Congestion Mitigation with Topology Optimization

CASE STUDIES AND A PATH TOWARD IMPLEMENTATION

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Midwestern Governors Association's
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Brattle newgrid

Agenda

- Topology Optimization Technology

  Finds reconfiguration options to reroute around congested/overloaded facilities
- Reconfigurations: Implementation and Practice

  Reconfigurations are applied by switching existing circuit breakers
- Reliability Criteria

  Reconfigurations meet operator-specified N-1 and other reliability criteria
- Impacts Quantified in Case Studies

  Reconfigurations adapt the grid to best address system conditions, providing resilience, reliability and economic benefits
  - Case Study 1 – SPP Operations
  - Case Study 2 – MISO North
- A Practical Path for Implementation

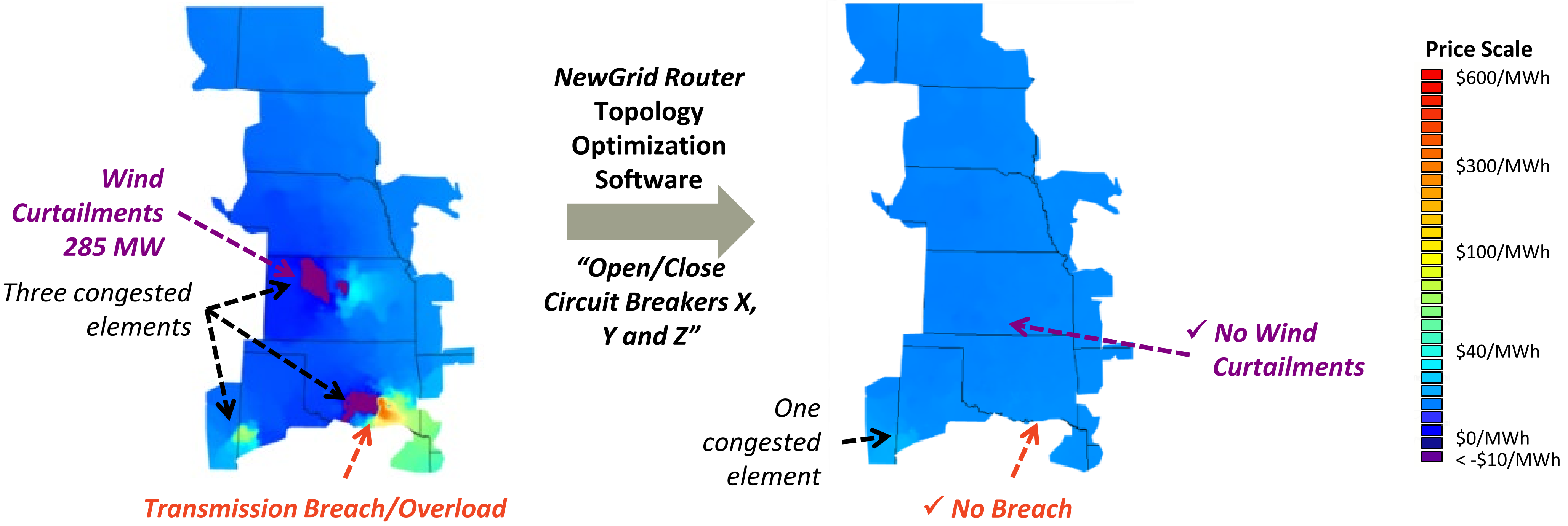
  Begin with ad hoc reconfiguration requests by market participants, MISO & TOs validate reliability and impacts prior to implementation
- Appendix – References

Topology Optimization Technology

Topology optimization software 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, one per historical constraint)



Case Study: Overload and Congestion Relief

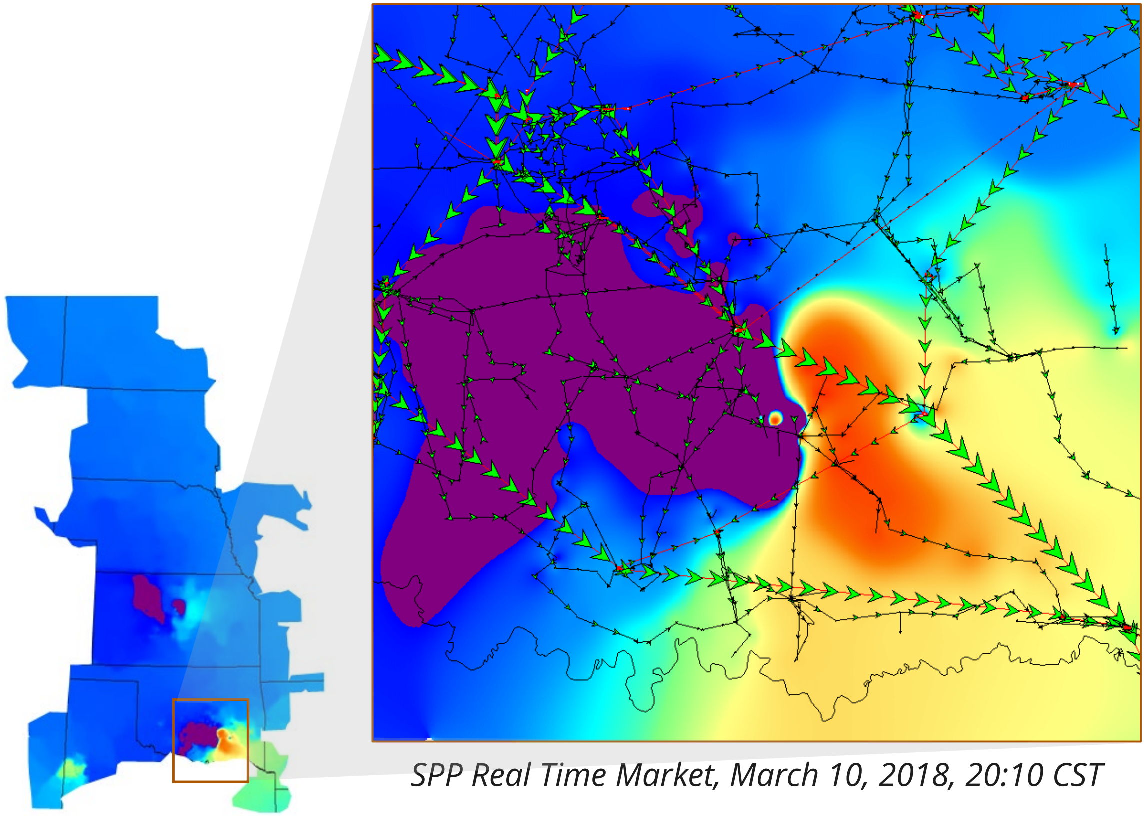
Found single-action reconfigurations that fully relieve overloads and congestion on a critical, frequent SPP constraint.

