Transmission Topology Optimization

APPLICATION IN OPERATIONS, MARKETS, AND PLANNING DECISION MAKING

PREPARED BY
Pablo A. Ruiz

May 2019

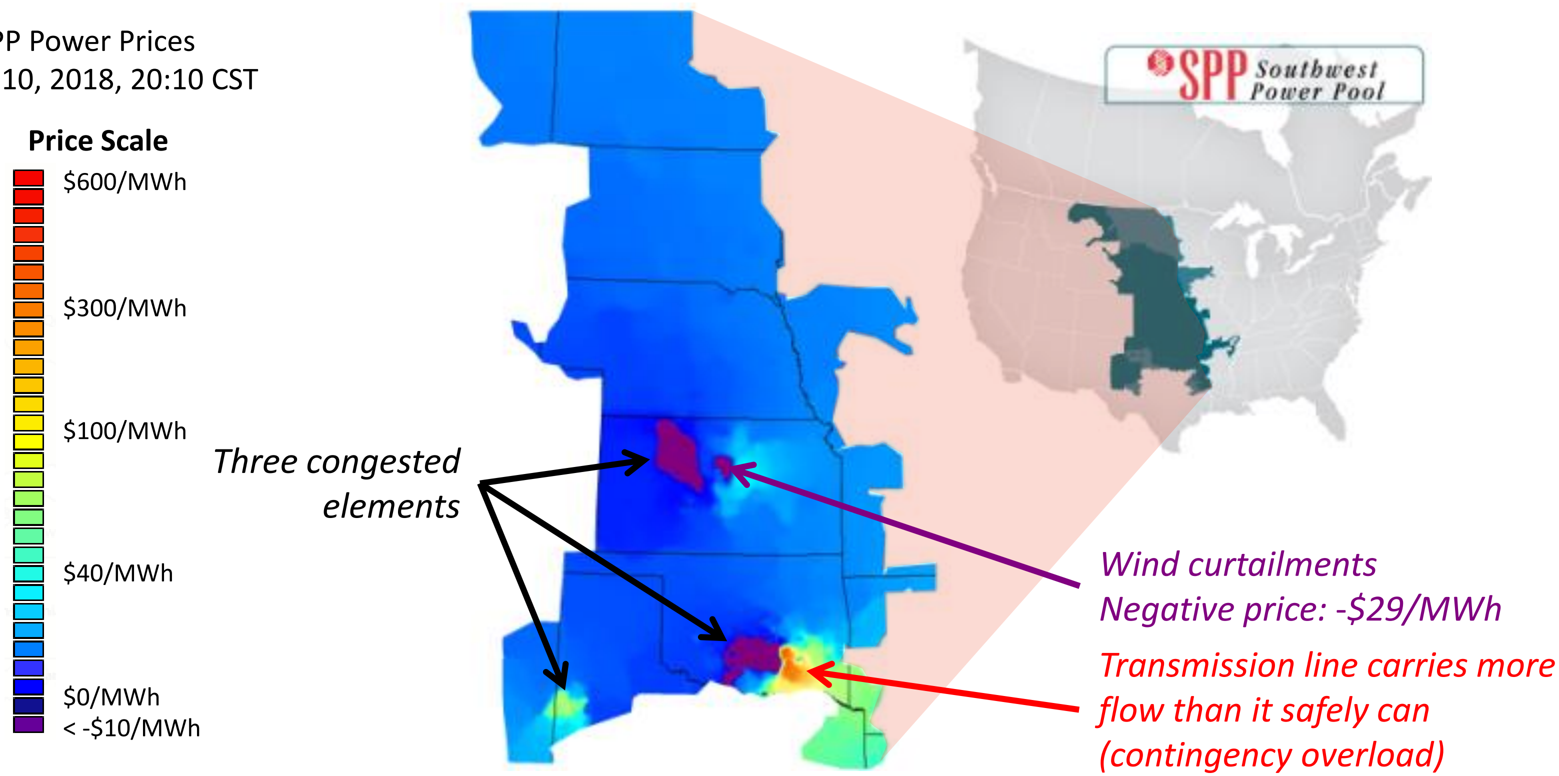
THE Brattle GROUP

Current Congestion Management Impacts

Annual US Impacts
- **Costs: $4-8 billion**
- **Reliability: overloads 5-20% of the time**
- **Wind and Solar: 2-17% curtailments**

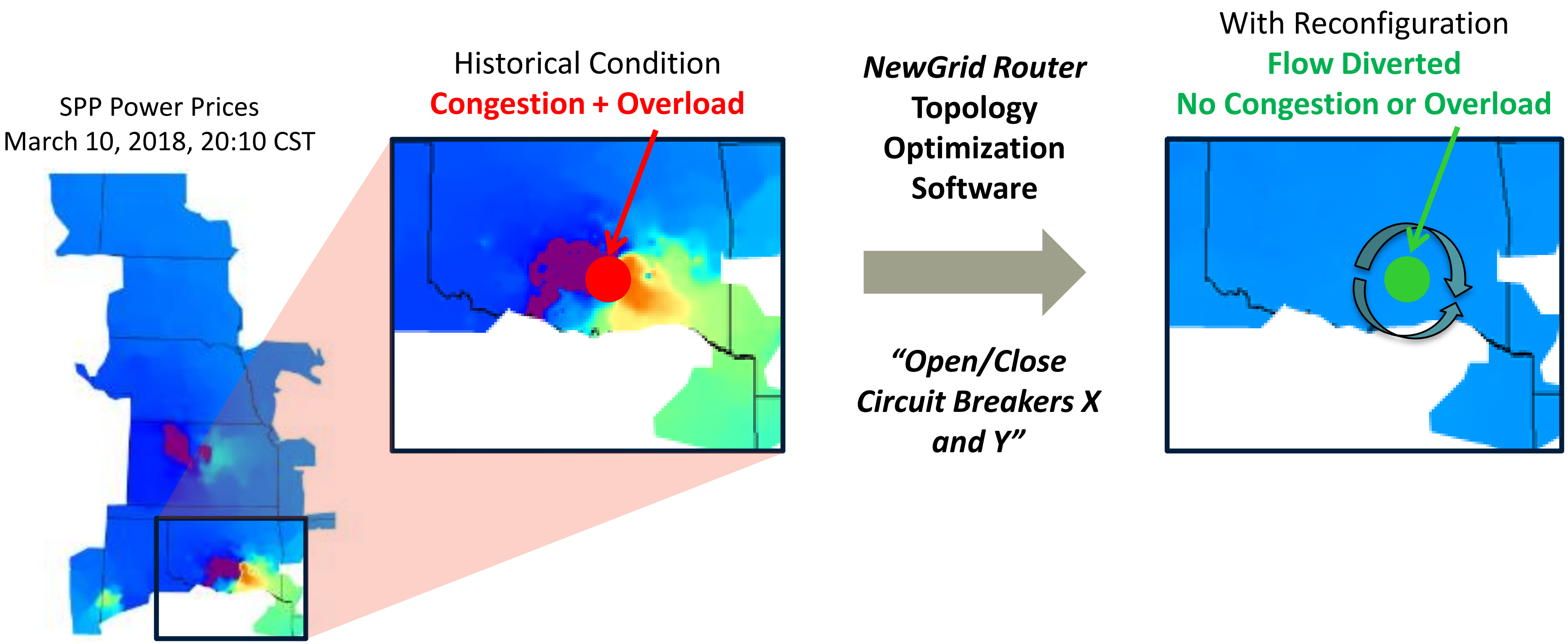
Example from Southwest Power Pool

SPP Power Prices
March 10, 2018, 20:10 CST



Topology Optimization Software

Software automatically finds reconfigurations to route flow around congested or overloaded elements (“*Waze for the transmission grid*”).

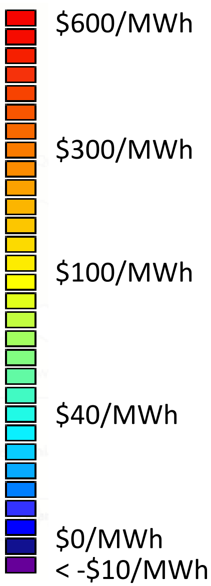


Case Study 1: SPP Operations

Congestion, Overload, Wind Curtailment Relief

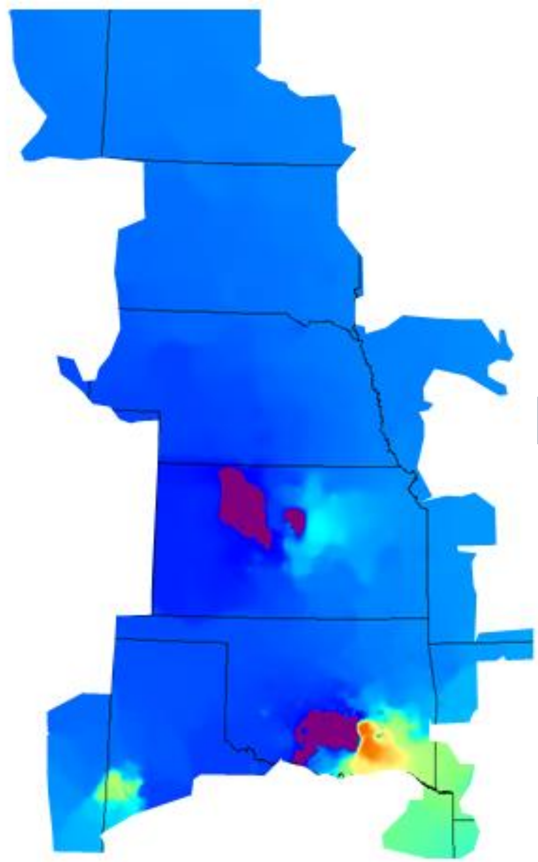
SPP
System Conditions
March 10, 2018,
20:10 CST

