Topology Control Algorithms (TCA): Economic and Corrective Applications

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Congestion in Transportation and Topology Control

I-93 Bridge Replacement, North of Boston

source: Massachusetts Department of Transportation

source: freelance photographer
Matthew Carter, Waltham, MA

nearby I-93 entry ramps were closed, relieving congestion

Agenda

- Topology Control Algorithms (TCA) Objectives and Motivation
- Illustration of TCA
- Optimal Topology Control Background
- Tractable Topology Control Sensitivity-based Approaches
- Simulation Results: Economics and Corrective Applications
- ARPA-E TCA Project
- Concluding Remarks

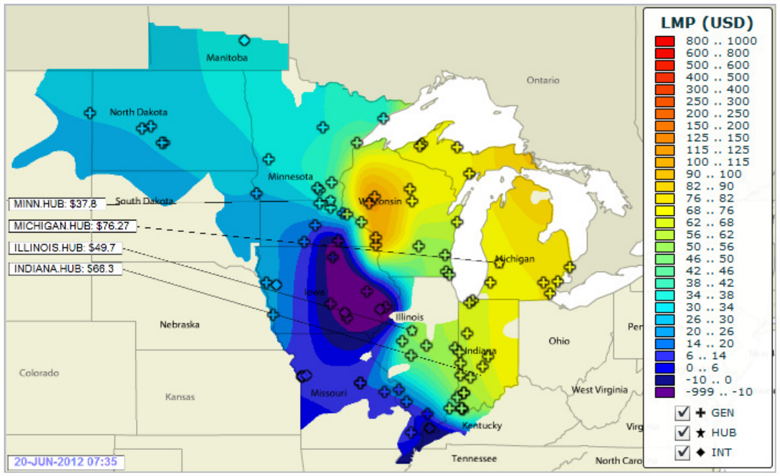
TCA Objectives

The goals of tractable control of the transmission network topology are to:

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
5. Extract more value out of existing transmission facilities

Congestion in Power Networks

Midwest ISO, 20-Jun-2012 07:30



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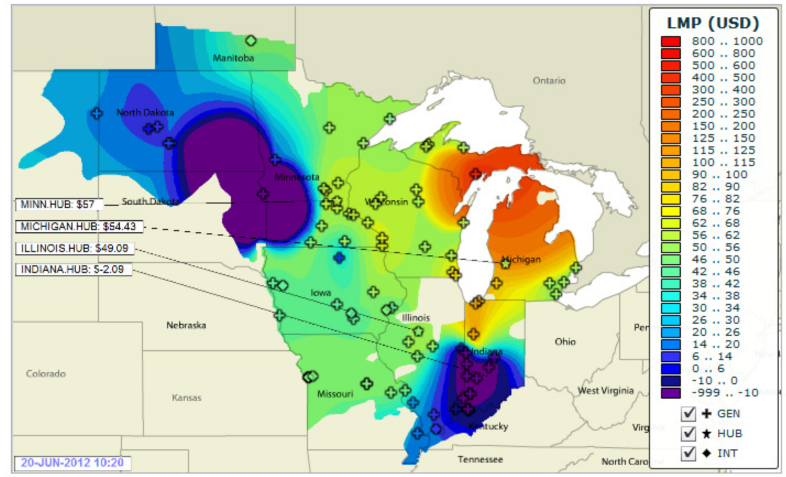

