Transmission Topology Optimization

Operations and Market Applications and Case Studies

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Austin, TX
November 17, 2016

Agenda

- Objectives and Motivation
- Illustrative Example
- Current Practice
- Topology Optimization Software
- Case Studies
  - Overview of Case Studies
  - Case Study 1: ERCOT Constraint Management Plans
  - Case Study 2: ERCOT Frequently Binding Constraint
  - Case Study 3: Topology Optimization in PJM RT Markets
- Concluding Remarks
- Appendix

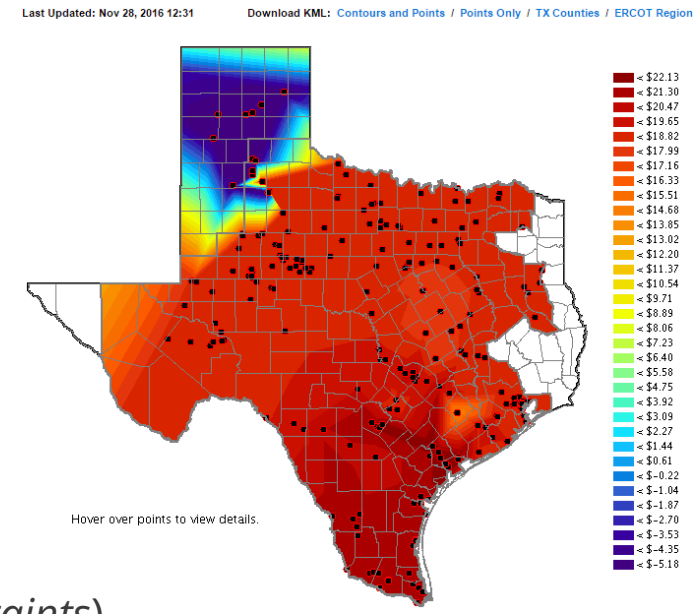
Topology Optimization Summary

- At any given time, 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.
  - 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

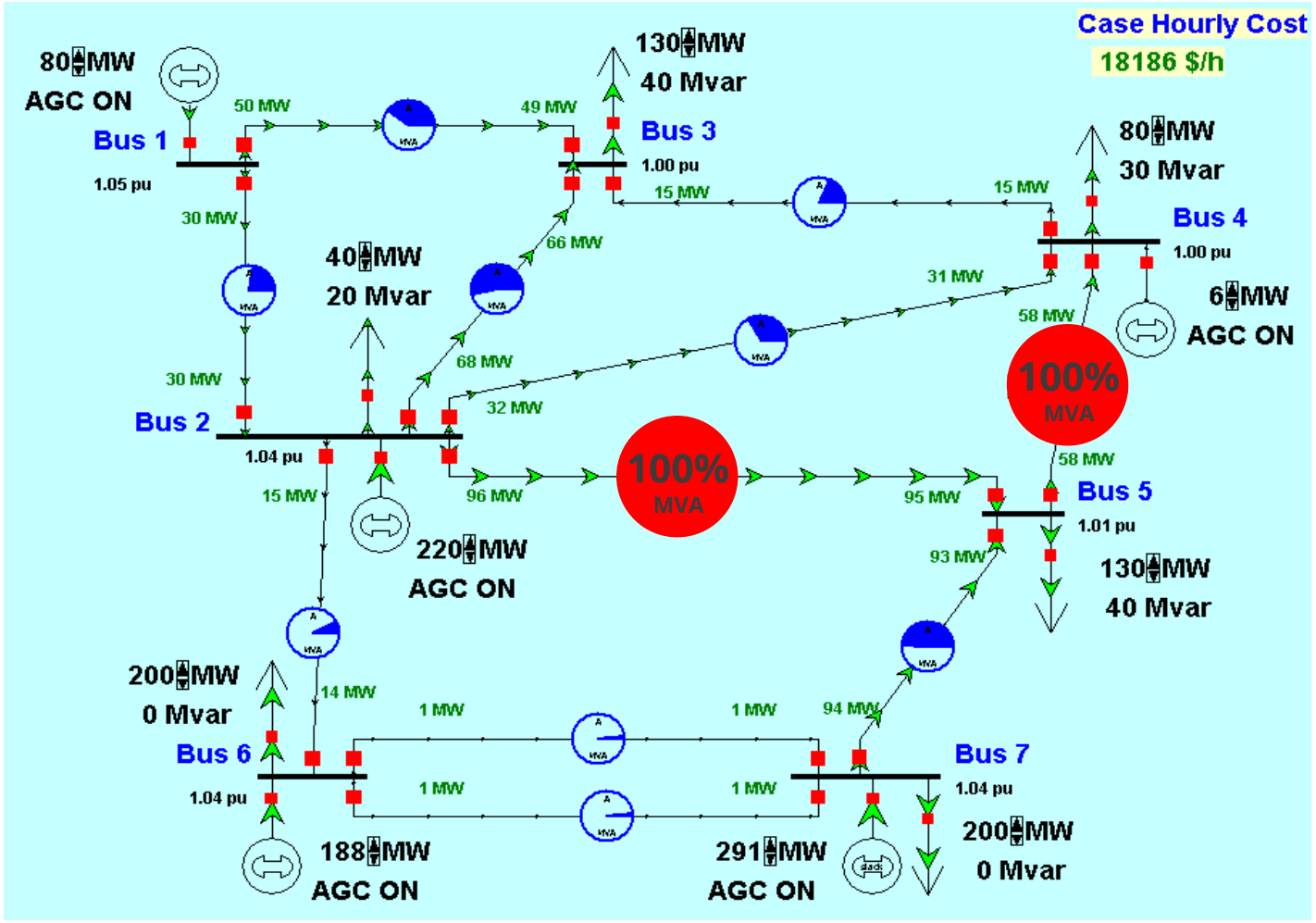
Topology optimization offers an effective *complement* to the current practice of resource-based and hardware-based flow control and congestion management.