Price Scale



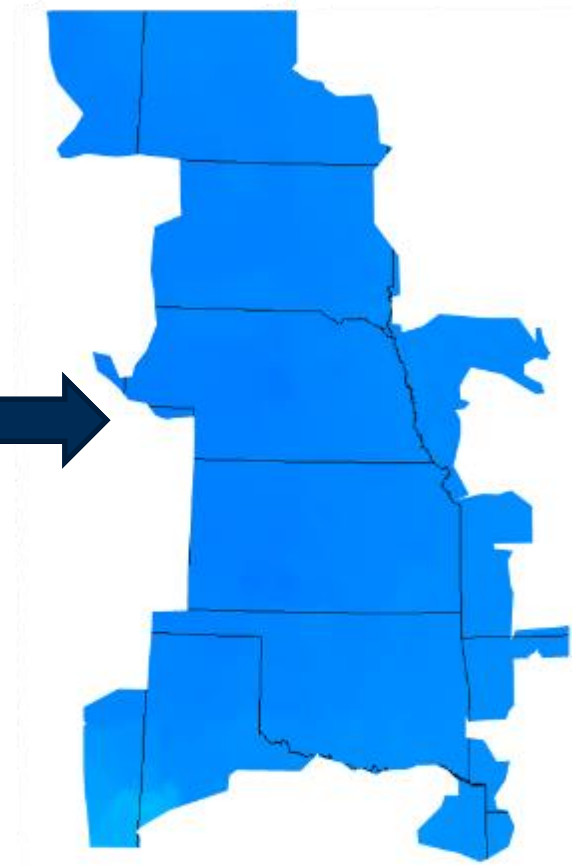
Historical Case

Binding constraints: 3
Shadow prices: **$174 – $984/MWh**
Breached constraints: **one**
Wind Curtailments: **285 MW**

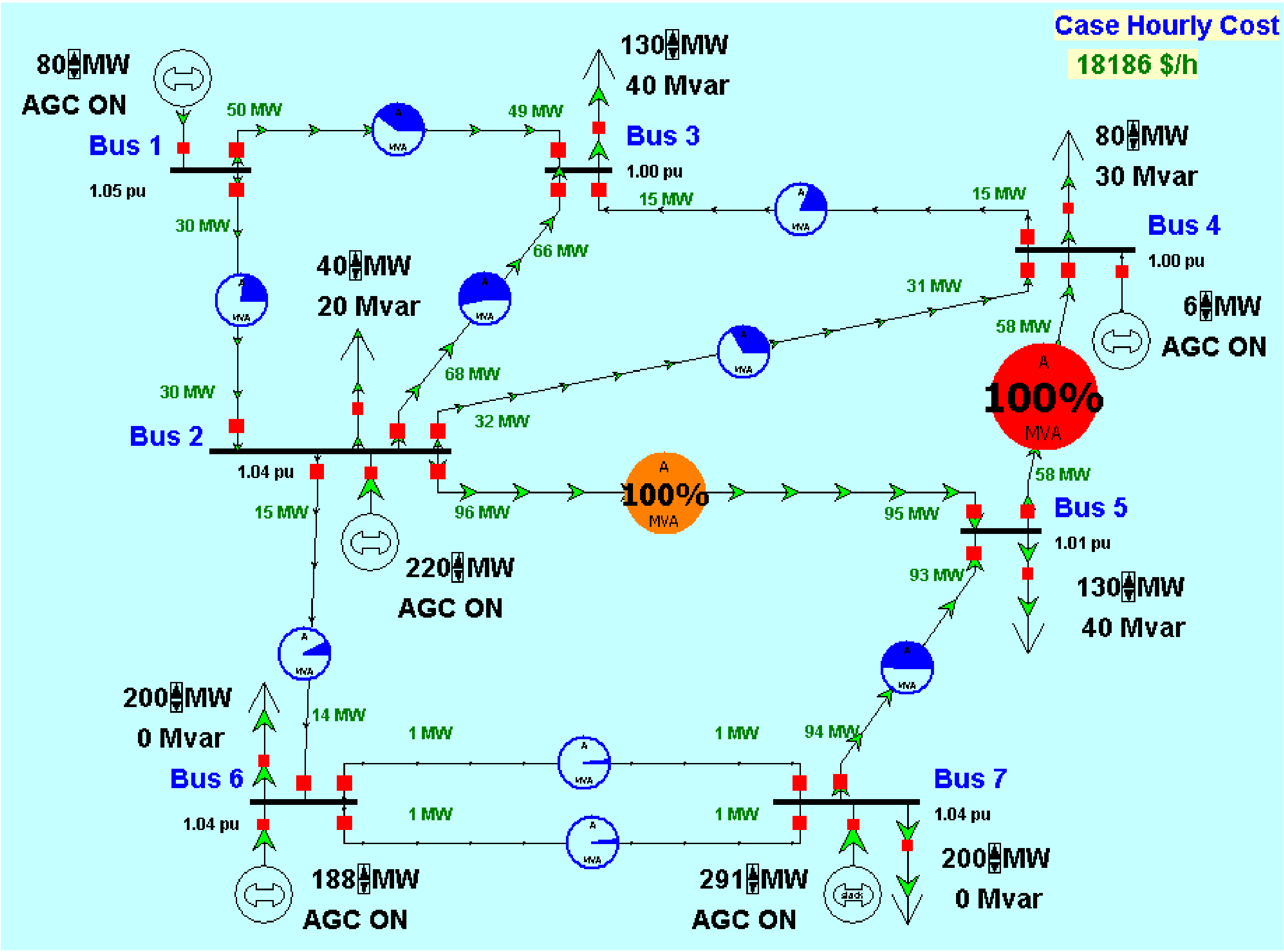


With Reconfigurations

Binding constraints: 1
Shadow price:
Breached constraints: **none** ✓
Wind Curtailments: **0 MW** ✓