Historical Case

Breached constraint

Shadow price: **$984/MWh**

Third most congested constraint in SPP in 2018*



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

NewGrid Router

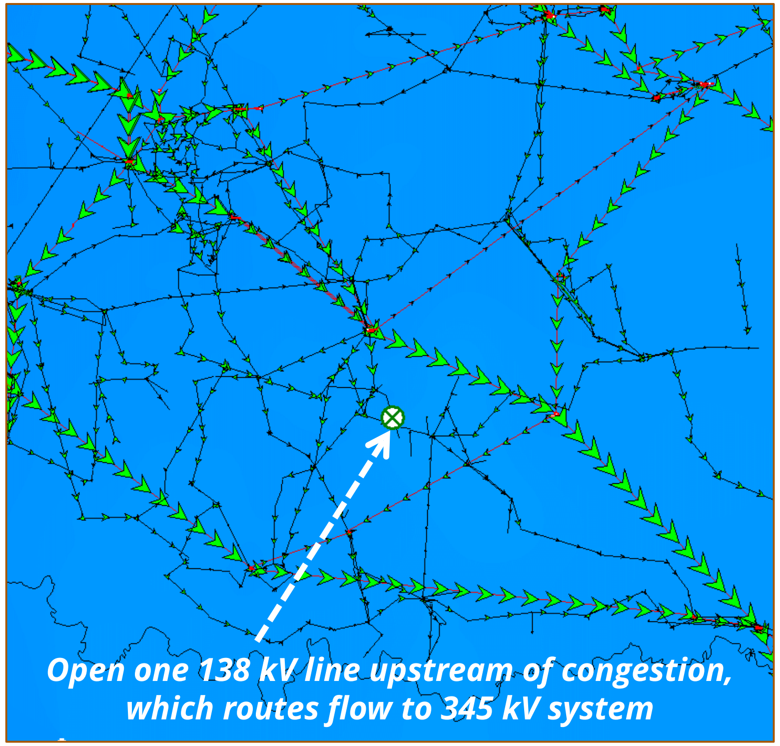
Topology Optimization Software

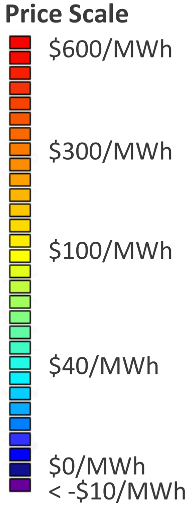
With Reconfiguration

No breach, full congestion relief

Over 25% flow reduction

Operating Guide developed, implemented



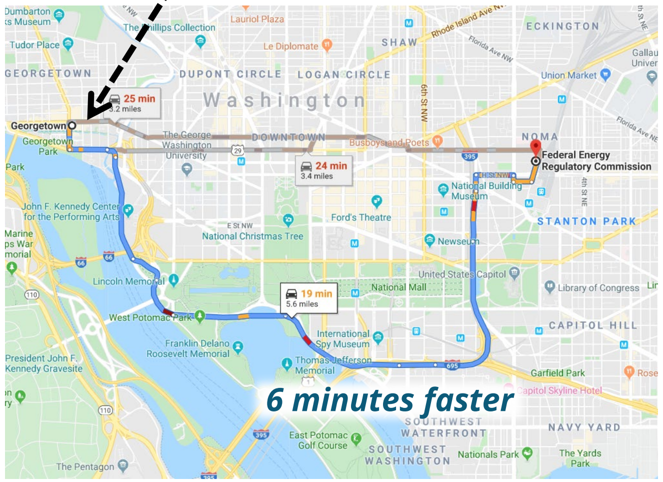


* SPP State of the Market 2018, Figure 5-5

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/

Applications

Topology optimization can support business processes across many time scales.

Real-time

- **<u>Adapt to emergency system conditions</u>**, 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
- **<u>Minimize congestion costs</u>** 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 **<u>outage scheduling and coordination</u>** (enable conflicting tickets)
- Mitigate the expected congestion impacts of outages
- **<u>Develop Operating Guides</u>** for extreme events that minimize load shedding

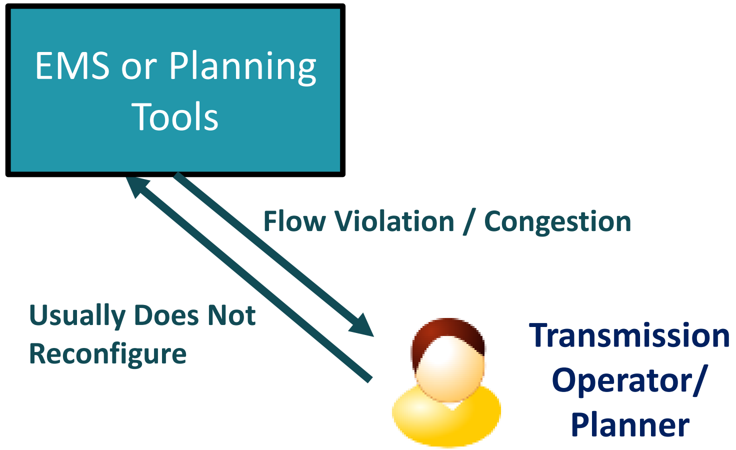
Long-Term

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

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, 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

✓ Decision support (advisory) technology

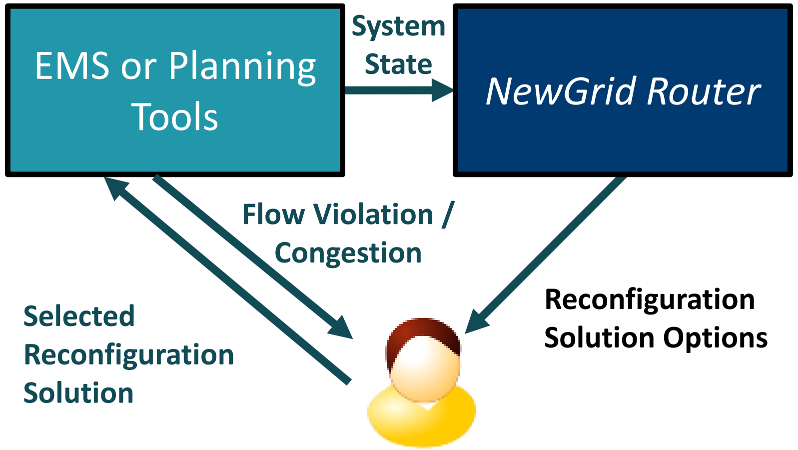
✓ Software finds reconfiguration solution *options*
  - Fast search time: 10 s – 2 min
  - Enables all operators to optimize the grid

✓ 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.

