Transmission Topology Optimization Software

Operations and Market Applications and Case Studies

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Agenda

- Objectives and Motivation
- Illustrative Example
- Current Practice
- Topology Optimization Software
- Case Studies
  - Overview of Case Studies
  - Case Study 1: ERCOT Constraint
  - Case Study 2: Topology Optimization in PJM RT Markets
- Concluding Remarks
- Appendix

Topology Optimization Summary

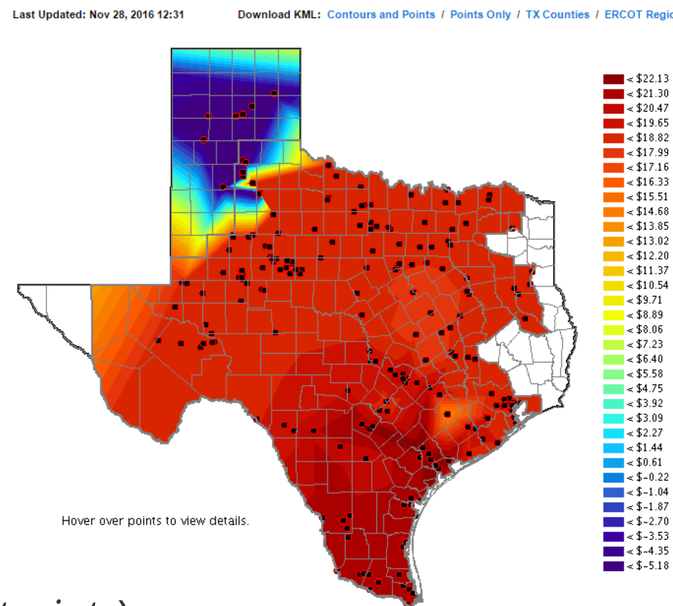
- At any given time, very few transmission lines or transformers are congested.
- Due to the built-in system robustness, usually there are transmission topology reconfigurations (line switching, bus splitting) that can reliably route power around the congested facilities.
- Today, operators use reconfigurations to manage some challenges, identifying them based on their knowledge of the system.
- Topology optimization software enables RTOs and TOs to increase the transmission system capability, by automatically identifying reconfiguration options to:
  - Manage congestion: reduce associated costs by up to 50%.
  - Respond during contingency situations: eliminate overloads/breaches.
  - Improve outage scheduling and coordination: enable more requested outage plans.
- Topology optimization software essentially is a fast “search engine” for identifying and evaluating viable, reliable and beneficial system reconfiguration options.

Current Practice for Congestion Management

Topology optimization offers an effective *complement* to the current practice of resource-based and hardware-based flow control and congestion management.

- **Resource-based flow control**: reduce (low-cost) generation upstream of congestion/overload and increase (costly) generation downstream.
  - Leads to geographic price separation.
  - *ERCOT 2015 congestion costs*: $352 million.
  - *ERCOT renewables curtailment impacts*: 1% of annual potential wind energy in 2015.
  - *ERCOT reliability impacts*: real-time flows exceeded post-contingency grid capacity in 4.6% of the intervals in 2011 (*irresolvable constraints*).

ERCOT Day-Ahead Prices
Nov 28, 2016 at 8am



- **Flow control hardware** (e.g., phase shifters, distributed series devices, FACTS devices) require capital investments and tend to be deployed in limited locations.