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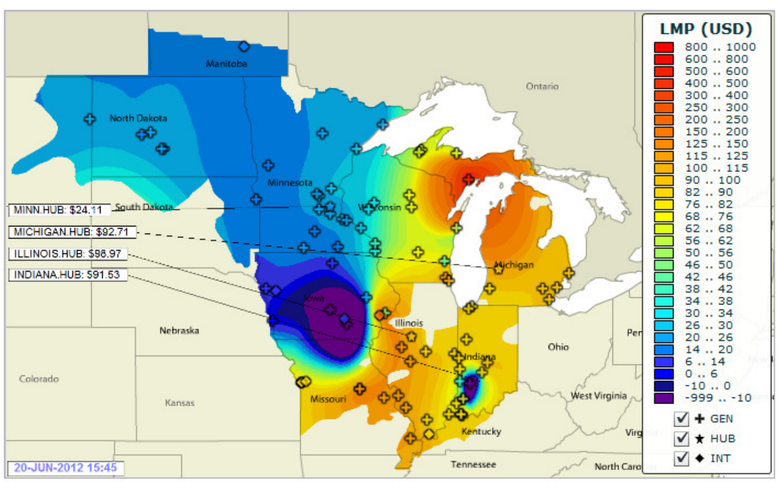
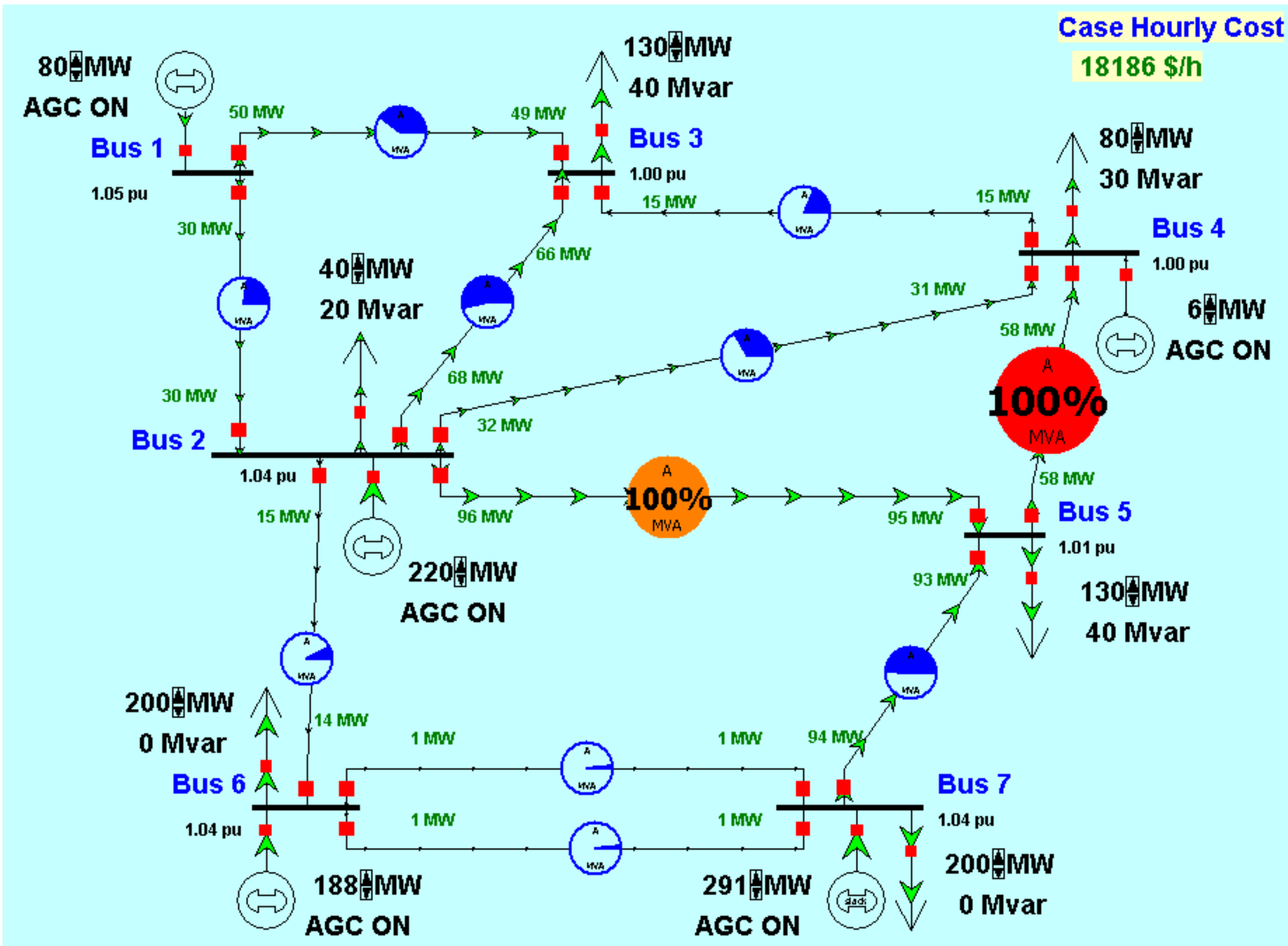
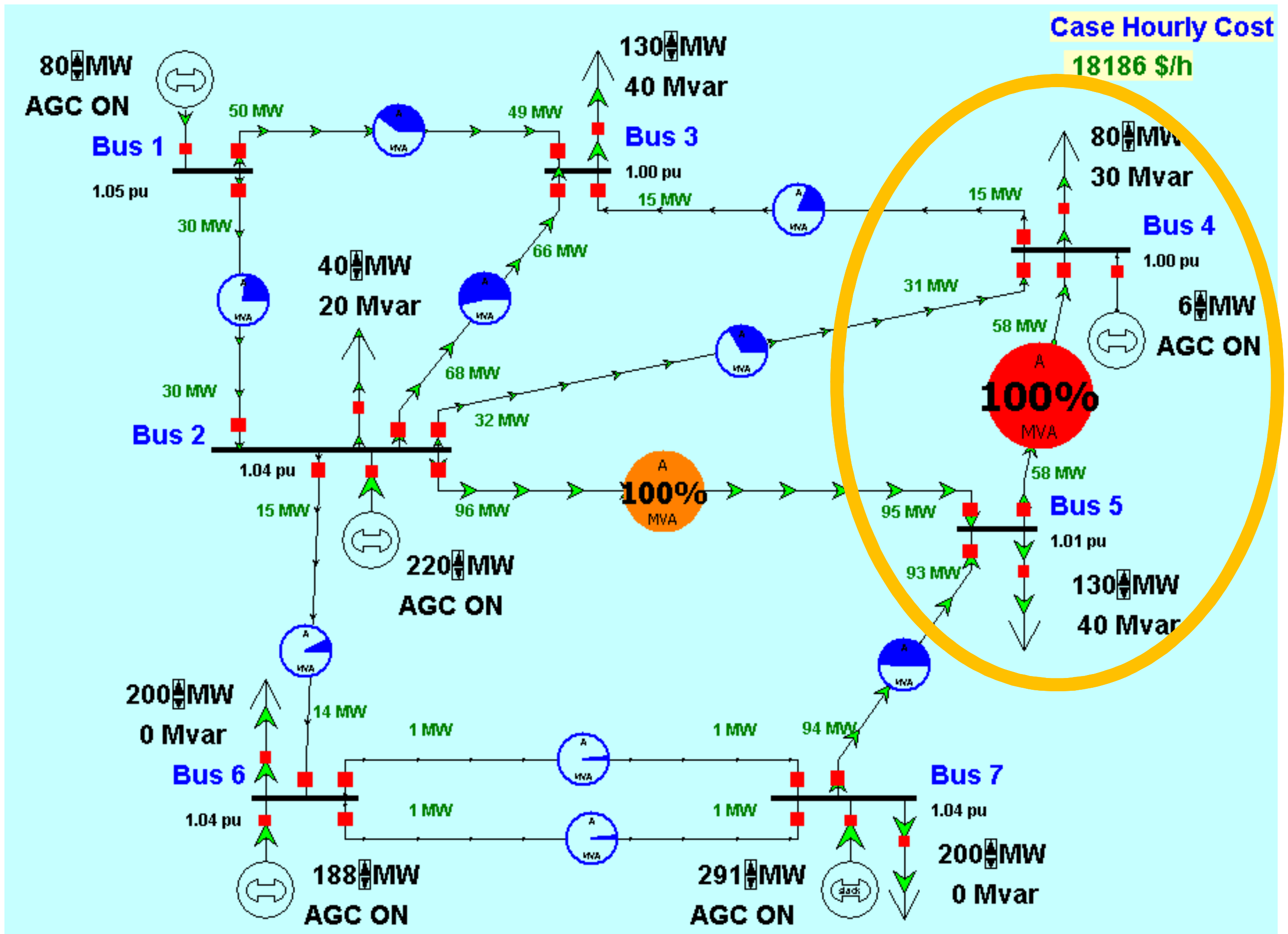


