

Advances in Topology Control Algorithms (TCA)

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FERC Technical Conference on
Increasing Market Efficiency through Improved Software
Docket AD10-12-004

Washington, DC, June 25, 2013



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Transmission Switching in PJM (Currently)

PJM has *switching solutions* that operators apply to alleviate congestion:

<http://www.pjm.com/markets-and-operations/etools/oasis/system-information/switching-solutions.aspx>

“The following is a list of potential transmission switching procedures identified by PJM that may assist to reduce or eliminate transmission system congestion. These identified potential transmission switching procedures may or may not be implemented by PJM based upon system conditions, either projected or actual, and ultimately are implemented solely at the discretion of PJM and its Transmission Owners. This posting is for informational purposes only. Consequently, PJM does not guarantee that any of these identified switching procedures will be included in any market-based auctions or in the real time analysis. Accordingly, PJM expressly disclaims any liability for financial consequences that a Member may incur in taking action in reliance on these informational postings.”



Agenda

- ◆ Topology Control Algorithms: Objectives and Motivation
- ◆ Illustration of Topology Control
- ◆ Topology Control Requirements
- ◆ ARPA-E TCA Project Update
- ◆ B-theta MIP Topology Control Formulation
- ◆ Shift Factor MIP Topology Control Formulation
- ◆ Concluding Remarks



TCA Objectives

The goal of tractable control of the transmission network topology is to extract more value out of existing transmission facilities:

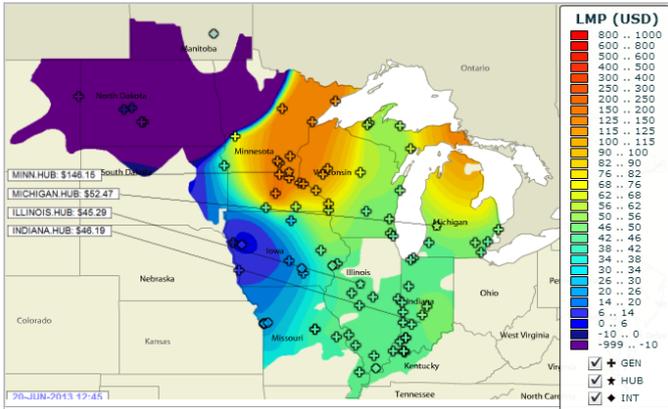
- 1. Significantly lower generation costs**
- 2. Provide additional operational controls**
 - ◆ manage congestion
 - ◆ respond during contingency situations
- 3. Enable higher levels of variable renewable penetration**
- 4. Increase system reliability**

TCA Timeframe: between a few days ahead up to real-time

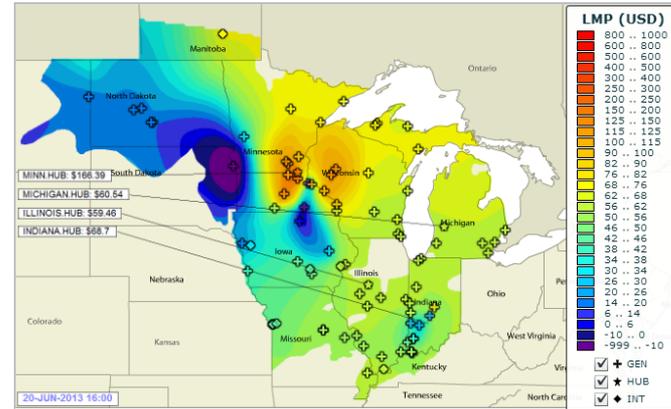


Congestion in RT Markets: Midwest ISO

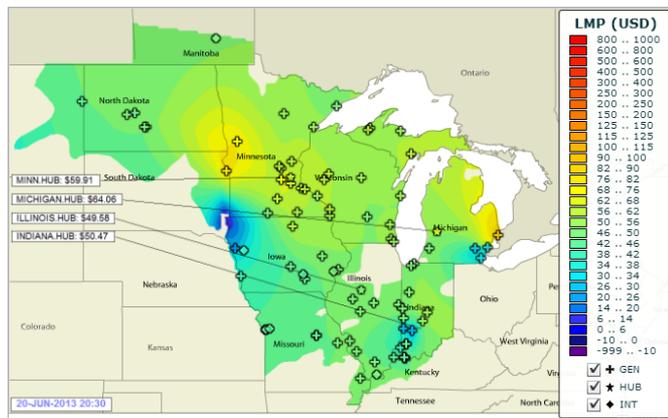
Midwest ISO, 20-Jun-2013 12:45



Midwest ISO, 20-Jun-2013 16:00



Midwest ISO, 20-Jun-2013 20:30



In the course of a day, geography of congestion moves along large territories and cause dynamic price contours:

- ◆ Fuel diversity
- ◆ Lack of flexibility in the resource mix

Having the ability to dynamically increase transfer capability from low price areas to high price areas will help to relieve congestion, improve dispatch of renewable resources and reduce dispatch costs



Topology Control Example: Open Branches that Feed Congested Branches

I-93 Bridge Replacement,
North of Boston



07.08.2011 23:47

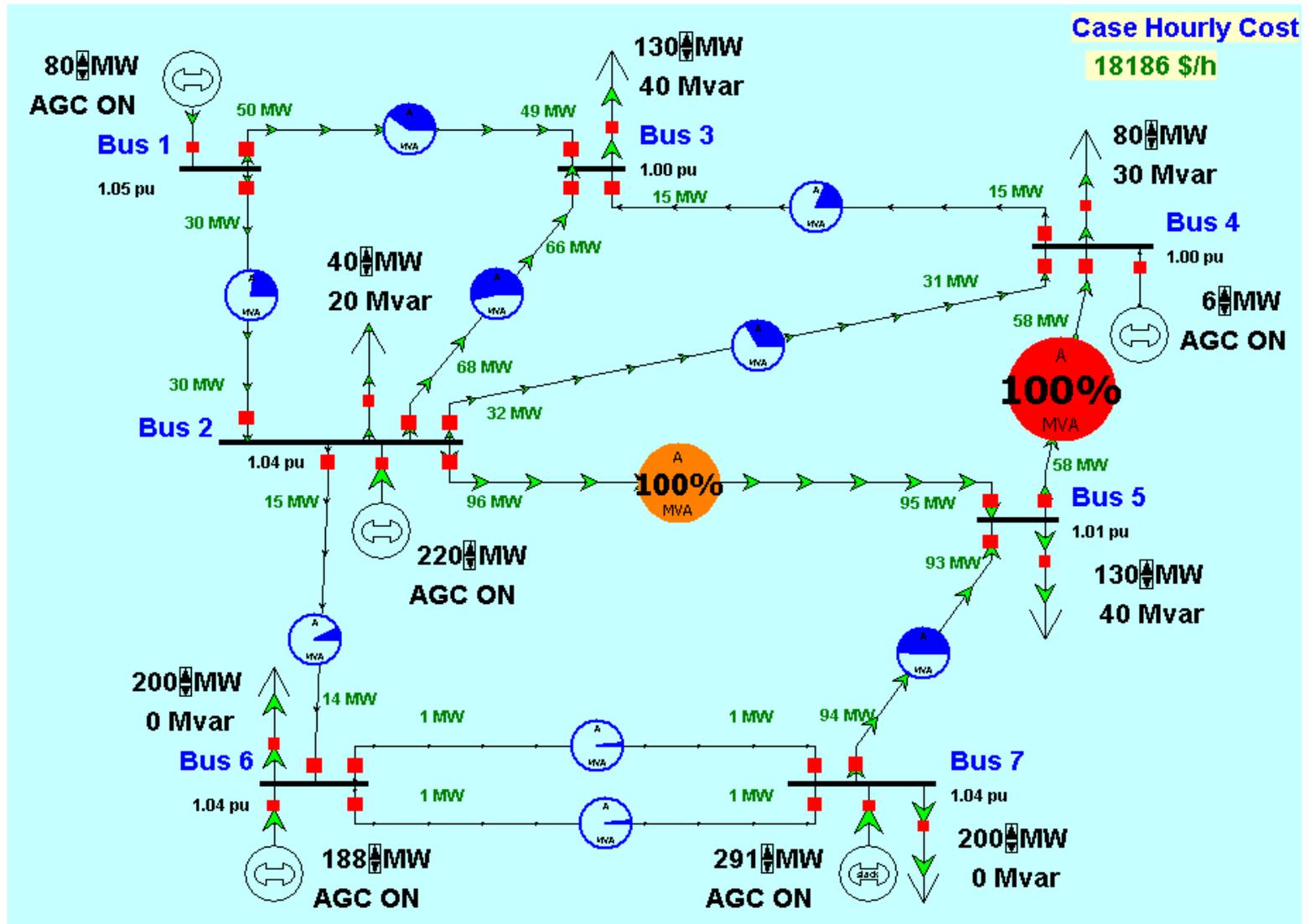
source: freelance photographer
Matthew Carter, Waltham, MA