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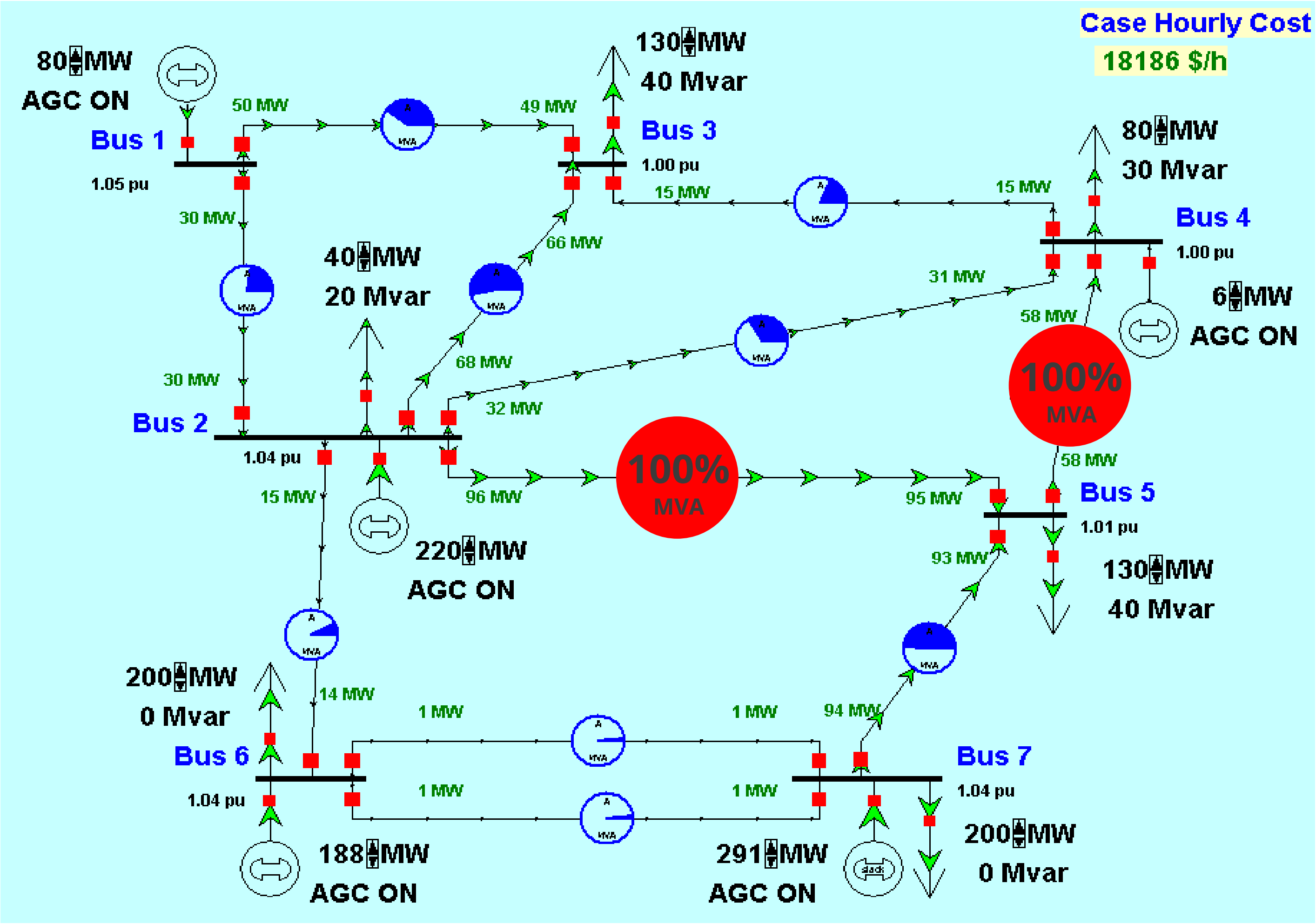
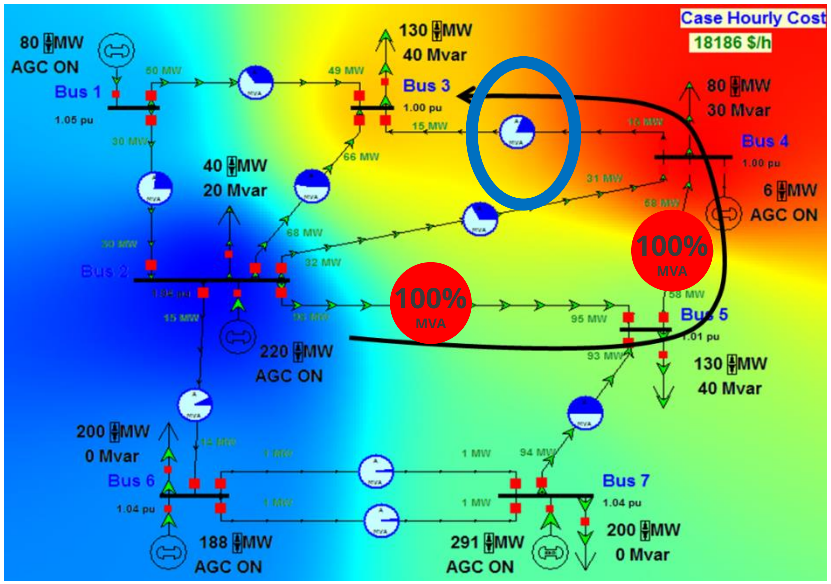
Illustrative Example