In the course of a day, geography of congestion moves along large territories and cause dynamic price contours. Having the ability to dynamically increase transfer capability from low price areas to high price areas will help to relieve congestion, improve dispatch of renewable resources and reduce dispatch costs

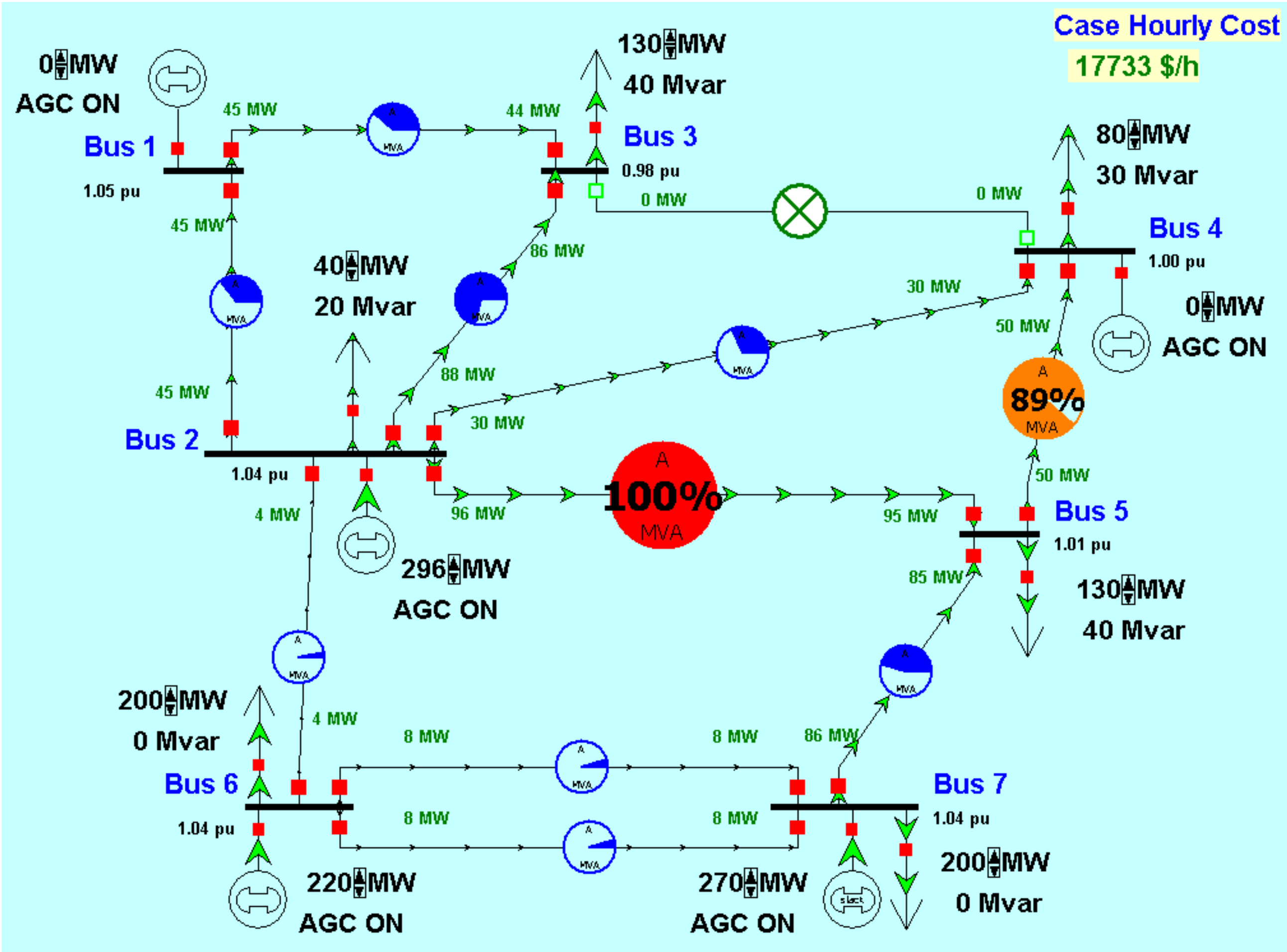
7-bus Example: All Lines Closed



7-bus Example: All Lines Closed



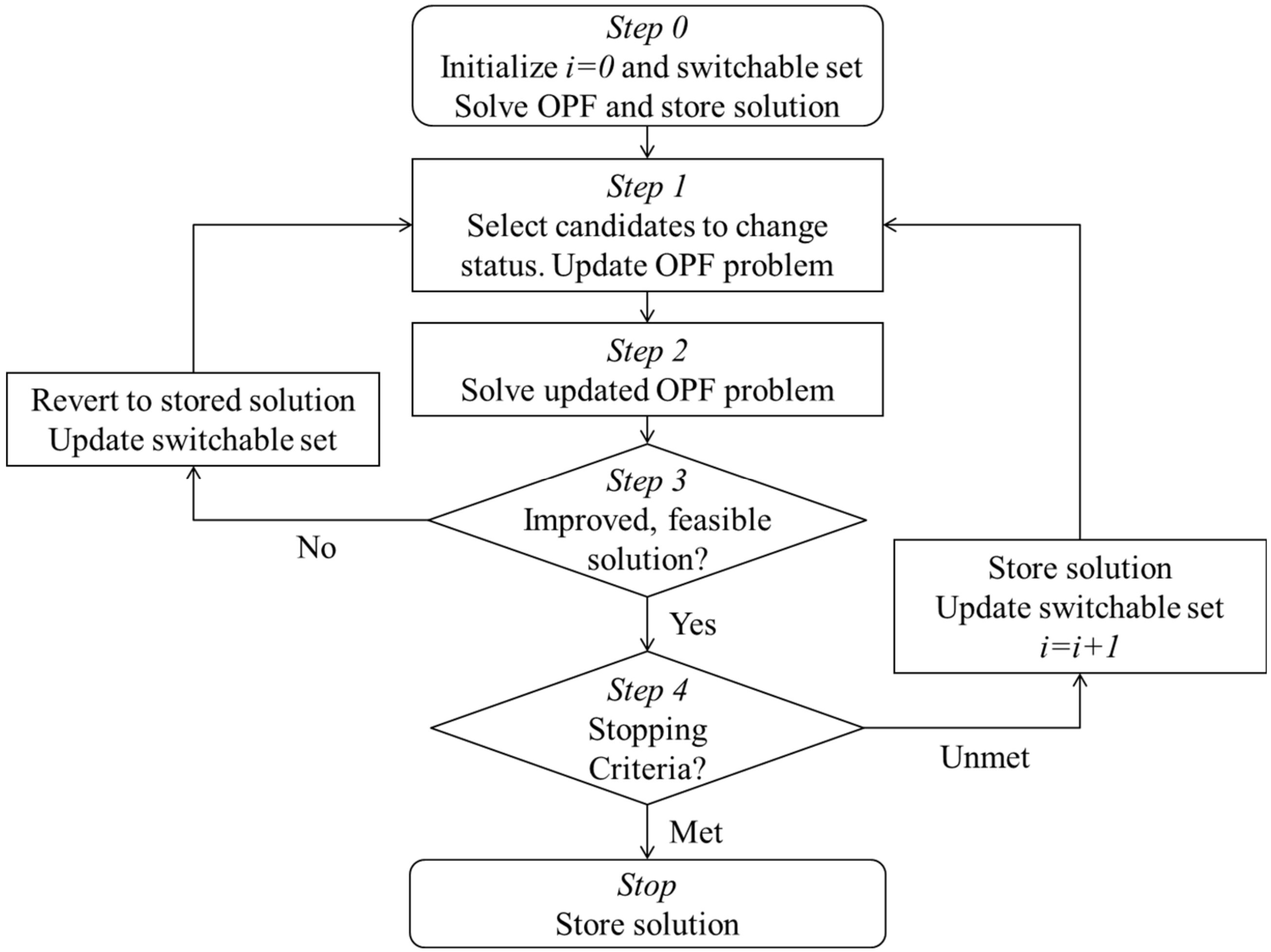
7-bus Example: Line 3 – 4 Opened



Optimal Topology Control Background

- Seminal papers by O'Neill, Fisher, Oren, Hedman and others
- The branch states are added to the OPF/ED/UC as decision variables, converting them into a MIP
- Flows modeled by embedding a DC power flow formulation in the optimization, including line susceptances and nodal voltage angles
- For each topology, the system state is obtained and then flows are determined
- Given the size of real systems and solution time requirements, global topology optimization through direct MIP formulations is computationally *intractable* with current technology

