Computationally Efficient Operation of Power Flow Controllers

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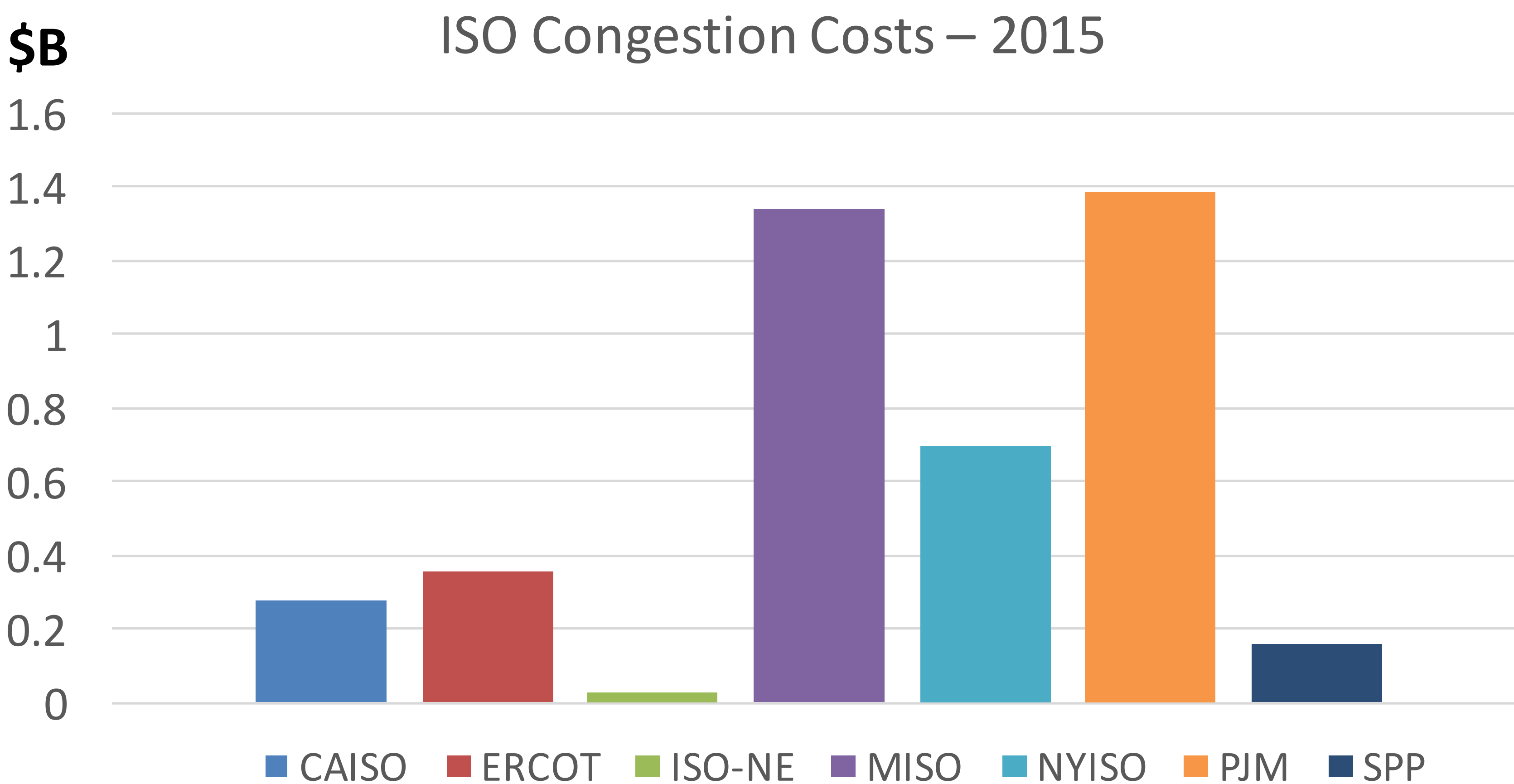
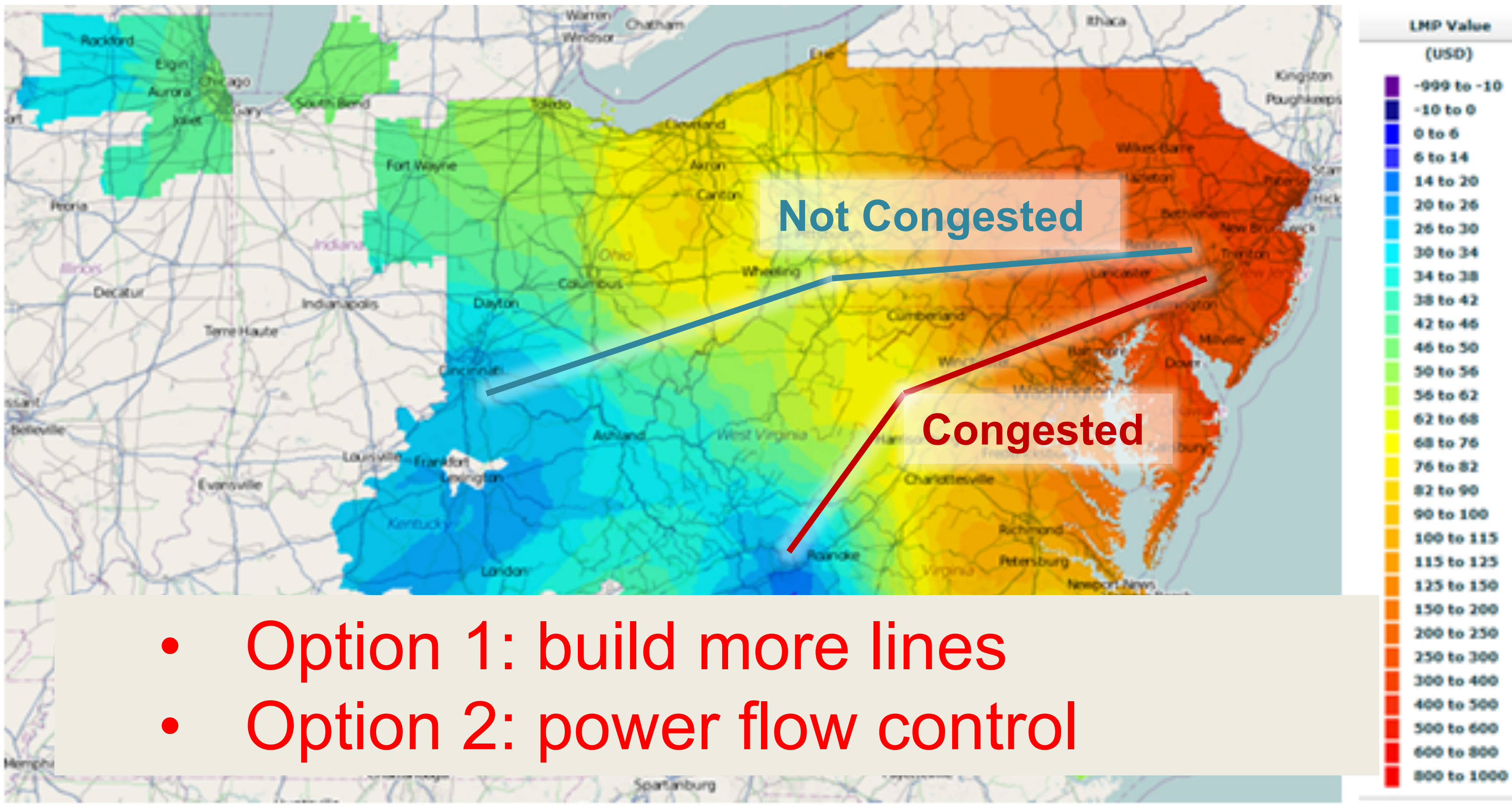
Congestion Cost in US ISO/RTOs