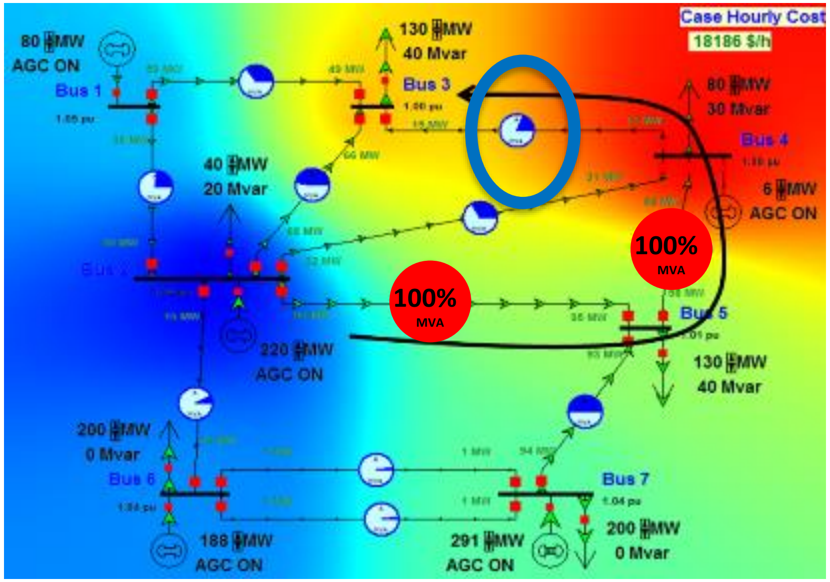


7-Bus Example: All Lines Closed



7-Bus Example Results: Before and After

Before: all lines Closed



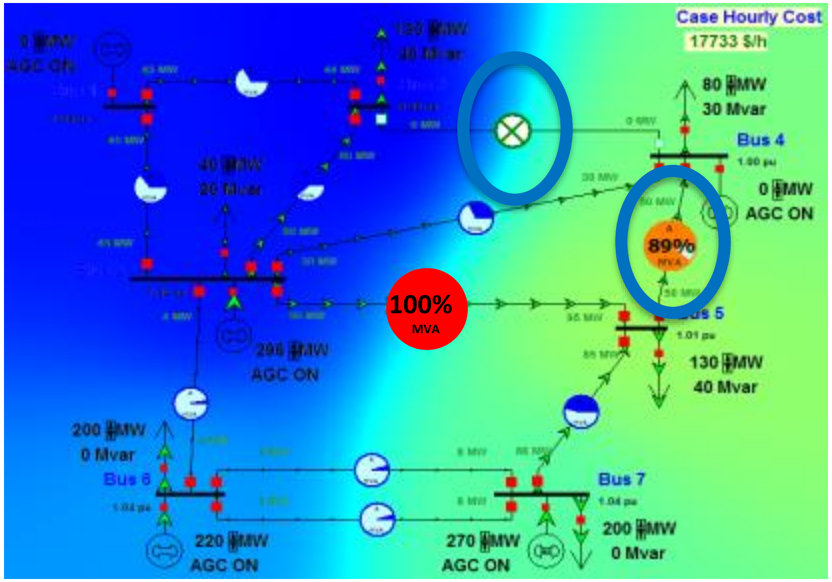
$40/MWh

$15/MWh

Hourly Cost

All lines Closed:	$18,186
Line 3-4 Opened:	$17,733
Savings:	**$453 (2.5%)**

After: line 3-4 Opened

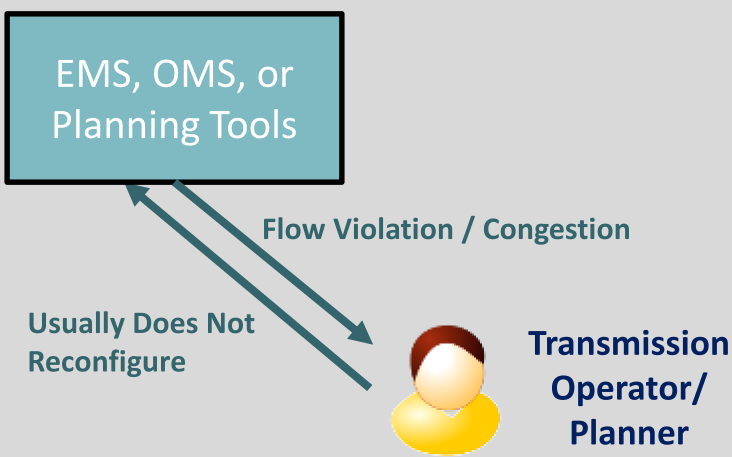


Generation	All lines closed	Line 3-4 open
Bus 1	80 MW	0 MW
Bus 2	220 MW	296 MW
Bus 4	6 MW	0 MW
Bus 6	188 MW	220 MW
Bus 7	291 MW	270 MW
Total	785 MW	786 MW

Reconfiguration Practice

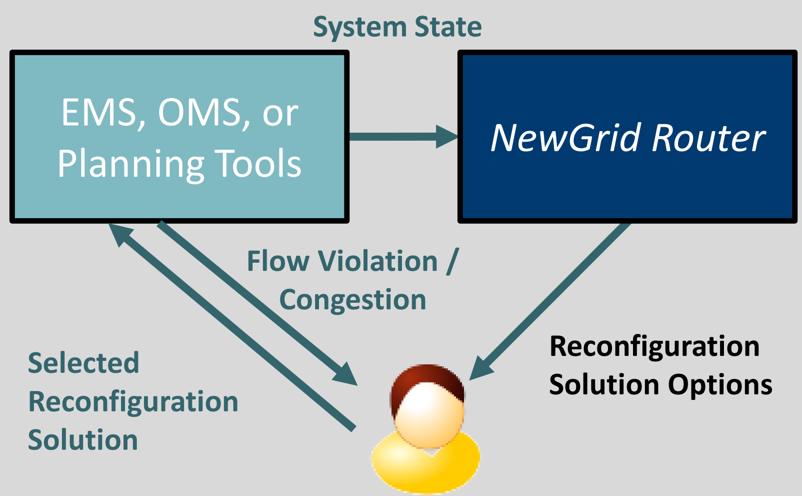
Traditional/Today

- Employed on an ad-hoc basis
- Reconfigurations are identified based on staff experience
- Reconfiguration development is a time-consuming process
- The transmission grid flexibility is underutilized



With Topology Optimization

- Software identifies reconfiguration solution *options* to select
- Fast identification: 10 s – 2 min
- Facilitate training of new operators
- Take full advantage of grid flexibility
- Achieve better outcomes

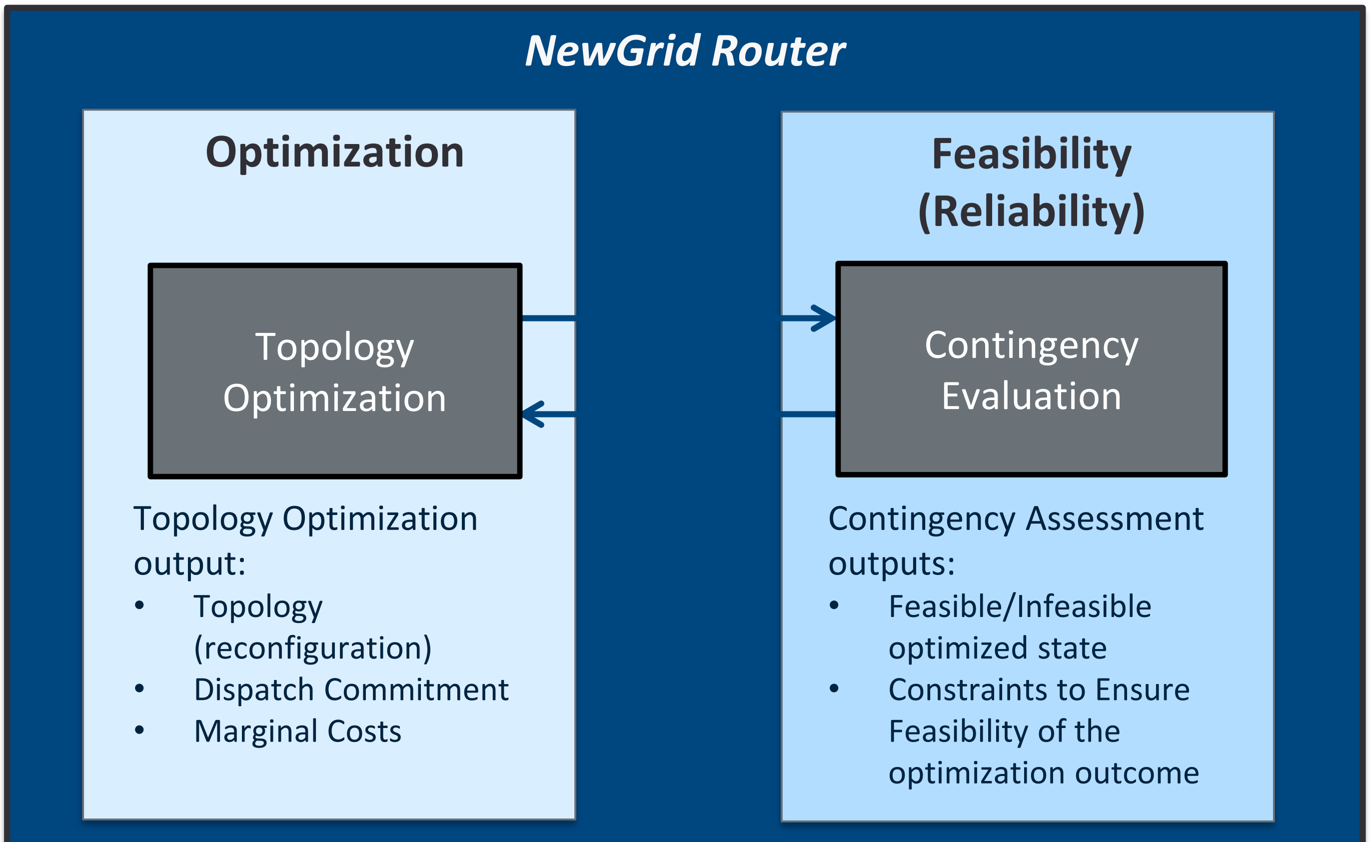


Transmission Topology Optimization Software

- We developed topology control algorithms (TCA) for optimizing transmission network topology with DOE ARPA-E support.
  - Designed to operate with existing systems and software (EMS, OMS, MMS).
  - *Decision Support*: Multiple options proposed, impacts evaluated for each option.
  - *Reliability*: Connectivity constraints including max admissible load radialized, contingency constraints, voltage criteria met.
  - *Speed*: Meets solution times that align with operations timeframes.
  - *High-Definition*: Handles operations (node-breaker, EMS) cases.
  - *Reconfiguration Types*: Line switching (open/close), bus-tie and bypass breaker state.
  - *Look-Ahead*: Optimization decisions with “topology continuity” constraints.
  - *Market Optimization*: SCED and SCUC co-optimized with transmission configuration.
- 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.

Reconfigurations Meet N-1 Reliability Criteria

As part of the reconfiguration search, *NewGrid Router* runs contingency analysis to ensure that the new configurations are feasible (*e.g.*, do not cause new contingency violations).