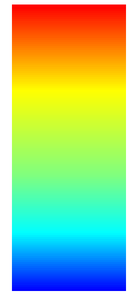
7-bus Example: All Lines Closed



7-bus Example Results: Before and After

Before: all lines Closed

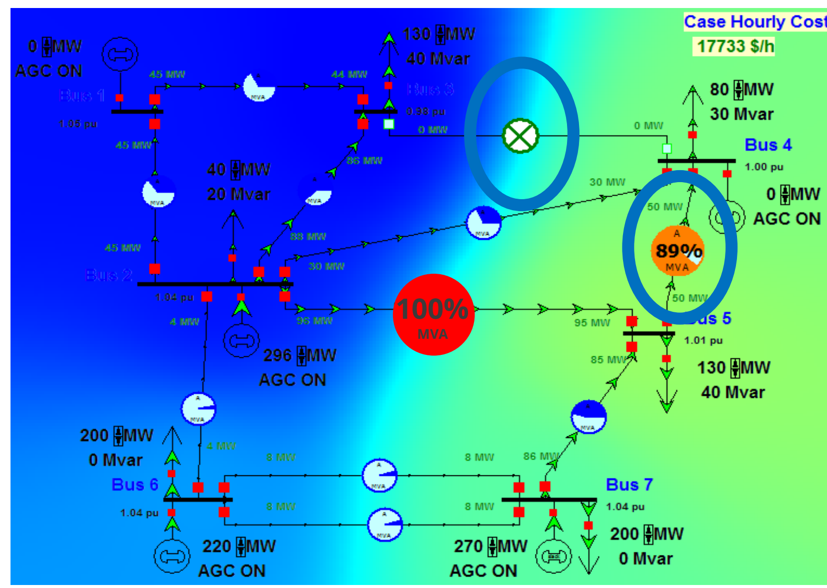




Hourly Cost
All lines Closed: $18,186
Line 3-4 Opened: $17,733
Savings: $453 (2.5%)

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

After: line 3-4 Opened



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Reconfigurations – Current Practice

Reconfigurations are already used to some extent across RTOs.

- Today, system operators adjust transmission topology on an ad-hoc basis for the following applications:
  - Contingency Planning: identify pre- and post-contingency reconfigurations to mitigate overloads (e.g., Remedial Action Plans – RAPs).
  - Outage Coordination/Scheduling: enable planned outages that otherwise would cause reliability violations/increases in congestion.
  - Constraint Management: allow more efficient unit commitment and economic dispatch (used in limited cases), maintain current commitment and dispatch plans.
- In order to identify beneficial reconfiguration options, operators rely on their prior experience and knowledge of the system.
- Currently, developing such switching solutions is a time-consuming, “manual” process, given the magnitude and complexity of the system.
- The flexibility that the transmission system offers is underutilized as a result.

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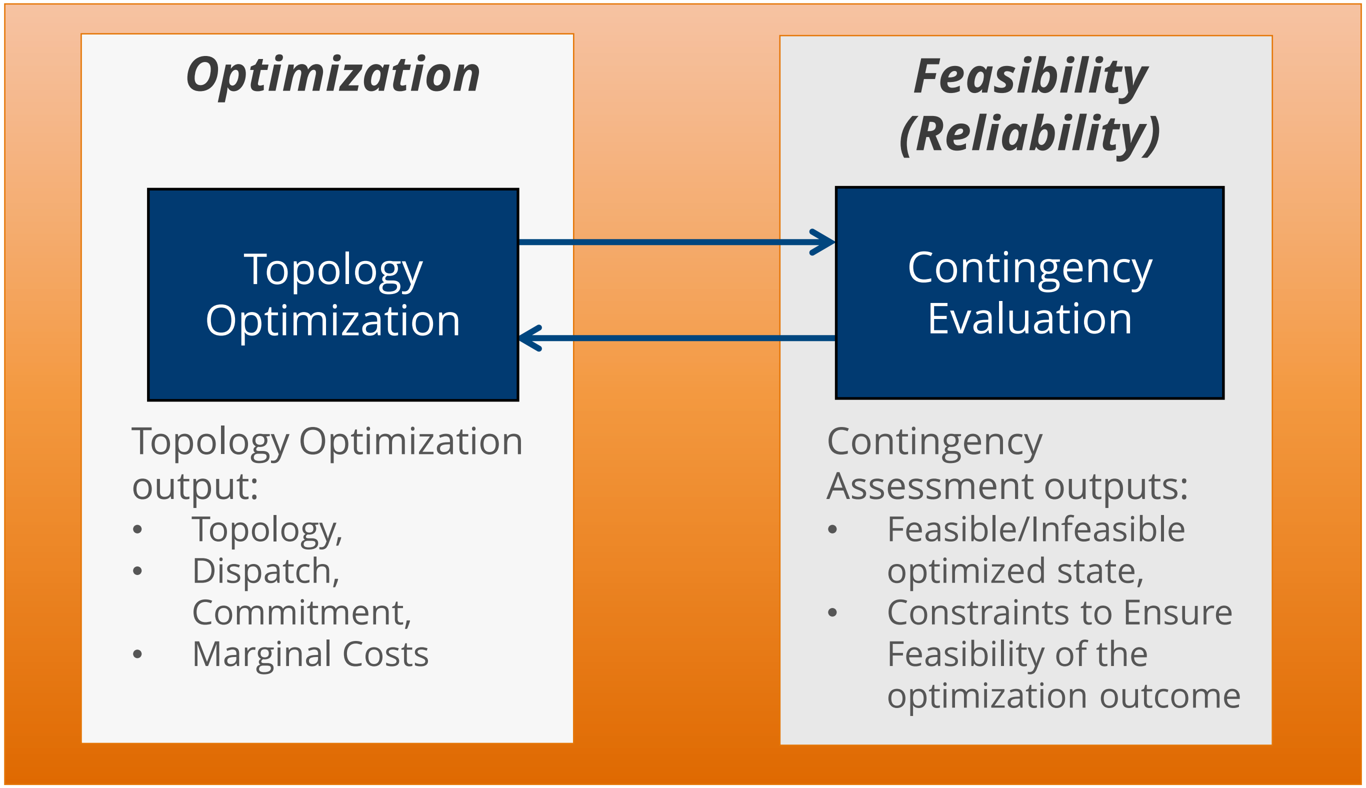
NewGrid Router

