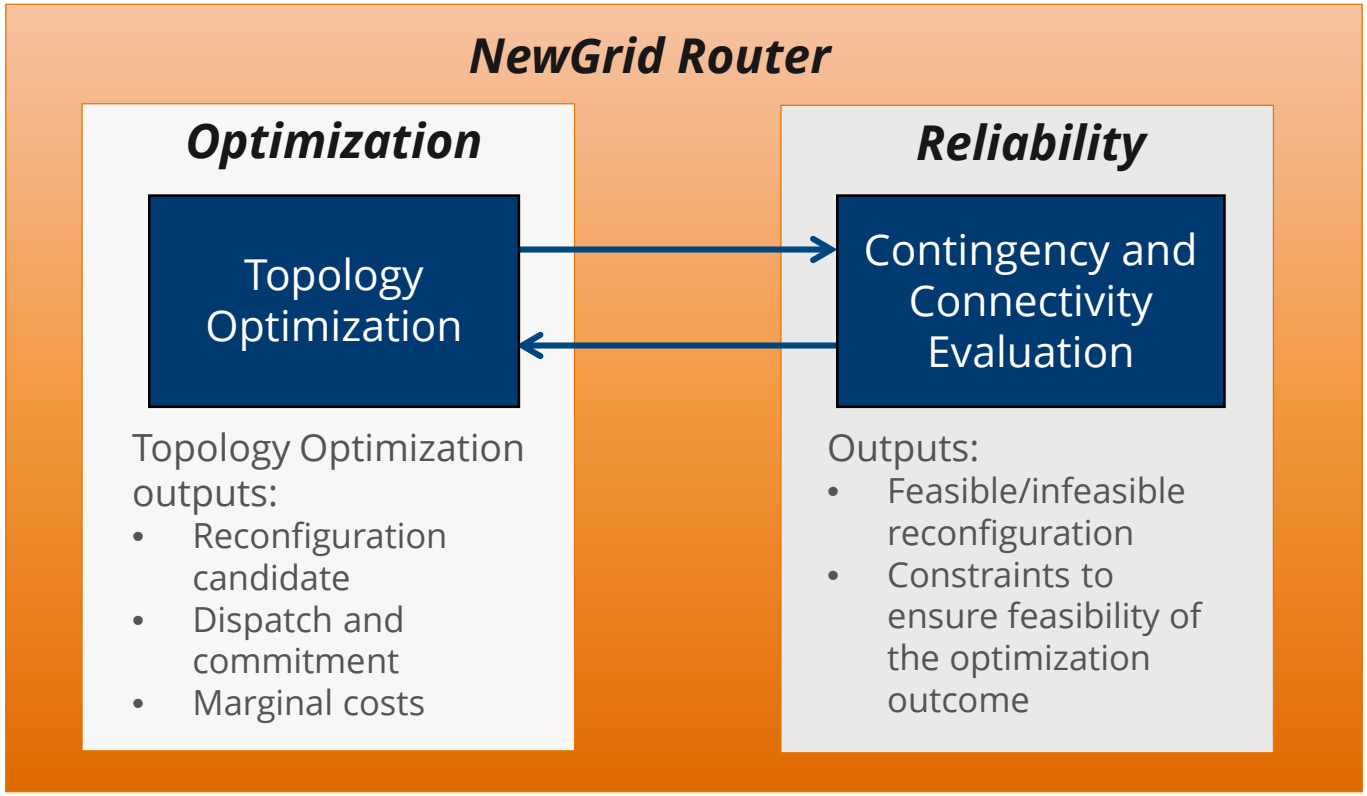
- ✓ Software finds reconfiguration solution *options*
  - Fast search time: 10 s – 2 min
  - Enables all operators to optimize the grid
- ✓ Enables broad application of reconfigurations in different processes
- ✓ Know when to restore/close open assets
- ✓ Analyzes current system conditions, continue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



* See list at https://www.pjm.com/markets-and-operations/etools/oasis/system-information/switching-solutions.aspx.

Reconfigurations Meet Reliability Criteria

The reconfigurations are N-1 feasible (e.g., do not introduce new problems, and are consistent with mitigating the ongoing risks in operations) under all specified contingencies 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.