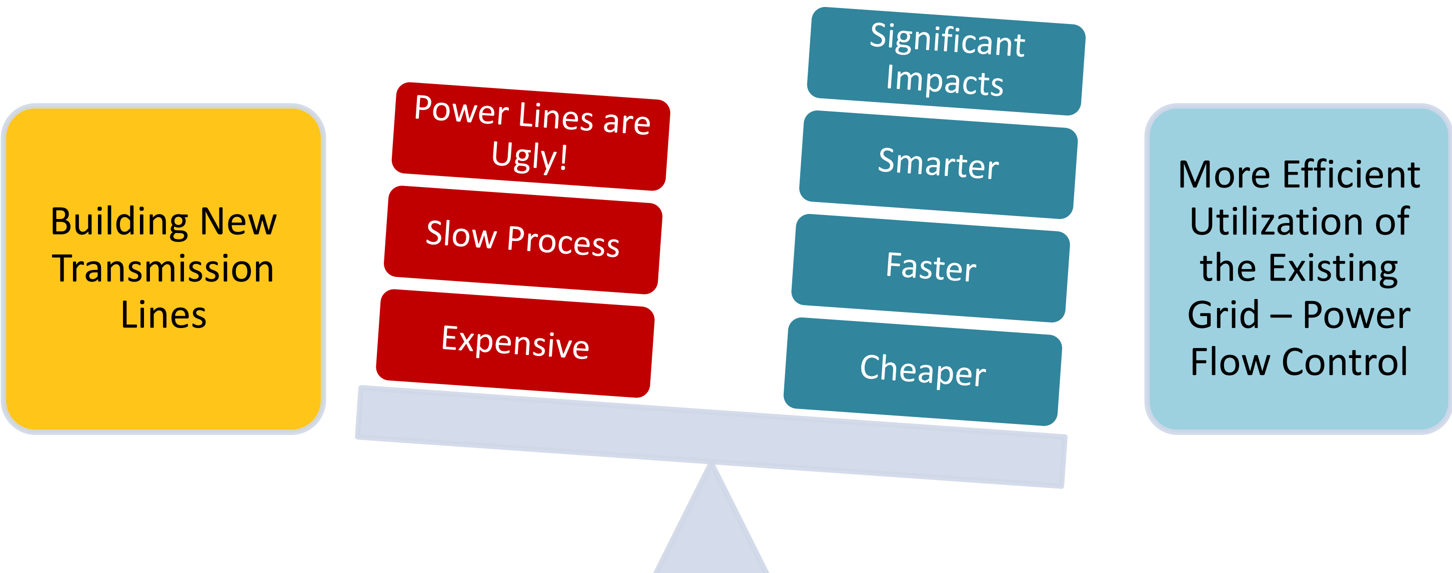


Transmission Bottlenecks



- Option 1: build more lines
- Option 2: power flow control

Choices



More efficient utilization of the existing network is cheaper and paramount!

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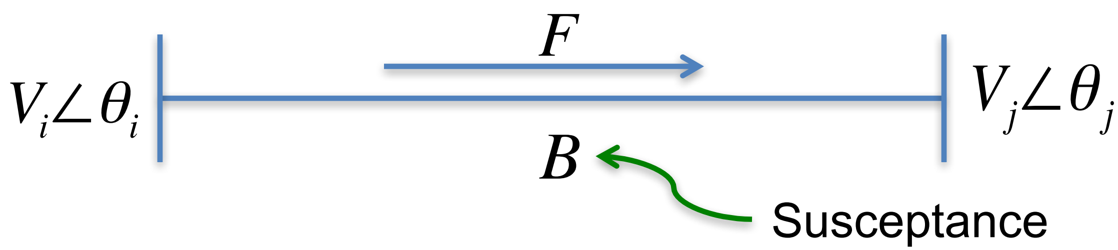
Power Flow Physics



Electricity flows according to the laws of physics, not economics!

