Transmission Topology Optimization

Simulation of Impacts in PJM Day-Ahead Markets

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Agenda

- Objectives and Motivation
- Illustrative Example
- Current Practice
- Topology Optimization Software
- Case Studies in PJM
  - Overview of Case Studies
  - Case Study 1: Topology Optimization in PJM DA Markets
  - Case Study 2: PJM FTR Settlements & Revenue Adequacy
- Concluding Remarks
- Appendices

Topology Optimization Summary

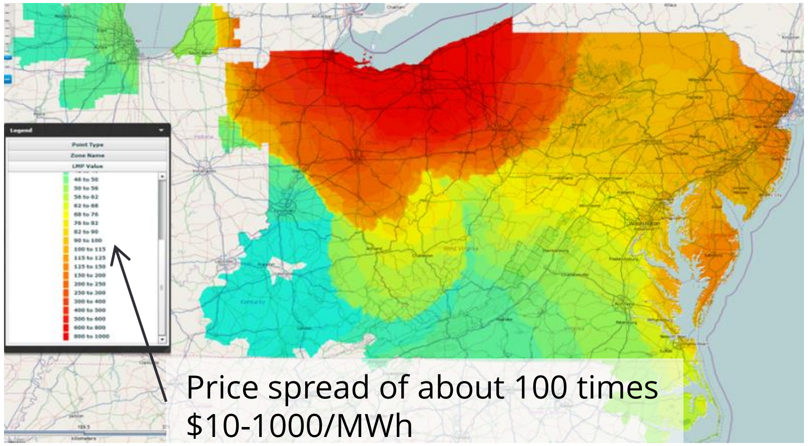
- At any given time, few transmission facilities are congested.
- Due to the built-in system redundancy, usually there are transmission topology reconfigurations (line switching, bus splitting) that can reliably route power around the congested facilities.
- Today, operators use reconfigurations to manage some challenges, identifying them based on their knowledge of the system.
- Topology optimization 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.
  - Accommodate outage requests: simplify transmission operations.
- Topology optimization software essentially is a fast “search engine” for identifying viable and beneficial system reconfiguration options.

Congestion Management

Topology optimization offers an effective complement to resource-based flow control and congestion management.

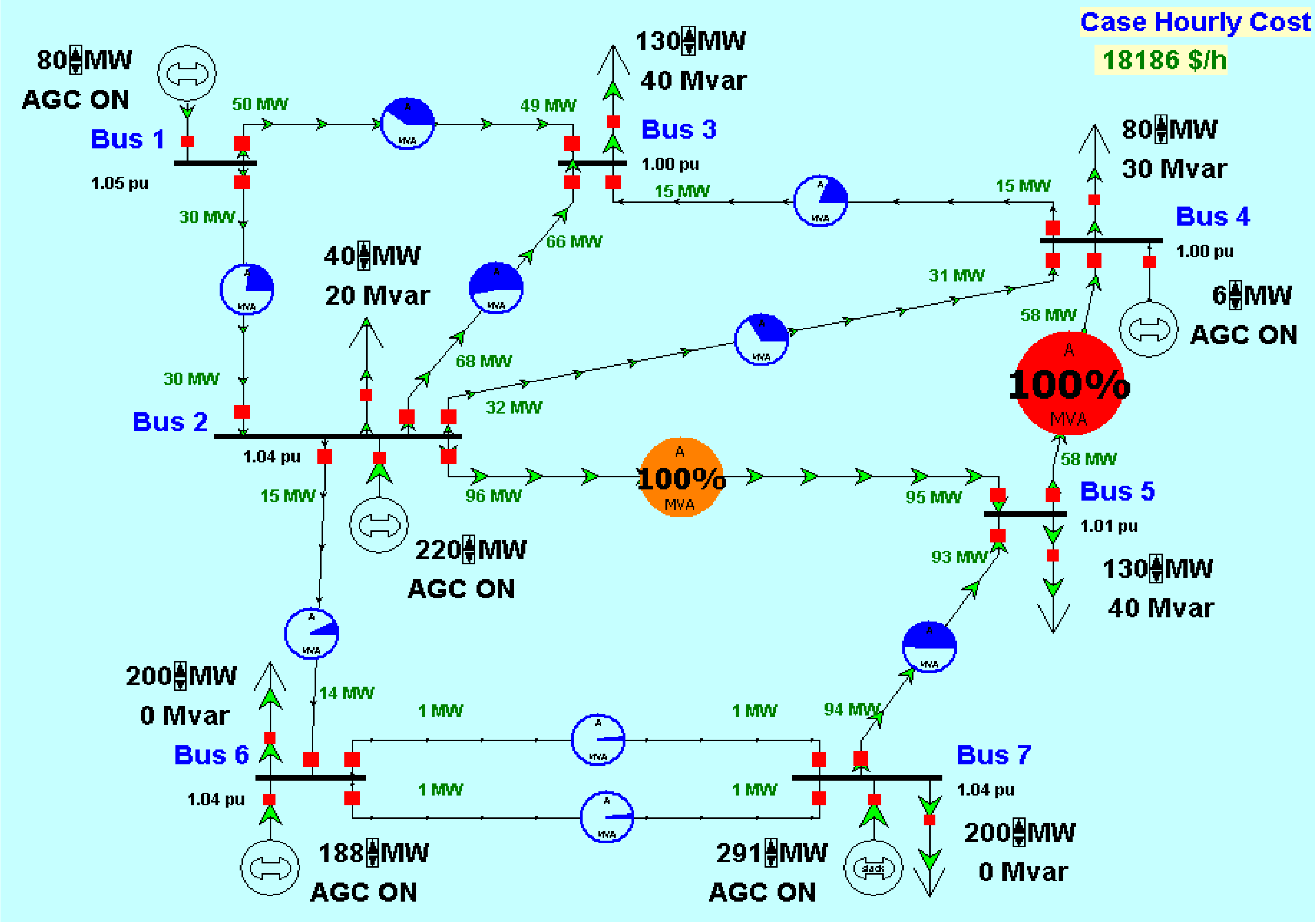
- Resource-based flow control: reduce (low-cost) generation upstream of congestion/overload and increase (costly) generation downstream.
  - Leads to geographic price separation.
  - Annual congestion costs: estimated to be $4-8 billion in the US.
  - Renewables curtailment impacts: up to 17% of annual potential energy in TX (ERCOT) wasted in recent past.
  - Insufficient to meet reliability standards: flows exceed post-contingency grid capacity in ~20% hours in various RTOs (e.g., SPP).