Optimization Scope

*The optimization routines can search for reconfigurations to relieve **one or multiple simultaneous constraints** across the system, and identify **preventive or corrective solutions**.*

The user selects (either in GUI or through scripts):

- Problem scope:
  - Monitored facilities and their ratings
  - Contingency list
  - Set of constraints to focus search on (e.g., all constraints, or a subset of them)
  - Solution type (preventive or corrective)
  - Search frequency: user requested or continuous ongoing search
- Search space and criteria:
  - Set of switchable branches (e.g., by nominal voltage, by area/zone)
  - Set of non-switchable branches (e.g., branches on outage)
  - When to restore open branches (e.g., minimize number of open branches, or minimize number of switching operations)
  - Maximum load radialization criteria (in MW, can be set to 0 MW)
  - Maximum number of actions
  - Minimum relief required per action

Applications

Topology optimization can support business processes across many scales; relative benefits tend to be higher in operations (real-time and intra-day), given lack of cost-effective alternatives.

Real-time	– Adapt to emergency system conditions, increasing grid resilience – Relieve N-1 flow violations
Intra-Day	– Minimize RUC and manual unit starts for constraint management – 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
Weeks Ahead	– Support outage scheduling and coordination (enable conflicting tickets) – Mitigate the expected congestion impacts of outages – Develop Op. Guides for extreme events that minimize load shedding
Long-Term	– Optimize transmission expansion portfolio – Maximize the benefit-to-cost ratio of new projects

Benefits Quantified in Case Studies

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)*

Increase Transfer Capability

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

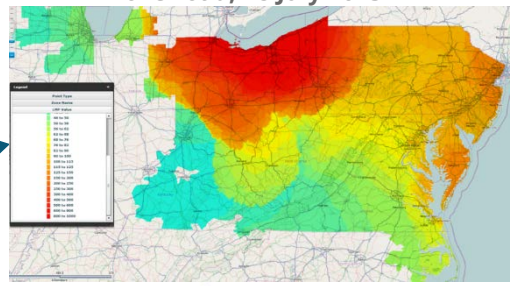
Reduce Congestion Costs

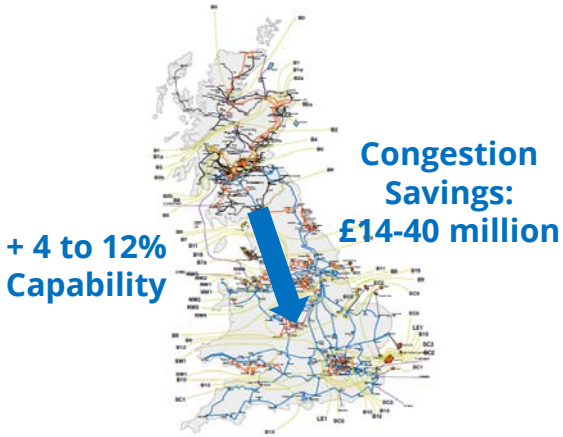
Real Time market congestion cost savings:

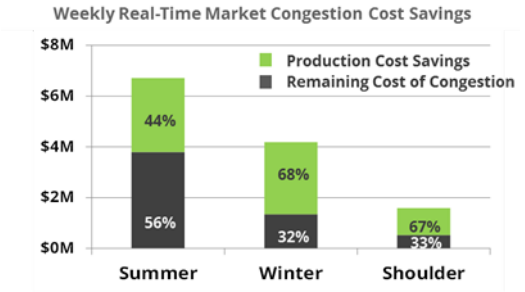
- **$100+ million/year savings** (PJM)†
- $18-44 million/year (SPP)††
- £14-40 million/year (Great Britain)**

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

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







* See references [1, 3, 4, 8, 12] in the Appendix.
** See references [5, 6] in the Appendix.
*** See references [3, 4] in the Appendix.
† See reference [8] in the Appendix.
†† See reference [3] in the Appendix.

