



## TOPOLOGY OPTIMIZATION CASE STUDIES

May 28, 2024

The following 22 case studies show how topology optimization can mitigate transmission constraints based on work by NewGrid with partners and clients using the NewGrid Router software to identify beneficial grid reconfigurations. The operational analyses are based on state estimator system snapshots of regional grid operators, accounting for node-breaker level detail of the grid. With an average run-time of a few seconds up to a few minutes per solution, NewGrid Router typically identifies multiple beneficial grid reconfiguration options that relieve the identified constraints by **expanding the grid's effective capability between 5% and 25%** while meeting all specified reliability requirements.

### TABLE OF CONTENTS

1. **Alliant Energy customers saved 49% in congestion costs** over the last two years. [\[page 2\]](#)
2. **Reconfiguration saves MISO \$3.5 million** in three weeks, **reduces wind curtailments by 86%**. [\[page 2\]](#)
3. MISO to Support Reconfiguration Requests to Mitigate Congestion Costs. [\[page 2\]](#)
4. **Overload Mitigation of Major Constraint in the SPP market.** [\[page 3\]](#)
5. Full Congestion Relief on a Frequently Binding Wind Generation Constraint. [\[page 3\]](#)
6. Topology Reconfigurations Could Have **Eliminated 98% of Transmission Overloads** and **Reduced Congestion Costs by 85%**. [\[page 3\]](#)
7. **SPP Released Stranded Generation During Winter Storm Elliott** with Reconfigurations. [\[page 4\]](#)
8. Combining Grid-Enhancing Technologies to Enable Additional Renewable Connections. [\[page 4\]](#)
9. **Mitigation of MISO/SPP Market Seam Constraints.** [\[page 4\]](#)
10. Temporary Transmission Solutions in SPP. [\[page 4\]](#)
11. Congestion Relief of Major Standing Constraint in MISO [\[page 5\]](#)
12. SPP Finds **Reconfiguration Solutions to 55% of Constraints** Analyzed with Topology Optimization in NewGrid Pilot. [\[page 5\]](#)
13. **Most Costly Constraint in SPP Permanently Fixed** with Reconfiguration. [\[page 5\]](#)
14. ERCOT uses Topology Optimization Software to Support Operations Planning and Avoids Load Shedding for Outage Mitigation Plan. [\[page 6\]](#)
15. Topology Optimization Can **Reduce System Operating Limit (SOL) Violation Frequency by 75%** in SPP. [\[page 6\]](#)
16. **Topology Optimization Avoids Load Shedding** for Planning Events in SPP. [\[page 7\]](#)
17. Study of Winter Storm Jupiter Found that Topology Optimization Can Mitigate Overhead Transmission Line Failure Risk Due to Icing. [\[page 7\]](#)
18. Reconfigurations can **Increase Zonal Transfer Capacity by up to 12% in the UK.** [\[page 7\]](#)
19. Transmission Reconfigurations **Relieve Congestion During Polar Vortex 2014** in MISO. [\[page 8\]](#)
20. Topology Optimization **Could Reduce Day-Ahead Congestion Costs in PJM by 30-50%.** [\[page 8\]](#)
21. Topology Optimization **Could Reduce Real-Time Congestion Costs in PJM by Over 50%.** [\[page 9\]](#)
22. Financial Transmission Rights (FTR) Revenue Adequacy Improves with Topology Optimization. [\[page 9\]](#)