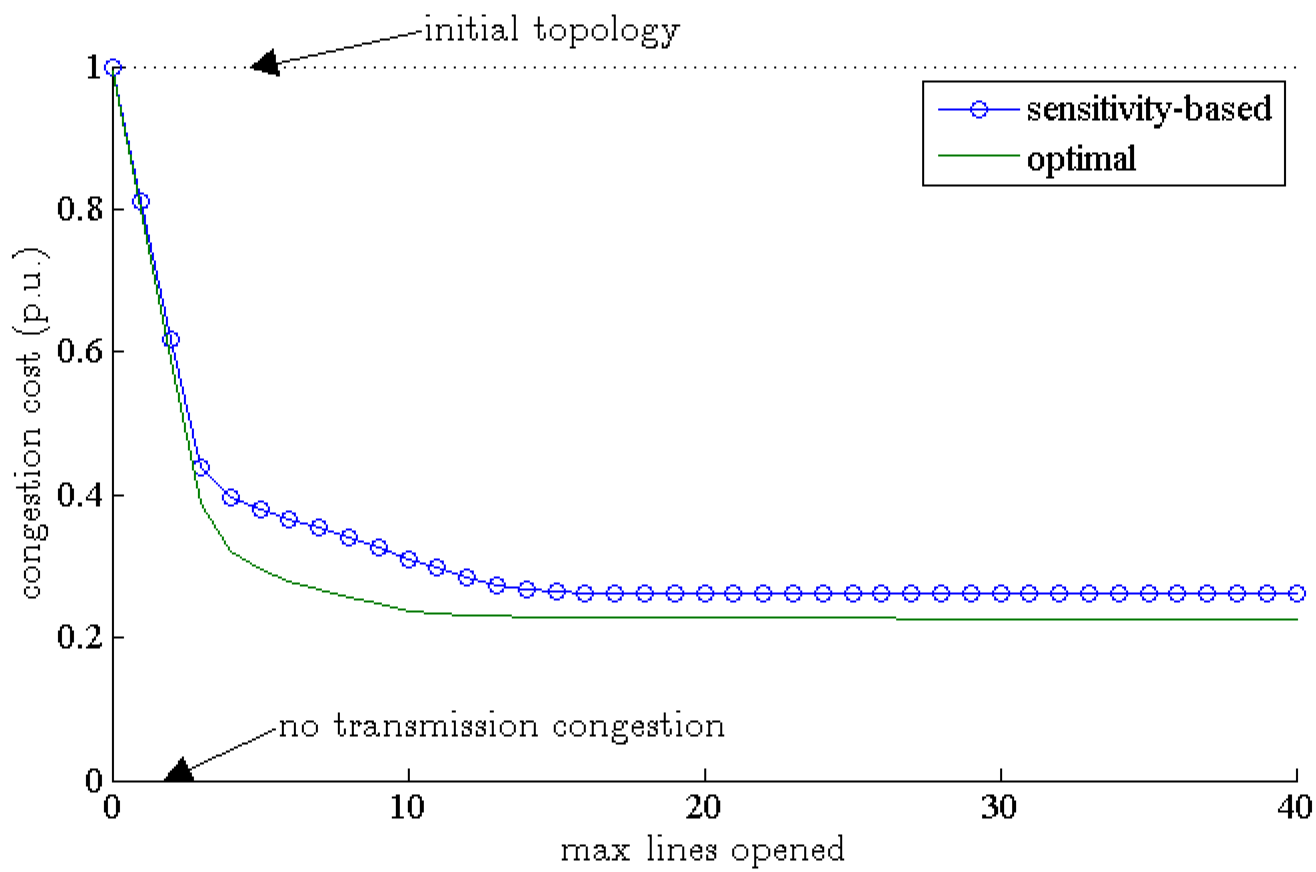
Tractable TCA: Basic Algorithm



Tractable TCA: Sample Sensitivity-based Switching Criterion

- Linearly parameterize switch status changes using line flows
- Cost sensitivity w.r.t. line flow: $\dfrac{\partial C}{\partial f_k} = \pi_{from_k} - \pi_{to_k}$
- Switch *single* line k with largest differential impact:
  - Closed line: $\dfrac{\partial C}{\partial f_k} > 0$ (*disconnect unprofitable lines*)
  - Open line: $\dfrac{\partial C}{\partial f_k} < 0$ (*connect profitable lines*):
- Properties:
  - ✓ Feasible at each iteration with monotonically decreasing costs
  - ✓ Maintains system connectivity (no islanding)