nearby I-93 entry
ramps were closed,
relieving congestion

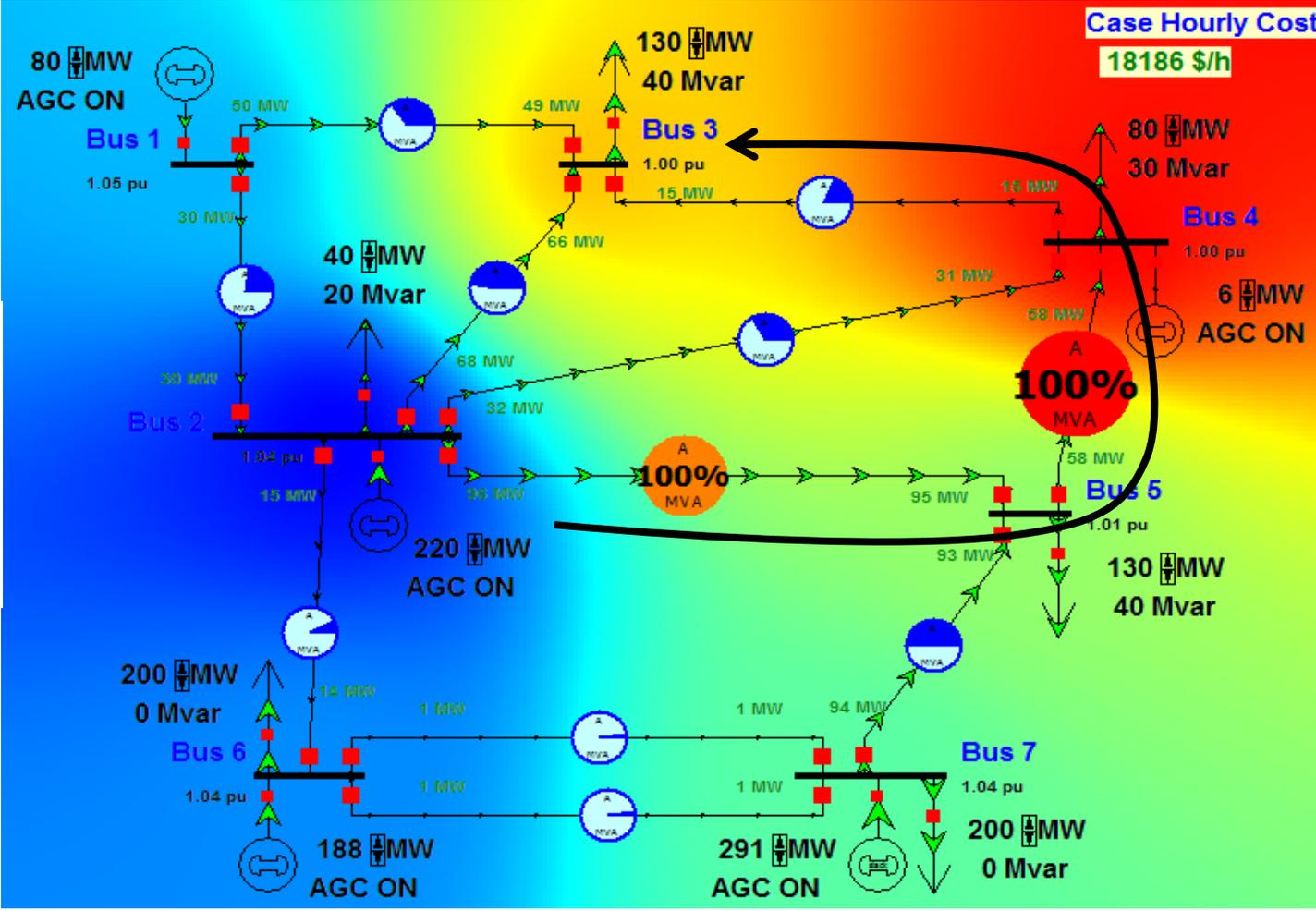
source: Massachusetts Department of Transportation