PJM Real Time Prices, 18/7/2013, 15:30



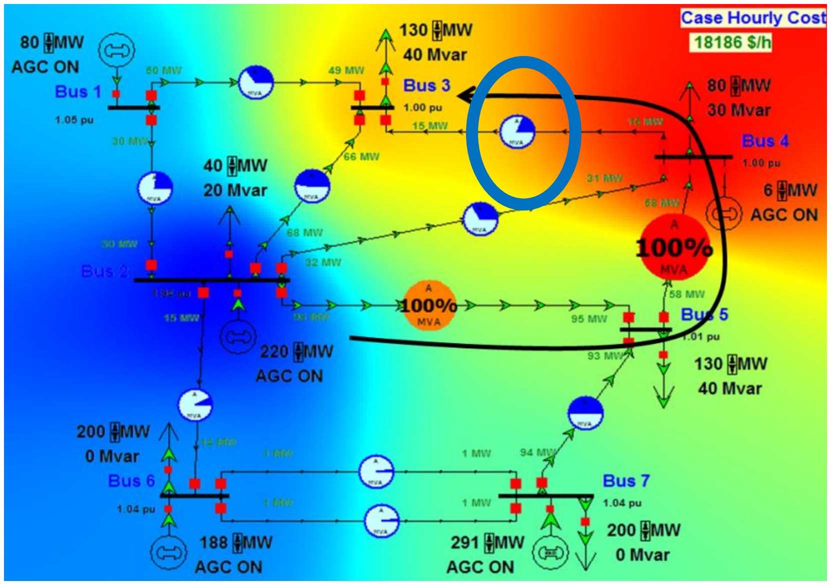
Illustrative Example

7-bus Example: All Lines Closed

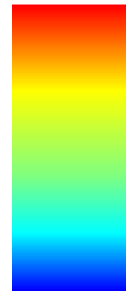


7-bus Example Results: Before and After

Before: all lines Closed



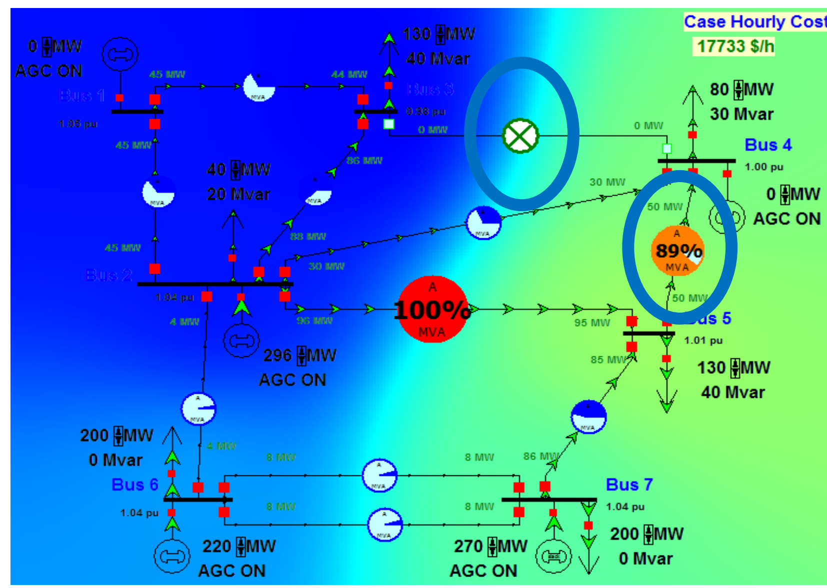
$40/MWh



$15/MWh

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

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

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., Operating Guides).
  - Outage Coordination/Scheduling: enable planned outages that otherwise would cause reliability violations/increases in congestion.
  - Congestion Management: allow more efficient unit commitment and economic dispatch (used in limited cases), maintain current commitment and dispatch plans.
- In identifying reconfiguration options, operators rely on their prior experience and knowledge of the system.
- Currently, developing such switching solutions and efficient topology changes is a time-consuming, "manual" process.
- The flexibility that the transmission system offers is underutilized as a result.