Topology Optimization Applications

Business Process

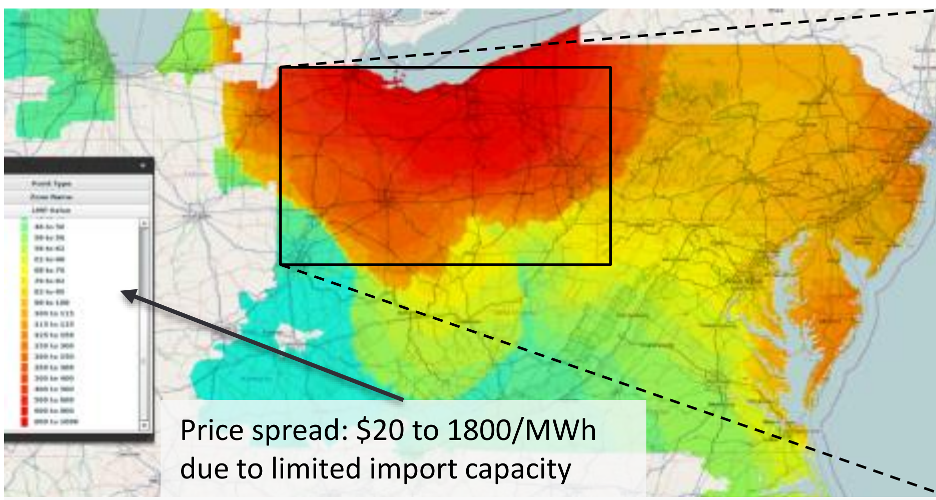
- Long-term planning
- Seasonal contingency planning
- Outage coordination
- Day-ahead market optimization
- Real-time market optimization
- Intra-day operations

Objectives

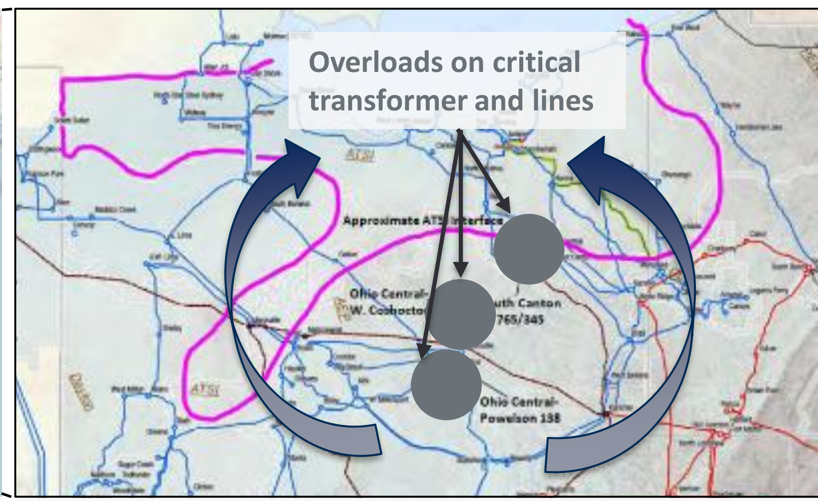
- ✓ Adapt to emergency system conditions
- ✓ Increase grid resilience
- ✓ Avoid load shedding
- ✓ Enable conflicting outages
- ✓ Train new staff
- ✓ Increase transfer capability
- ✓ Relieve flow violations
- ✓ Minimize congestion costs
- ✓ Reduce wind curtailments

Increased Grid Resilience

- Resilience: “ability to reduce the magnitude and/or duration of disruptive events.”
  - NewGrid Router identifies grid reconfigurations to:
  - Quickly adapt the grid to the disruptive event conditions
  - Minimize impacts by more quickly relieving overloads and consumer disconnections
  - Expedite recovery from events by providing more operational options.
- Case Study: 15-18 July, 2013 Extreme Heat Wave in PJM with Key Outages [Ref. 16]



PJM Real Time Prices, 18/7/2013, 15:30 (pjm.com)



Fully relieve overloads by diverting flow around them, and **increase import capacity** to N Ohio

Sources:
National Infrastructure Advisory Council (NIAC), *Critical Infrastructure Resilience Final Report and Recommendations*, 2009, pages 2-11.
http://www.pjm.com/~/media/committees-groups/committees/mrc/20130829/20130829-item-13-hot-weather-operations-presentation.ashx

Case Studies Overview

Topology optimization finds highly beneficial reconfigurations.

Case 1. Constraint Loading Relief in Operations – SPP

- Full overload and wind curtailment relief under recent real-time conditions, Refs. [1]-[3].

Case 2. Congestion Cost Relief in Real Time Markets – PJM

- Co-optimization of topology and dispatch provides 40-70% congestion cost relief, Refs. [14], [17].

Case 3. Additional Transfer Capacity in Days-Ahead – National Grid UK

- Increased transfer capability 3-12% for critical constraints under severe outages, Refs. [6], [7].

Case 4. Constraint Mitigation Plan in Seasonal Planning – ERCOT

- Identified new seasonal plan that avoids load shedding, Ref. [5].

Case 5. Long-Term Planning Applications – SPP

- Avoided up-to 243 MW of load shedding for severe NERC TPL-001 planning events, Ref. [3].

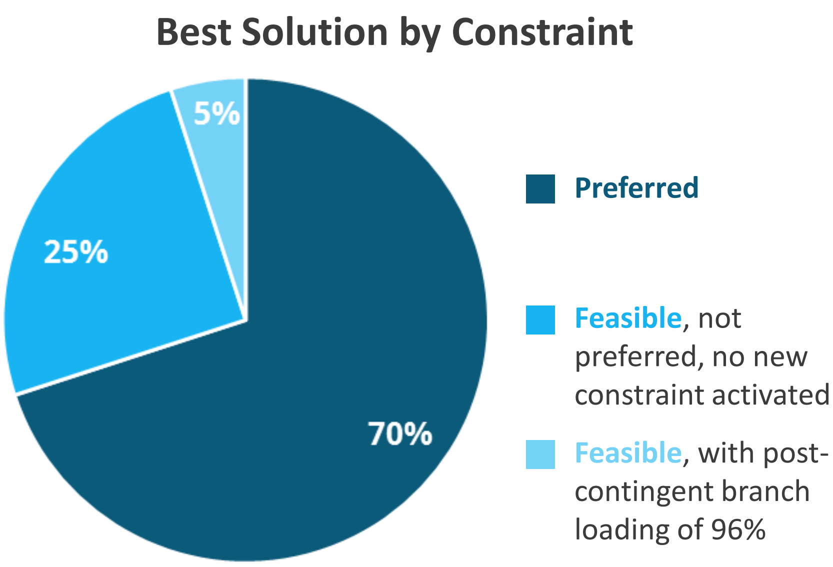
Additional analyses to date (Appendix 1):

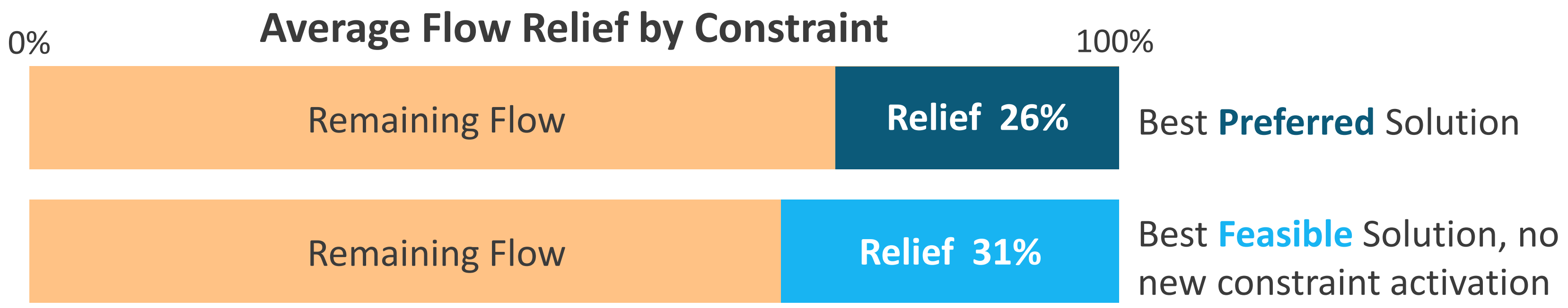
- ERCOT Relief of most frequent market constraint in 2014-2015, Ref. [8].
- PJM operations: Relief of critical historical base-case overloads, Ref. [16].
- PJM DA markets: 30-50% congestion cost relief, Ref. [6].

See the list of references in Appendix 2.