DC Power Flow Equation

$$F = B(\theta_j - \theta_i)$$

This is a linear approximation of AC power flow equation:

- Relatively accurate
- Facilitates efficient computation

$$\begin{cases} F_k = B_k(\theta_j - \theta_i) \\ B^{\min} \le B \le B^{\max} \end{cases}$$

Variable Impedance FACTS

Nonlinear ➔ Computational Burden

Power Flow Physics

Computational Burden

No FACTS set point adjustment within EMS or MMS software

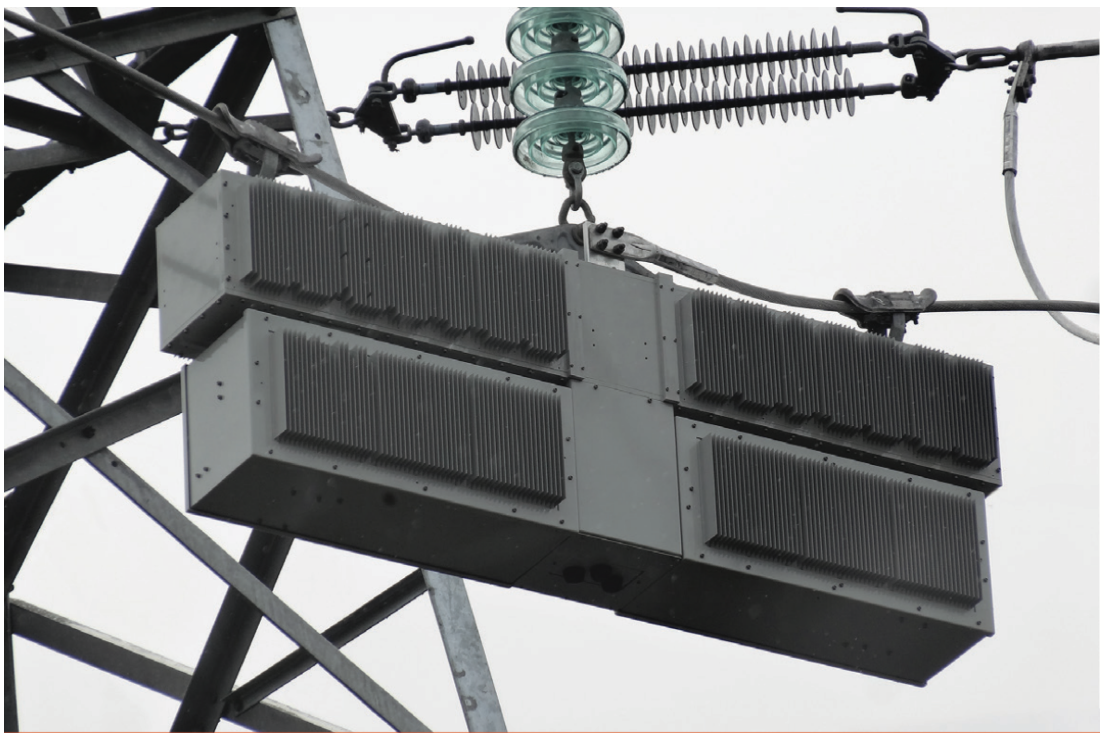
Infrequent ad hoc adjustments

Technology – TCSC

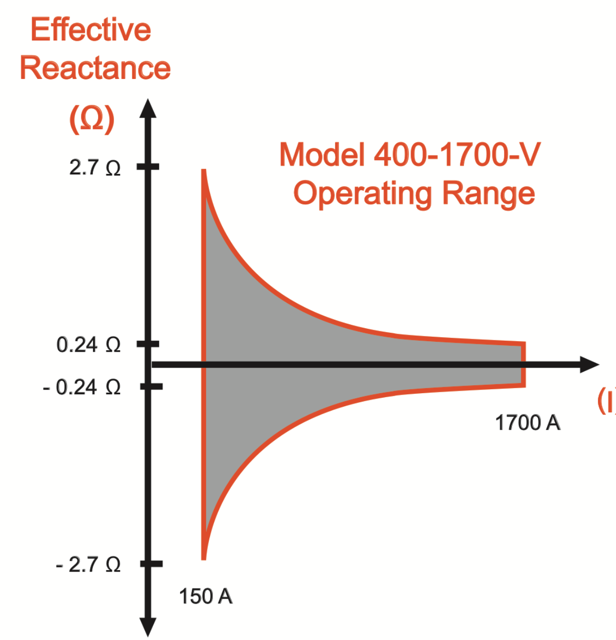
- Thyristor-Controlled Series Compensator

