Transmission Topology Control
Applications to Outage Scheduling, Market Efficiency and Overload Relief

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What is Topology Control?

- **Topology control** was used to control wireless sensor networks that collect and send data from geographically dispersed areas. Topology control algorithms were applied to increase the efficiency of the network. (Applications include: monitoring, tracking and surveillance of borders and the battlefields; traffic and road conditions; changes in environment.)

- Applied to electric transmission network, **Transmission Topology Control** (line switching) can reduce system congestion and reduce the cost of delivered power.

- Today, transmission topology control is conducted via manual ad-hoc interventions by system operators. The interventions usually are based on prior experience or on fixed procedures.
Topology Control can increase transfer capabilities from low-cost generation to high cost regions, relieve overloads, reduce congestion, and increase system flexibility.

Today, system operators adjust transmission topology on an ad-hoc basis for the following applications:

- **Contingency Planning:** identify pre- and post-contingency reconfiguration to mitigate overloads (e.g., Operating Guides)

- **Outage Coordination/Scheduling:** enable planned outages that otherwise would cause reliability violations/congestion increase

- **Congestion Management:** allow more efficient unit commitment and economic dispatch (used in limited cases)

Developing switching solutions and efficient topology changes is a time-consuming process.
Automated Topology Control Technology

- **Automated Topology Control** is now possible with fast computers, parallel processing and new optimization approaches.
  - With DOE’s Advanced Research Project (ARPA-E) support, a team developed software technology that automates and speeds up the identification of switching solutions to address reliability- and congestion-related challenges.

- **Topology Control Algorithms (TCA) co-optimize** electricity generation economic dispatch with the connectivity of transmission network elements (breaker status).

- The TCA can **automatically identify** operational controls that support system operators’ in:
  - Responding to contingency situations
  - Planning for outages
  - Managing congestion
Illustrative Example

Overloaded Bus with High Locational Price

$40/MWh

$15/MWh
Illustrative Example

Relieve Overloads and Reduce Prices

Case Hourly Cost
17733 $/h

$40/MWh

$15/MWh
With Department of Energy’s Advanced Research Projects Agency-Energy (ARPA-E) support, a team of experts developed full-scale algorithms and software for transmission topology control

- Teamed up with PJM Operations to test the software and the solutions obtained.
- The project team designed and developed a protocol that replicates PJM’s market operations.
- The technology can be used with existing operations and market tools (including Energy Management Systems, Market Management Systems, and contingency planning).
- The tool meets PJM’s computational time requirements for operations.

Specifications of Protocol:

- Handled simulating large systems: PJM’s >20,000 bus (>100,000 EMS nodes).
- Applied forward-looking topology control in Economic Dispatch and Unit Commitment.
- Delivered solutions that meet reliability criteria, including connectivity, security constraints, stability and voltage criteria.
ARPA-E Topology Control Algorithm Project

Topology Control Software Architecture

**Optimization:** Reduces System Costs

- Topology Control
  - Topology, Dispatch, Commitment, Marginal Costs

**Feasibility:** Maintains Reliability

- Contingency and Voltage Stability Evaluation
  - Voltage, MVA and Stability Assessment: Feasible/Infeasible, Constraints to Return to Feasibility

* The simulation results in this presentation include AC modeling and linear contingency evaluation and enforcement, but do not include transient stability evaluation.
Example from Experience with PJM: Relieving Overloads Through TCA

South Canton Potential Overload Relief

Source: http://www.pjm.com/~/media/committees-groups/committees/mrc/20130829/20130829-item-13-hot-weather-operations-presentation.ashx
Example from Experience with PJM: Relieving Overloads Through TCA

South Canton Potential Overload Relief

PJM Real Time Prices, 18-Jul-2013, 15:30

Source: http://www.pjm.com/
Example from Experience with PJM: Relieving Overloads Through TCA

**PJM Overload Relief**

July 15th, 2013 at 3PM

**Before**
South Canton transformer was overloaded in base case, and 4 post contingency constraints were also overloaded

**After**
8 branches (three 345 kV and five <200 kV) were opened to divert flows and relieve all overloads in the area, without changing the system dispatch
Example from Experience with PJM: Relieving Overloads Through TCA