Transmission Topology Optimization Software

- With support from the U.S. Department of Energy Advanced Research Projects Agency – Energy (ARPA-E), we developed algorithms for optimizing electricity network topology (2012-2016).
  - Designed to operate with existing systems and software (EMS, MMS).
  - *Reliability*: Connectivity, contingency constraints, voltage criteria met.
  - *Speed*: Meets solution times that align with operations and planning timeframes.
  - *High-Definition*: Support both operations (node-breaker) and planning (bus-branch) cases.
  - *Reconfiguration Types*: Line switching (open/close), bus-tie and bypass breaker state.
  - *Look-Ahead*: Optimization decisions with "topology continuity" constraints.
  - *Market Optimization*: Unit dispatch and commitment co-optimized with network configuration.
- During the ARPA-E project (with PJM staff), we tested and assessed the TCA impacts in a simulated environment replicating PJM market operations and outage coordination.
- With ERCOT staff, we performed assessments on operations planning cases.
- NewGrid has developed *NewGrid Router*, the first production-grade topology decision support software tool, based on the TCA technology.

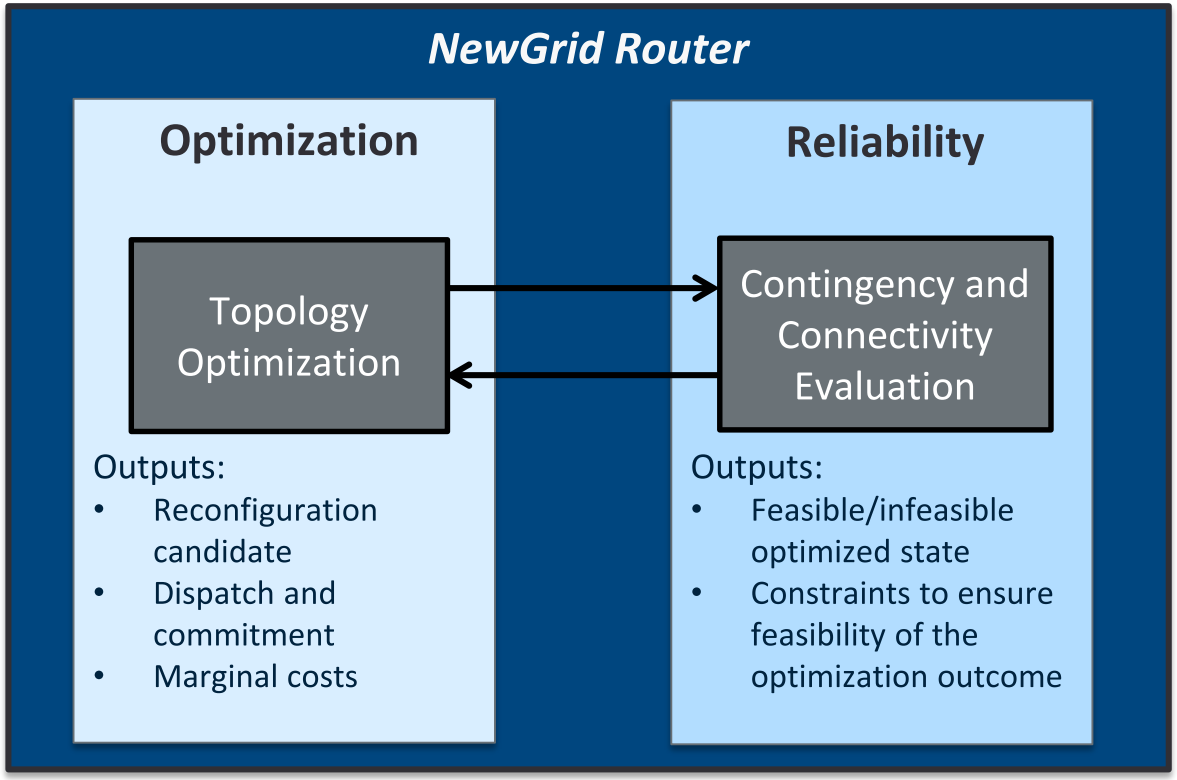
arpa·e CHANGING WHAT'S POSSIBLE

newgrid

Today's applications: *Decision Support* → Future applications: *Market Optimization*

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.



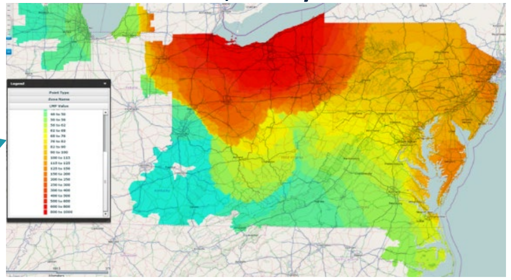
Benefits Quantified in Case Studies

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)*

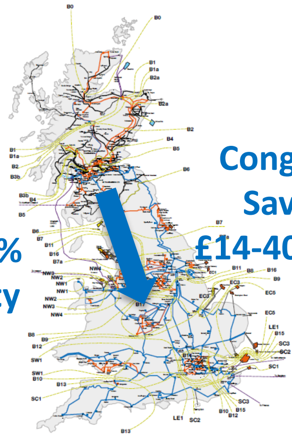
PJM RT prices w/critical transformer overload, 18 July 2013



Increase Transfer Capability

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

+ 4 to 12% Capability



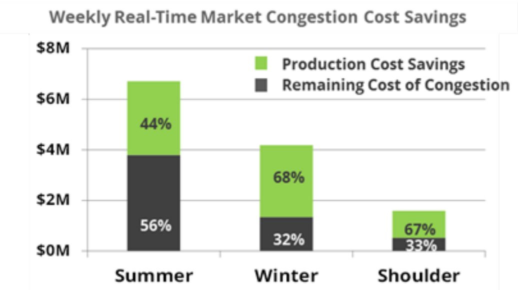
Congestion Savings: £14-40 million

Reduce Congestion Costs

Real Time market congestion cost savings:

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

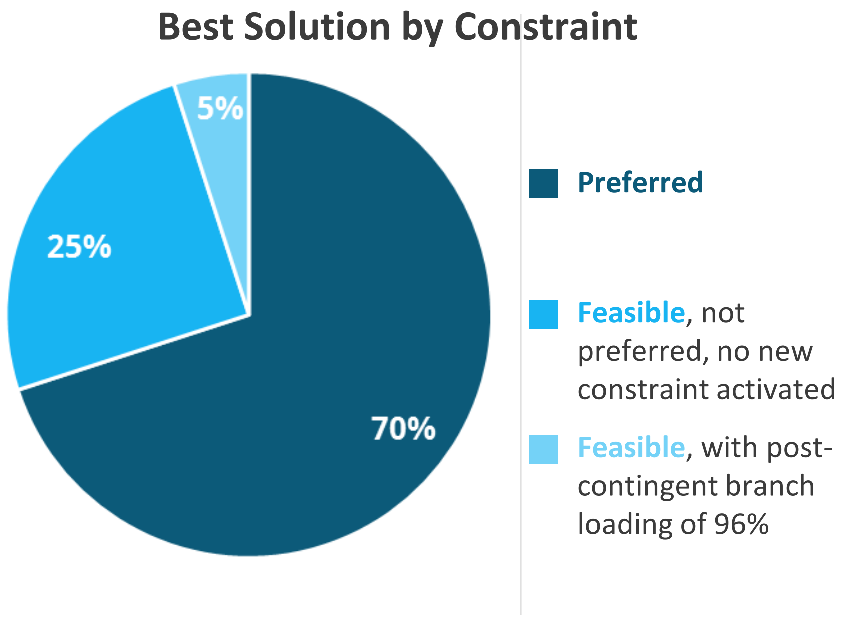
Day Ahead savings: $145 million/year (PJM – ARPA-E)†