ABB – TCSC brochure

Technology – Smart Wires



Power Router brochure

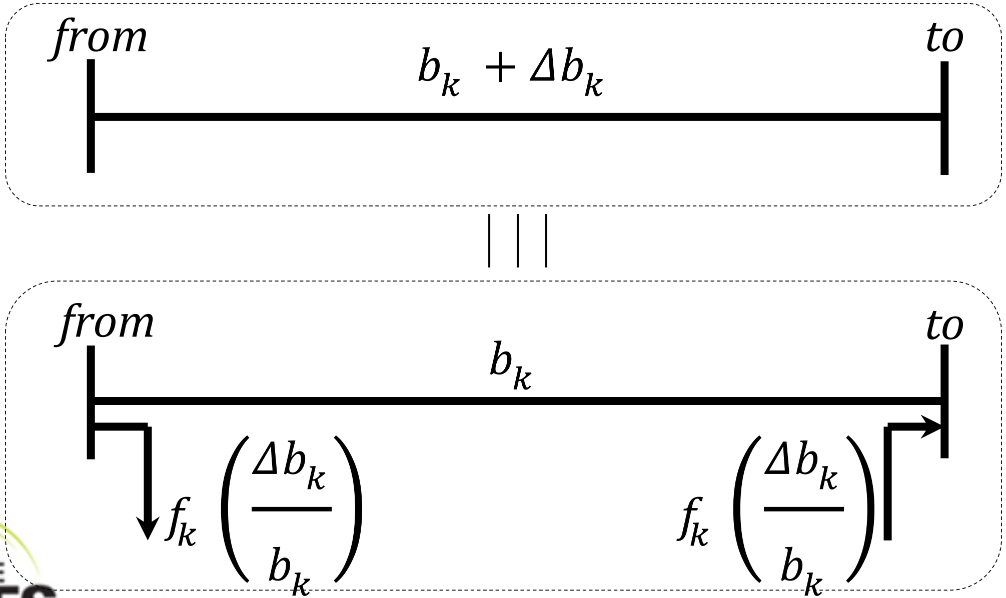


Objective:

Design a Computationally-efficient Algorithm to Control the Power Flow Controller Set Points