## TOPOLOGY OPTIMIZATION CASE STUDIES

- 1. Alliant Energy (Interstate Power and Light) Customers Saved 49% in Congestion Costs Over the Last Two Years.** Alliant and NewGrid are using NewGrid's topology optimization software and expertise to find regionally beneficial reconfiguration solutions to congestion events affecting Alliant Energy customers. The proposed solutions relieve congestion while respecting system security limits. The analysis identifies simple and robust reconfiguration solutions. Over the 2-year period since October 2021, the effort has delivered \$24 million in savings to Alliant customers in Iowa (49% reduction in congestion costs, net of congestion hedging impacts), in addition to further regional savings. Congestion costs would have been reduced by another 31% (\$17 million) if additional reconfigurations identified in the Alliant and NewGrid efforts had been implemented, for a total cost reduction estimate of 80%. Further, additional reconfigurations identified could have reduced constraint overload risks by 90%, providing significant reliability benefits. These efforts leverage the reconfiguration request process that has been implemented by MISO.<sup>1</sup>
- 2. Single Transmission Reconfiguration Saves MISO \$3.5 million in Three Weeks, Reduced Wind Curtailments by 86%.** In November 2023, a major 345 kV line across the Iowa/Minnesota border was on planned maintenance for three weeks. A reconfiguration solution developed and requested to MISO by NewGrid on behalf of MISO members was implemented and reduced regional congestion costs by \$3.5 million over the three-week outage, as evaluated ex-post using all available state estimator snapshots during the period. The associated production cost savings were \$1.1 million. During the outage, the total generation by the area wind sites was 483 GWh. The reconfiguration reduced wind curtailments by 86% (37 GWh of wind) over the three-week period.<sup>2</sup>
- 3. MISO to Support Reconfiguration Requests to Mitigate Congestion Costs.** MISO, in support of a group of stakeholders, created a formal process to verify and approve economic reconfiguration requests from MISO members to ensure that the requests are assessed in a consistent, reliable, and timely manner across the MISO

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1 Pablo Ruiz and Mitchell Myhre, [Congestion Mitigation with Transmission Reconfigurations](#), Organization of MISO States Market and Transmission Work Groups meeting, March 11, 2024, slides 10 and 17.

2 Pablo Ruiz and Mitchell Myhre, [Congestion Mitigation with Transmission Reconfigurations](#), Organization of MISO States Market and Transmission Work Groups Meeting, March 11, 2024, slides 8 and 9.

footprint by MISO, Transmission Operators (TOPs) and, when applicable, Generation Operators (GOPs) and Load Serving Entities. The process has 4 phases: Initial screening, evaluation, implementation, and exit. The average time from submission to evaluation completion is expected to be 15 business days. For the period June 2023 – March 2024, MISO received 16 requests under this process and approved 6 (37.5% approval rate).<sup>3</sup>

4. **Overload Mitigation of Major Constraint in the SPP Market.** One of the most significant constraints in SPP in 2022 was a key transformer providing a transmission connection for a major metropolitan area. Under high load conditions, especially with medium to high wind, this constraint could overload due to limited generation options to manage it. During the summer of 2022, SPP implemented a reconfiguration identified by NewGrid to fully mitigate this congestion when the constraint was overloading and uncontrollable with redispatch. The reconfiguration provided approximately 20% reduction in flow for this constraint.<sup>4</sup>
5. **Full Congestion Relief on a Frequently Binding Wind Generation Constraint.** Evergy has implemented a reconfiguration in its footprint that provided full relief on a constraint that was binding 48% of the time during high wind generation levels. The reconfiguration has been in place since May 2022.<sup>5</sup>
6. **Topology Reconfigurations Could have Eliminated 98% of Transmission Overloads, Reducing Congestion Costs by 85%.** NewGrid and Evergy analyzed (after the fact) ten significant constraints in the Evergy footprint that are difficult to control and are thus prone to reliability challenges. The identified reconfigurations, had they been implemented, could eliminate 98% of overloads and reduce congestion costs by 85% for congestion patterns associated to those constraints, and including the impacts of further constraints once the reconfigurations are implemented. This ex-post analysis was conducted using all state estimator system snapshots posted by SPP over a 4-month period in the spring and summer of 2022, also leveraging historical market data.<sup>6</sup>

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3 Midcontinent ISO, [Process to Support Congestion Cost Reconfigurations in the MISO Footprint](#), MISO Reliability Subcommittee April 16, 2024 Meeting, RSC Liaison Report, June 30, 2023, slide 7.

4 Kathryn Dial, [Flowgate Metrics & Congestion Management Discussion](#), SPP ORWG September 28-29, 2022 Meeting. Agenda item 9, slides 9-10.

5 Pablo Ruiz and Derek Brown, [Reliable and Efficient Congestion Mitigation using Transmission Reconfigurations](#), SPP SAG October 7, 2022 Meeting. Agenda item 5, slides 8-10.