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



- **Resource-based flow control**: reduce (low-cost) generation upstream of congestion/overload and increase (costly) generation downstream.
  - Leads to geographic price separation.
  - *ERCOT 2016 congestion costs*: $497 million.
  - *ERCOT renewables curtailment impacts*: 2% of annual potential wind energy in 2016.
  - *ERCOT reliability impacts*: real-time flows exceeded post-contingency grid capacity in 3% of the intervals in 2016 (*irresolvable constraints*).
- **Flow control hardware** (e.g., phase shifters, distributed series devices, FACTS devices) require capital investments and tend to be deployed in limited locations.

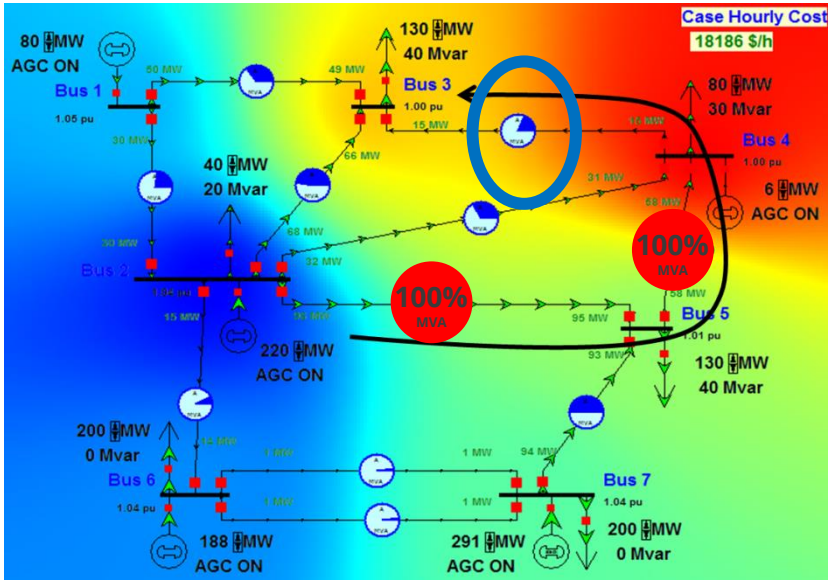
7-bus Example: All Lines Closed



Illustrative Example

7-bus Example Results: Before and After

Before: all lines Closed



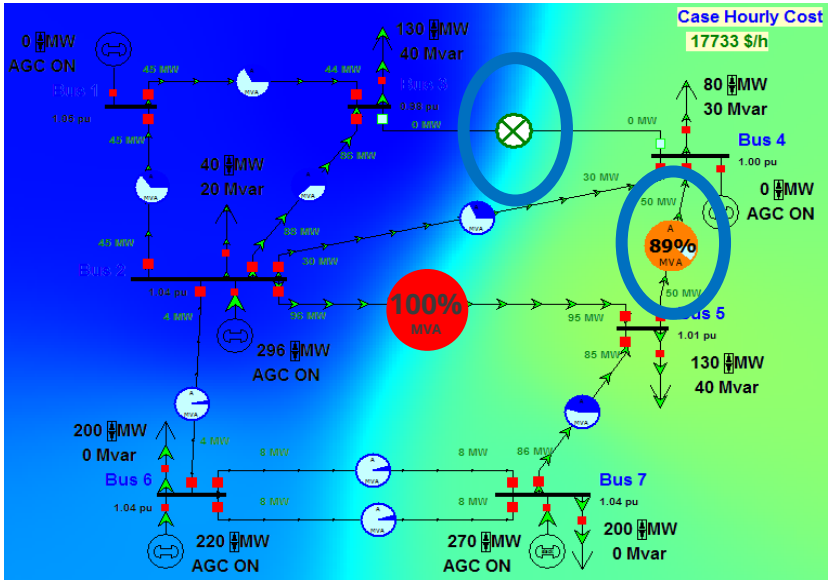
Generation	All lines closed	Line 3-4 open
Bus 1	80 MW	0 MW
Bus 2	220 MW	296 MW
Bus 4	6 MW	0 MW
Bus 6	188 MW	220 MW
Bus 7	291 MW	270 MW
Total	785 MW	786 MW

$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



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.