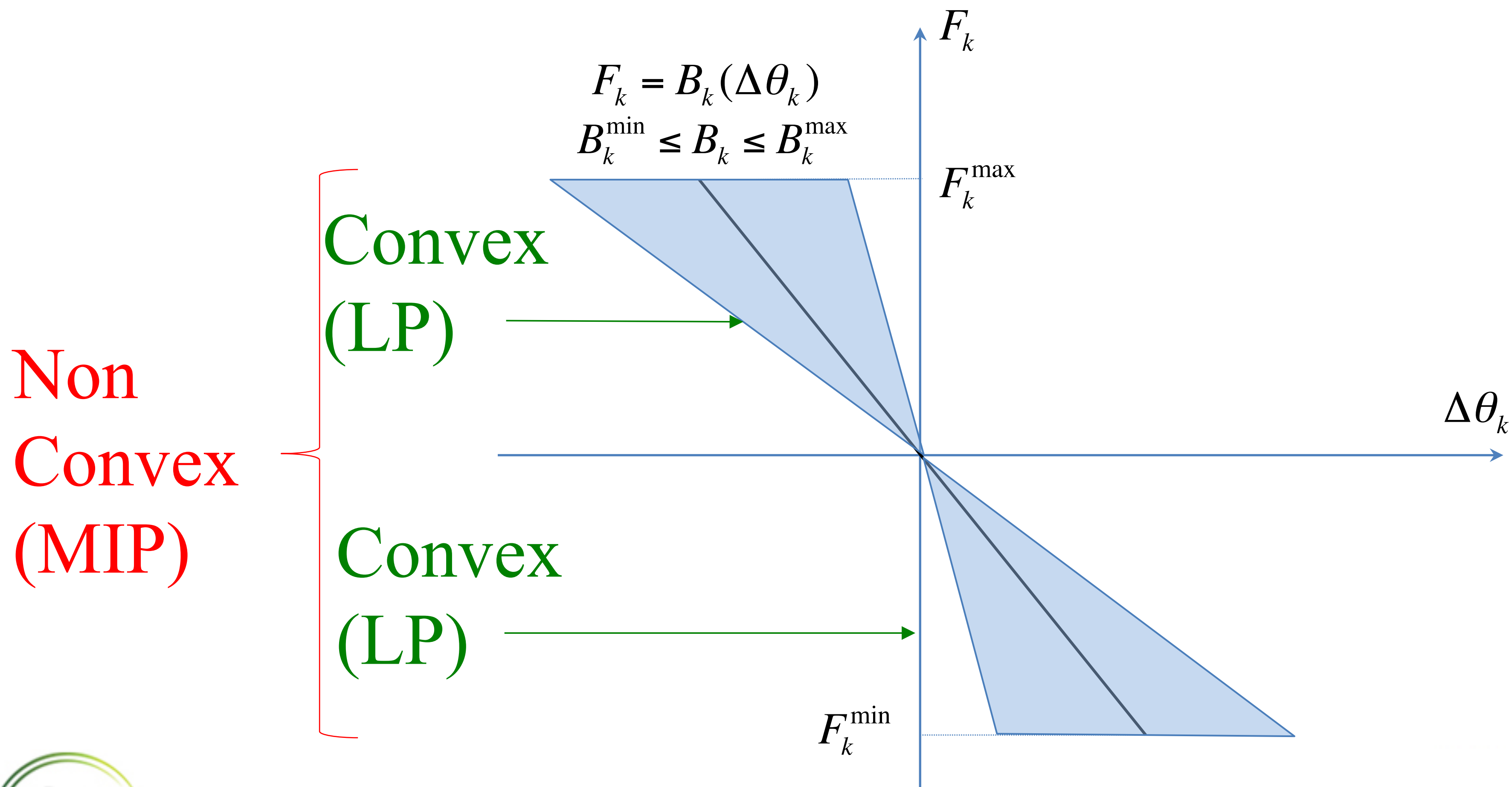
Shift Factor Structure

- Industry implementations of SCUC and SCED do not use $B-\theta$ structure; they use PTDFs.
  - No need to model all the voltage angles
  - No need to calculate all the flows
  - Significantly faster compared to $B\theta$



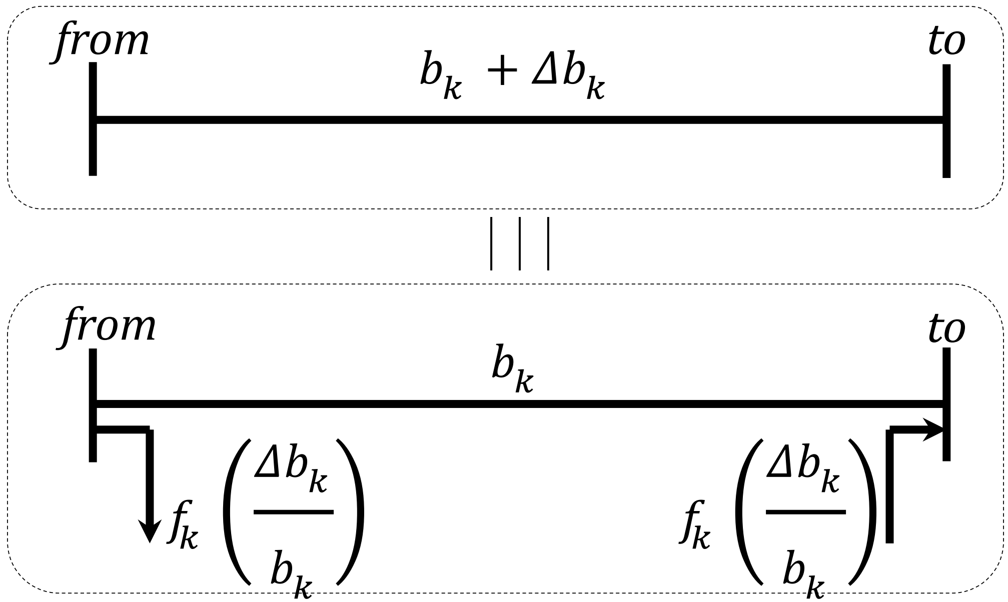
The injection pair involves NONLINEAR terms.