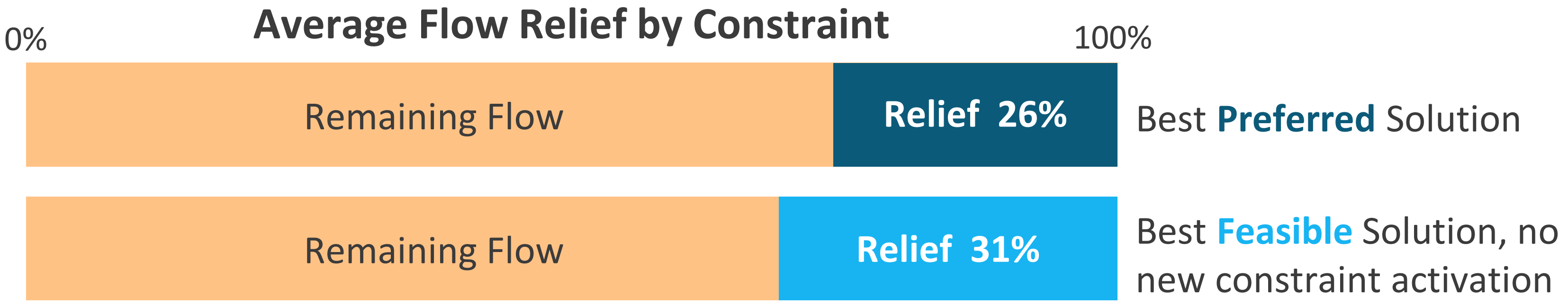


* See references [2, 4, 5, 9, 13] in the Appendix.
** See references [1, 5, 6] in the Appendix.
*** See references [3, 4] in the Appendix.
† See reference [9] in the Appendix.
†† See reference [4] in the Appendix.

Constraint Flow Relief in Real-Time SPP Operations

- SPP selected **20 real-time events** with high congestion/overloads on key constraints.
- *NewGrid Router* identified reconfiguration options, SPP validated them on the EMS.
- **Feasible** Solution: meets pre- and post-contingency criteria, validated in the EMS.
- **Preferred** Solution by SPP, in addition:
  - Loading on any new constraints below 95%
  - Comprises a single action below 345 kV
  - Radializes less than 30 MW of load
  - Provides at least 10% relief



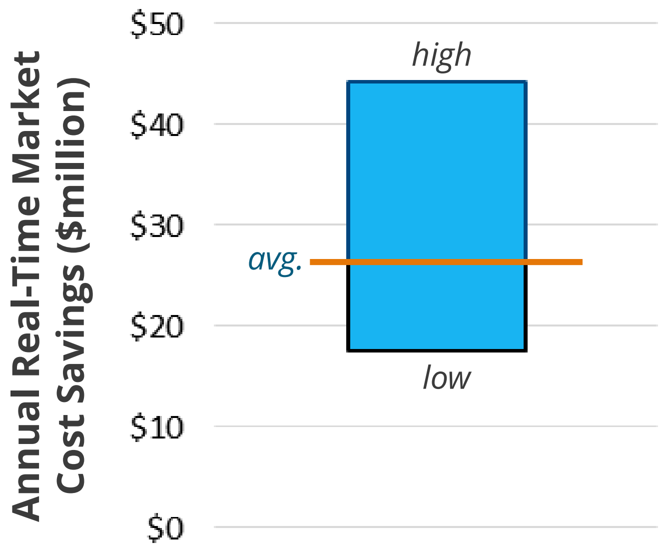


For more details, see reference [4] in the Appendix.

Real-Time Production Cost Savings in SPP

Topology optimization would provide annual Real Time Market (RTM) **production cost savings of over $18-44 million** if used in RTM optimization.

- Based on the cases simulated, the real-time market cost savings provided by topology optimization is about 3% (+2%/-1%) of the initial congestion rent of the constraints relieved.
- We extrapolated the market savings based on the historical Real Time Market congestion rent ($1.2 billion in 2017), conservatively assuming that topology optimization can effectively provide relief for 75% of the constraints.*
- Application in other processes beyond RTM would provide additional savings (e.g., RUC, Day-Ahead Market, etc.).



* *In the study of the 20 selected historical constraints, 95% of them were relieved with topology optimization.*

For more details, see reference [4] in the Appendix.

Congestion Relief during Polar Vortex 2014

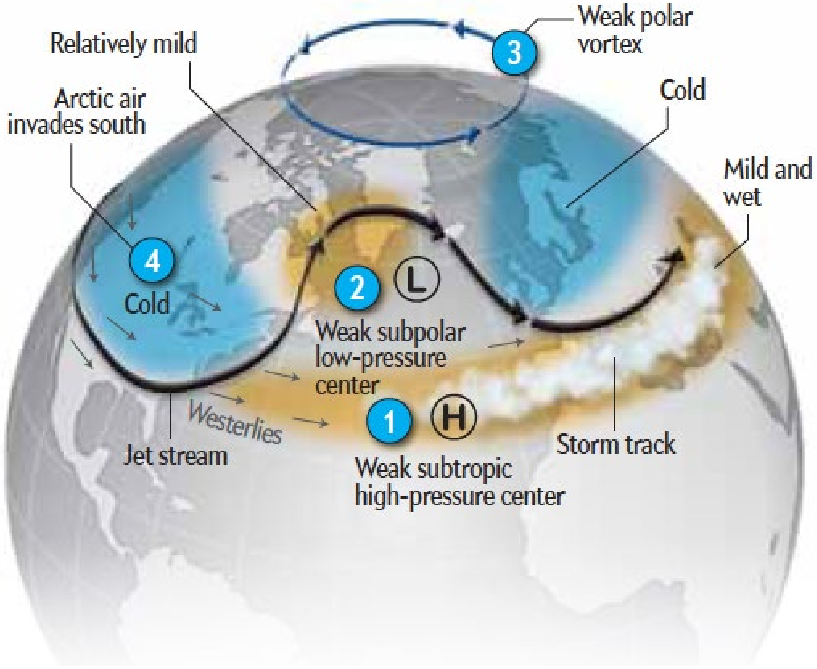
During the Polar Vortex event of 2014,Brattle supported a utility in the upper Midwest to mitigate congestion and overloads under those critical conditions.