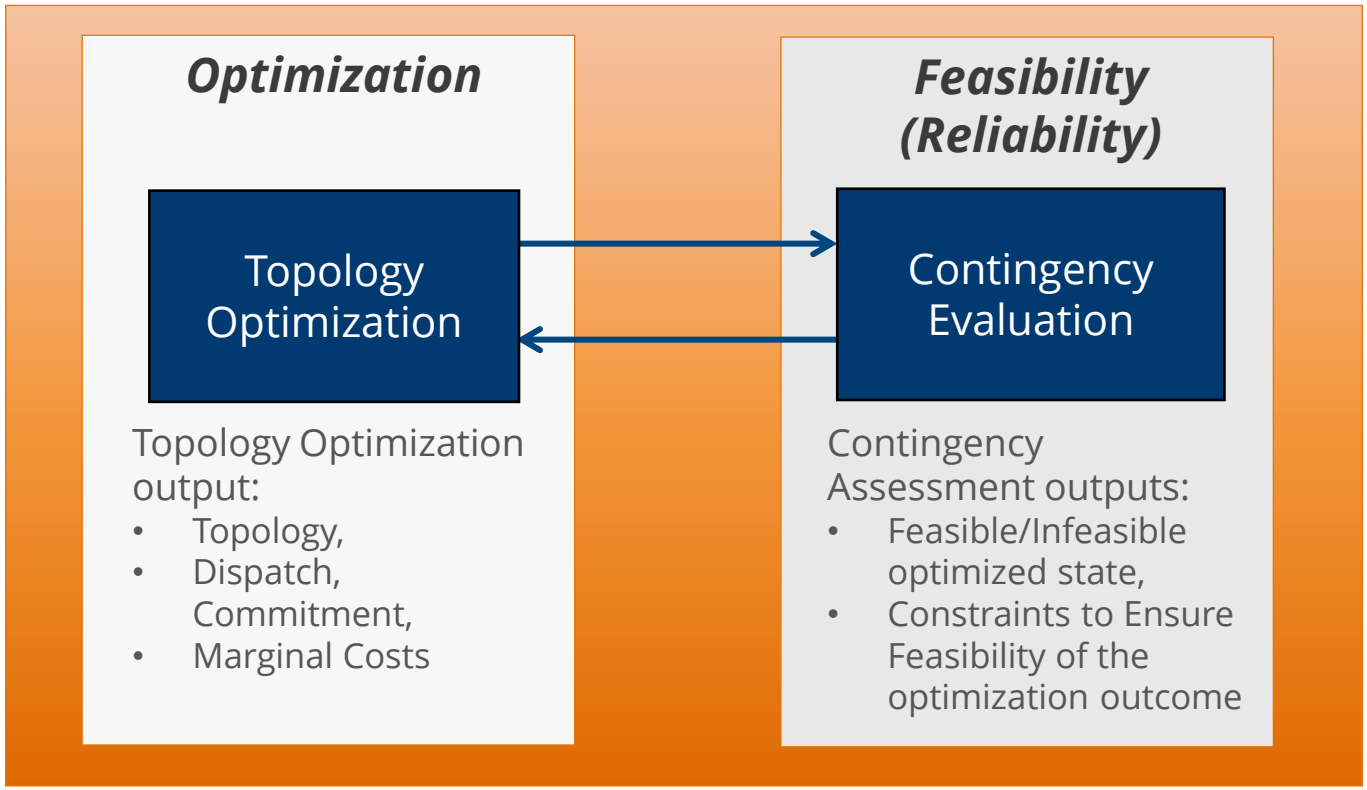
Topology Optimization Software

Topology optimization software automatically identifies reconfiguration options.

- With DOE ARPA-E support, developed topology control algorithms (TCA) for optimizing transmission network topology.
  - Designed to operate with existing systems and software (EMS, OMS, MMS).
  - Decision Support: Multiple options proposed, impacts evaluated for each option.
  - Reliability: Connectivity, contingency constraints, voltage criteria met.
  - Speed: Meets solution times that align with operations timeframes.
  - High-Definition: Handles operations (node-breaker, EMS) cases.
  - Look-Ahead: Optimization decisions with "topology continuity" constraints.
- With PJM staff, tested the algorithms developed and assessed their impacts in a simulated environment replicating PJM market operations and outage coordination.
- With ERCOT staff, 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.

NewGrid Router Architecture

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



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Case Studies Overview

Topology optimization finds highly beneficial reconfigurations.

- Case Study 1 – ERCOT Constraint Management Plans Review
  - Identified new plan that avoids load shedding.
- Case Study 2 – ERCOT (Ref. [3]):
  - Relief of most frequent market constraint in 2014-2015 (operations planning case).
- Case Study 3 – PJM (Ref. [9]):
  - Use in RT Markets provides 40-70% congestion cost relief (2010 conditions).
- Additional analyses to date:
  - National Grid UK: Increased transfer capability 3-12% for critical constraints under severe outages (Ref. [1], [2]).
  - PJM operations: Relief of critical historical base-case overloads (Ref. [9]).
  - PJM DA markets: 30-50% congestion cost relief, 2010 conditions (Ref. [5]).
  - PJM high renewables: Reduced curtailments under 30% penetration case (Ref. [11]).
  - PJM outage coordination: overload and congestion relief (EMS cases).
  - SPP operations: Full relief of recurring post-contingency overloads (Ref. [4]).
  - MISO operations: Relief of recurring overloads under outage and high load conditions.
  - MISO wind plant: Increase of transfer capability out of often-constrained wind plant.