NewGrid Router **automatically identifies reconfiguration options.**

- With DOE ARPA-E support, developed topology control algorithms (TCA) for optimizing transmission network topology.
  - Searches for viable reconfiguration options that meet specified reliability requirement.
  - Able to operate in conjunction with market engines for security-constrained unit commitment (UC) and economic dispatch (ED).
  - Speed: meets solution time requirements that align with RT and DA market timeframes.
- With PJM staff, tested the algorithms developed and assessed their impacts in a simulated environment replicating PJM market operations.
- NewGrid has developed *Router*, the first production-grade topology decision support software tool based on the TCA technology.
  - <u>Decision Support</u>: Multiple solutions proposed, impacts evaluated for each solution.
  - <u>Reliability</u>: Connectivity, security constraints, voltage criteria met.
  - <u>Tractability</u>: Able to handle PJM-size EMS cases.
  - <u>Look-Ahead</u>: Optimization decisions with “topology continuity” constraints.

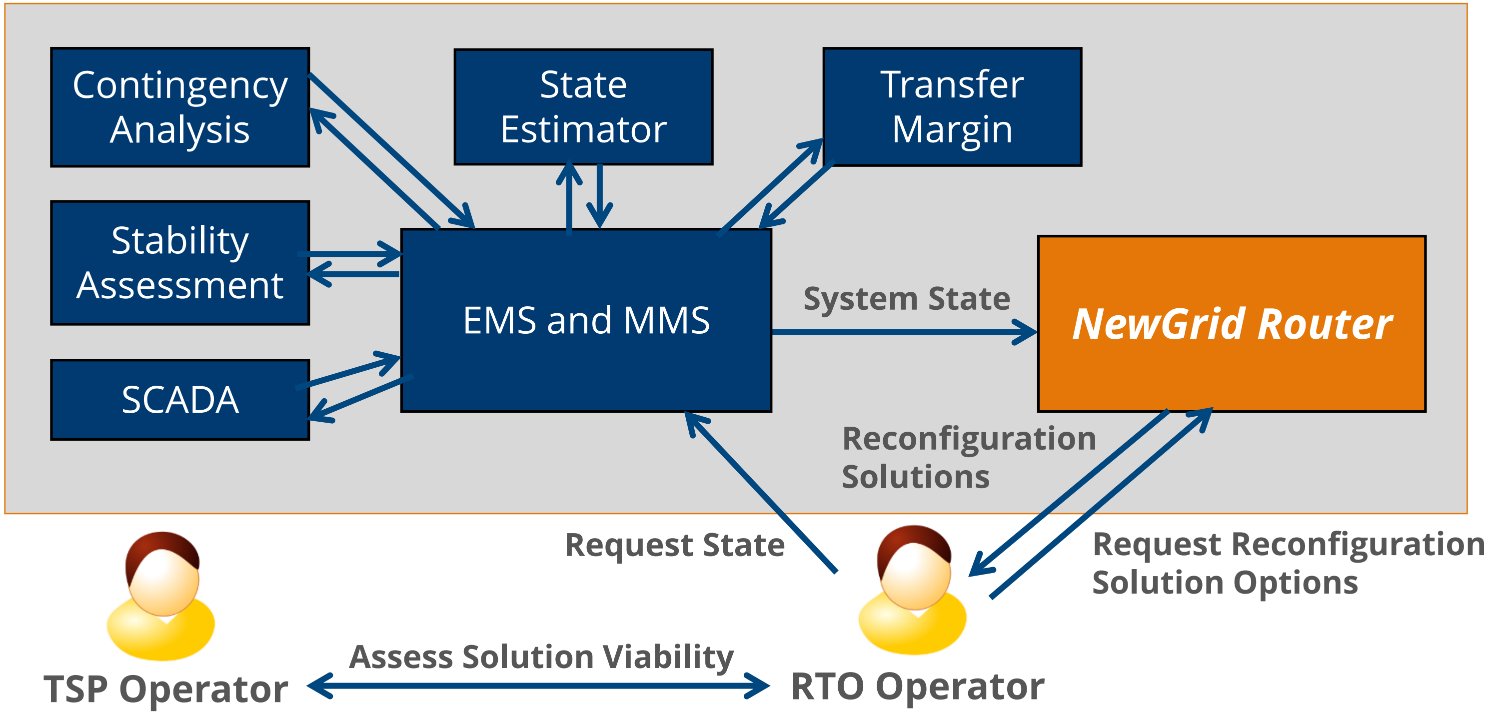
NewGrid Router Architecture

NewGrid Router uses the same general architecture used by Energy Management Systems (EMS) and Market Management Systems (MMS).