6 Pablo Ruiz and Derek Brown, [Reliable and Efficient Congestion Mitigation using Transmission Reconfigurations](#), SPP SAG October 7, 2022 Meeting. Agenda item 5, slides 19-21.

7. **SPP Released Stranded Generation During Winter Storm Elliott with Reconfigurations.** During Winter Storm Elliott (December 23-24, 2022), heavy congestion limited supply to a major metropolitan area in the Southwest Power Pool. SPP implemented two transmission reconfigurations that released up to 845 MW from otherwise stranded generation under Energy Emergency Alert conditions, which supplied 14 GWh of additional energy during the event. Two complementary reconfigurations identified but not used during the storm would have released up to another 600 MW of constrained-off generation to supply an additional 9 GWh during the event. Together, these reconfigurations could avoid 36 hours of transmission constraints.<sup>7</sup>
8. **Combining Grid-Enhancing Technologies to Enable Additional Renewable Connections.** The Brattle Group's analysis of applying a combination of topology optimization, dynamic line ratings and power flow control devices to the Kansas and Oklahoma portion of the SPP grid demonstrates that the combination of these technologies could reduce congestion and more than double the existing headroom for interconnecting renewable resources, adding 3.7 GW of headroom with a payback period of only 6 months (a \$90 million investment yielding \$175 million/year in reduced annual production costs).<sup>8</sup>
9. **Mitigation of MISO/SPP Market Seam Constraints.** Market seam constraints tend to be very difficult to manage using market redispatch, leading to high costs and inefficiencies, especially in the Day-Ahead Markets. Working on behalf of MISO members, NewGrid developed reconfiguration solutions for some of the most heavily binding MISO/SPP seam constraints in MISO North and they have been implemented. For example, one of these reconfigurations was implemented for over 7 months to mitigate the impacts of a major 345 kV outage in 2021. The reconfiguration re-routed flow to reliably enable increased throughput in the area by up to 56%, as measured ex-post using state estimator snapshots.<sup>9</sup>
10. **Temporary Transmission Solutions in SPP.** Reconfigurations can be effective mitigation solutions for constraints that are expected to bind heavily, until a

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<sup>7</sup> Slide 25 of <https://www.ferc.gov/media/pablo-ruiz-newgrid-somerville-ma>

<sup>8</sup> [Unlocking the Queue with Grid Enhancing Technologies](#)

<sup>9</sup> Slide 14 at <https://www.ferc.gov/media/congestion-and-overload-mitigation-using-optimal-transmission-reconfigurations-experience>

transmission expansion project can be completed (usually in 3+ years). NewGrid identified reconfigurations to mitigate two such major constraints in Oklahoma identified by SPP in the ITP process as transmission needs. The reconfigurations enable 10-23% increases in flow throughput in the area.<sup>10</sup>

**11. Congestion relief of major standing constraint in MISO.** The Rochester – Wabaco 161 kV line drove over \$57 million of MISO congestion costs in the summer of 2021. Had reconfigurations been used to mitigate these constraints, congestion on the line would have been eliminated and area congestion costs would have been reduced by roughly 2/3rds. The congestion cost savings over the summer would have exceeded \$38 million. The reconfiguration would have enabled over 25% additional throughput for this constraint.<sup>11</sup>

**12. SPP Finds Reconfiguration Solutions to 55% of Constraints Analyzed with Topology Optimization in NewGrid Pilot.** SPP conducted an extended pilot with the NewGrid Router topology optimization software tool in Q3 and Q4, 2018. The pilot was conducted by the SPP Transmission Operations Analysis & Planning with a reliability focus on finding ‘preferred’ solutions consisting of a single switching action at or below 230 kV with at least 5% N-1 loading reduction, less than 30 MW of newly radialized load, and no resultant constraint loading over 95% post-contingent. SPP engineers evaluated 100 flowgates with congestion during real-time operations using NewGrid Router and found ‘preferred’ solutions to 55 flowgates. Some of these reconfigurations were then implemented in real-time operations.<sup>12</sup>

**13. Most Costly Constraint in SPP Permanently Fixed with Reconfiguration.** The most expensive constraint in SPP in 2019 as well as the fourth most expensive, both resulting from contingency limitations of a 69 kV line in Oklahoma, were permanently resolved with a transmission reconfiguration. Prior to their resolution in 2020, these constraints had been binding 16% of all the real-time market intervals in 2019, costing the market about \$25 million that year in the day-ahead and real-

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10 FERC, [Congestion and Overload Mitigation Using Optimal Transmission Reconfiguration](#), Slide 15.