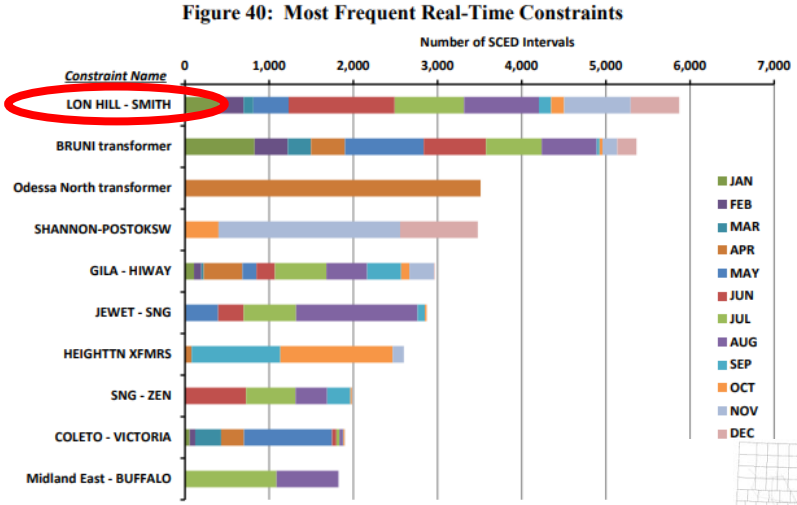
Topology Optimization use in Ops Planning

- "A Constraint Management Plans (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 this year:
  - 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.

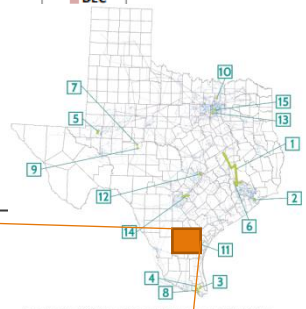
* *ERCOT Nodal Protocols*, Section 2, September 14, 2017, page 2-11.

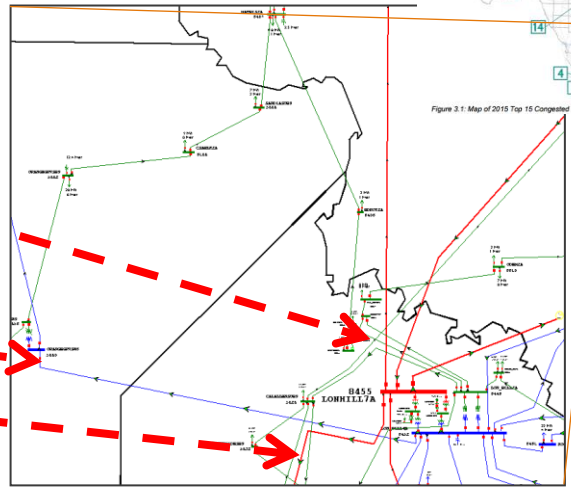
Lon Hill – Smith 69 kV Constraint

- 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 loss of
  - Lon Hill to Orange Grove 138 kV,
  - Lon Hill to North Edinburg 345 kV.



Source: ERCOT State of the Market Report 2014





Assumptions on Solution Requirements

- 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,
  - 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 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

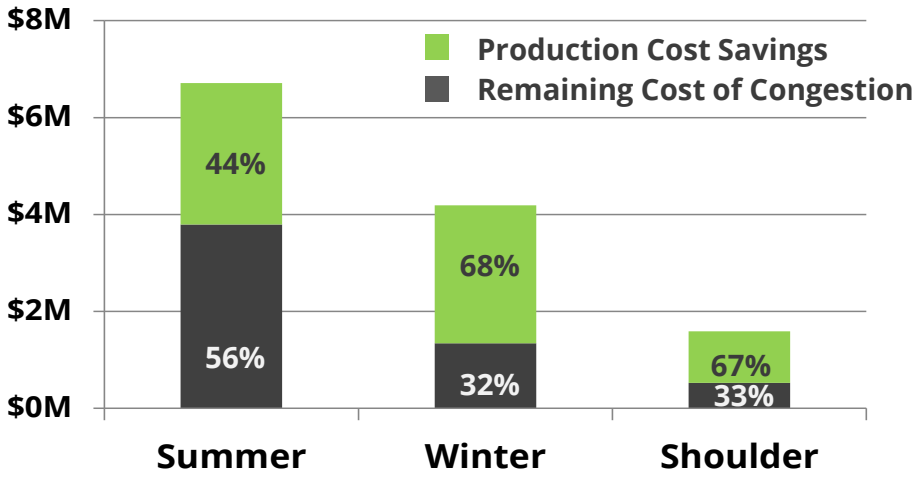
Two-Element Contingency:
Lon Hill to Orange Grove 138 kV
Lon Hill to North Edinburg 345 kV

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.