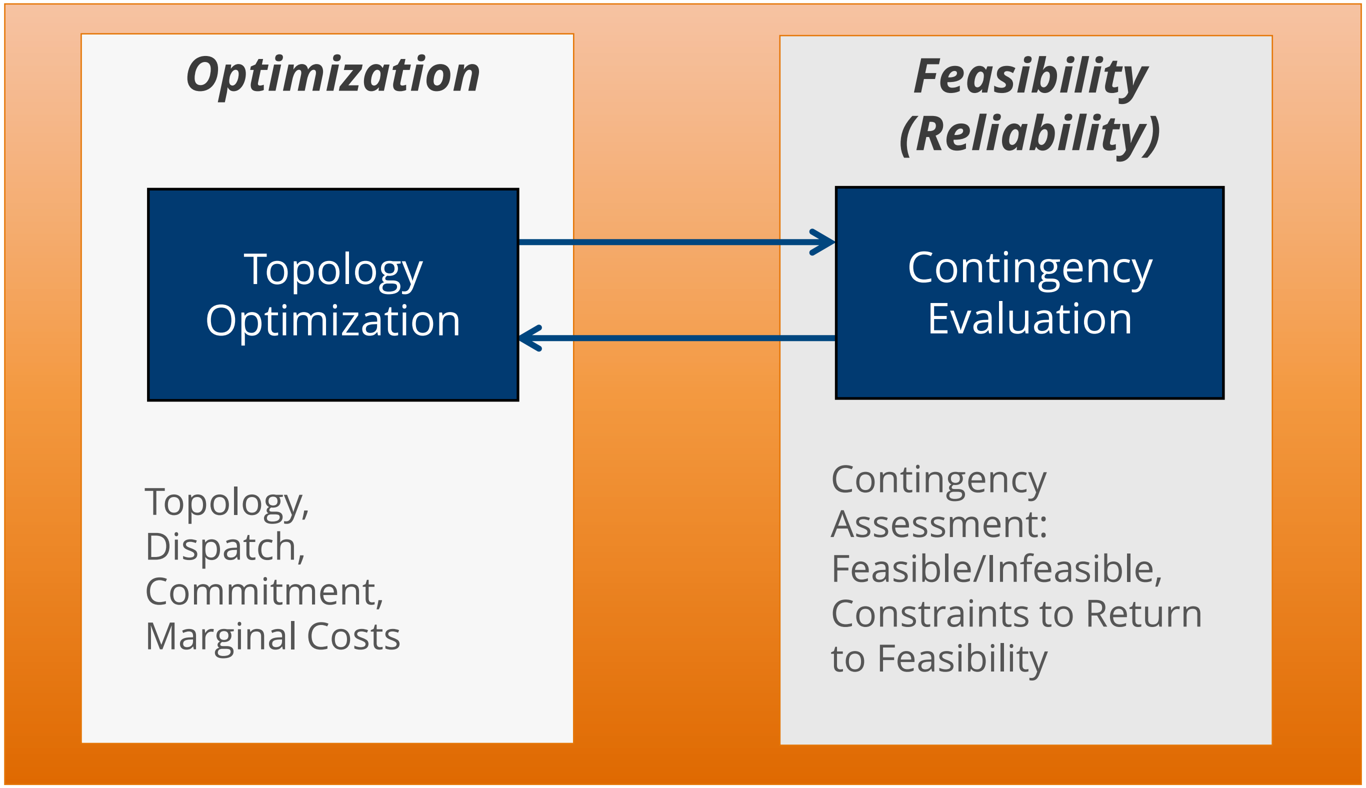
NewGrid Router

NewGrid Router **automatically identifies reconfiguration options.**

- With DOE ARPA-E support, we 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.
- We, with PJM staff, tested the algorithms developed and assessed their impacts in a simulated environment replicating PJM market operations.
- NewGrid is developing *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, transient stability, voltage criteria met.
  - <u>Tractability</u>: Can handle PJM-size EMS cases.
  - <u>Look-Ahead</u>: Optimization decisions with “topology continuity” constraints.

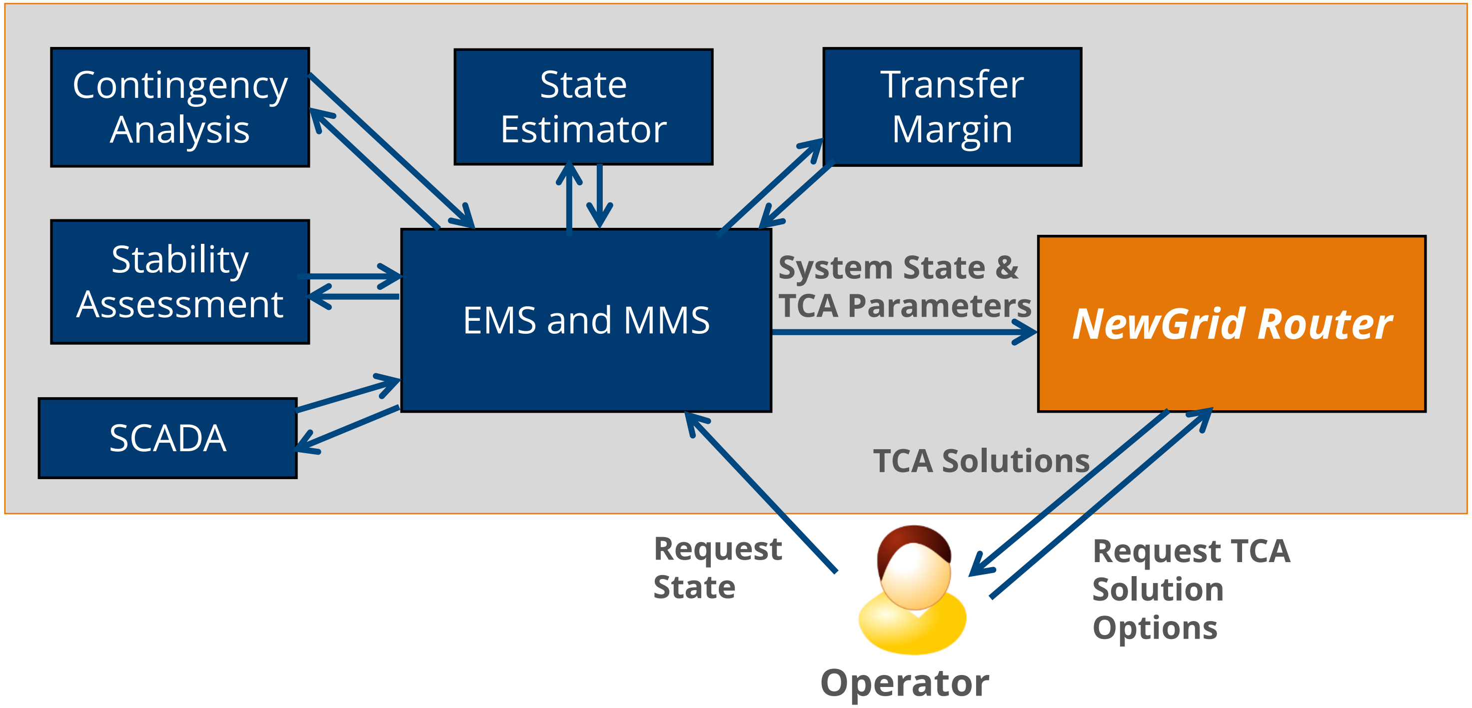
NewGrid Router Architecture

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



Advisory Application in Operations Planning

- In operations planning decision making, *Router* provides the engineer with reconfiguration options to select and further analyze.
- *Router* speeds up options identification and leads to better outcomes:
  - Consistent application of Op. Guides.
  - Develop Op Guides on the fly to relieve overloads if existing ones do not work.
  - Resolve outage request conflicts.
  - Reduce outage impacts when conditions change.



Overview of Case Studies in PJM

Topology optimization finds highly beneficial reconfigurations.

