TRANSMISSION TOPOLOGY OPTIMIZATION FOR RELIABLE AND EFFICIENT CONGESTION MANAGEMENT

A Software-Only Grid-Enhancing Technology

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AGENDA

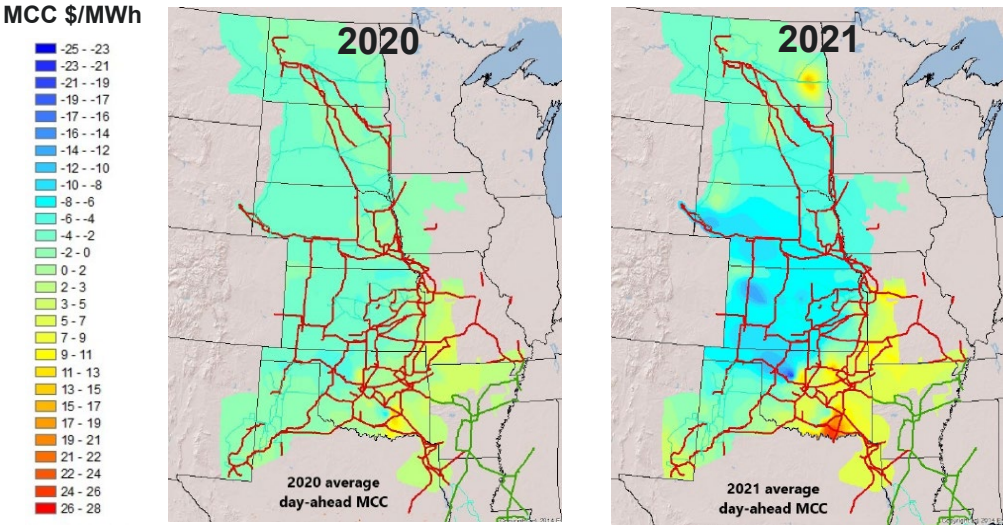
- Congestion Management and Topology Optimization Background
- Applications
- Technology Integration to ISO/TSO Processes: A Path for Incremental Implementation
- Topology Optimization Pilot with Partner Utility in SPP
  - Reliability and Efficiency Improvements during Normal System Conditions
  - Reliability and Resource Availability Improvements during Winter Storm Elliott Conditions
- Appendix

TRANSMISSION CONGESTION MANAGEMENT

Traditional congestion management treats the transmission grid as a fixed asset

- Congestion management approach: redispatch – "***increase the tolls!***"
- SPP congestion costs increased from $1.4 billion to $2.6 billion from 2021 to 2022 [1]
- Frequent overloads
- Congestion has been a key factor during extreme events, with resulting customer outages [2]

Average Day-Ahead Marginal Congestion



[1] We indicate the sum of the congestion payments ($1.2 and $2.0 billion in 2021 and 2022, respectively), and the real-time congestion revenue neutrality uplift ($226 and $653 million in 2021 and 2022, respectively). See SPP MMU, State of the Market 2022, May 15, 2023, pp.1-2.

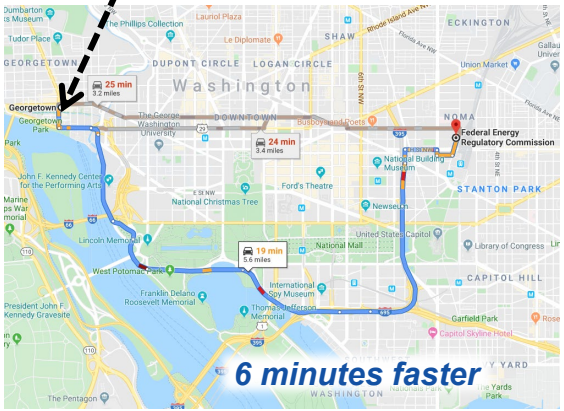
[2] For example, transmission congestion led to customer outages in SPP during the Arctic Blast, see Bitter cold overwhelms grid, leaves millions in dark, Edward Klump, Peter Behr and Mike Lee, Energywire, February 16, 2021.

Figure sources: SPP MMU State of the Market 2021 and SPP MMU State of the Market 2020

TOPOLOGY OPTIMIZATION: FLEXIBLE GRID OPERATION

Topology optimization software technology finds reliable reconfigurations to reroute flow around congestion ("***Waze for the transmission grid***")

- Reconfigurations implemented by opening or closing circuit breakers
  - Analogous to temporarily diverting traffic away from congested roads to make traffic flow smoother
- **Reconfigurations are implementable today!**
  - Switching infrastructure is already in place
  - Circuit breakers are capable of high duty cycles & extremely reliable*
  - Minimal cost: usually $10-$100 per switching cycle**
- Reconfigurations are **reliable** under all specified contingencies and do not radialize load beyond a user-specified value.