South Canton Potential Overload Relief

- **July 15, 2013, 3 PM Event:** The South Canton transformer was severely congested and with base case overloads.
  - There were post-contingency overloads in the area as well.
  - PJM deployed demand response to reduce congestion in the area.
- We simulated using solely transmission topology modifications to relieve overloads.
- **TCA produced solutions to divert flow away from the transformer** and fully relieved the base case and post contingency overloads in the area (without causing other overloads).
- **TCA could have reduced the required DR deployment.**
- Very little change in base case voltage profile after the topology change.
TC Congestion Impacts – PJM Simulation Results

- **Simulated PJM’s system** and provided security-constrained topology control solutions
  - Each solution is obtained for a snapshot of the system in only a few minutes.

- When **applied to constraint overload events**, TCA identified switching solutions that would have alleviated the events.
  - Solutions deemed innovative relative to experience by PJM staff.

- **The team estimates PJM congestion-related costs can be reduced by about 50%** based on simulations of PJM’s 5-minute real time market with system-wide “re-dispatch” of the system enabled by TCA.
  - **Estimated annual savings >$100 million in 2010.**

- Currently, continuing to evaluate the potential impact of using Topology Control Algorithm on financial transmission right settlements and FTR revenue adequacy (expected by Q3 2015).
Valuable Applications for Practical Use Today

While the TCA 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:

- TCA can very efficiently *identify switching solutions to address specific reliability and congestion events.*

- TCA can *define temporary operating guides 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.

- TCA can *identify operating guides to reduce congestion* on a regular basis and reduce utilities’ exposures to unhedged congestion costs.
Long-Term benefits for Transmission Planning

**A Transmission Owner’s Perspective**

- TCA helps to reduce the costs and increase feasibility of construction-related outages.
- TCA Increases the value of system expansions that provide operational flexibility (e.g., investments that create more switching options).
- TCA Increases the effective capability of the existing grid.
  - Would 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).
- TCA increases the long-term attractiveness of transmission solutions compared to non-transmission alternatives (such as generation-heavier solutions).
  - TCA will likely move the optimal spending mix more toward transmission (i.e., spending more on transmission and less on generation will be the more cost effective overall solution).
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Appendix
Appendix

PJM RT Market Models: Historical Conditions

- Models based on one operational power flow snapshot per hour for the summer peak week in 2013 (July 14-20) and for three representative historical weeks in 2010 (summer, shoulder and winter weeks).
  - Data used from the power flows: transmission topology, branch parameters, unit commitment and dispatch, loads, shunt devices, interchange, initial voltage state

- Generation economic and transmission constraint data from real-time market

- Assumptions made include:
  - Fixed interface constraint limits at historical value used by RTO for same interval
  - Fixed dispatch of hydro, wind, landfill, nuclear and reliability must-run thermal units for the interval
  - Network service requirements for all non-radial loads and generators

- Model dimensions: up to 15,200 nodes and 650 dispatchable thermal units, about 4,700 monitored branches and 6,100 single and multi-element contingencies (fixed contingency list assumed to be sufficient for all relevant topology changes)
Appendix: TCA Simulation on PJM RT Markets

RT Market Production Cost Savings

Savings in the Representative Weeks

* Savings and remaining cost of congestion shown as a percentage of the initial cost of congestion

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
Appendix: TCA Simulation on PJM RT Markets

Transfers Enabled by TC and Breaker Ops.

Summer Peak 2013 Week

Transfer Between RTO Regions

Percentages are in reference to the weekly transfer without TCA. Flow pattern and transfer vary depending on seasons and system conditions. Overall, TCA significantly increases the transfer capability within the system.

Breaker Operations by Voltage

Hours Facilities are Open by Voltage

765 kV equipment is primarily switched out of service in anticipation of low load periods, such as the weekend or very early mornings, when they are not needed for reliability, are lightly loaded, and may cause over-voltage issues.
References