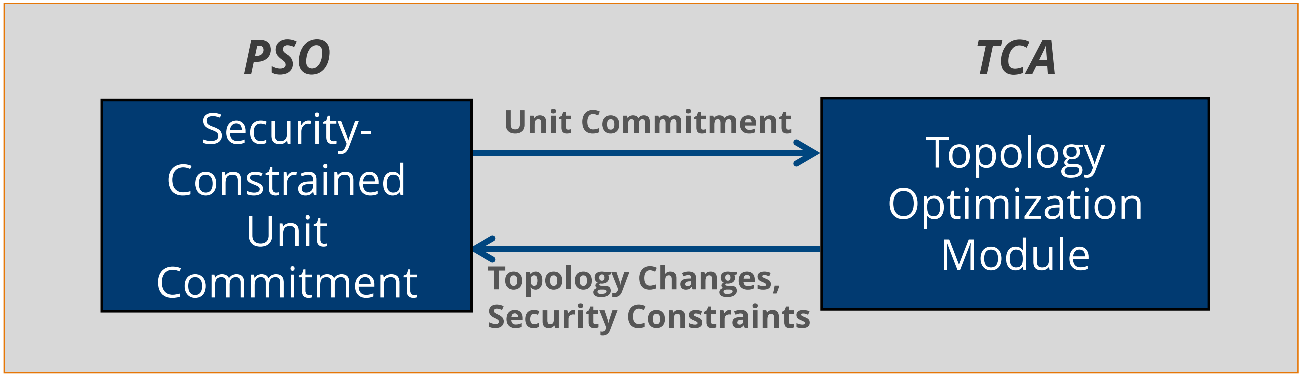
- High Renewables scenario (Appendix 3, Ref. [6]).
  - Reductions of about 40% of curtailed renewable energy.
- Relief of critical historical overloads (Appendix 2).
  - *Full relief* of critical historical pre-contingency (base case) and post-contingency overloads.
- Historical PJM RT market simulations (Appendix 1).
  - 50% congestion cost relief on average.
  - $100M in RT market cost savings (extrapolated from weekly simulations).
- Historical PJM DA market simulation (Case Study 1).
  - 30-50% congestion cost relief on average.
  - $145M in DA market cost savings (extrapolated from weekly simulations).
  - Significant reductions in congestion rent (40%), but FTR DA relative surplus tends to increase (Case Study 2).

Historical PJM DA Market Models

- 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 and branch parameters.
  - External system conditions (e.g., interchange, reciprocal flowgate use).
  - Dispatch of hydro, wind, landfill, nuclear, and RMR thermal units.
  - Load time series (adjusted based on DA load forecasts for the day).
- 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.

DA Topology Optimization Approach

- Security-Constrained Unit Commitment (SCUC) and TCA are solved iteratively until convergence criteria are met.
- PSO* is used to provide SCUC solutions:
  - MIP-based security-constrained SCUC.
  - Integrated with TCA.
  - Efficiently updates topology of the model.
- TCA solves a multi-period problem with topology change constraints enforced.
  - Minimum open/close duration of 4 hours used in these simulations.



** Provided by Polaris Systems Optimization, http://www.psopt.com*

DA Topology Optimization Settings

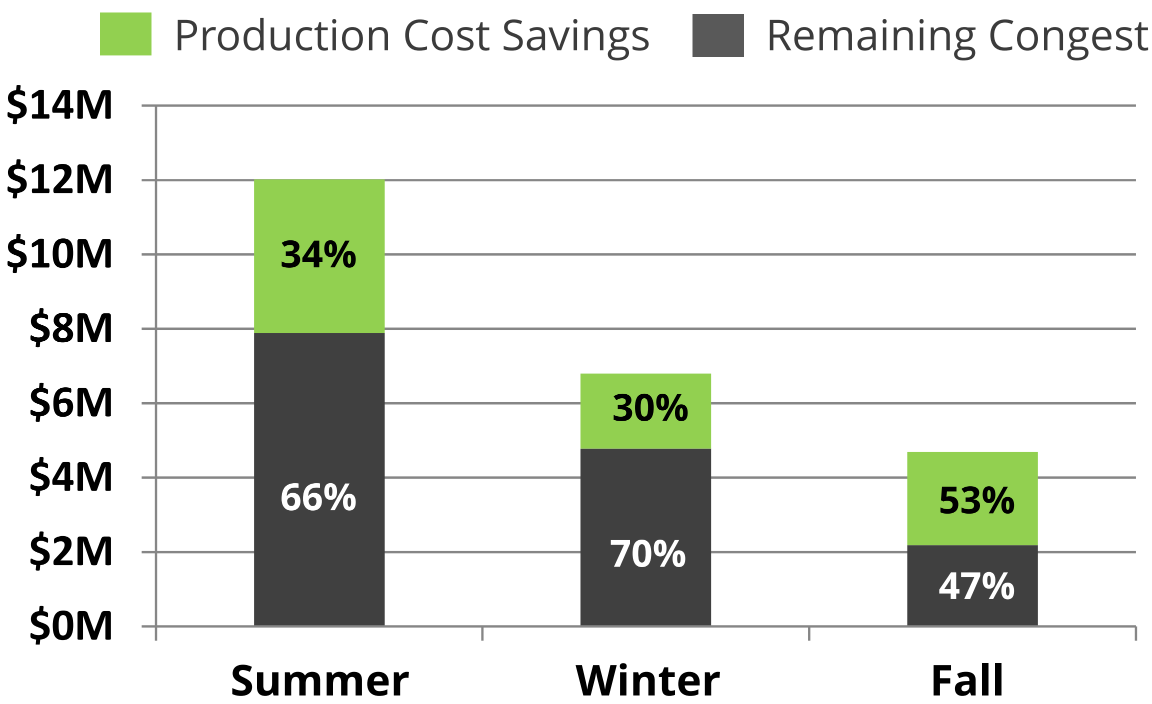
- SCUC Horizon: 72 hours for each DA simulation.
- Switching threshold: $800 (summer), $400 (winter, fall) savings per switching.
- Switchable Set: all PJM monitored branches (about 4700 branches).
- Connectivity: no load radialization for non-radial loads larger than 100 MW.
- Reliability: security evaluation & enforcement (6,000 contingencies).
- Solution time:
  - Single-period TCA optimization time limit: 5 minutes
  - No time restrictions on multi-period TCA+SCUC optimization; observed time varied between 6 and 16 hours per three-day DA simulation (using slow, 2 GHz server).
    - Can be reduced by using faster hardware, limiting the switchable set, and limiting the number of topology optimization/SCUC iterations.

Caveat: the congestion saving figures in the following slides assume that the TCA solutions are viable. In practice, each solution requires full solution verification by PJM RTO and TO staff.