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

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



Source: http://blogs.scientificamerican.com

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

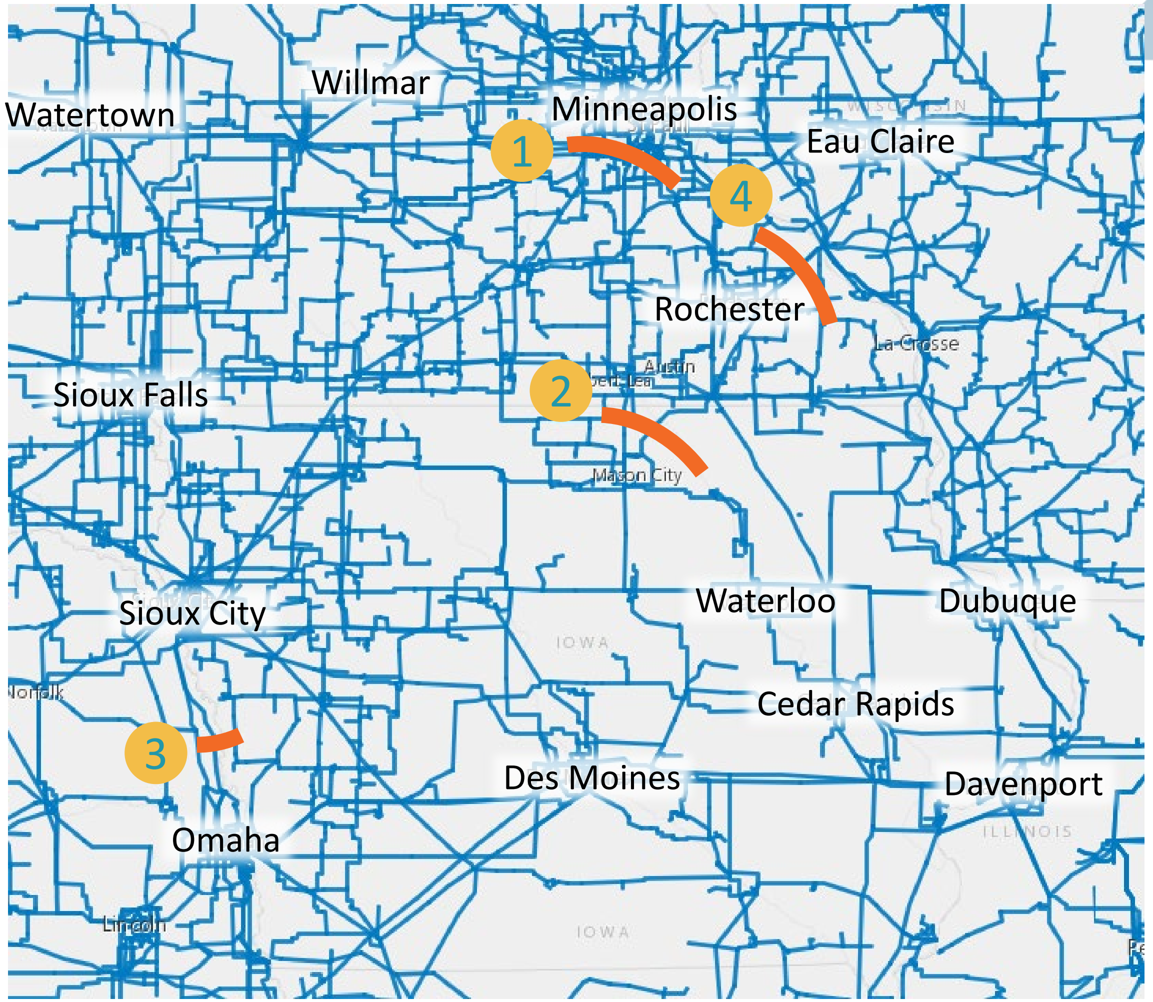
For more details, see reference [2] in the Appendix.

Analysis and Mitigation of Recent Congested Constraints

We developed reconfiguration solutions for some of the most heavily binding constraints in MISO North:

1. Chub Lake 345/115 kV for loss of Chub Lake – Hampton 345 kV
2. Lime Creek – Barton 161 kV for loss of Quinn – Blackhawk 345 kV
3. Raun – Tekamah for loss of Raun – Ft. Calhoun 345kV
4. Rochester – Wabaco 161 kV constraints