Advisory Application: Markets and Operations

- In markets and operations decision making, *Router* provides the engineers with reconfiguration options to select and further evaluate.
- *Router* reduces time to identify options and leads to better outcomes:
  - Develop RAPs/CMPs quickly for *irresolvable constraints* if existing plans do not work.
  - Increase operator visibility of reconfiguration options in congestion management.
  - Resolve outage request conflicts.
  - Reduce outage impacts when conditions change.



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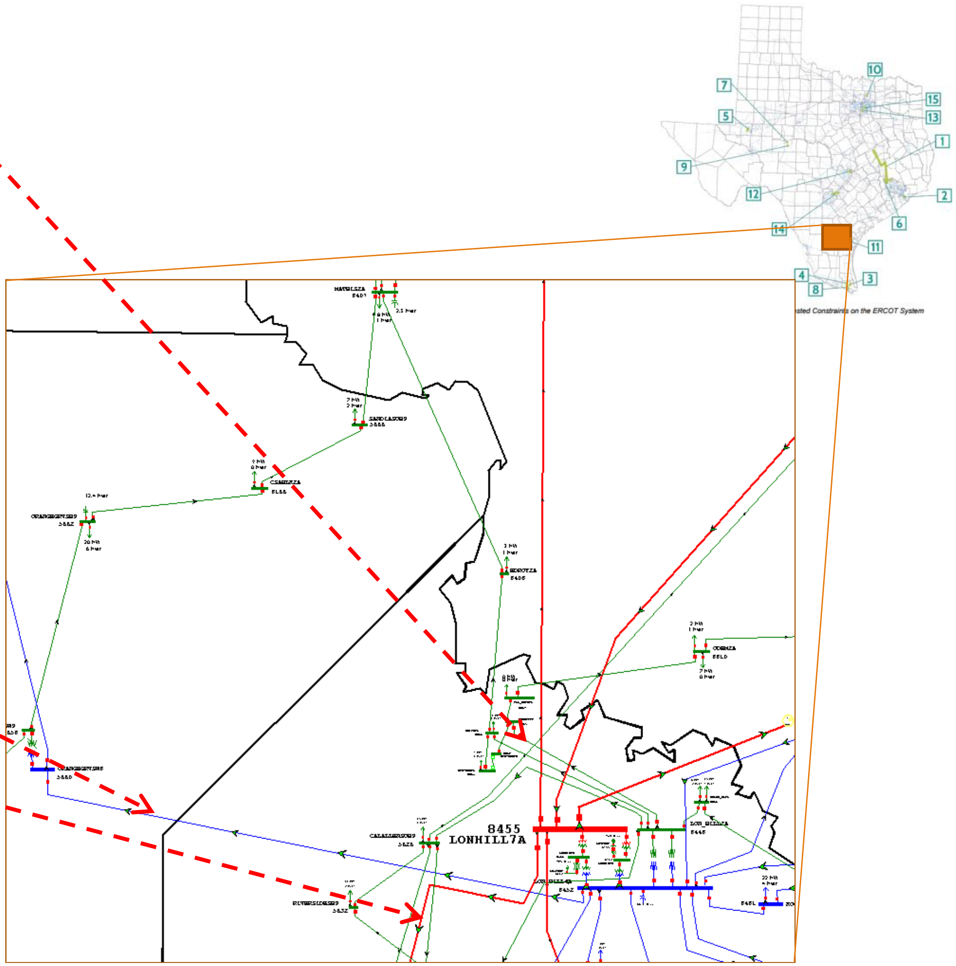
Case Study 1: ERCOT Constraint Relief