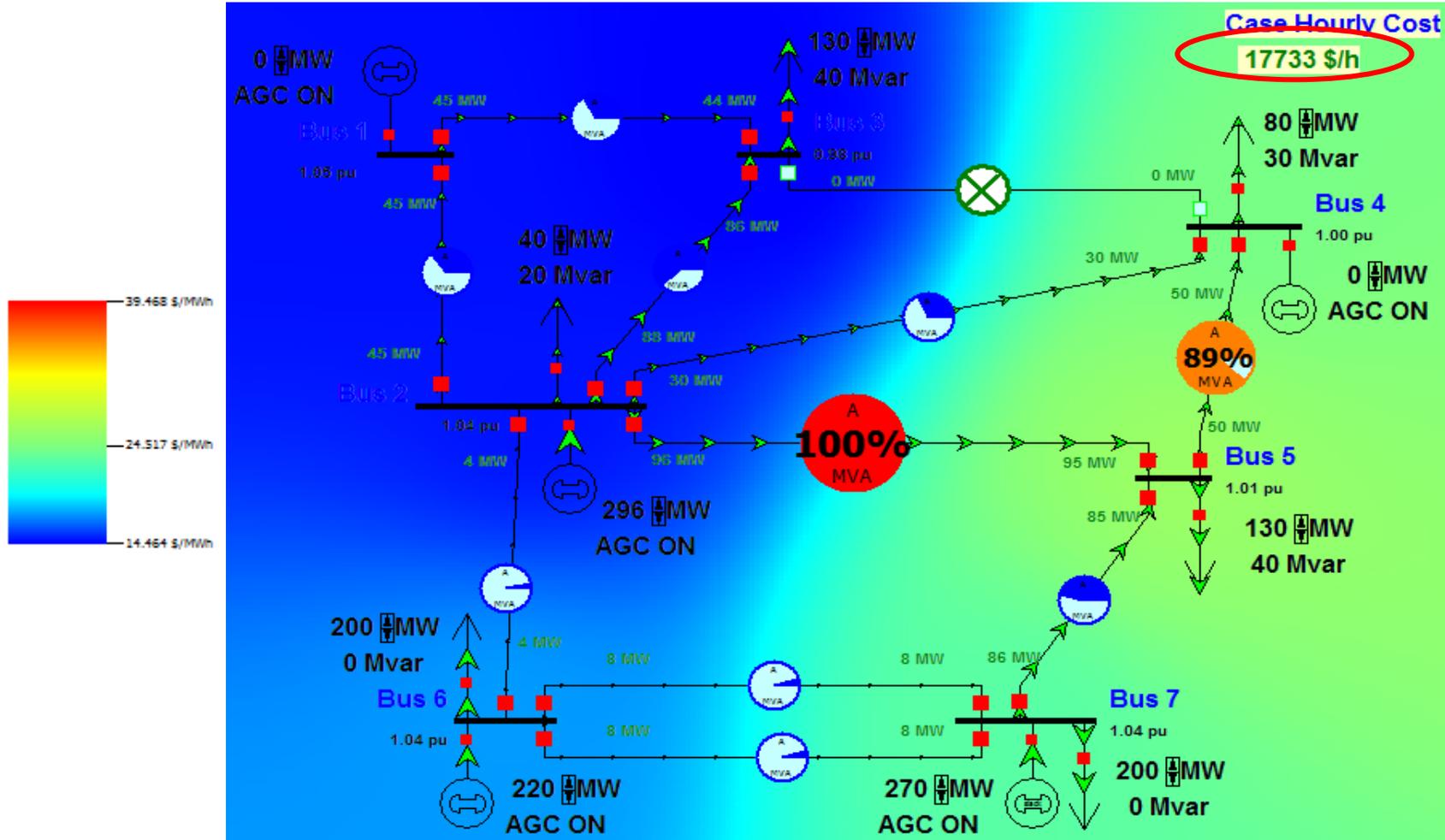
7-bus Example: All Lines Closed



7-bus Example: All Lines Closed



7-bus Example: Open Branch Fed by Congested Facility (Line 3 – 4)



Savings!