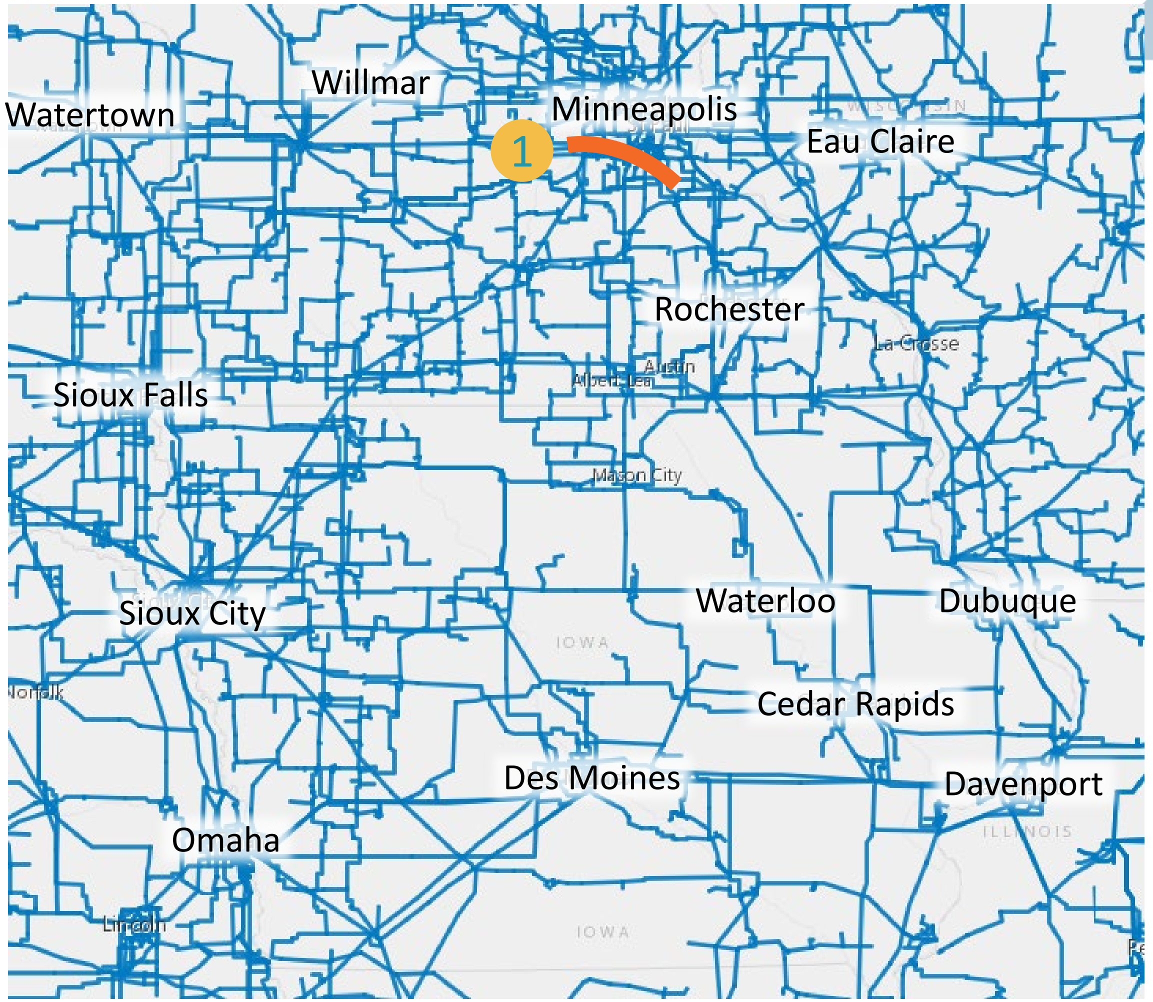
See details on next slides…



Map source: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::electric-power-transmission-lines/about

Mitigation of Congested Constraints during Outages (I/II)

1. Full relief of Chub Lake 345/115 FLO Chub Lake – Hampton 345 constraint
   - Constraint binding due to the Helena – Scott County 345 kV outage, scheduled April 5 – November 19
   - Found solution to mitigate the constraint impacts
     - Solution enabled re-routing of 25% of the flow that would otherwise go through the constraint
   - Solution evaluated by MISO and TO, implemented (request took about six weeks)
   - **Real-time congestion *rent* reduction: over $1.8 million during the first six days of implementation (April 25-30)**

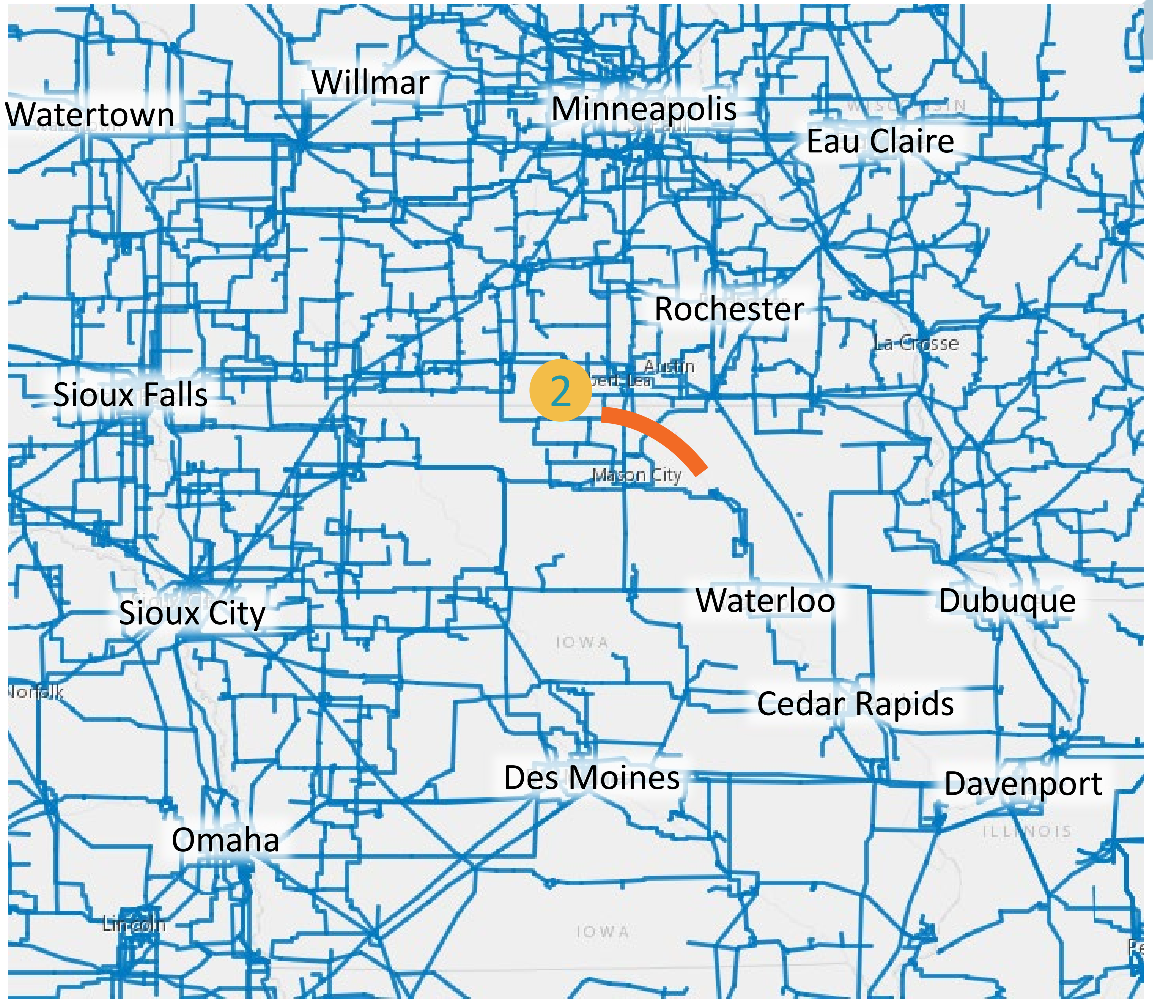


Map source: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::electric-power-transmission-lines/about

Mitigation of Congested Constraints during Outages (II/II)

2 Constraint Lime Creek – Barton 161 kV FLO Quinn – Blackhawk 345

- Constraint flow has increased with the extended planned outage of Crandall – Fieldon – Wilmarth 345 kV
- Constraint was binding 7.6% of the time in 2020
- Found solution to mitigate the constraint impacts
  - Solution re-routes 1-10% constraint flow during the outage (function of wind pattern)
- Solution evaluated by MISO and TO, implemented
- **Estimated production cost savings to the region: about $250k in May 2021**