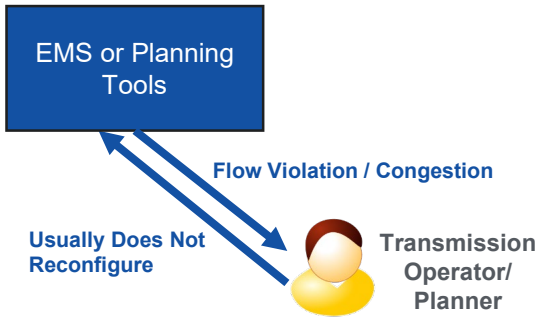
* Failure occurs less than once in 20,000 switching cycles for single-pressure SF6 breakers. Based on a CIGRE survey of 281,090 breaker-years with responses from 82 utilities from 26 countries, source: A. Janssen, D. Makareinis and C.-E. Sölver, "International surveys on circuit-breaker reliability data 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

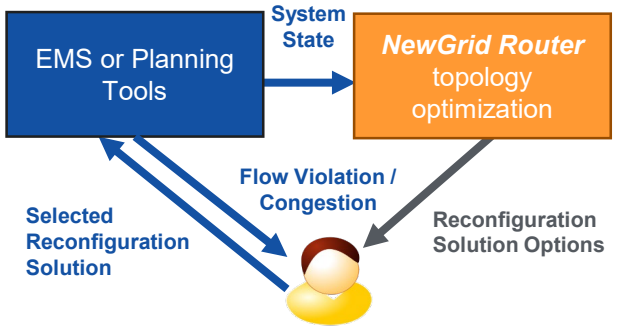
Traditional Practice

- 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

- ✓ Advanced software finds reconfiguration solution *options*
  - Fast search time: 10 seconds – 2 minutes
  - 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



A PATH FOR INCREMENTAL TECHNOLOGY IMPLEMENTATION

Simplest ↕ *Highest benefits*

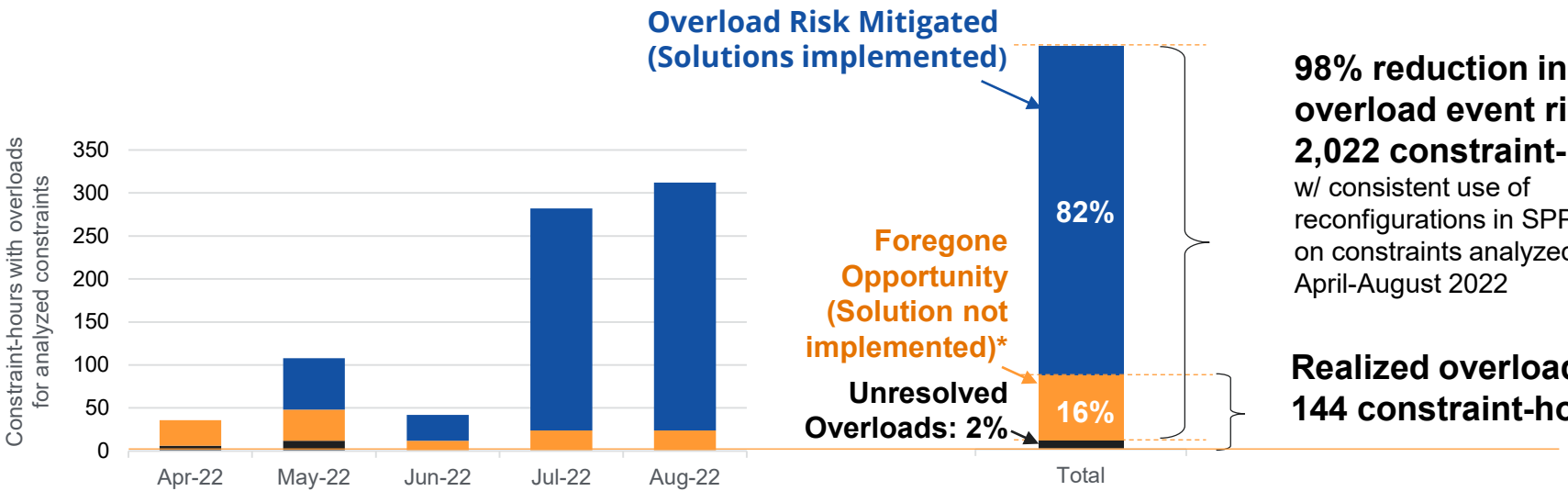
Process	Technology User	Application	System Integration	Timeframe
Step 1 **Reconfiguration Request Process**	**Market Participants** (RTOs, RCs and TOs have the software needed to evaluate requests)	mitigation of major expected constraints	none	days / weeks / months ahead
Step 2 **Planning and Operations Planning Support**	**RTO, RC, TOP**	operating/mitigation plan development, outage scheduling support, optimize transmission expansion	none to minimal (offline advisory tool)	days / weeks / months ahead
Step 3 **Real-Time Operations Support**	**RTO, RC, TOP**	reconfiguration options tailored to real-time conditions	EMS	days ahead to real time
Step 4 **Market Clearing**	**RTO**	continuous optimization of topology as conditions evolve	EMS and MMS	days ahead to real time