Case Study 1

Ops Planning Support in ERCOT

- "A Constraint Management Plans (CMP) is a set of pre-defined… transmission system actions… executed in response to system conditions to prevent or to resolve… transmission security violations or to optimize the transmission system… ERCOT will employ CMPs to facilitate the market use of the ERCOT Transmission Grid, while maintaining system security and reliability…" *
- For the past four years, ERCOT has utilized NewGrid Router to support its Annual CMP Review:
  - Search for reconfigurations to replace mitigation plans that employ post-contingency load-shed.
  - In some cases, **identified such alternative solutions and removed post-contingency load shedding actions from the plans**.
  - Helped analyze and select the most effective corrective and preventive reconfiguration plans,** by providing alternative switching actions and their analysis for comparison and verification purposes.
- ERCOT has also used NewGrid Router to search for possible switching solutions for irresolvable constraints, outside of the Annual CMP Review.
  - When no solutions are found, confirmed that constraints are irresolvable.

* *ERCOT Nodal Protocols*, Section 2, June 10, 2020, page 13.
** Remedial Action Plans (RAPs) and Pre-Contingency Action Plans (PCAPs), respectively.

Case Study 2

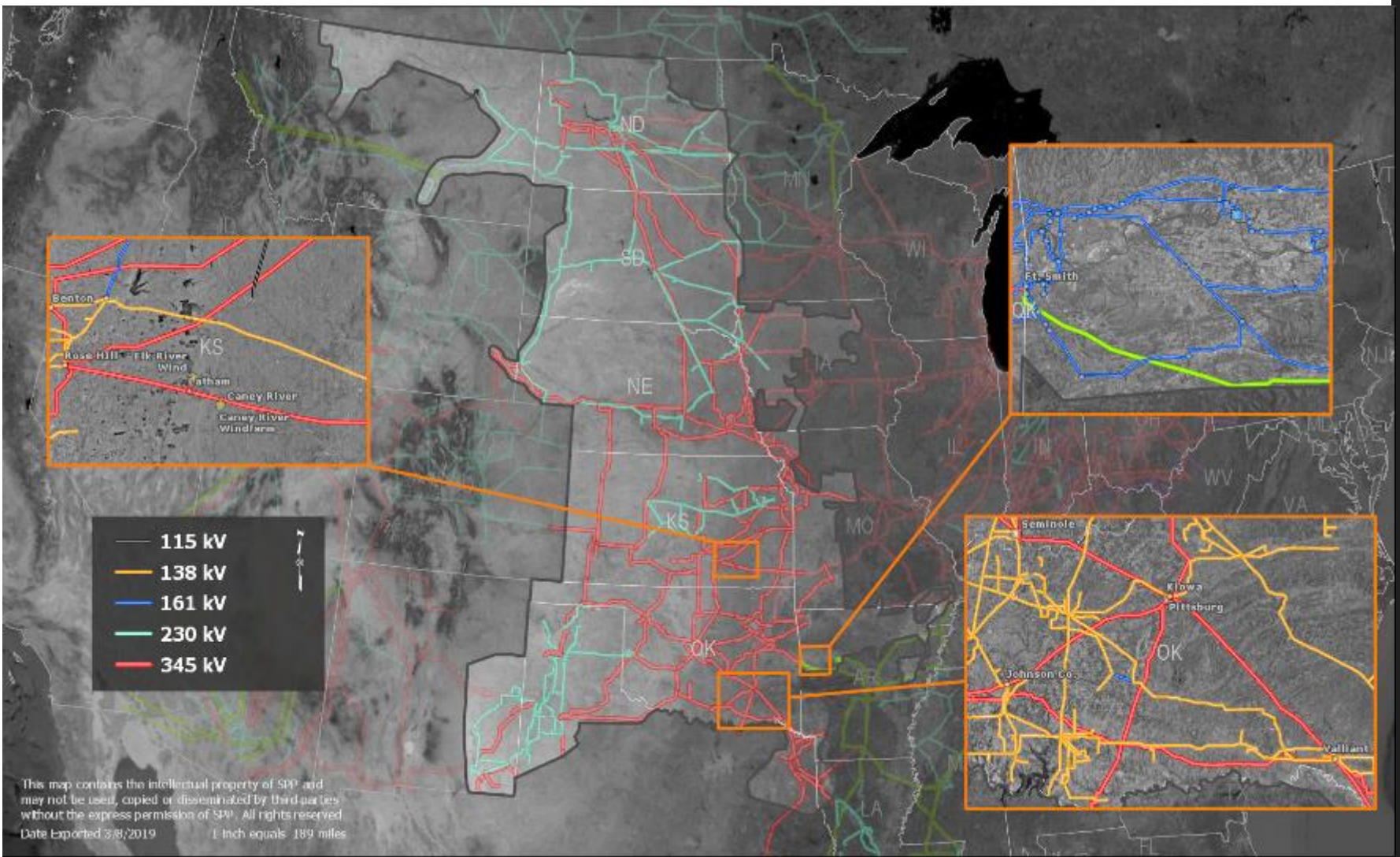
Pilot to Support SPP Operations

SPP conducted an extended pilot with NewGrid Router. The pilot was discussed at the June 2019 ESIG webinar, the findings are summarized in the next slides.