11 Potomac Economics, [2021 MISO State of the Market Report](#), June 22, 2022., and FERC, [Congestion and Overload Mitigation Using Optimal Transmission Reconfiguration](#), Slide 13.

12 Pablo Ruiz, Jay Caspary and Luke Butler, [Transmission Topology Optimization Case Studies in SPP and ERCOT](#), FERC Tech Conf on Increasing Day-Ahead and Real-Time Market Efficiency and Enhancing Resilience through Improved Software (Docket No. AD10-12-011), June 24, 2020. Slides 12-20.

time markets. In addition to being costly and frequently binding, these constraints had resulted in \$30 million of TCR underfunding.<sup>13</sup>

**14. ERCOT uses Topology Optimization Software to Support Operations Planning and Avoids Load Shedding for Outage Mitigation Plan.** ERCOT has been using NewGrid Router topology optimization software to support their Constraint Management Plan (CMP) review and development. ERCOT engineers use the software to search for reconfigurations to replace mitigation plans that employ post-contingency load-shed. In some cases, ERCOT has identified such alternative solutions and removed post-contingency load shedding actions from the plans. They have also used NewGrid Router to analyze and select the most effective corrective and preventive reconfiguration plans by providing alternative switching actions as well as for their analysis and verification in comparison of alternative strategies. ERCOT has also used NewGrid Router to search for possible switching solutions for irresolvable constraints outside of the CMP Review. When no solutions are found this has confirmed that constraints are indeed irresolvable.<sup>14</sup>

**15. Topology Optimization Can Reduce System Operating Limit (SOL) Violation Frequency by 75% in SPP.** In 2018, NewGrid, SPP and The Brattle Group evaluated the potential of using topology optimization to identify reconfigurations to support decision making in Operations Planning. Working with SPP transmission operations staff and using 20 selected state estimation cases with major constraints binding or overloading, the evaluation found that historical SOL violations could be eliminated for 75% for the constraints analyzed. The resulting congestion cost savings in the real-time markets were estimated to be in the range of \$18-44 million annually. Mitigation options identified during the evaluation were implemented by SPP and memorialised in Op Guides.<sup>15</sup>

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13 Southwest Power Pool MMU, [State of the Market 2019](#), May 11, 2020. Pages 194-195, 199 and 214.

14 Pablo Ruiz, Jay Caspary and Luke Butler, [Transmission Topology Optimization Case Studies in SPP and ERCOT](#), FERC Tech Conf on Increasing Day-Ahead and Real-Time Market Efficiency and Enhancing Resilience through Improved Software (Docket No. AD10-12-011), June 24, 2020, slide 11., and Pablo Ruiz and Nick Steffan, [Transmission Topology Optimization Operations and Market Applications and Case Studies](#), ERCOT DSWG Nov 17, 2017. Slide 12.

15 Pablo A. Ruiz, Doug Bowman, Kathryn Dial, Xiao Li, Ryan Schoppe, Zachary Sharp, Jason Terhune, Bruce Tsuchida, [Transmission Topology Optimization Applications to Enhance System Reliability and Resilience and to Increase Market and Planning Efficiency in Southwest Power Pool](#), FERC Tech Conf on Increasing Day-Ahead and Real-Time Market Efficiency and Enhancing Resilience through Improved Software (Docket No. AD10-12-009), June 26, 2018. Slides 13-21., and Pablo A. Ruiz, Doug Bowman, Kathryn Dial, Xiao Li, Ryan Schoppe, Zachary Sharp, Bruce Tsuchida, [Transmission Topology Optimization Pilot Study to Support Congestion Management and Ice Buildup Mitigation](#), November 15, 2018. Presentation #6, slides 16-20.