PILOT SUMMARY AND EXPERIENCE

NewGrid is conducting a topology optimization pilot with a partner utility in SPP.

- The partner utility selected **ten significant constraints** in its footprint that are difficult to control and are thus prone to reliability challenges under certain conditions.
- We jointly developed and analyzed **reconfiguration options to mitigate these constraints**.
- The partner utility discussed the reconfigurations with SPP staff for implementation.
- Challenges and lessons learned during the pilot:
  - SPP transmission operations historical practice has been to rely on market redispatch for congestion management, and only approve topology changes when constraints breach.
  - This made proactive implementation of reconfigurations difficult.
  - As a result, SPP has created standard requirements for implementing reliability reconfigurations in 2023.
  - SPP is currently exploring creation of an open process for requesting reconfiguration evaluations.
- We **evaluated the ex post reconfigurations impacts** by conducting analyses on state estimator cases, similar to the SPP and TOP outage scheduling and coordination studies.

TOPOLOGY OPTIMIZATION COULD RESOLVE 98% OF OVERLOADS



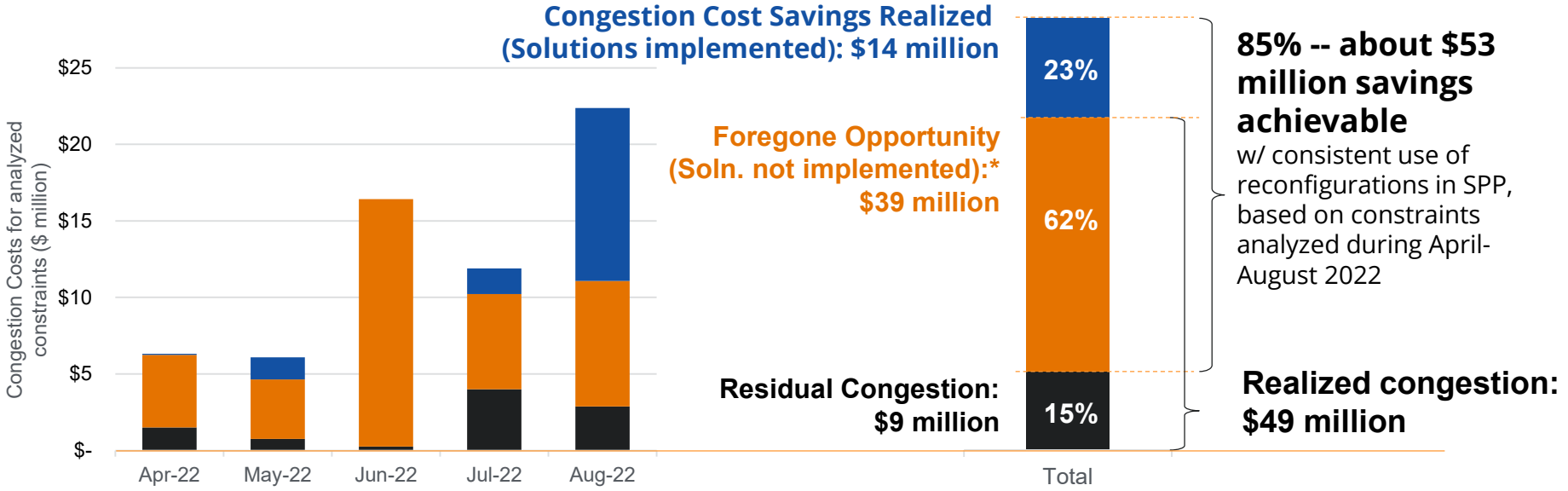
98% reduction in overload event risk – 2,022 constraint-hours
w/ consistent use of reconfigurations in SPP, based on constraints analyzed during April-August 2022

Realized overloads: 144 constraint-hours

Reliability impacts calculated ex-post based on analyses of SPP state estimator (SE) cases. The number of overload constraint-hours is estimated as 6 times the number constraints in SE cases with flow over 100% of their rating (without redispatch), where the number 6 is used because only 4 SE cases are made available to market participants by SPP per day (one SE case every 6 hours). **Only constraints analyzed in the pilot were included in this analysis – overloads on other constraints are not included.**

* Solution not implemented includes the impacts of all solutions that were not used for reasons other than technical, including solutions identified but not pursued due to the lack of an established request process or that were found after the congestion had started.