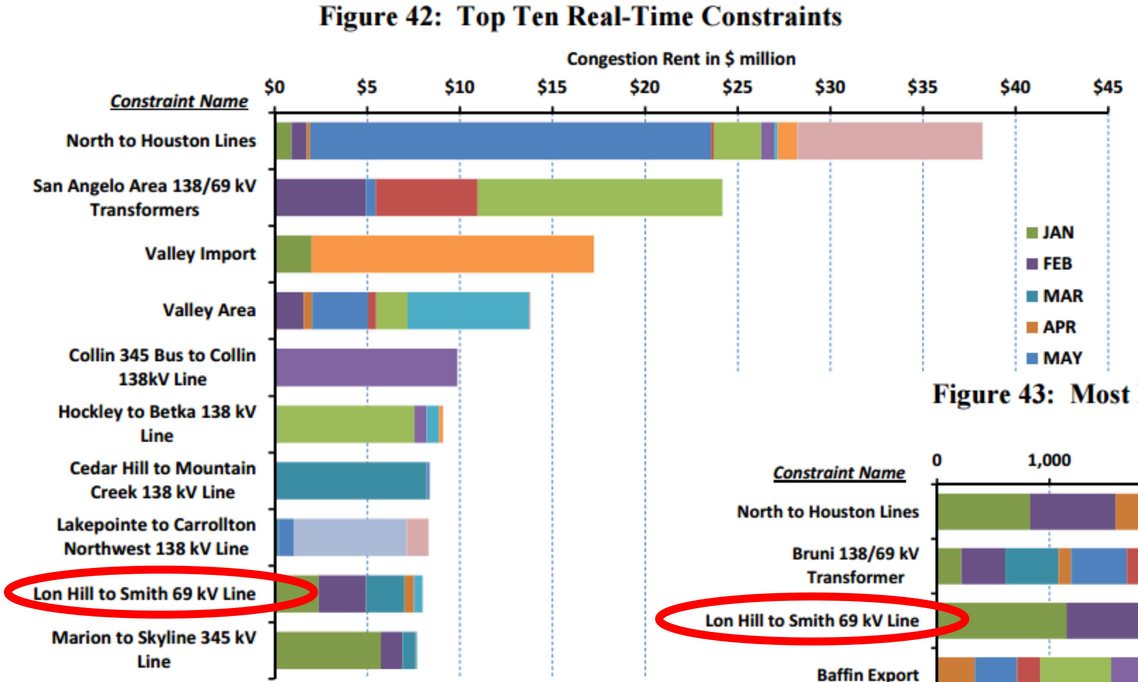
Lon Hill – Smith 69 kV Constraint

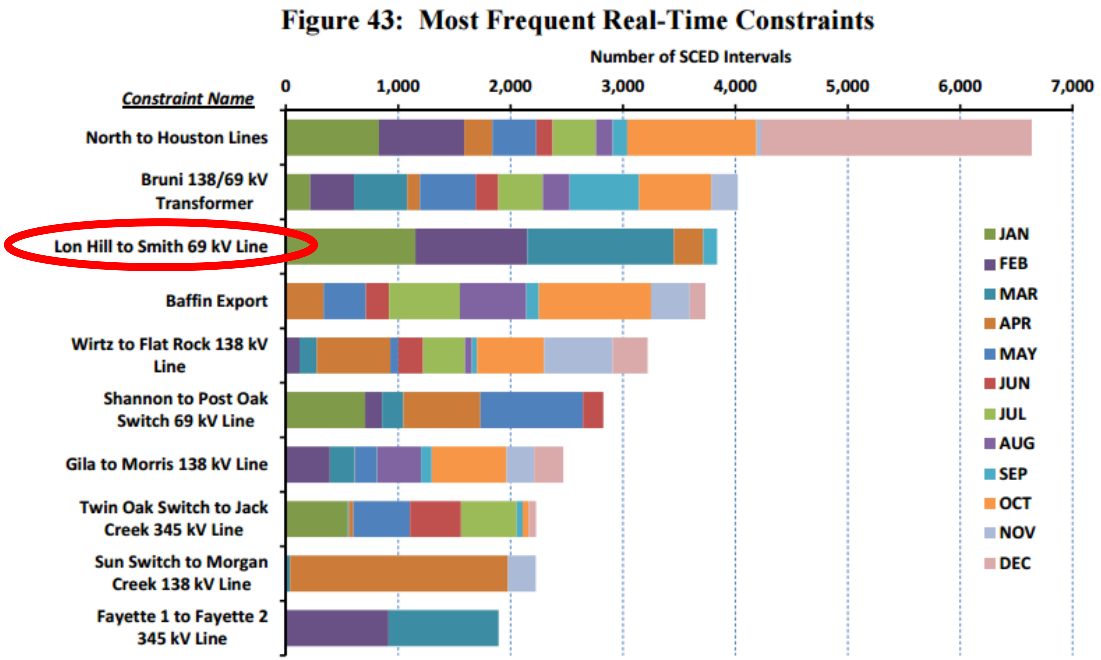
- The Lon Hill – Smith 69 kV line was frequently congested
  - Congestion was due to increased demand related to oil and natural gas development in the Eagle Ford Shale.
  - A transmission upgrade in the area solved the congestion after May 2015.
- The constraint of interest monitors Lon Hill – Smith 69 kV line for the double loss of
  - Lon Hill to Orange Grove 138 kV,
  - Lon Hill to North Edinburg 345 kV.
- ERCOT Operations Planning provided a 2015 Summer Peak case (from the 2015 Annual CMP Study) for reconfiguration analysis
  - Case has a 24% violation on the contingency constraint.