Topology Control Requirements

- ◆ Feasibility: all demand supplied, no transmission overloads
- ◆ Cost-reduction: transmission topology changes allow a lower out-of-merit cost dispatch
- ◆ Reliability: redundant topology and robust dispatch enables system to withstand contingencies (*e.g.*, $n - 1$ security)
- ◆ Connectivity: topology changes do not cause system separation (islanding) in pre or post contingency situations
- ◆ Stability: faults do not lead to instabilities



ARPA-E TCA Project: Objectives and Focus

To develop a full-scale algorithm and software implementation for transmission network topology control

- ◆ operating in conjunction with market engines for security-constrained unit commitment (UC) and economic dispatch (ED);
- ◆ meeting tight computational effort requirements

The developed algorithms will be tested in a simulated environment replicating PJM market operations.

Focus:

- ◆ Tractability: TCA must work on 13,000+ bus systems
- ◆ Dynamics: look-ahead TC decisions in ED and UC contexts
- ◆ Reliability: security constraints, transient stability and voltage criteria met
- ◆ Impacts: economic and renewable integration benefit evaluation, with expected production cost savings in PJM of over \$100 million/year



PJM RT Market Test Systems

- ◆ Based on 5-minute operational power flow cases from the week of June 20-26, 2010
 - Unit commitment and limits
 - Losses
 - Loads
 - Interchange
 - Fixed dispatch of hydro, wind, landfill and nuclear units
 - (Starting) transmission topology
 - Branch and interface constraint limits based on real-time operations data
- ◆ Generation data from real-time market (including must-run schedules)
- ◆ About 13,400 nodes, and 400-500 dispatchable thermal PJM units
- ◆ Monitored facilities from PJM (approx. 3,500 monitored branches)
- ◆ Approximately 6,000 single- and multi-element contingencies



PJM RT Markets: Simulations with TCA

**Congestion cost =: market costs with transmission constraints
– market costs without transmission constraints**

Promising preliminary results on the June 20-26, 2010 model:

- ◆ Under review with PJM staff
- ◆ Obtain significant savings (compared to congestion cost)
- ◆ Indicate that the >\$100 million annual savings target is realistic
- ◆ Full security-constrained solutions (DC assumptions; AC and stability issues will be evaluated in coming months)
- ◆ Computational performance: TCA optimization is fast enough to be implementable on an hourly and intra-hourly basis



$B-\theta$ Formulation of DC SCOPF With Topology Control

Description	Representation	Constraint Count
Obj. Function (Generation Cost)	$\min_{p,\theta,f,z} c^T p$	
Unit Constraints	$\underline{p} \leq p \leq \bar{p}$	# of units
Voltage angles	$\underline{\theta} \leq \theta(t) \leq \bar{\theta}$	# of nodes x # of contingencies + 1
Line flows	$-\underline{F}(t)z \leq f(t) \leq \bar{F}(t)z$	# of lines x # of contingencies + 1
Power Balance	$p - L - Af(t) = 0$	# of nodes x # of contingencies + 1
2 nd Kirchhoff Law	$-M(1-z) \leq BA^T \theta(t) - f(t) \leq M(1-z)$	# of lines x # of contingencies + 1



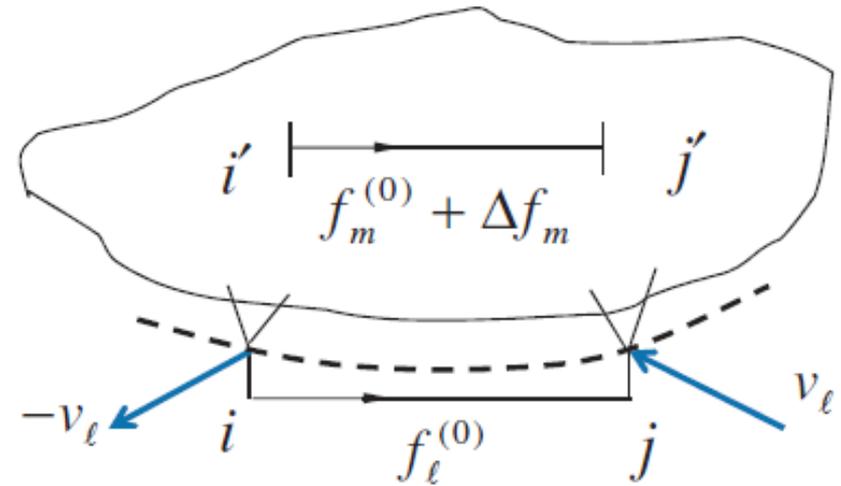
Usual Formulation of DC SCOPF (No Topology Control)