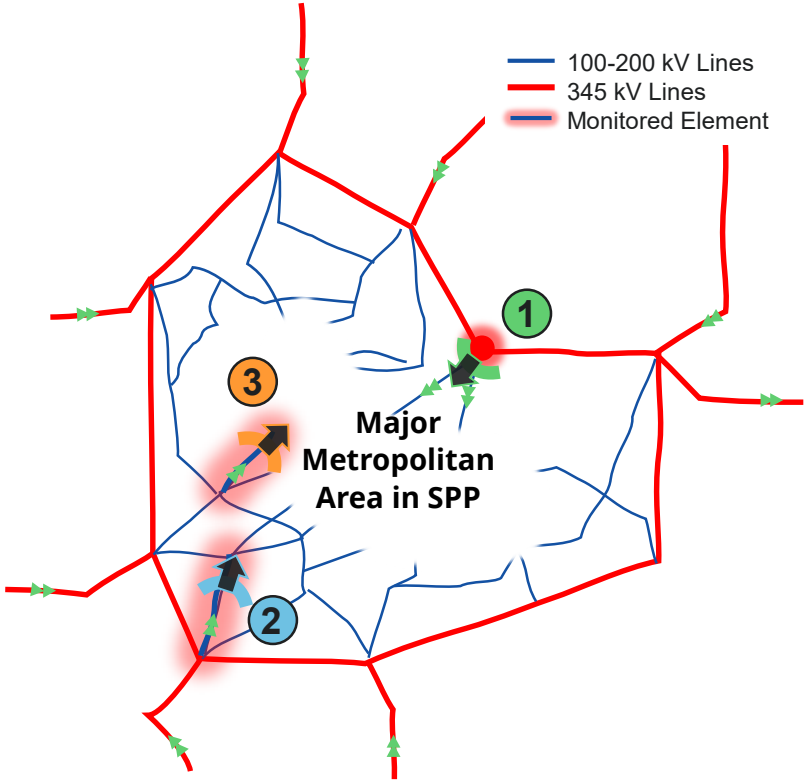
TOPOLOGY OPTIMIZATION COULD SAVE 85% OF CONGESTION COSTS



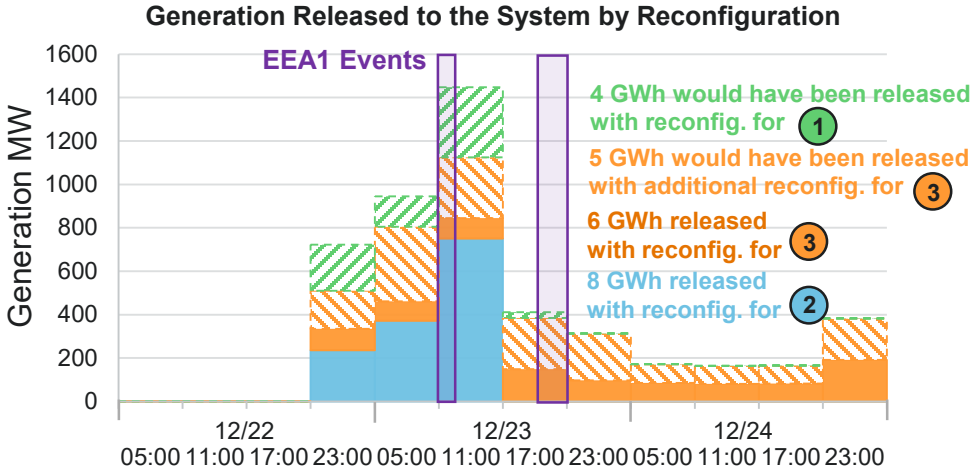
The impacts were calculated ex-post based on analyses of state estimator cases published by SPP and of historical market data. **Only constraints analyzed in the pilot were included in this analysis – congestion costs due to other constraints are not included.**

* Solution not implemented includes the impacts of reconfigurations that were not used for reasons other than technical, including solutions identified but not pursued due to the lack of an established request process or that were found after the congestion had started.