Computational Complexity – NLP/MILP



What if we knew which B&B tree node is the optimal node?

Reformulation to an MILP



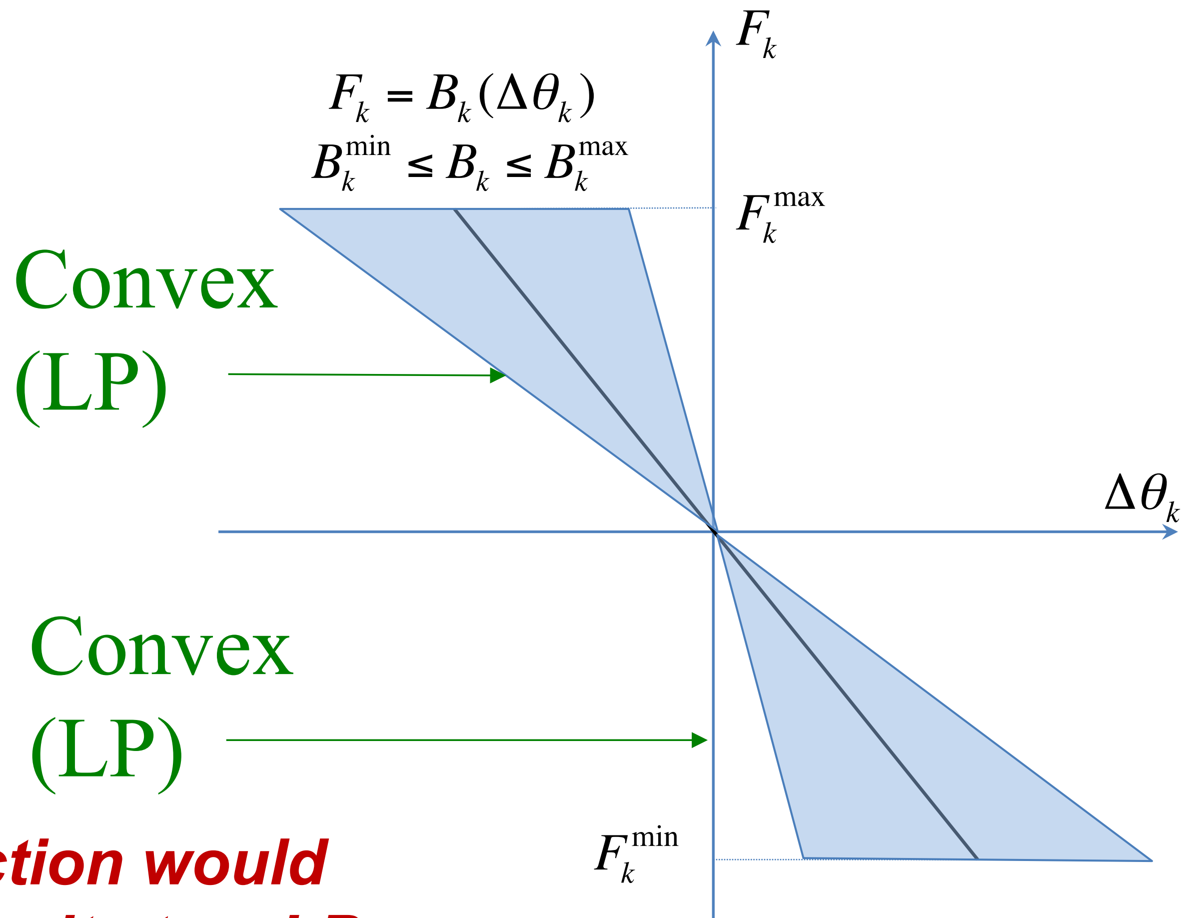
$$\psi_k = \frac{f_k \Delta b_k}{b_k}$$

$$f_k \geq 0: \quad \frac{f_k \Delta b_k^{max}}{b_k} \leq \psi_k \leq \frac{f_k \Delta b_k^{min}}{b_k}$$