Case Study 1: ERCOT Constraint Relief

Lon Hill – Smith 69 kV Congestion





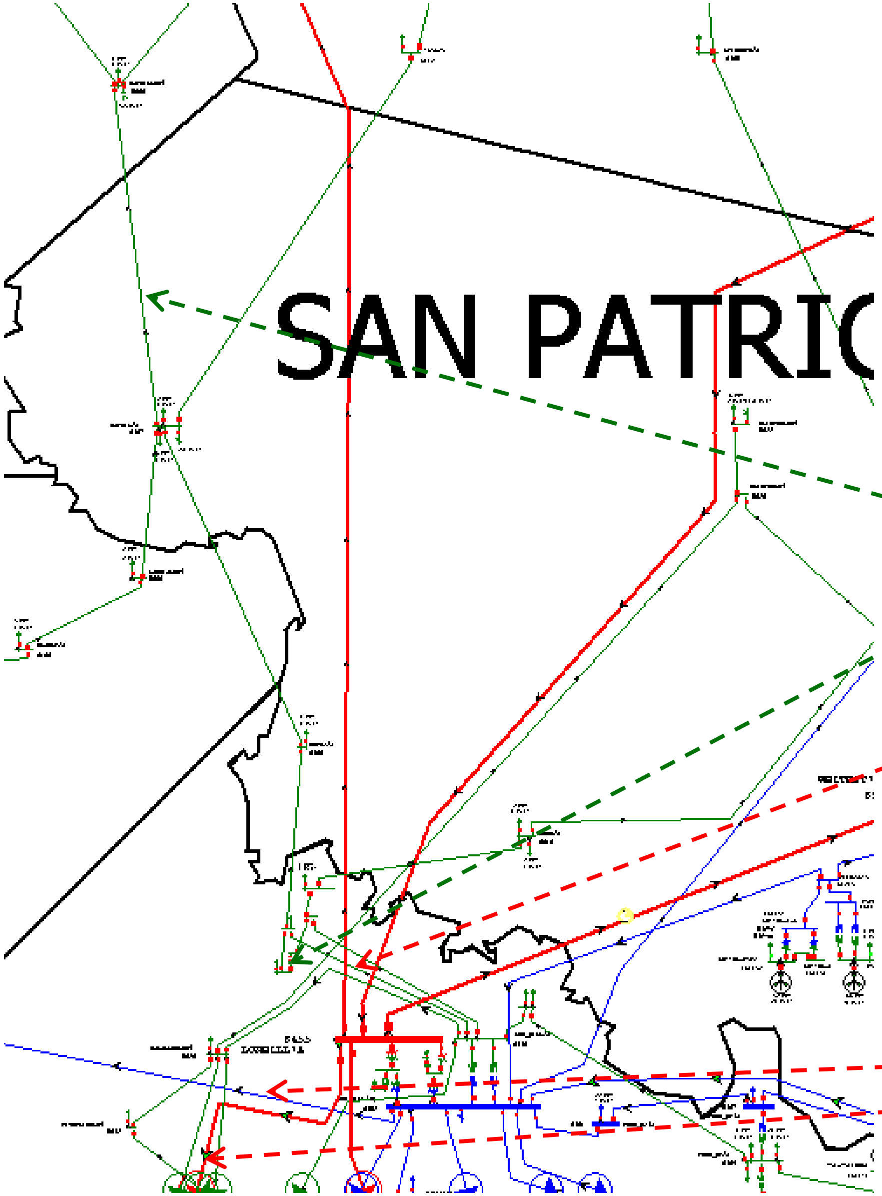
Source: ERCOT State of the Market Report 2015

Assumptions on Solution Requirements

- The topology optimization software searched for topology changes that would relieve the constraint violations while:
  - Keeping the generation dispatch fixed,
  - Limiting additional violations (pre- or post-contingency, thermal or voltage).
- Allowing for dispatch changes could enable more or better solutions (the dispatch was fixed for demonstration purposes only).
- 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 solution found:
  - Close one 69 kV tie and open one 69 kV line,
  - Fully relieves the 24% (14 MVA) violation, causing a 4% (2 MVA) violation on a different 69 kV line,
  - Effectively increases local system capacity by 20% (under the conditions analyzed).