PJM DA Topology Optimization: Savings

Topology Optimization Savings in the Representative Weeks

(relative to the initial cost of congestion)

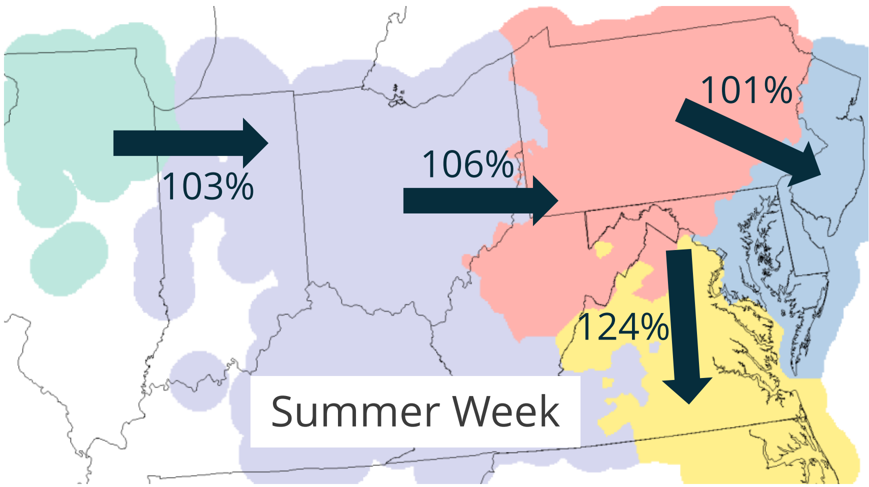


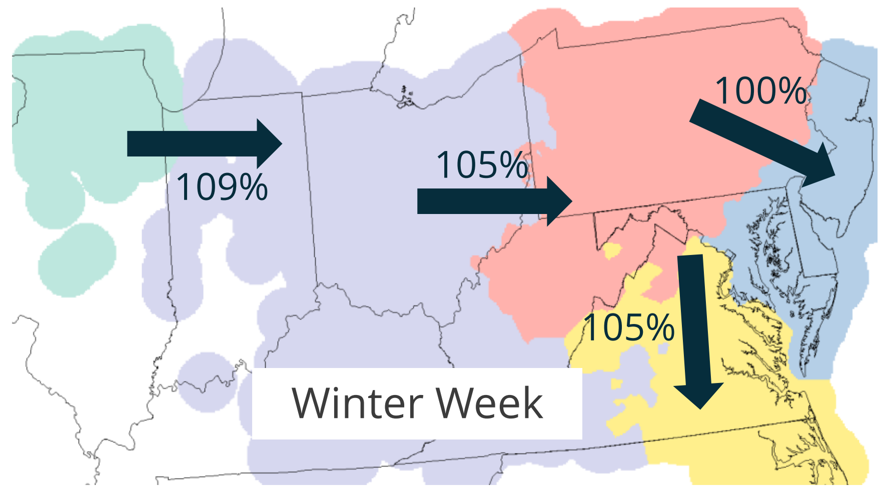
Savings amount to 30-50% of the initial cost of congestion. The extrapolated annual production cost savings in PJM DA markets under 2010 conditions are $145 million.

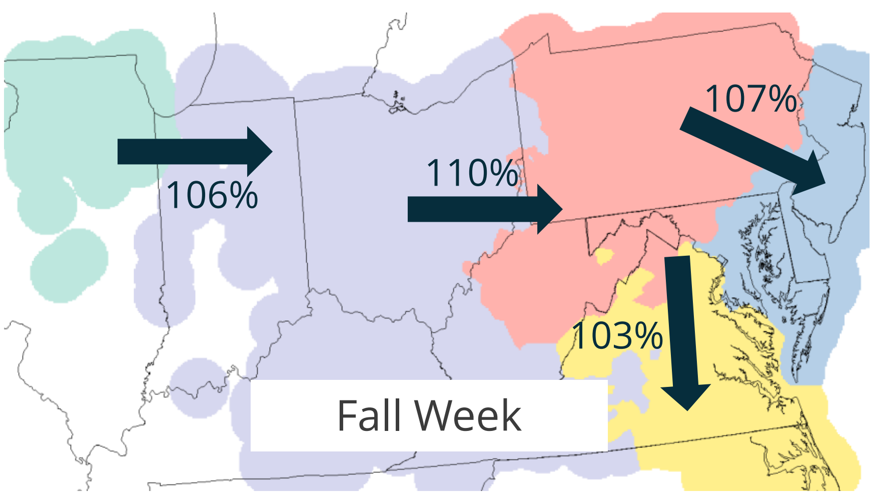
Production Cost Savings = production cost without TCA (full topology) – production costs with TCA

Cost of Congestion = production cost with transmission constraints – production costs without transmission constraints

Change in Transfers Between PJM Regions

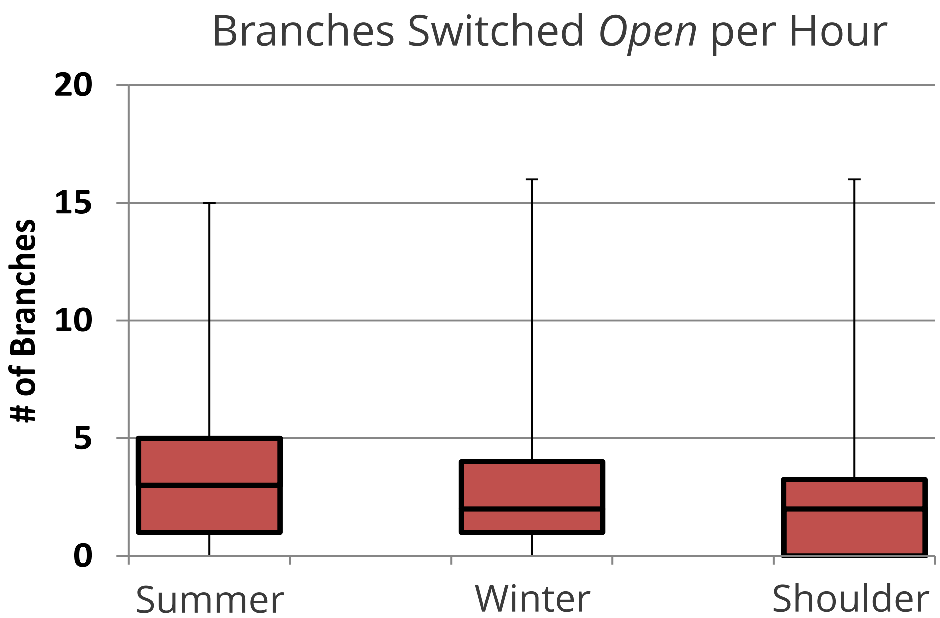


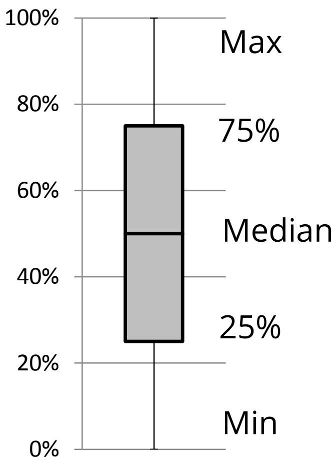




Percentages are in reference to the weekly transfer without topology optimization. Flow pattern and transfer vary depending on seasons and system conditions. Overall, transfer capability is significantly increased.