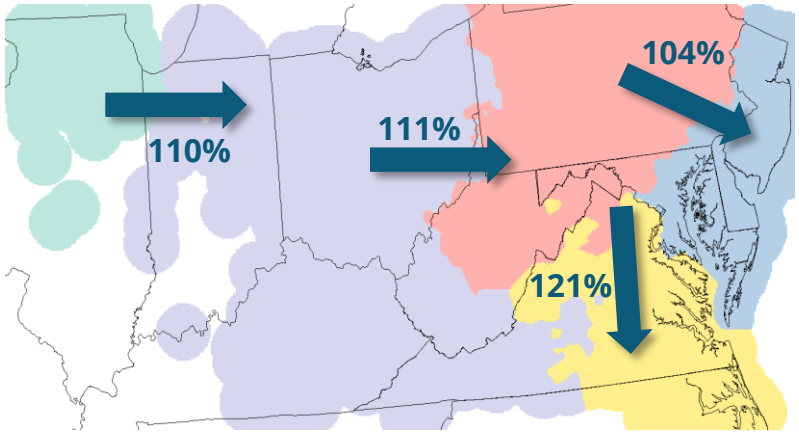
Topology Optimization Impacts on RT Market

Weekly Real-Time Market Congestion Cost Savings

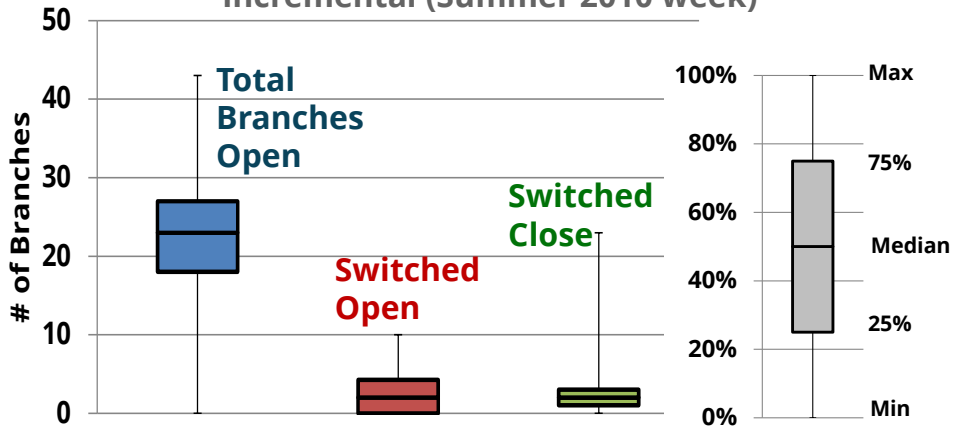


50% reduction in Real Time PJM congestion costs
⇒ extrapolate to a potential for $100 million savings in annual production costs

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



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



Potential Impacts on ERCOT Markets

Based on the market impacts on other systems, the *order of magnitude* of the potential impacts of topology optimization on ERCOT markets could be:*

- Congestion cost reduction of 25-50%
  - Savings of **$125-250 million/year**
- Renewables curtailment reduction of about 50%
  - Additional +**1% of annual potential wind energy**
- Reduced frequency and severity of irresolvable constraints by about 50%
  - Improved reliability: no irresolvable constraints on 1600 RT intervals that would otherwise have the potential to shed load under contingency conditions

* *Note: The impacts on ERCOT market have not yet been quantified. The indicative figures shown are based on the relative impacts observed in other systems, and on the 2016 ERCOT congestion costs, wind curtailment and frequency of irresolvable constraints.*

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, such as to address:
  - Unit retirements,
  - Fast load growth,
  - Unforeseen outages (generation and transmission),
  - Planned outages,
  - Change in renewable patterns.
- Help transmission operators plan for and manage transmission outages by developing temporary reconfigurations. This can significantly reduce the typical reliability and cost impacts of construction-related outages.
- Reduce congestion on a regular basis and reduce utilities' exposures to unhedged congestion costs by using appropriate reconfigurations.