Case Study 1: ERCOT Constraint Relief

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

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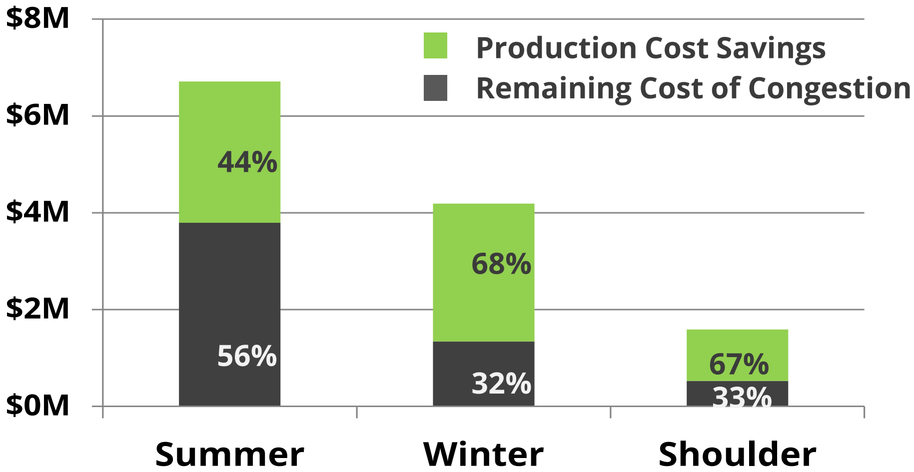
Historical PJM RT Market Models

- 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: Topology Optimization in PJM RT Markets

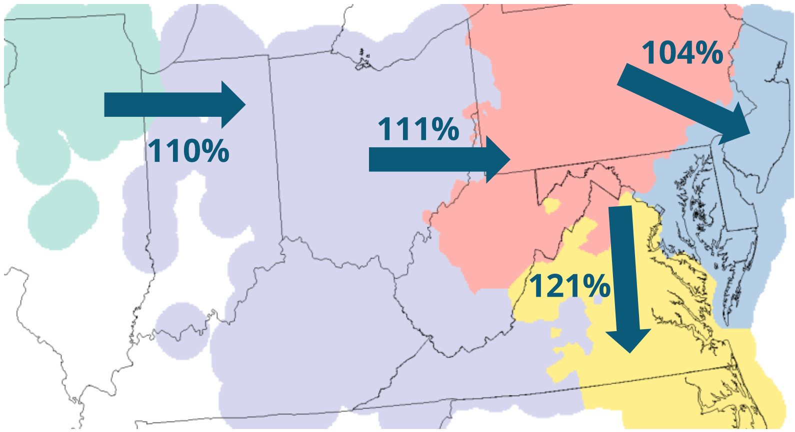
Topology Optimization Impacts on RT Market

Weekly Real-Time Market Congestion Cost Savings

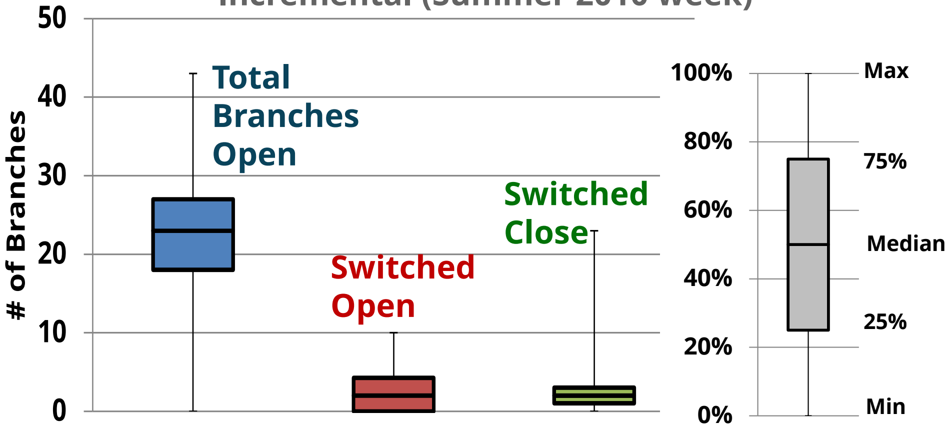


50% reduction in Real Time PJM congestion costs
⇒ extrapolate to a potential for $100 million savings in annual production costs

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



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



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A Transmission Owner's Perspective

NewGrid *Router* finds system reconfiguration options to:

- Help reduce the costs and increase the feasibility of construction-related outages.
- Increase the value of system expansions that provide operational flexibility (e.g., investments that create more switching options).
- Increase the effective capability and resiliency of the existing grid.
  - Could avoid/defer certain upgrades (usually lower voltage ones).
  - May increase the reliability and economic benefit of system expansions and upgrades (making it easier to pass B/C test).
- Increase the long-term attractiveness of transmission solutions compared to non-transmission alternatives.
  - Topology optimization will likely move the optimal spending mix more toward transmission, as transmission would become more cost effective.

Valuable Applications for Practical Use Today

While topology optimization technology is developed with the long-term goal of automating transmission system switching in day-ahead and real-time, several practical applications are available now:

- Quickly identify switching solutions to address specific reliability and congestion events efficiently.
- Identify temporary reconfiguration plans that help transmission owners/operators plan for and manage transmission outages. This can significantly reduce the typical reliability and cost impacts of construction-related outages.
- Identify reconfiguration plans to reduce congestion on a regular basis and reduce utilities' exposures to unhedged congestion costs.

Router **solutions are currently available as a consulting service.**

Router **will be available for licensing by Q1 2017.**

Contact

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Appendix

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