UP TO 1445 MW GENERATION RELEASED DURING EMERGENCY



System Diagram Source: NewGrid.



- Two implemented reconfigurations allowed higher transfers, releasing up to **845 MW** from available plants upstream of the constraint.
- Two other reconfigurations would have released up to **600 MW of additional generation** to the system.
- The capacity released varies by SE case, depending on system conditions.

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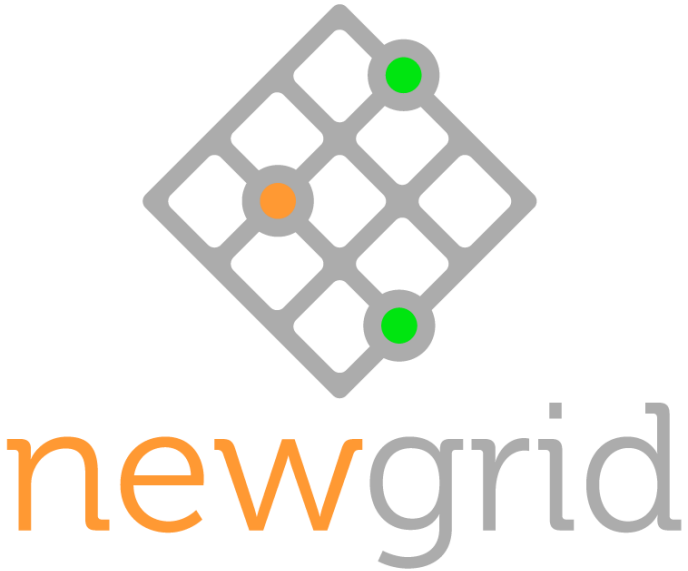


http://www.newgridinc.com

RELIABLE RECONFIGURATIONS

The reconfigurations are **reliable 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.

NEWGRID TOPOLOGY OPTIMIZATION SOFTWARE

OPTIMIZATION

TOPOLOGY OPTIMIZATION

OUTPUTS

- Reconfiguration candidate
- Dispatch and commitment
- Marginal costs

RELIABILITY

CONTINGENCY AND CONNECTIVITY EVALUATION

OUTPUTS

- Feasible/infeasible reconfiguration
- Constraints to ensure feasibility of the optimization outcome

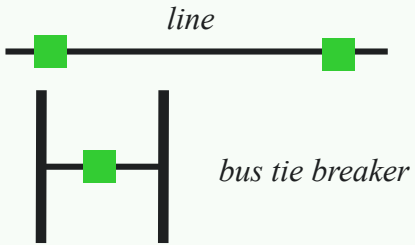
THERE IS A VARIETY OF RECONFIGURATION TYPES

Optimization routines search reconfigurations to relieve **one or more simultaneous constraints**, and identify **preventive or corrective solutions**. Reconfiguration types vary depending on system topology, system conditions and congestion problem characteristics.

Open/close branch

Branch types:

- Lines
- Transformers
- Bus tie breakers
- Reactor by-pass breakers

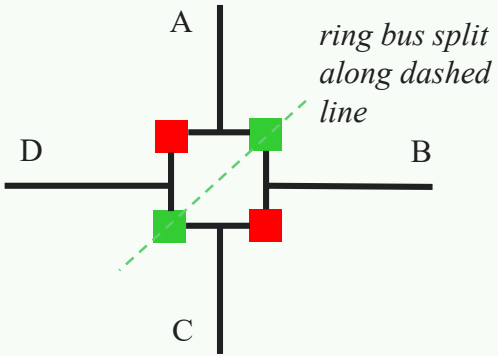


Legend: open breaker
closed breaker

Bus split/merge

Some substation arrangements allow bus splits:

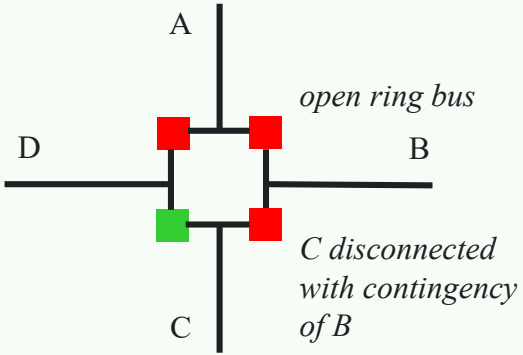
- Ring bus
- Double bus double breaker
- Breaker and a half



Contingency-change

Substation reconfigurations

- Bus normally connected
- Split bus or disconnected element under specific contingency conditions



APPLICATIONS

Topology optimization can support business processes across many scales.

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