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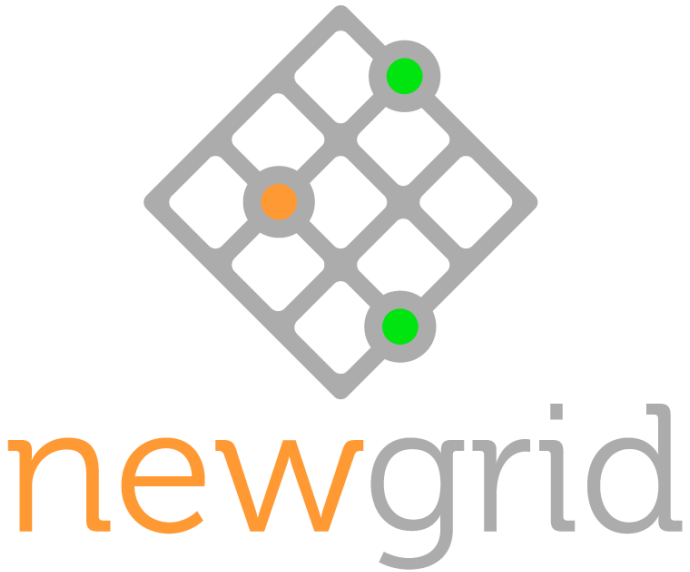
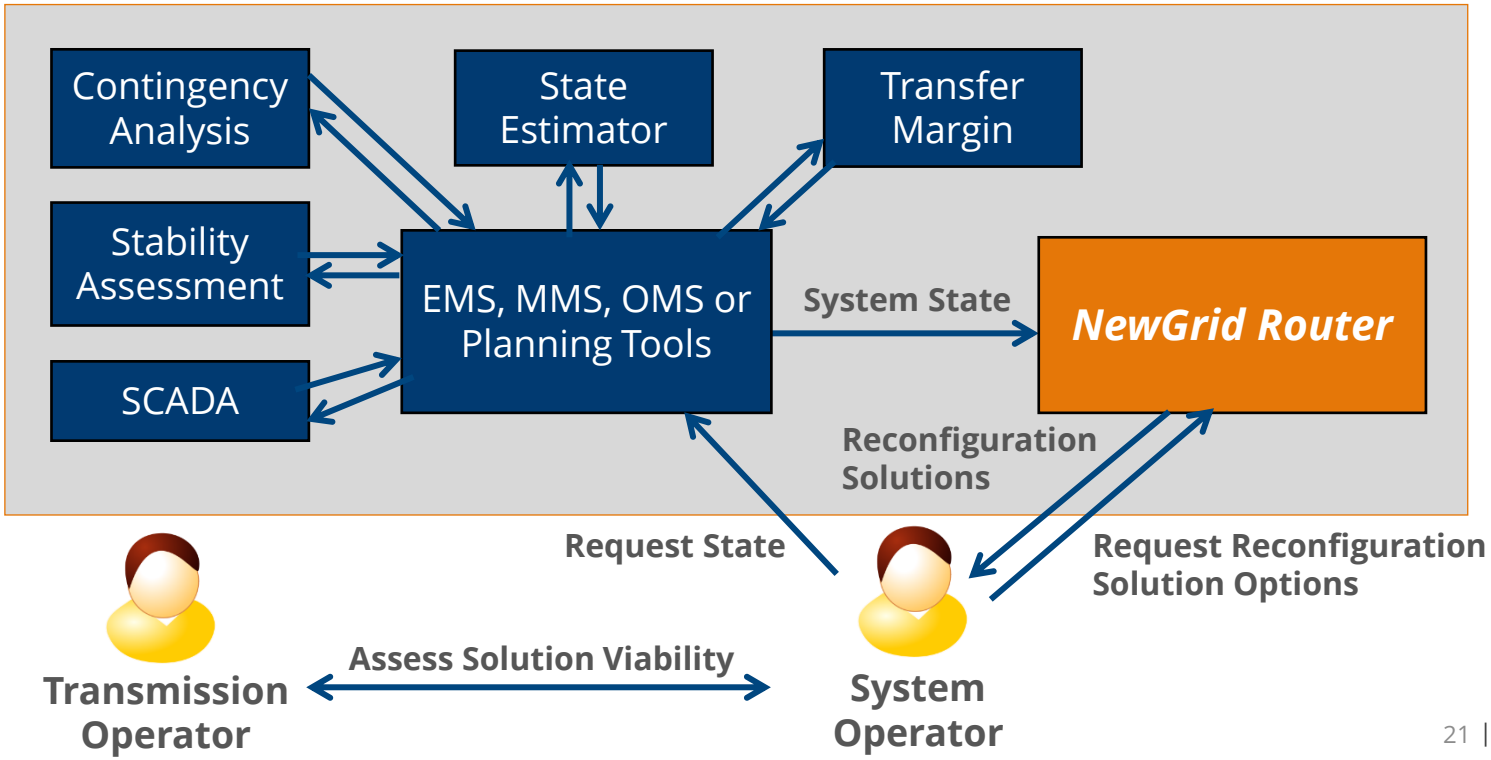