Constraint Flow Relief in SPP

- SPP selected real-time snapshots with high congestion/overloads on focus 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





Case Study 2: Congestion Relief in PJM RT Markets

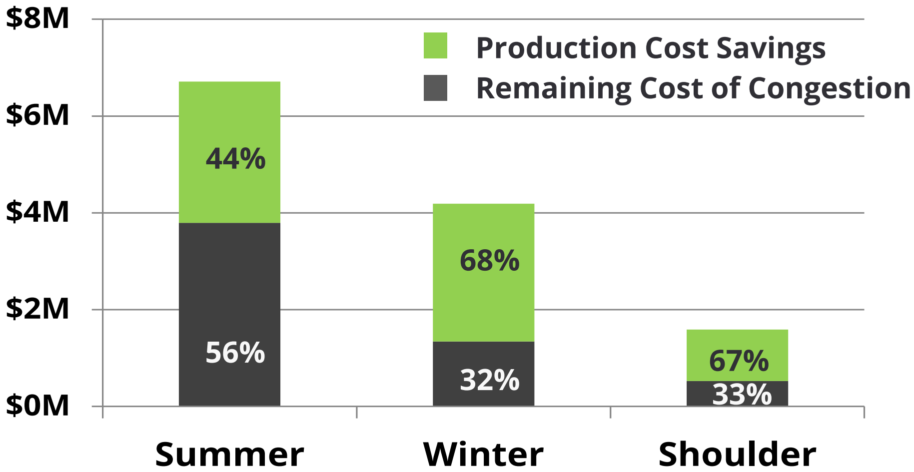
Historical PJM RT Market Models

- As part of the ARPA-E TCA project, we simulated the impacts of topology optimization on PJM RT markets.
- Models based on one operational power flow real-time snapshot per hour for three representative historical weeks of average conditions in 2010—summer, shoulder (fall), and winter weeks. Data used from the power flows:
  - Transmission topology, branch parameters, initial voltage state.
  - External system conditions (*e.g.*, interchange, reciprocal flowgate use).
  - Nodal load levels; unit commitment for all units.
  - Dispatch of hydro, wind, landfill, nuclear, and RMR thermal units.
- Generation economic and transmission constraint data from operations and historical market conditions.
- Model dimensions: up to 15,200 nodes and 650 dispatchable thermal PJM units, about 4,700 monitored branches and 6,100 single and multi-element contingencies.

Case Study 2: Congestion Relief in PJM RT Markets

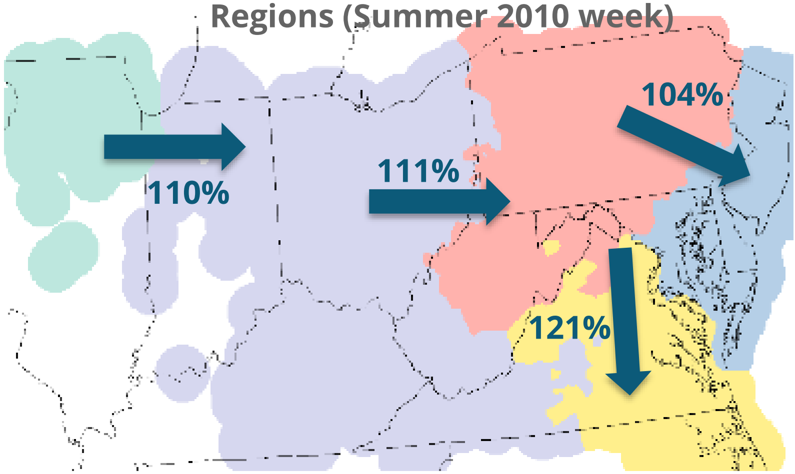
Impacts on PJM Real Time Market

Weekly Real-Time Market Congestion Cost Savings

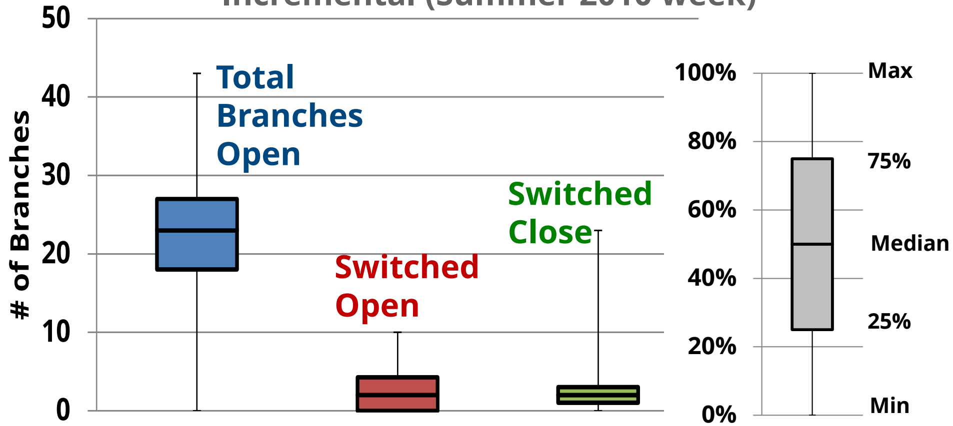


50% reduction in Real Time PJM congestion costs ⇒ extrapolate to a potential for $100 million savings in annual production costs

Increase in Weekly Energy Transfers Between PJM Regions (Summer 2010 week)



Hourly Topology Statistics – Cumulative and Incremental (Summer 2010 week)



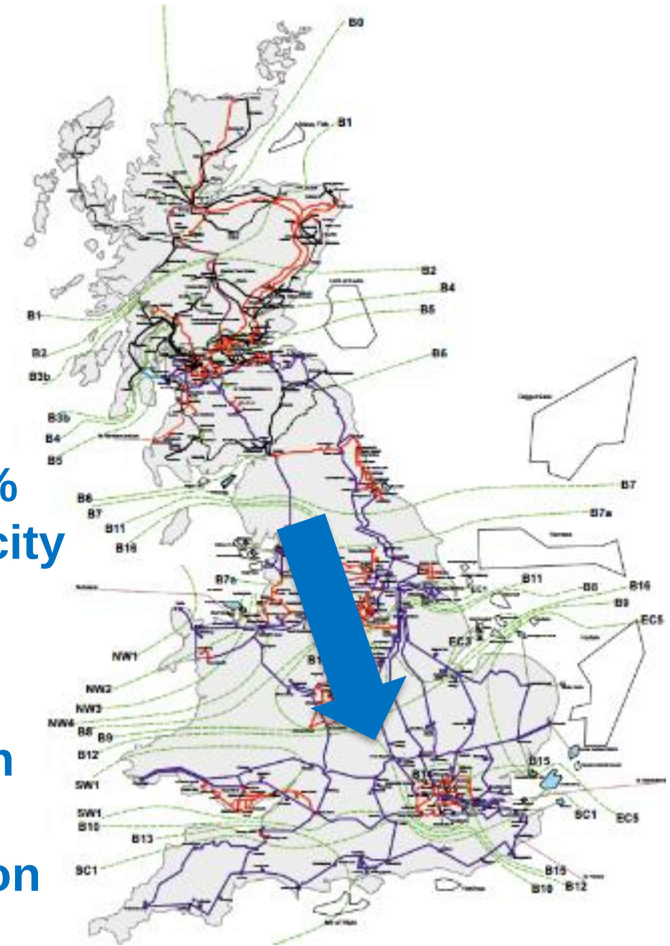
Case Study 3: National Grid UK Operations Planning

Increased Transfer Capability in Great Britain

- National Grid and Brattle studied the potential to increase transfer capability and reduce constraint management costs with topology optimization.
- Iteratively and collaborative analysis:
  - National Grid identified historical outage scenarios where thermal limits had been active on major (zonal) "boundary constraints."
  - Brattle identified reconfigurations for them.
  - National Grid assessed the reconfiguration impacts and provided feedback.
- Decision variables: line switching, substation reconfigurations, phase-shifting transformer settings.

+ 4 – 12%
Grid Capacity

Congestion Savings: £14-40 million



Source: Electricity Ten Year Statement 2015, National Grid, November 2015, Figure 3.1.

Case Study 4: ERCOT Seasonal Operations Planning

Efficient Contingency Plan Development

Topology optimization enabled ERCOT to replace a legacy contingency plan that relied on load shedding, with a new plan that avoids customer interruptions under a transmission outage condition.

- "A Constraint Management Plan (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 in accordance with the Protocols, Operating Guides and North American Electric Reliability Corporation (NERC) Reliability Standards." *
- ERCOT has been using topology optimization software to support the CMP review and development since 2017 [Ref. 1]:
  - Identified an alternative solution to a plan that would have required load shedding.
  - New plan avoids customer interruptions under a transmission outage in northern Texas.
  - Helped verify that the plans selected are the most effective solutions.

* *ERCOT Nodal Protocols*, Section 2, September 14, 2017, page 2-11.

Case Study 5: SPP Long-Term Planning

Avoiding Non-Consequential Load Loss

- NERC allows load shedding as part of the *Corrective Action Plan* (CAP) for specified planning events involving multiple transmission outages that would otherwise result in NERC TPL-001-4 violations.*
- SPP identified three severe multiple-contingency events** (P6, P7 and Extreme) for which the CAPs rely on substantial load shedding (re-dispatch is ineffective).
- We found corrective reconfigurations for all three cases that:
  - *Relieve the violations without load shedding*.
  - Do not cause other violations.

* NERC Standard TPL-001-4 — Transmission System Planning Performance Requirements.
** P6 Events involve two sequential, overlapping single contingencies. P7 Events are multiple contingency as a result of a common structure or other single failure. Extreme Events include loss of a transmission corridor, of an entire substation or power plant, or of multiple elements due to a regional event or critical cyber attack. See NERC Standard TPL-001-4.