Topology Optimization Pilot Overview

- SPP Operations conducted a pilot with the NewGrid Router topology optimization tool (Q3 2018 – Q4 2018)
- Operations Analysis & Planning (Reliability focus)
  - Focus was on finding ‘preferred’ solutions:
    - At least 5% N-1 loading reduction
    - Up-to 30 MW newly radialized load
    - Single switching action
    - 230 kV or below only (230 kV XFR low side)
    - No resultant constraint loading over 95% post-contingent
  - Evaluated 100 flowgates with congestion during real-time operations
  - Found ‘preferred’ solutions to 55 flowgates
- Some reconfigurations were used in real-time operations:
  - Johnson County – Russet Op Guide
  - Mitigation of the DARCLAANOFTS permanent flowgate

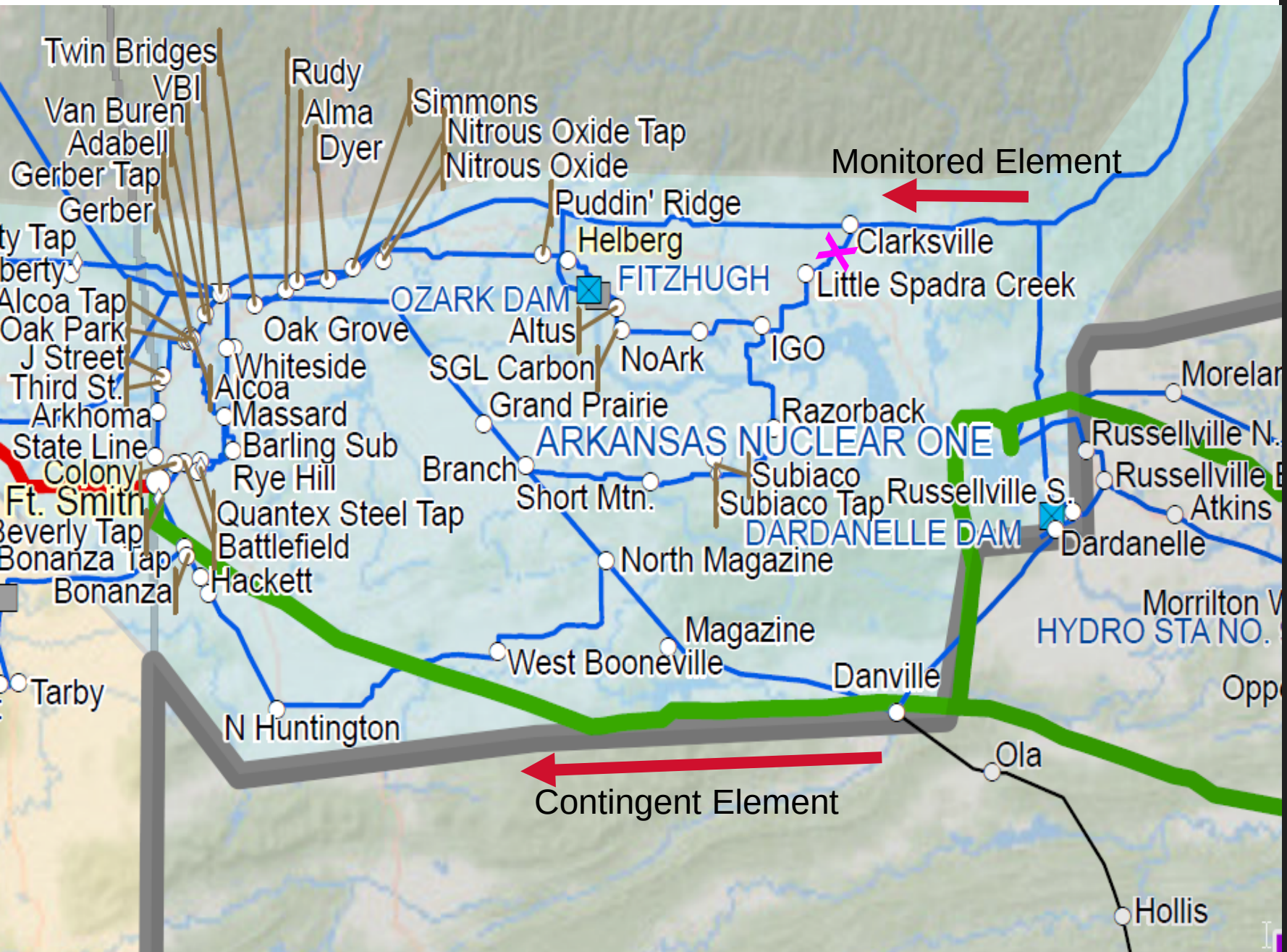
SPP Topology Optimization Pilot Example Locations