Description	Representation	Constraint Count
Obj. Function (Generation Cost)	$\min_{p,f} c^T p$	
Unit Constraints	$\underline{p} \leq p \leq \bar{p}$	# of units
Voltage angles	n/a (embedded in Ψ)	0
Line flows	$-\underline{F} \leq \Psi(p - L) \leq \bar{F}$	# of monitored – contingency pairs
Power Balance	$1^T (p - L) = 0$	1
2 nd Kirchhoff Law	n/a (embedded in Ψ)	0



Flow-Cancelling Transactions (FCT)

- ◆ An FCT for a line ℓ is a concurrent injection and withdrawal at the two ends of the line which force the flow on the line *interface to zero*.
- ◆ FCT makes the same impact on flows on other lines as physical opening of the line in question
- ◆ FCT does not affect the balance of power in the system
- ◆ Multiple line openings are emulated by the superposition of multiple FCTs, one FCT per line opening



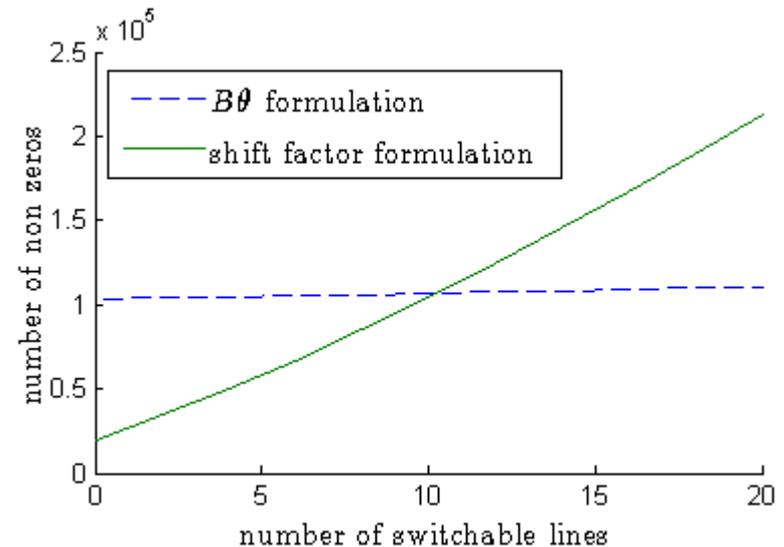
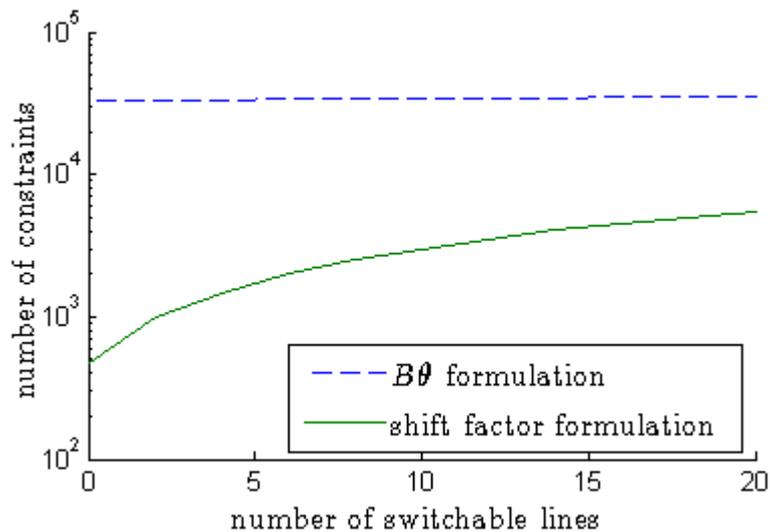
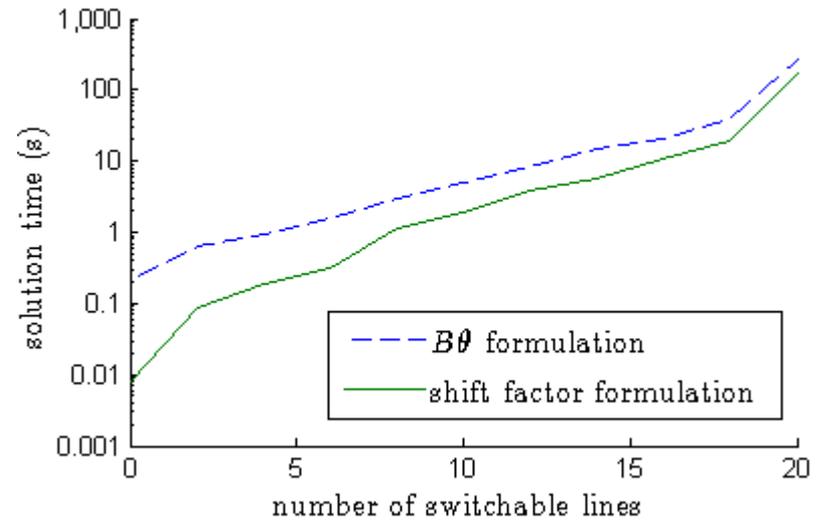
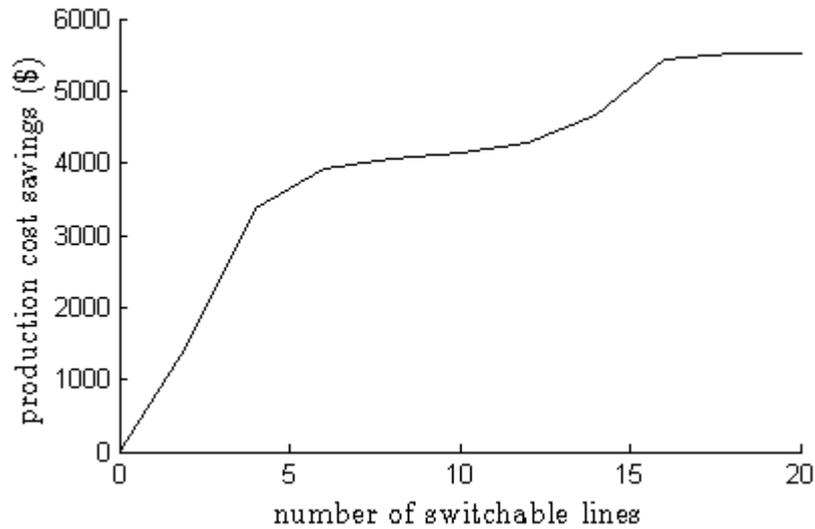
$$f + (\Phi_s - I)v = 0$$