Case Study 5: SPP Long-Term Planning

Avoiding Non-Consequential Load Loss

Case Study Type	Flow on Violated Branch Initial [% of Rating]	Flow on Violated Branch With Solution [% of Rating]	Avoided Load Loss [MW]	No. of Actions	No. of New Constraints >95% flow	No. of New Constraints >100% flow	No. of New Constraints <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	1	0	0	0

Concluding Remarks

Options for Transmission System Operators

- Topology optimization solutions and analyses are available as a consulting service.
  - Feasibility and exploratory studies.
  - Benefit assessment analyses.
  - Assessment of impacts on resource revenues and demand costs.
- *NewGrid Router* is available for licensing from NewGrid.
- Possible applications:
  - Quickly identify switching solutions to address reliability and congestion events efficiently.
  - 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.
  - Adapt system configuration as flow patterns change:
    - Increased wind and solar generation.
    - Retirement of legacy thermal units.
    - Manage transmission outages.
    - Address high load growth in load pockets.

PREPARED BY

Pablo A. Ruiz

Senior Consultant | Boston
+1.617.234.5748
Pablo.Ruiz@brattle.com

Dr. Pablo A. Ruiz, a senior consultant at The Brattle Group, is an electrical engineer with over ten years of experience in electric power systems and markets analysis and research. He specializes in power operations, planning and market design under high levels of renewable penetration, modeling and analysis of electricity markets, and advanced technologies for the power grid.

Dr. Ruiz is also an Associate Research Professor at Boston University, where he served as the Principal Investigator for the DOE ARPA-E Topology Control Algorithms project, leading a team of researchers from seven institutions in the development of transmission topology control technology. This technology is being used to develop decision support and simulation tools by NewGrid Inc., a software company co-founded by Dr. Ruiz.

Dr. Ruiz has published journal articles and has presented at international conferences on renewables integration and uncertainty management, power flow analysis, operating reserve requirements and valuation, transmission system operations and expansion and unit commitment.

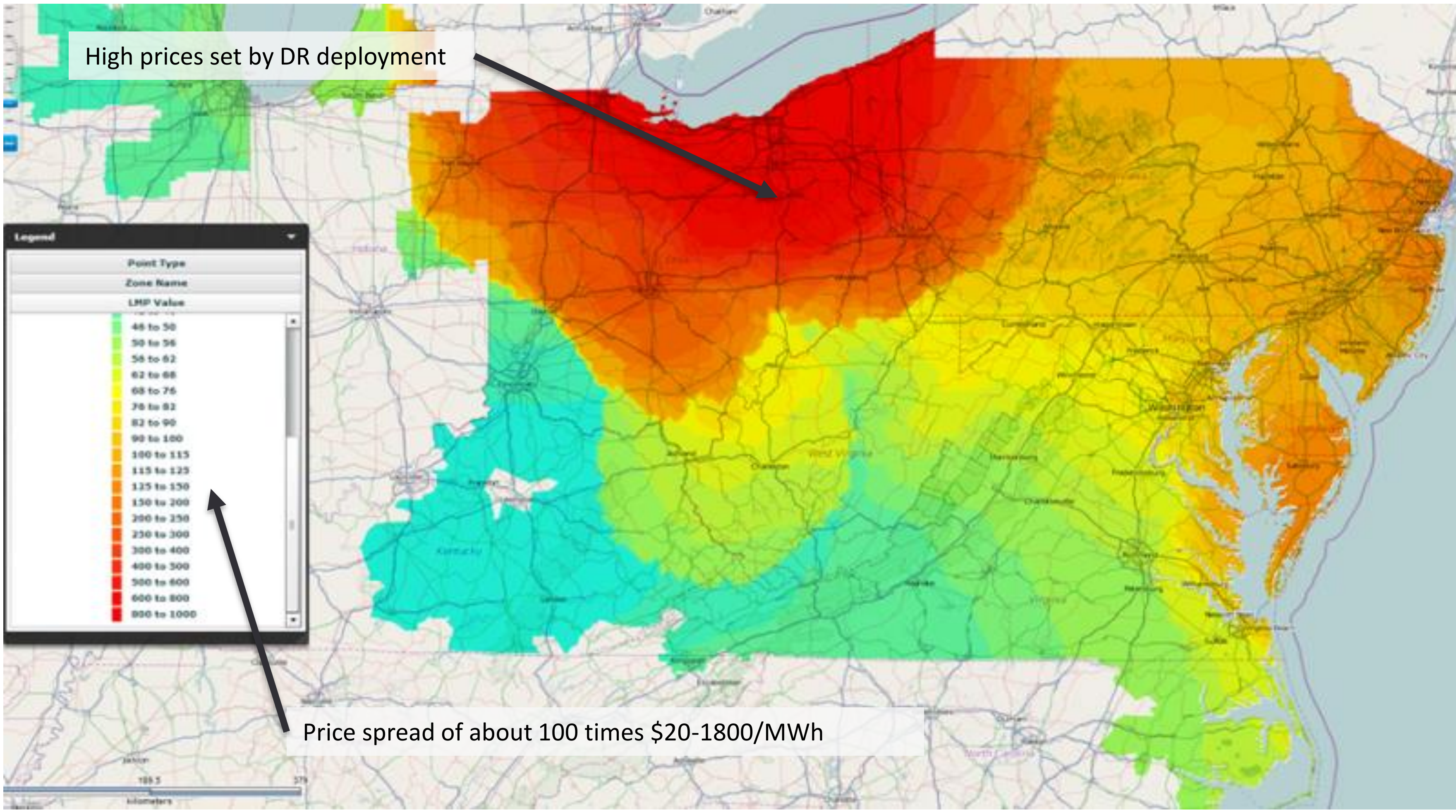
Prior to joining Brattle, Dr. Ruiz was an Associate Principal at Charles River Associates (CRA) and a Power Systems Engineer at AREVA T&D, and has held Research and Teaching Assistant positions at the University of Illinois and at Universidad Tecnológica Nacional. Dr. Ruiz holds a Ph.D. in Electrical and Computer Engineering from the University of Illinois at Urbana-Champaign.

Appendix Contents

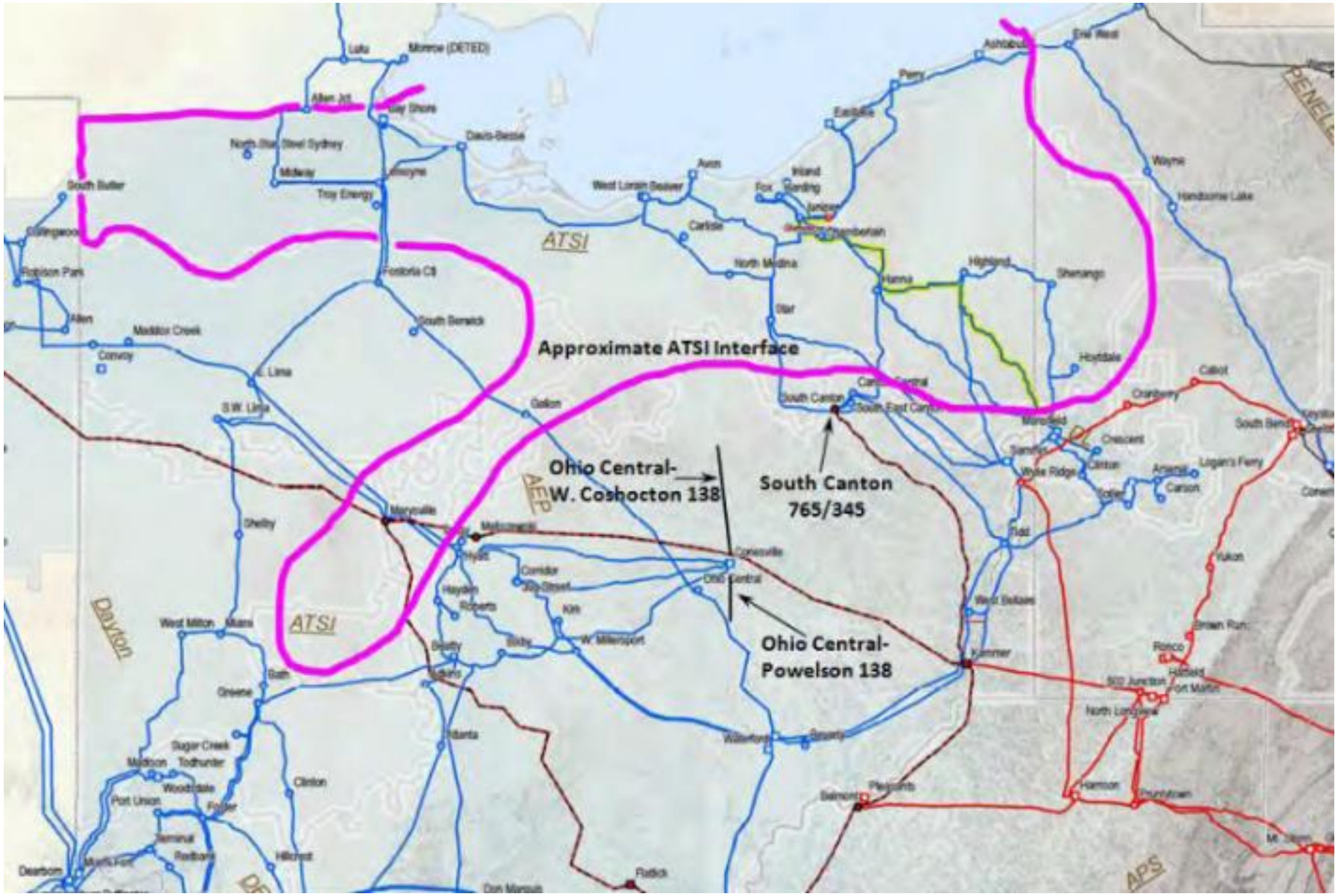
Appendix 1: PJM Overload Relief Under Extreme Conditions