Topology Change Frequency

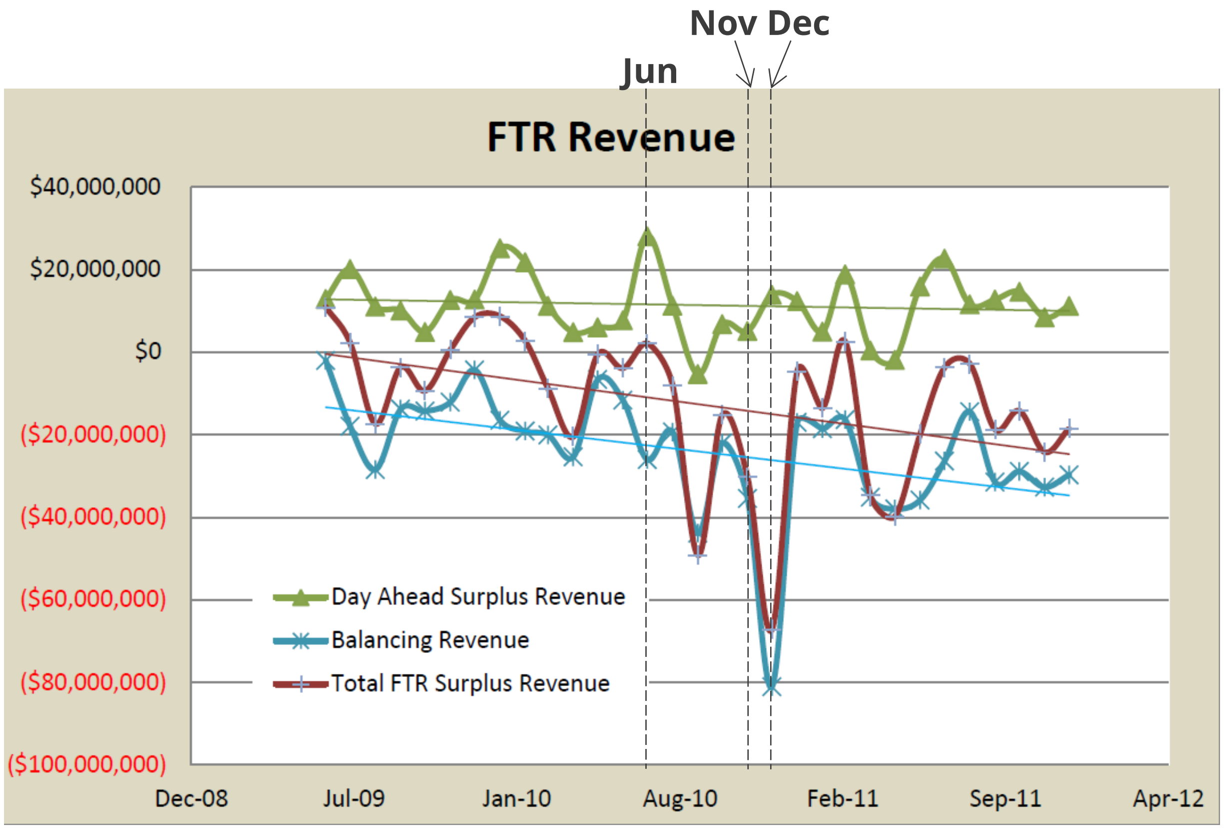




- There are very few switching operations in each hour, on average.
- When a branch is switched open, it stays open for over 8-10 hours on average, and it is then reclosed.
- The number of switching operations are less than the number of outage requests that PJM receives currently.

Background: Sources of FTR Revenue in PJM

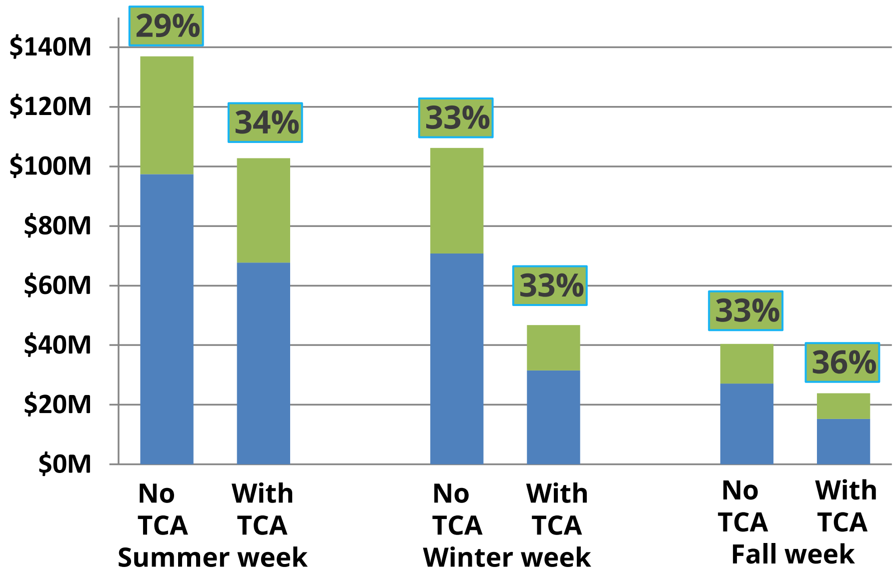
- *Balancing Congestion Revenue* = DA – RT congestion expenses.
- *Day-Ahead FTR Surplus* = DA congestion rent – DA FTR settlements.



Source: http://www.pjm.com/~/media/committees-groups/task-forces/ftrtf/20120906/20120906-ftr-revenue-report-review-2012.ashx

Impacts on DA FTR Surplus Revenue

- We calculated DA FTR Settlements and Surplus for the weeks simulated.