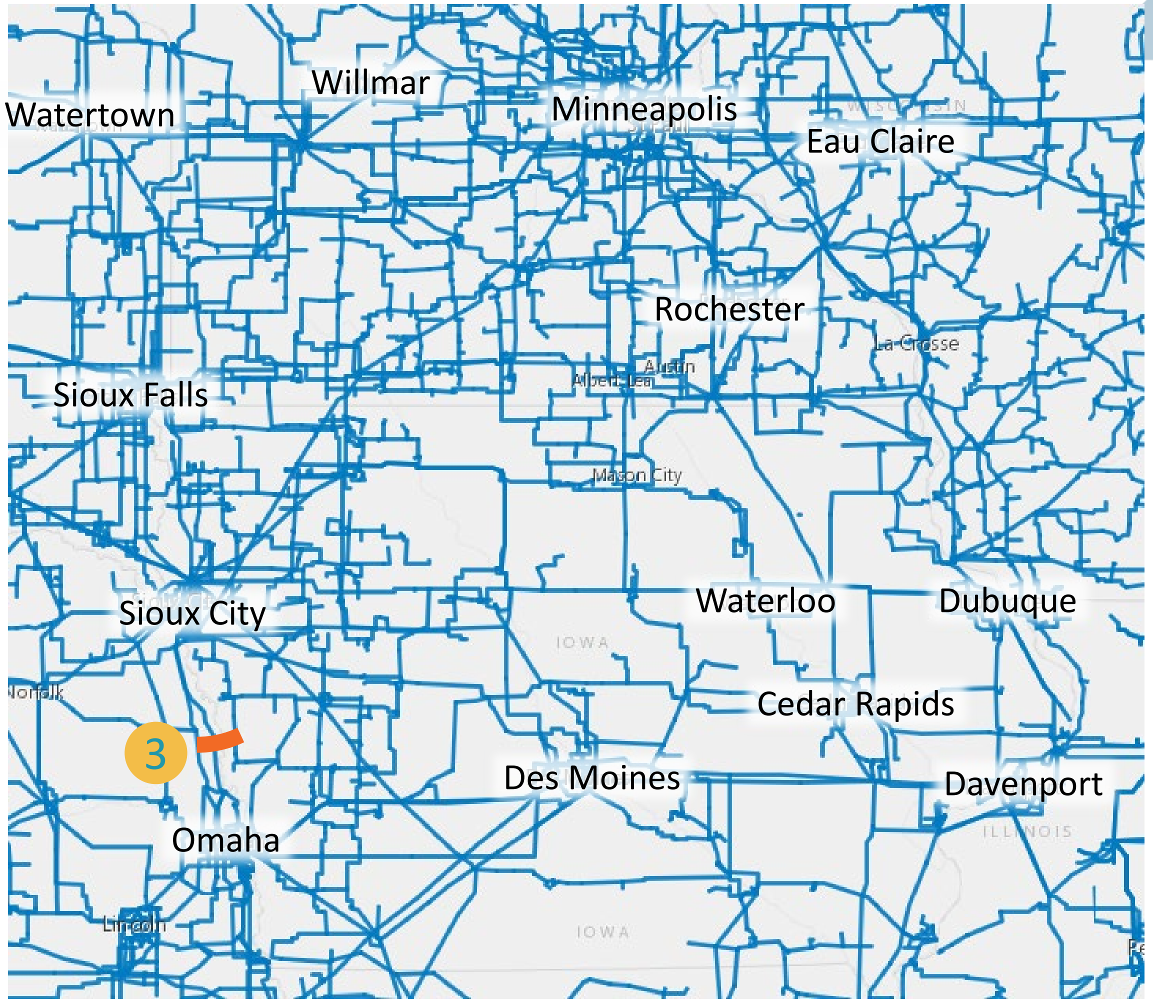


Map source: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::electric-power-transmission-lines/about

Mitigation of Congested Constraints during Outages (II/II)

3 Constraint: Raun – Tekamah 161 FLO Raun – Ft. Calhoun 345

- Major standing market-to-market constraint at the MISO/SPP seam (binding 7.5% of the time in 2020)
- Found solution to mitigate the impacts of the 3-week planned outage of Grimes – Beaver Creek 345 in 12/2020
  - Solution re-routed 7-8% constraint flow during the outage
- Constraint and solution identified 3 weeks prior to the outage
- Solution evaluated by MISO and TO, implemented
- **Estimated production cost savings to the region: over $350k (in 3 weeks)**