Initial Results on 118-Bus Test System



- Basic algorithm tracks savings of optimal topology as a function of max topology changes.
- Two orders of magnitude computational time savings vs. MIP.
- Few topology changes bring most of the potential benefits

Corrective Switching on 118-Bus Test System

metric	initial	feasibility		optimality	
	topology	MIP	sensitivity	MIP (10^{-3} gap)	sensitivity
expected generator cost (k$)	138.1	135.0	132.0	120.3	122.9
expected generator savings (%)	n/a	3.18	5.33	13.63	11.78
med / max iterations	n/a	n/a	1 / 2	n/a	73 / 99
lines disconnected (median)	n/a	0	0	26	18
lines connected (median)	n/a	28	1	21	11
expected computation time (s)	0.0087	0.0451	0.0058	7.3865	0.6623

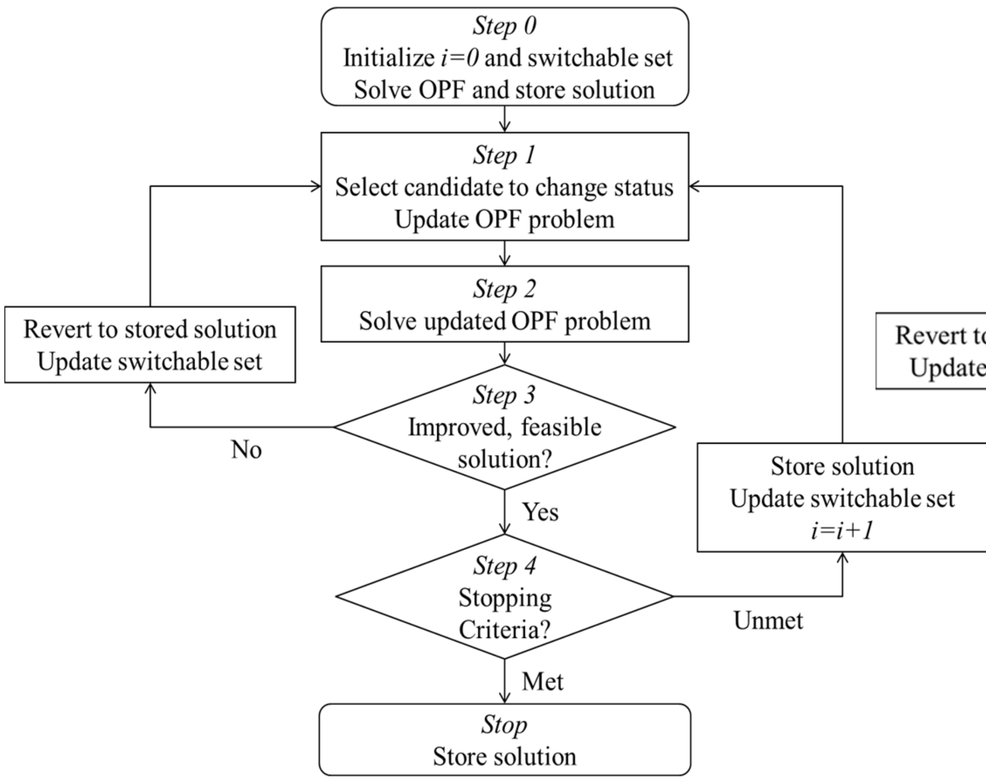
- Simulations on the IEEE 118-bus test system; average results over 100 samples of wind + fuel costs
- Starting from infeasible topology (30 lines open), and the two most promising lines on outage
- Quickly identify a feasible topology after forced outages lead to an infeasible state.
- Much fewer topology changes than MIP approach, an order of magnitude faster.