Congestion Rent = Surplus + FTR Settlements
No TCA: simulation without topology optimization, historical topology
With TCA: simulation with topology optimization, Full Switchable Set (all branches)

- Topology optimization tends to:
  - Decrease DA Congestion Rent.
  - Increase DA FTR Surplus relative to the DA Congestion Rent.
- As topology optimization is especially effective in relieving RT congestion,* we anticipate that Balancing Congestion would be significantly reduced.

* See Appendix 1 and Appendix 2, Reference [4].

Concluding Remarks

- Operators employ reconfigurations today on an ad-hoc basis.
- We have developed software technology to enable transparent, consistent, and routine identification of topology changes with significant efficiency and reliability gains.
- Lessons from the PJM evaluation:
  - Security-constrained topology optimization solutions with AC, full EMS detail modeling are obtained in only a few minutes. These are very useful to support outage coordination processes and Op. Guide development.
  - Simulations on detailed PJM DA market models indicate that annual savings may be a large fraction of the total costs of congestion (estimated to be about $145 million under 2010 conditions).
  - Topology optimization tends to improve FTR DA surplus on a relative basis, and would likely significantly reduce Balancing Congestion.
- Topology optimization is currently available as a consulting service.
- *NewGrid Router*, the first production-grade topology decision support software tool, will be available for licensing by Q1 2017.

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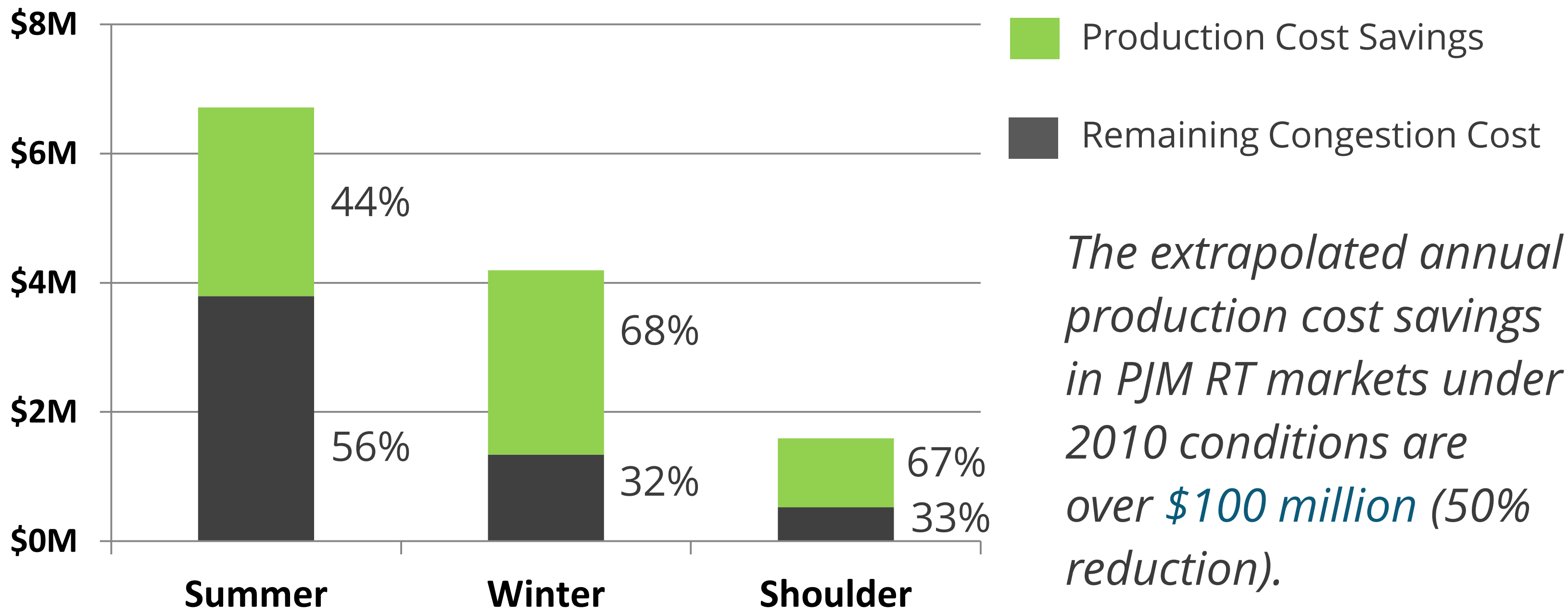
RT Market Production Cost Savings

Topology Optimization Savings in the Representative Weeks

(relative to the initial cost of congestion)