Real-time Solution Example

- In August 9, 2018 SPP Operations was experiencing a post-contingent overload on the DARCLAANOFTS permanent flowgate
- This constraint can be challenging to control due to significant external parallel flow impacts
- Real-time staff requested Operations Support to perform a Topology Control assessment of this constraint
- Operations Support was able to quickly identify a pre-contingent mitigation plan which reduced the constraint flow by over 20% and eliminated the post-contingent overload

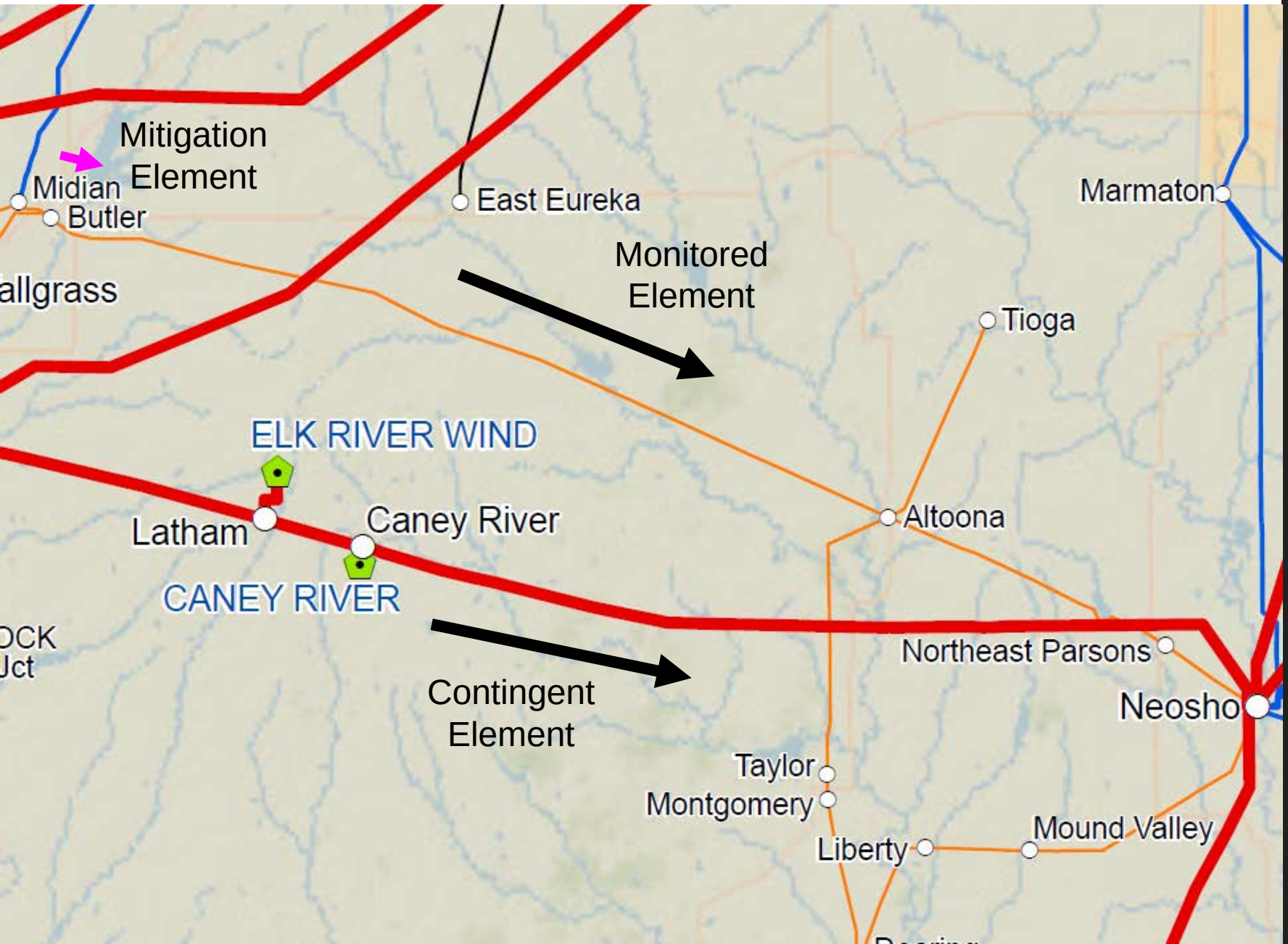
Router Mitigation: Open the Clarksville – Little Spadra 161 kV line pre-contingent