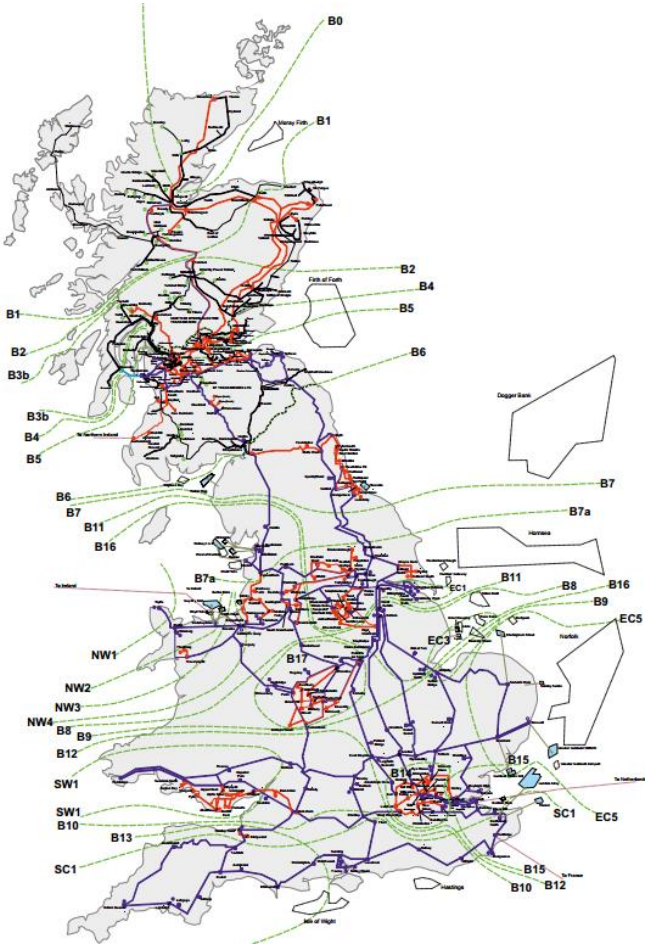
Advisory Application: Markets and Operations

- In markets and operations decision making, NewGrid *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.



Increased Transfer Capability in Great Britain

- National Grid (NG) 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 scenarios where thermal limits had been active on major (zonal) "boundary constraints."
  - Brattle identified reconfigurations for those scenarios.
  - National Grid assessed the reconfiguration impacts and provided feedback.
- Decision variables: line switching, substation reconfigurations, phase-shifting transformer settings.
- Topology optimization impacts:
  - Increases in boundary constraint capacity: 3% to 12% per National Grid assessment.
  - Annual Balancing Market costs savings: £14-40 million, under historical conditions.



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

Appendix 3

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Appendix 3

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