DC SCOPF with Topology Control: Shift Factor Formulation

Description	Representation	Constraint Count
Obj. Function (Gen. Cost)	$\min_{p,f,v,z} c^T p$	
Unit Constraints	$\underline{p} \leq p \leq \bar{p}$	# of units
Power Balance	$1^T (p - L) = 0$	1
Monitored Line Flows	$-\underline{F}(t) \leq \Psi (p - L) + \Phi (t) v (t) \leq \bar{F}(t)$	# of monitored – cont. pairs
Switchable Line Flows	$-\underline{F}_s(t) z \leq \Psi_s (p - L) + (\Phi_s (t) - I) v (t) \leq \bar{F}_s(t) z$	# of switchable lines x # cont.+1
FCT Constraints	$-M(1 - z) \leq v(t) \leq M(1 - z)$	# of switchable lines x # cont.+1



IEEE 118-Bus Simulations: Variations in Switchable Set Size



Concluding Remarks and Work in Progress

- ◆ Most system operators employ TC today, mainly on an ad-hoc basis using operators' previous experience
- ◆ The TCA project will provide practical technology to enable transparent, consistent and routine implementation of topology control
- ◆ The technology is being assessed on detailed models of PJM markets
 - Security-constrained TCA solutions for RT markets can be obtained quickly
 - Preliminary RT market results are promising, and indicate that expected annual PJM savings of over \$100 million are realistic
- ◆ The shift factor TC formulation outperforms the B-theta formulation for reduced switchable sets, and is consistent with the usual power market formulations



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Please sign up for the TCA periodic updates!

References

- [1] 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.
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