Confirmation of existing mitigation plans

- SPP also found Router useful as a means to ensure that existing mitigation plans are the most effective and efficient
- Example existing plan check:
  - Constraint: Butler – Altoona 138 kV (flo) Caney River – Neosho 345 kV
  - Existing Mitigation: Open Butler – Midian 138 kV
  - Router quickly found the same mitigation solution!

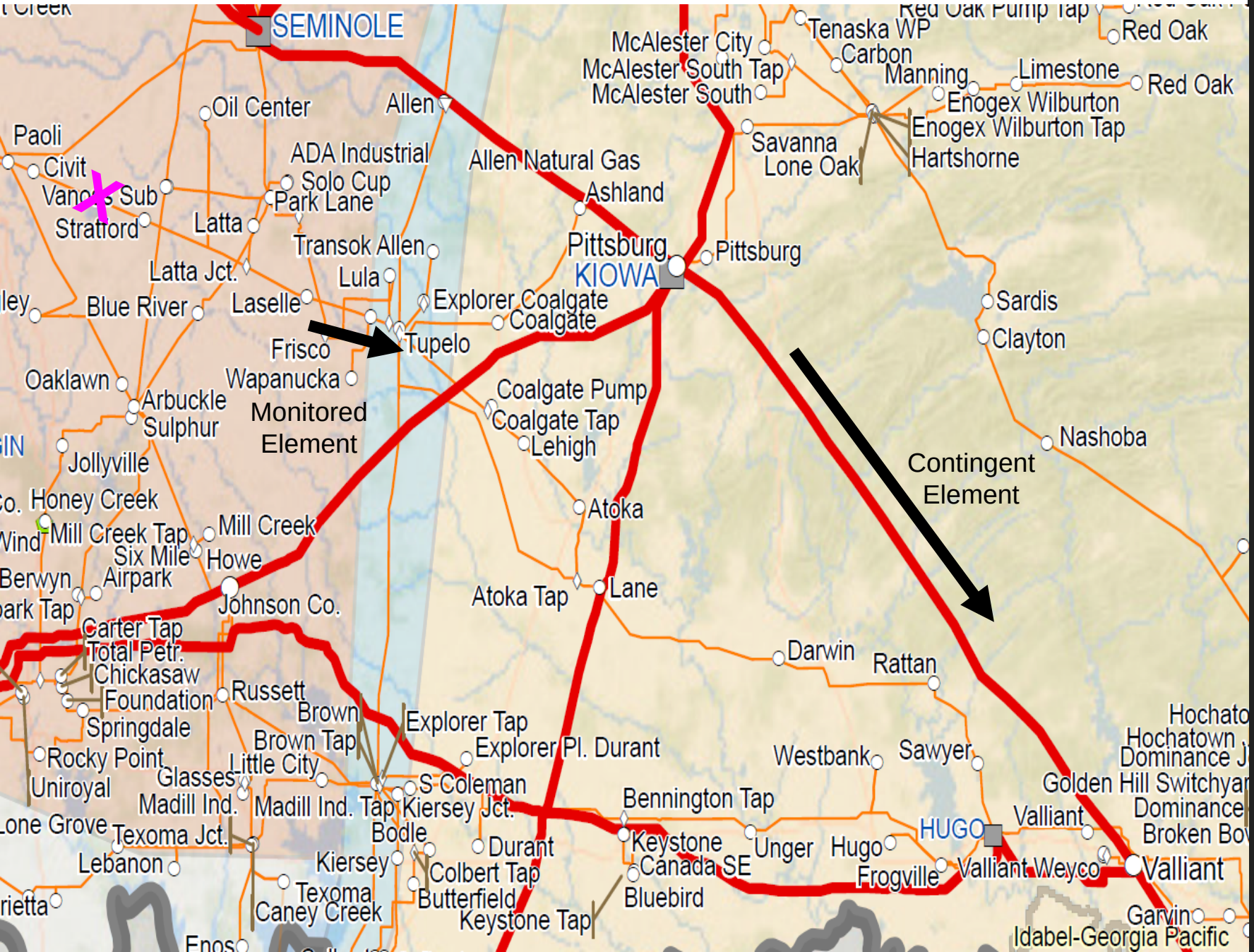
Router Mitigation: Open Butler - Midian138 kV line