## 16. Topology Optimization Avoids Load Shedding for NERC TPL-001-4 Planning

**Events in SPP.** In 2018, NewGrid, SPP and The Brattle Group evaluated the potential of using topology optimization to develop Corrective Action Plans (CAP) that relied on reconfigurations and avoided load shedding for NERC P6, P7 and Extreme Event violations. SPP Planning selected three events for evaluation, one of each NERC type listed, that had CAPs consisting of load shedding (up to 243 MW of load shed). The reconfiguration solutions identified and validated by SPP provided full relief under NERC TPL-001-4 in SPP and eliminated the need of load shed actions in those CAPs.<sup>16</sup>

## 17. Study of Winter Storm Jupiter Found that Topology Optimization Can Mitigate Overhead Transmission Line Failure Risk Due to Icing in Sunflower Electric.

In 2018, NewGrid, SPP and The Brattle Group evaluated the potential of using topology optimization during icing conditions to mitigate mechanical line failure risk. The analysis focused on reconfigurations to redirect flow to critical lines at risk of failure due to ice accumulation to prevent or limit ice formation. The study was performed for the January 2017 Winter Storm Jupiter conditions, which caused multiple transmission outages due to ice accumulation, and focused on the Sunflower Electric footprint. The study identified two reconfiguration solutions that could have significantly relieved the ice buildup on selected critical lines, while meeting reliability criteria. The estimated savings of avoiding the hypothetical outages of these critical lines are \$10 to \$17 million, in addition to avoided system restoration costs.<sup>17</sup>

## 18. Transmission Reconfigurations can Increase Zonal Transfer Capacity by up to 12% in the UK.

National Grid ESO and The Brattle Group studied the potential to increase transfer capability and reduce constraint management costs with topology optimization. The study focused on major (zonal) interface constraints that had been congested under historical outage scenarios selected by NGENSO. Topology optimization identified reconfigurations that met NGENSO criteria and provided up to

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16 Pablo A. Ruiz, Doug Bowman, Kathryn Dial, Xiao Li, Ryan Schoppe, Zachary Sharp, Jason Terhune, Bruce Tsuchida, [Transmission Topology Optimization Applications to Enhance System Reliability and Resilience and to Increase Market and Planning Efficiency in Southwest Power Pool](#), FERC Tech Conf on Increasing Day-Ahead and Real-Time Market Efficiency and Enhancing Resilience through Improved Software (Docket No. AD10-12-009), June 26, 2018. Slides 23-24.

17 Pablo A. Ruiz, Doug Bowman, Kathryn Dial, Xiao Li, Ryan Schoppe, Zachary Sharp, Bruce Tsuchida, [Transmission Topology Optimization Pilot Study to Support Congestion Management and Ice Buildup Mitigation](#), November 15, 2018. Presentation #6, slides 22-32.



12% increase in transfer capability (1289 MW increase), as assessed by NGENSO. The reconfigurations did not radialize load and consisted of up to six topology change actions (line switching, substation reconfiguration and phase-shifting transformer adjustments).<sup>18</sup>

- 19. Transmission Reconfigurations Relieve Congestion During Polar Vortex 2014 in MISO.** During the Polar Vortex event of 2014, The Brattle Group supported a utility in the upper Midwest to mitigate congestion and overloads under those critical conditions. Severe transmission congestion affected the upper Midwest due to record-setting high loads in MISO North and a substantial number of unplanned generation outages, both resulting from the extreme cold weather, compounded by the impacts of extended 230 kV planned transmission outages that could not be recalled during the event. The cost of electricity to customers in the area increased by over \$15 million in the first 10 weeks of 2014 due to congestion. Energy prices at load in the affected areas at times more than doubled the corresponding generation energy prices. Using topology optimization, Brattle 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.<sup>19</sup>
- 20. Topology Optimization Could Reduce Day-Ahead Congestion Costs in PJM by 30 to 50%.** Detailed simulation of the PJM day-ahead market for representative weeks showed that the day-ahead cost of congestion could be reduced by 30-50% if market clearing includes topology optimization decision variables in addition to resource bids and offers. The simulation solved each day in the week sequentially, and incorporated “topology persistence” constraints, requiring that each reconfiguration be beneficial and remain in place for at least a few hours. Under 2010 market conditions, these savings would add up to \$145 million annual reduced production costs in the PJM footprint. The reconfigurations enable increases of up to 10% in transfers between PJM regions. These impacts are achieved by only using 2-3