South Canton Transf. Overload Relief

PJM Real Time Prices, 18/7/2013, 15:30 (pjm.com)



South Canton Transf. Overload Relief

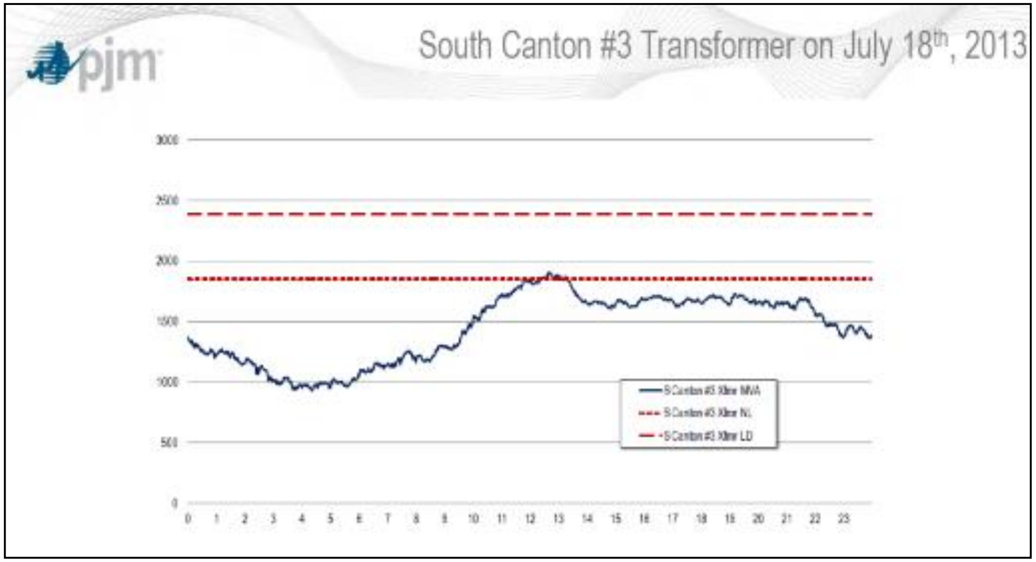


Source: http://www.pjm.com/~/media/committees-groups/committees/mrc/20130829/20130829-item-13-hot-weather-operations-presentation.ashx

South Canton Transf. Overload Relief

The South Canton 765/345 kV transformer was severely congested, even overloaded, on July 15, 17 and 18, 2013.

- Unplanned generation outages in the area: 2700 MW.
- PJM deployed demand response (DR) to lower congestion in the area (650 MW).
- There were four 138 kV line post contingency overloads in the area as well.



Source: http://www.pjm.com/~/media/committees-groups/committees/mrc/20130829/20130829-item-13-hot-weather-operations-presentation.ashx

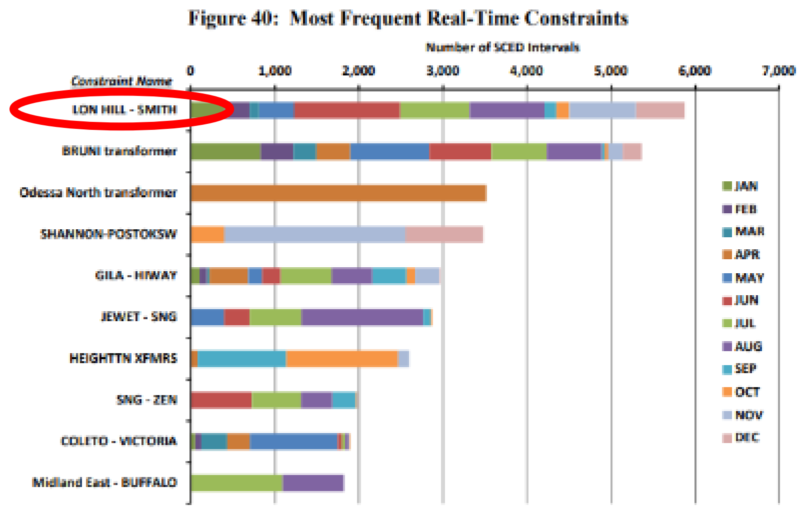
South Canton Transf. Overload Relief

We automatically found reconfigurations that fully relieved historical PJM overloads under worst-case conditions.

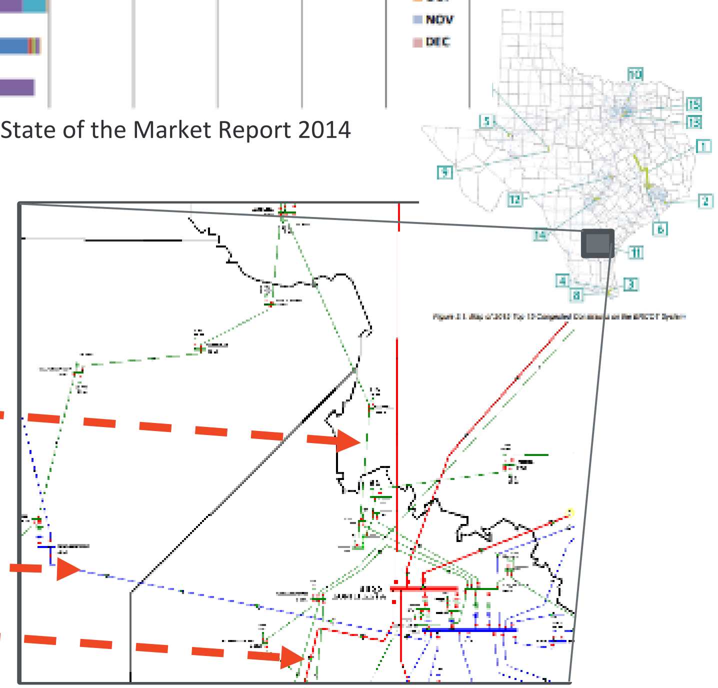
- In our analysis, transmission topology was the only variable allowed to be modified to relieve overloads
  - Due to the extreme conditions for that day, the dispatch was kept the same as the initial EMS dispatch to capture any additional generation operation constraints not captured in the case
- TC was able to divert flow away from the transformer and fully relieved the base case and post contingency overloads in the area
- TC application would have reduced the required DR deployment.
- Voltage profiles with and without reconfigurations were very similar.

Lon Hill-Smith 69 kV Constraint

- The Lon Hill-Smith 69 kV line was the most frequent constraint in ERCOT in 2014-2015.
  - Constraint was binding during almost 6,000 real-time market intervals (5 minutes) in 2014.
  - Congestion was caused by increased demand due to oil and gas activity in the Eagle Ford Shale.
  - A transmission upgrade in the area solved the congestion after May 2015.
- Constraint monitors Lon Hill-Smith 69 kV line for the double outage of:
  - Lon Hill to Orange Grove 138 kV,
  - Lon Hill to North Edinburg 345 kV.