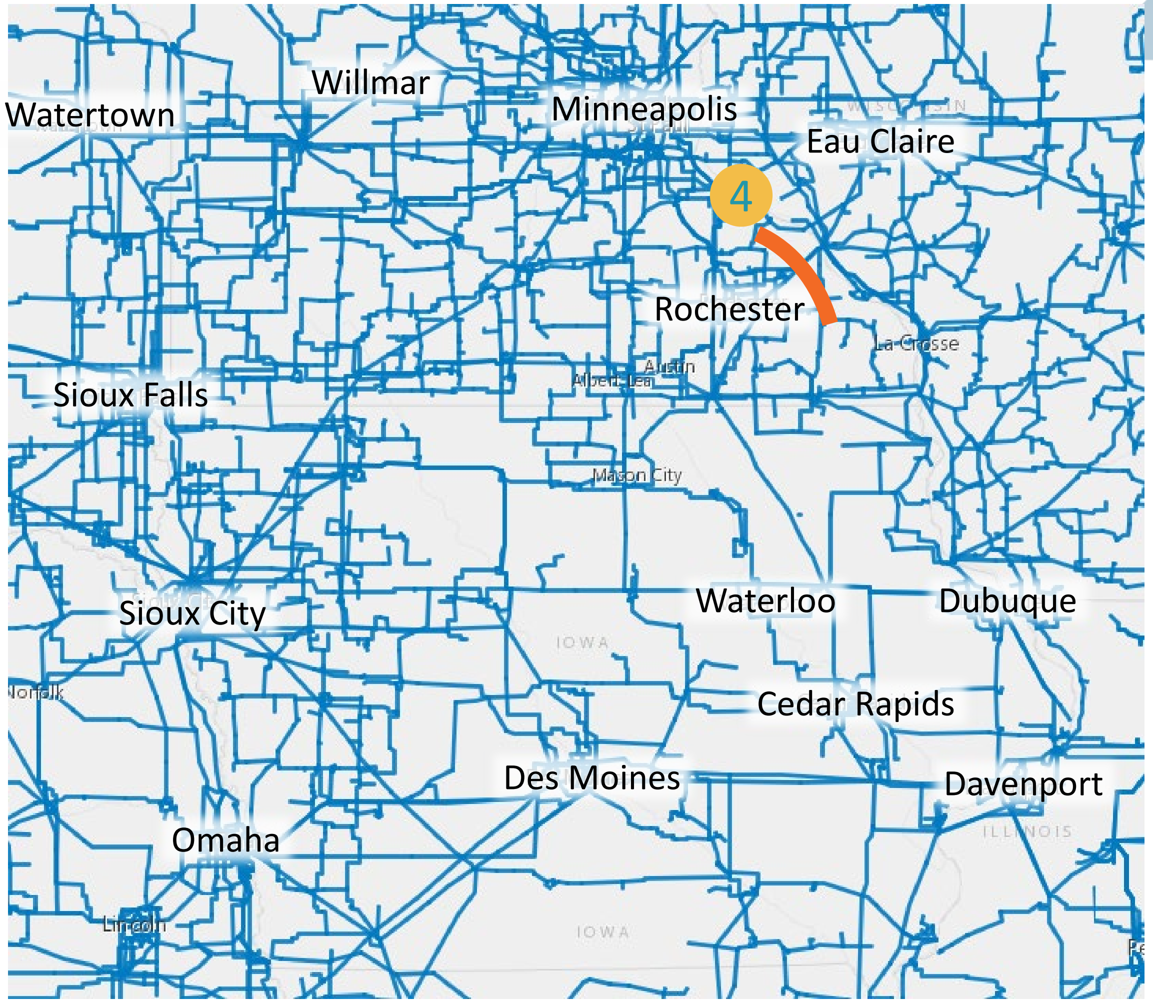


Map source: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::electric-power-transmission-lines/about

Reconfiguration to Relieve a Long-Standing Constraint

4 We found a reconfiguration solution to Rochester – Wabaco 161 kV contingency constraints

- Constraints were binding 28% of the time in 2020
- Reconfiguration Solution: open the tie lines Rochester – Chester 161 kV (DPC - RPU)
  - Re-routes about 25% flow around the constraint under the conditions analyzed
  - MISO has an Op. Guide in place to mitigate the Rochester – Wabaco 161 kV constraints
  - Op. Guides are not accessible to market participants per MISO policy
  - We believe the Op Guide includes the Rochester – Chester open ties reconfiguration (based on our ex-post analysis of state estimator snapshots)
- Other potential solutions may exist



Map source: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::electric-power-transmission-lines/about

A Path Towards Implementation in MISO

Incremental technology implementation

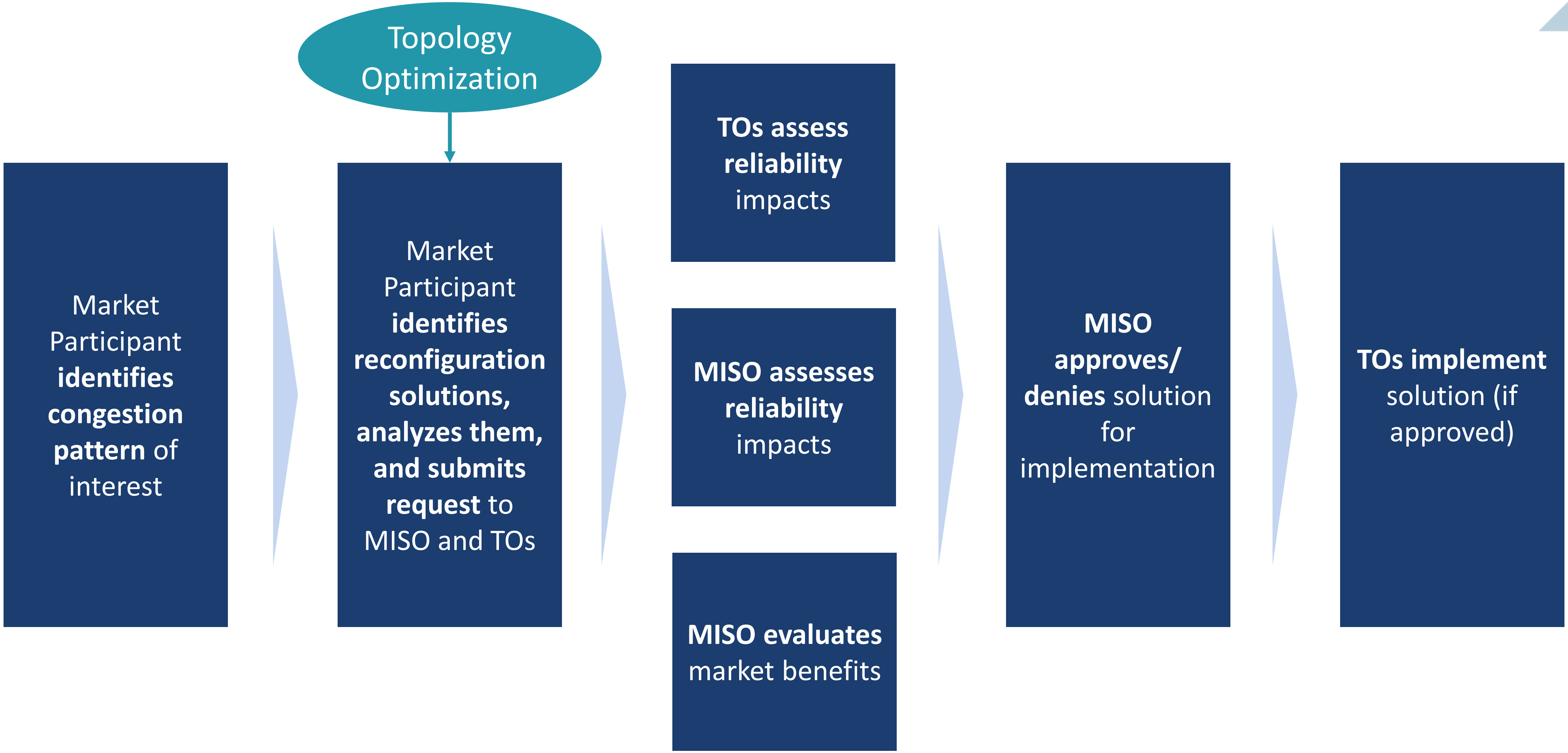
I. **Market participants** use technology to identify solutions, request evaluation and implementation to MISO and TOs
   - Simplest first step for ratepayers to capture the low-hanging fruit in congestion mitigation right away
   - Burden to find the solutions is on the market participants
   - MISO or TOs need not deploy the software, as they already have the required software to evaluate requests
   - Least effort required from MISO and TO staff

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

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

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

Process for Market Participants to Request Reconfigurations



MISO and TO Resource Needs to Support MP Requests

The MISO and TO staff needs to support a **market-participant (MP) reconfiguration request process** are very modest:

- Market participants conduct reconfiguration search and analysis
  - MISO and TO roles are reactive
- MISO and TO reliability and market assessments of reconfiguration requests are similar to an outage request assessment
  - MISO and TOs process over 4000 outage tickets per year in MISO North
    - 4107 in 2020
    - 4714 in 2019
    - 3887 in 2018
- A MP reconfiguration request process may lead to between one reconfiguration request per week to one per business day (50-250/year). The extra effort by MISO and TOs would be similar to an 1-7% increase in the number of outage request tickets.
  - The increased effort is lower than the annual variation in outage tickets observed

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