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18 Pablo A. Ruiz and Xiao Li, [Transmission Topology Optimization to Efficiently Mitigate Congestion & Overloads](#), FERC Tech Conf on Increasing Day-Ahead and Real-Time Market Efficiency and Enhancing Resilience through Improved Software (Docket No. AD10-12-012), June 23, 2021. Slides 9-13.

19 Pablo A. Ruiz and Xiao Li, [Transmission Topology Optimization to Efficiently Mitigate Congestion & Overloads](#), FERC Tech Conf on Increasing Day-Ahead and Real-Time Market Efficiency and Enhancing Resilience through Improved Software (Docket No. AD10-12-012), June 23, 2021. Slide 14.



switching operations per hour across PJM, which is much lower than the switching actions associated to maintenance outages.<sup>20</sup>

## **21. Financial Transmission Rights (FTR) Revenue Adequacy Improve with Topology**

**Optimization.** Based on detailed simulation of the PJM day-ahead market for representative weeks in PJM, use of topology optimization significantly reduced congestion rent, by 30-50%. At the same time, it increased the day-ahead FTR surplus relative to the congestion rent by up to 5%. This makes sense since the FTR portfolio tends to be consistent with least cost power transfers across the network. Revenue inadequacy results when those transfers become infeasible, for example due to outages. Topology optimization tends to increase transfer capacity and make those economic transfers more feasible, improving overall FTR revenue adequacy.<sup>21</sup>

## **22. Topology Optimization Could Reduce Real-Time Congestion Costs in PJM by**

**Over 50%.** Detailed simulation of the PJM real-time market for representative weeks in PJM showed that the real-time cost of congestion could be reduced by 44-68%, depending on the seasonal week, if market clearing includes topology optimization decision variables in addition to resource bids and offers. The simulation solved each hour in the week sequentially, and incorporated “topology persistence” constraints, requiring that each reconfiguration be beneficial and remain in place for at least a few hours. Under 2010 market conditions, these savings would add up to over \$100 million annual reduced production costs in the PJM footprint, even if unit commitment changes are not accounted for. The reconfigurations enable increases of up to 11% in transfers between PJM regions. These impacts are achieved by only using 1-2 switching operations per hour across PJM, which is much lower than the switching actions associated to maintenance outages.<sup>22</sup>

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20 Pablo A. Ruiz, Michael Caramanis, Evgeniy Goldis, Xiaoguang Li, Keyurbhai Patel, Russ Philbrick, Alex Rudkevich, Richard Tabors, Bruce Tsuchida, [Transmission Topology Optimization Simulation of Impacts in PJM Day-Ahead Markets, FERC Tech Conf on Increasing Market Efficiency through Improved Software \(Docket No. AD10-12-007\)](#), June 28, 2016. Slides 12-17.

21 Pablo A. Ruiz, Michael Caramanis, Evgeniy Goldis, Xiaoguang Li, Keyurbhai Patel, Russ Philbrick, Alex Rudkevich, Richard Tabors, Bruce Tsuchida, [Transmission Topology Optimization Simulation of Impacts in PJM Day-Ahead Markets, FERC Tech Conf on Increasing Market Efficiency through Improved Software \(Docket No. AD10-12-007\)](#), June 28, 2016. Slides 18-19.

22 Pablo A. Ruiz, Michael Caramanis, Evgeniy Goldis, David Hislop, Bhavana Keshavamurthy, Xiaoguang Li, Daniel Moscovitz, Russ Philbrick, Alex Rudkevich, Richard Tabors, Bruce Tsuchida, [Topology Control Algorithms \(TCA\) Simulations in PJM with AC Modeling](#), FERC Tech Conf on Increasing Market Efficiency through Improved Software (Docket No. AD10-12-005), June 23, 2014. Slides 8-20.