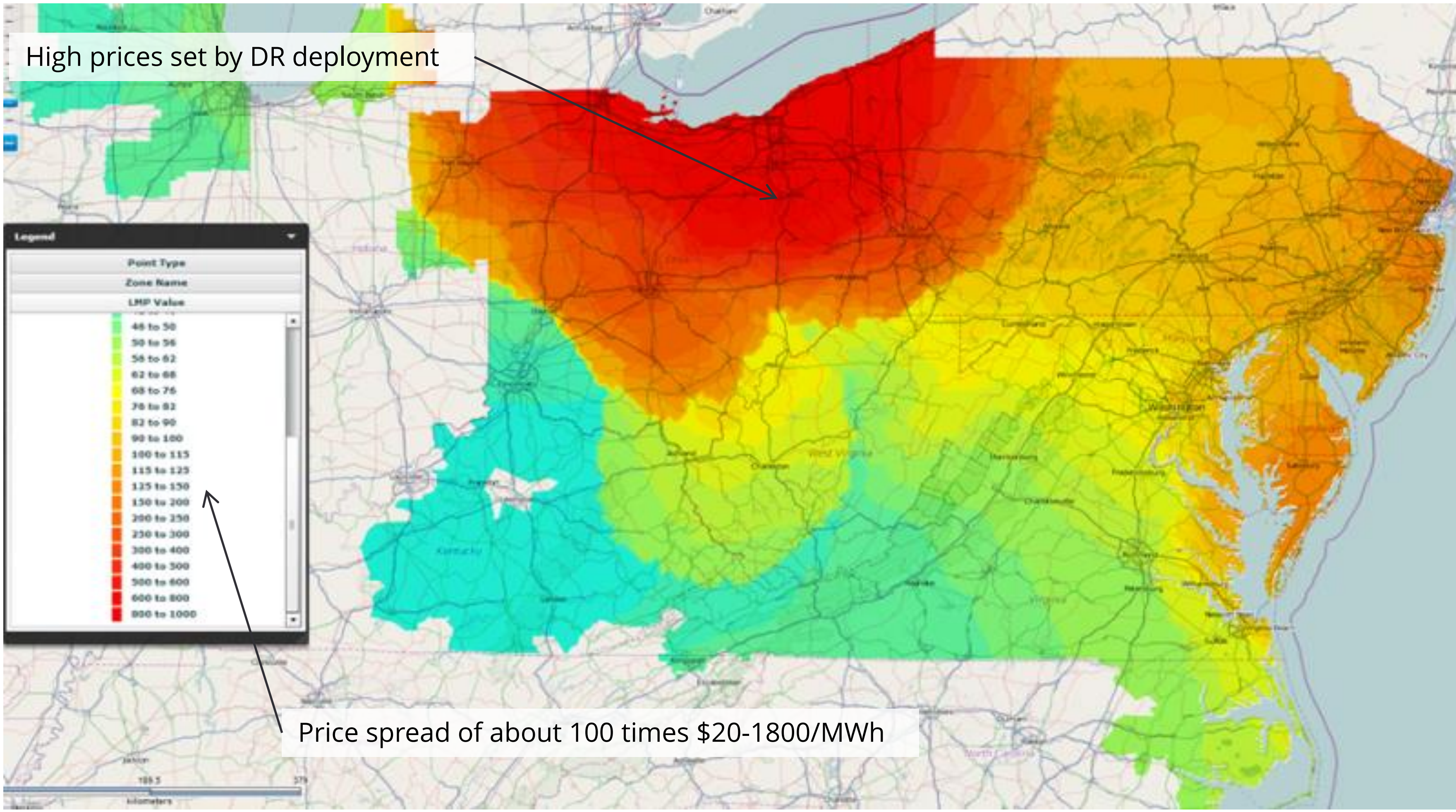
The extrapolated annual production cost savings in PJM RT markets under 2010 conditions are over $100 million (50% reduction).

Production Cost Savings = production cost without TCA (full topology) – production costs with TCA

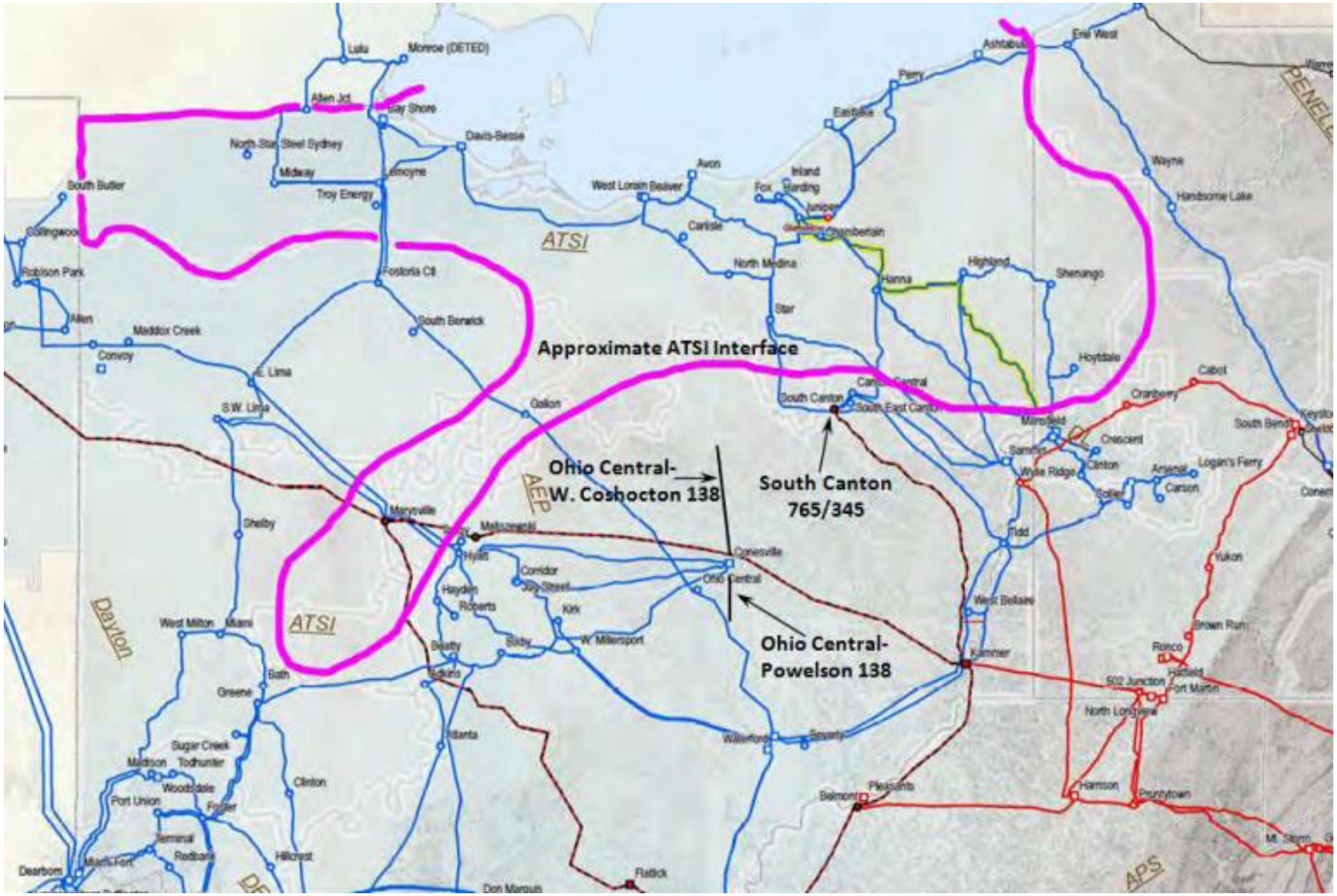
Cost of Congestion = production cost with transmission constraints – production costs without transmission constraints

South Canton Transformer Overload Relief

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



South Canton Transformer Overload Relief



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

South Canton Transformer Overload Relief

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

- The South Canton 765/345 kV transformer was severely congested and with base case overloads on July 15th, 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.
- 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.

Appendix 3
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Appendix 3

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