ARPA-E TCA Project Objectives and Focus

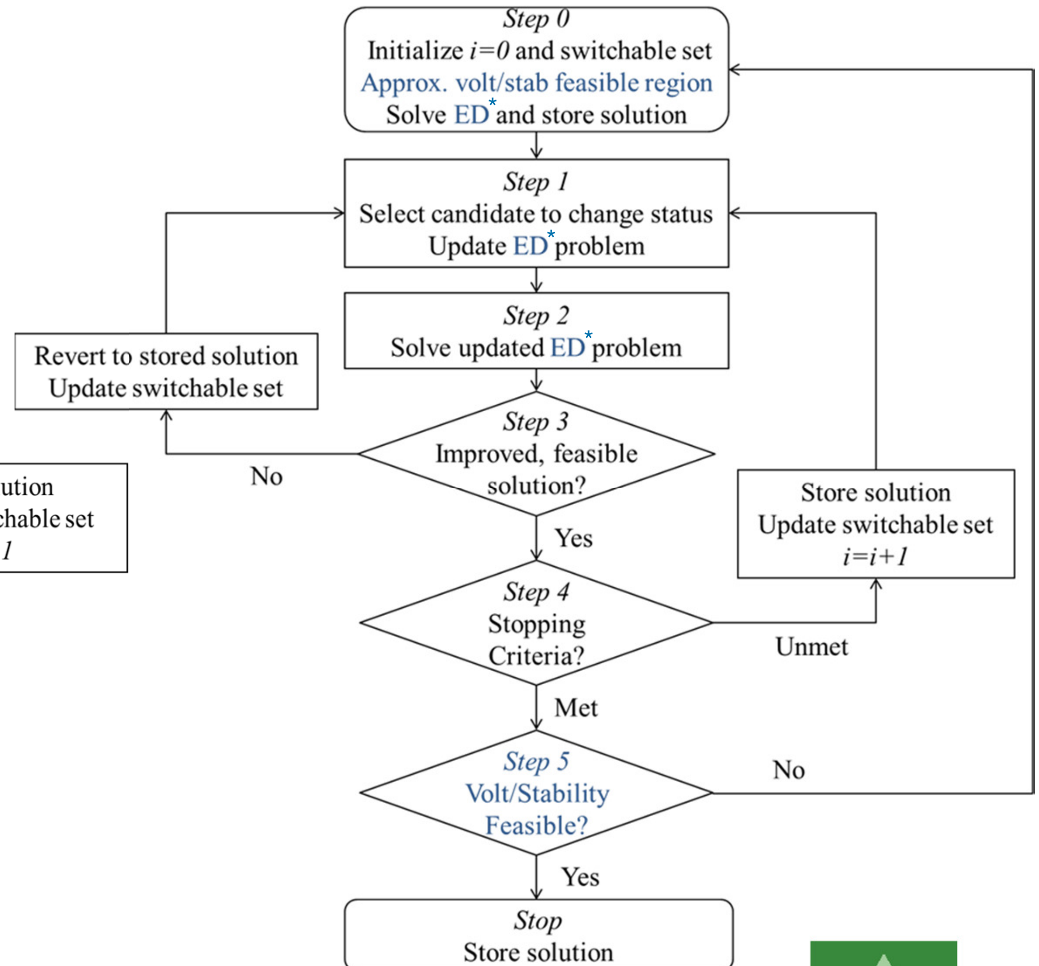
- To develop a full-scale algorithm and software implementation for transmission network topology control
  - operating in conjunction with market engines for security-constrained unit commitment (UC) and economic dispatch (ED);
  - meeting tight computational effort requirements
- The developed algorithms 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

ARPA-E TCA Developments

Basic TC Algorithm



Proposed TC Algorithm



* OPF or UC if appropriate;
security constraints enforced

ARPA-E TCA Work in Progress

- Security-constrained OPF: simulation of Simple TCA with full SCOPF in IEEE 118-bus test system gave relative cost savings similar to those with OPF, and 2x increase in solution time.
- Optimal TC: refining MIP approach to reduce computational time for the SCOPF with optimal TC for benchmarking and to develop tractable heuristics for dynamic TC.
- Simulation environment: PJM providing historical 2010 data to build an operations simulation model (PSO), benchmark it against historical results, and to evaluate the impacts of TCA. High wind + solar penetration cases will be simulated with TCA using PJM Renewable Integration Study scenarios.

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[2] J. M. Foster, P. A. Ruiz, A. Rudkevich and M. C. Caramanis, “Economic and corrective applications of tractable transmission topology control,” in *Proc. 49th Allerton Conference on Communications, Control and Computing*, Monticello, IL, September 2011.

[3] P. A. Ruiz, J. M. Foster, A. Rudkevich and M. C. Caramanis, “On fast transmission topology control heuristics,” in *Proc. 2011 IEEE Power and Energy Society General Meeting*, Detroit, MI, July 2011.