Congestion during High Wind Penetration Intervals

- SPP transmission can be exposed to heavy transfers of wind generation during high wind & low load conditions
- These transfers typically flow from West to East across SPP
- Constraints exposed to these system transfers and located far away from generation can be difficult to control, as generation shift factors are too low for the market to effectively redispatch resources
- Example high wind transfer constraint:
  - Constraint: Stonewall – Tupelo 138 kV (flo) Pittsburg – Valliant 345 kV
  - Router Solution: Open Civit – Stratford 138 kV for 24% relief
  - Newly radialized load < 10 MW
- Topology Optimization made it possible to quickly find a solution while minimizing the amount of load radialized

Router Mitigation: Open the Civit – Stratford 138 kV line



Concluding Remarks

- Topology optimization is very effective at routing flow around congested/ overloaded transmission facilities.
- Possible applications:
  - Quickly identify reconfigurations to address reliability and congestion events efficiently.
    - Manage transmission and generation outages.
    - High renewables events.
  - Improve grid resilience: identify reconfigurations to best deal with disruptive events.
    - Minimize the impacts by relieving overloads and consumer disconnections.
    - Expedite the recovery by providing more operational options.
    - Mitigate impacts of ice storms.
  - Adapt system configuration as flow patterns change:
    - Increased wind and solar generation.
    - Retirement of legacy thermal units.
    - Address high load growth in load pockets.
  - Improve cost/benefit performance of new large transmission projects.
    - Relieve underlying system constraints to improve utilization of new high-capacity lines.

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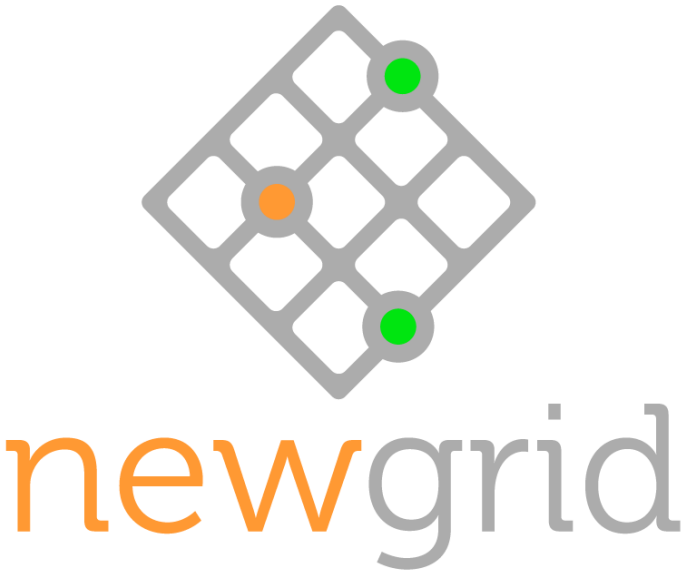

http://www.newgridinc.com

Appendix

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Appendix

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