Source: ERCOT State of the Market Report 2014



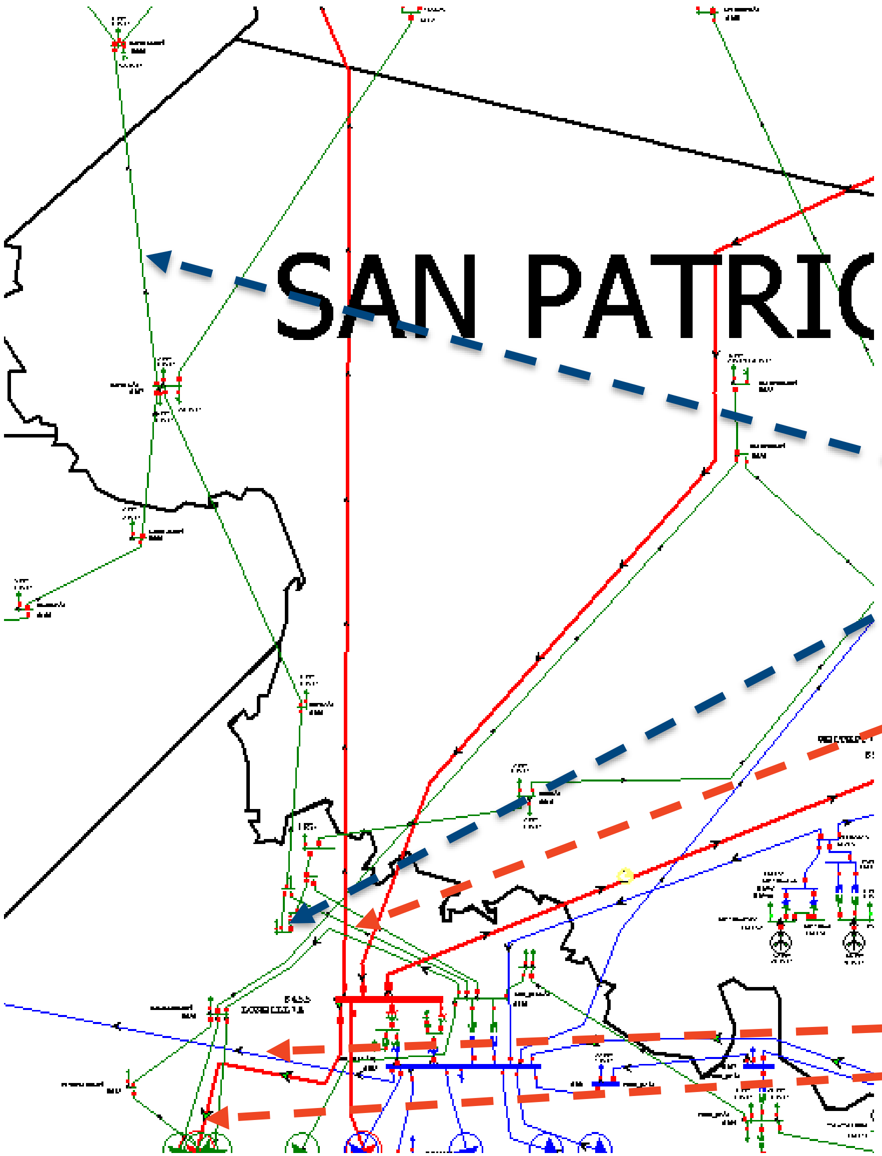
Source: ERCOT ETWG Dec 2016 Meeting presentation (Ref. [3])

Appendix 1: ERCOT Historical Constraint Relief

Solution Search Criteria and Results

- ERCOT Operations Planning provided a 2015 Summer Peak case for reconfiguration analysis, which had a 24% violation on the contingency constraint.
- The topology optimization software searched for topology changes that would relieve the constraint violations while:
  - Keeping the generation dispatch fixed (for demonstration purposes only; allowing for dispatch changes could enable more or better solutions),
  - Limiting additional violations (pre- or post-contingency, thermal or voltage).
- The solutions would be implemented in corrective mode.
  - Corrective mode—implement the reconfigurations after the occurrence of the specified contingency, should it occur, to avoid the post-contingency overload.
  - The reconfiguration does not worsen potential contingency overloads for a subsequent contingency (N –1–1).
- Sample reconfiguration found effectively **increases local system capacity by 20%** (under the conditions analyzed):
  - Close one 69 kV tie and open one 69 kV line,
  - Relieves the 24% (14 MVA) violation, causing a 4% (2 MVA) violation on another 69 kV line.

Reconfiguration Alternative



Closing the Stevens 69 kV bus tie breaker diverts some flow from Lon Hill – Smith to Lon Hill – W Work – Stevens – Smith, fully relieving the overload but causing another, smaller overload downstream, at Smith – Edroy – Mathis 69 kV.
Opening the Mathis – Mathis Sub 69 kV line fully relieves the overload, causing a 2 MVA overload downstream.

Reconfiguration

Open Mathis – Mathis Sub 69 kV
Close Stevens 69 kV bus tie

Lon Hill – Smith 69 kV

Initial Configuration:

24%, 14 MVA overload

With Reconfiguration:

Full relief on Lon Hill – Smith

4%, 2 MVA overload on different 69kV line

Two-Element Contingency:
Lon Hill to Orange Grove 138 kV
Lon Hill to North Edinburg 345 kV

Appendix 2

References (I/II)

[1] P. A. Ruiz and J. Caspary, "SPP Transmission Topology Optimization Pilot," ESIG Spring Technical Workshop, Bernalillo, NM, March 2019. https://brattlefiles.blob.core.windows.net/files/15769_spp_transmission_topology_optimization_pilot.pdf

[2] P. A. Ruiz et al, "Transmission topology optimization: congestion relief in operations and operations planning," *SPP Market Working Group Meeting*, Oct 2018. https://spp.org/Documents/58737/MWG%20Agenda%20&%20Background%20Materials%2020181009%2010.zip

[3] P. A. Ruiz et al, "Transmission topology optimization: performance and benefit assessment in SPP Operations and Operations Planning," *SPP Operating Reliability Working Group Meeting*, Little Rock, AR, May 2018. https://www.spp.org/Documents/57991/ORWG%20Meeting%20Materials%205-30-18.zip

[4] P. A. Ruiz, "Power Flow Control Through Topology Optimization Software: Applications and Case Studies," *IEEE PES Transmission & Distribution Conference and Expo*, Denver, CO, April 2018.

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

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

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

[8] P. A. Ruiz, "Transmission topology optimization software: operations and market applications and case studies," *ERCOT Emerging Technologies Working Group Meeting*, Austin, TX, Dec 2016. http://www.ercot.com/content/wcm/key_documents_lists/85542/05._Transmission_topology_control_--_ERCOT_ETWG_12616.pdf

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

[10] P. A. Ruiz et al, "Transmission topology optimization: simulation of impacts in PJM day-ahead markets," presented at *FERC Tech. Conf. on Increasing Market Efficiency through Improved Software*, Docket AD10-12-007, Washington, DC, June 2016.

Appendix 2

References (II/II)

[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. A. Goldis, P. A. Ruiz, M. C. Caramanis, X. Li, C. R. Philbrick, A. M. 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] J. Chang and P. A. Ruiz, “Transmission Topology Control – Applications to Outage Scheduling, Market Efficiency and Overload Relief,” presented at *WIRES Summer Meeting*, Boston, MA, July 2015.

[14] P. Ruiz et al, “Topology Control Algorithms (TCA) – Simulations in PJM Day Ahead Market and Outage Coordination,” *FERC Tech. Conf. Increasing Market Efficiency through Improved Software*, Docket AD10-12-006, Washington, DC, June 2015.

[15] 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.

[16] P. A. Ruiz et al, “Topology control algorithms (TCA) – Simulations in PJM with AC Modeling,” *FERC Tech. Conf. Increasing Market Efficiency through Improved Software*, Docket AD10-12-005, Washington, DC, June 2014.

[17] P. A. Ruiz et al, “Transmission Topology Control Algorithms (TCA) Simulations on PJM Real Time Markets,” *Workshop on Topology Control*, PJM Conference and Training Center, Norristown, PA, Nov 19, 2013.

[18] 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.

[19] 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.

[20] 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.

[21] E. B. Fisher, R. P. O’Neill, M. C. Ferris, “Optimal transmission switching,” *IEEE Trans Power Syst.*, vol. 23, no. 3, pp. 1346–1355, Aug. 2008.

[22] 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.

About Brattle

The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governments around the world. We aim for the highest level of client service and quality in our industry.

OUR SERVICES

Research and Consulting

Litigation Support

Expert Testimony

OUR PEOPLE

Renowned Experts

Global Teams

Intellectual Rigor

OUR INSIGHTS

Thoughtful Analysis

Exceptional Quality

Clear Communication

Electric Power

Brattle's economists provide clients with regulatory economic consulting, business strategy, and expert testimony before regulatory agencies, courts, and arbitration panels.

AREAS OF EXPERTISE

- Auctions
- Climate Change Policy and Planning
- Demand Response, Energy Efficiency, and the Smart Grid
- Electricity Market Modeling
- Energy Asset Valuation
- Energy Contract Litigation
- Energy Mergers and Acquisitions
- Energy Risk Management
- Environmental Compliance
- European Energy Markets
- Fuel and Power Procurement
- Market-Based Rates
- Market Design and Competitive Analysis
- Renewable Energy
- Transmission

Our Practices and Industries

ENERGY & UTILITIES

Competition & Market Manipulation
Distributed Energy Resources
Electric Transmission
Electricity Market Modeling & Resource Planning
Electrification & Growth Opportunities
Energy Litigation
Energy Storage
Environmental Policy, Planning and Compliance
Finance and Ratemaking
Gas/Electric Coordination
Market Design
Natural Gas & Petroleum
Nuclear
Renewable & Alternative Energy

LITIGATION

Accounting
Analysis of Market Manipulation
Antitrust/Competition
Bankruptcy & Restructuring
Big Data & Document Analytics
Commercial Damages
Environmental Litigation & Regulation
Intellectual Property
International Arbitration
International Trade
Labor & Employment
Mergers & Acquisitions Litigation
Product Liability
Securities & Finance
Tax Controversy & Transfer Pricing
Valuation
White Collar Investigations & Litigation

INDUSTRIES

Electric Power
Financial Institutions
Infrastructure
Natural Gas & Petroleum
Pharmaceuticals & Medical Devices
Telecommunications, Internet, and Media
Transportation
Water

Our Offices

BOSTON

NEW YORK

SAN FRANCISCO

WASHINGTON

TORONTO

LONDON

MADRID

ROME

SYDNEY

THE POWER OF **ECONOMICS**

brattle.com