$$f_k \geq 0: \quad \frac{f_k \Delta b_k^{max}}{b_k} \leq \psi_k \leq \frac{f_k \Delta b_k^{min}}{b_k}$$

Engineering Insight

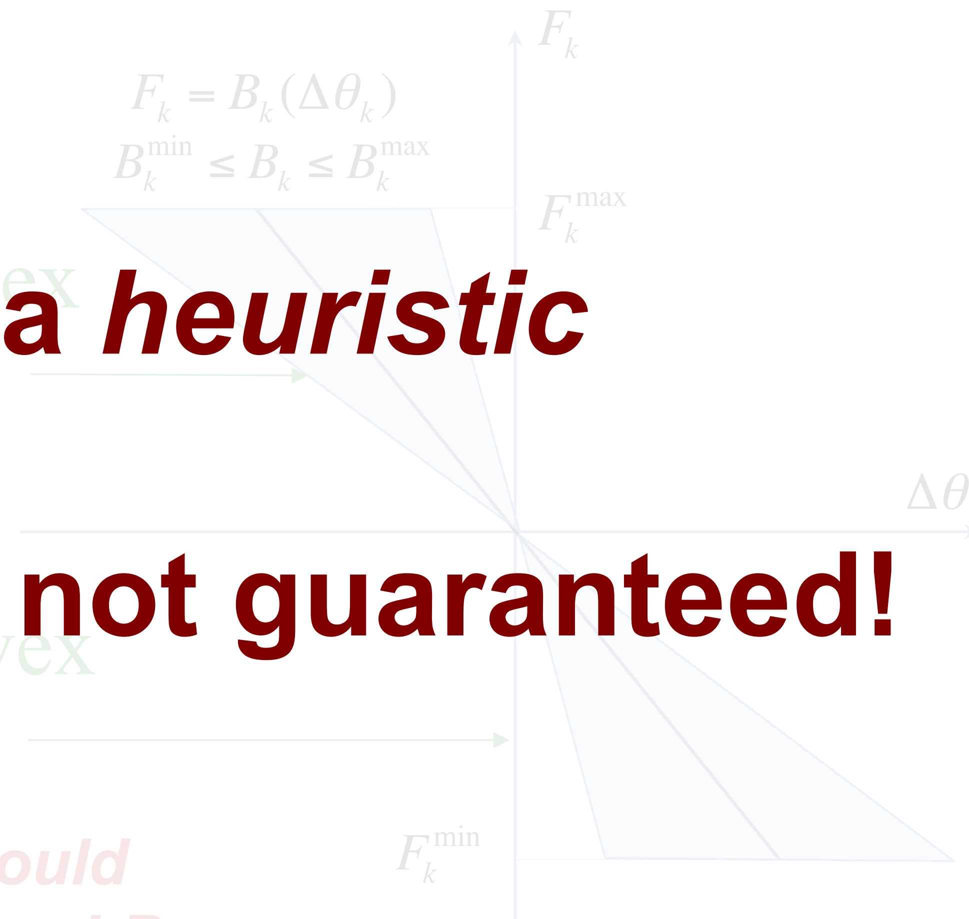
- We only need to know the direction of the power flow
- We know this direction for major lines (COI)
- ***Even if we do not know the direction, we can run a two-stage DCOPF and identify it.***



Knowing the direction would reduce the complexity to a LP

Engineering Insight

- We only need to know the direction of the power flow
- We know this direction for major lines ([illegible])
- *Even if we do not know the direction, we can run a two-stage DCOPF and identify it.*



This is a *heuristic*

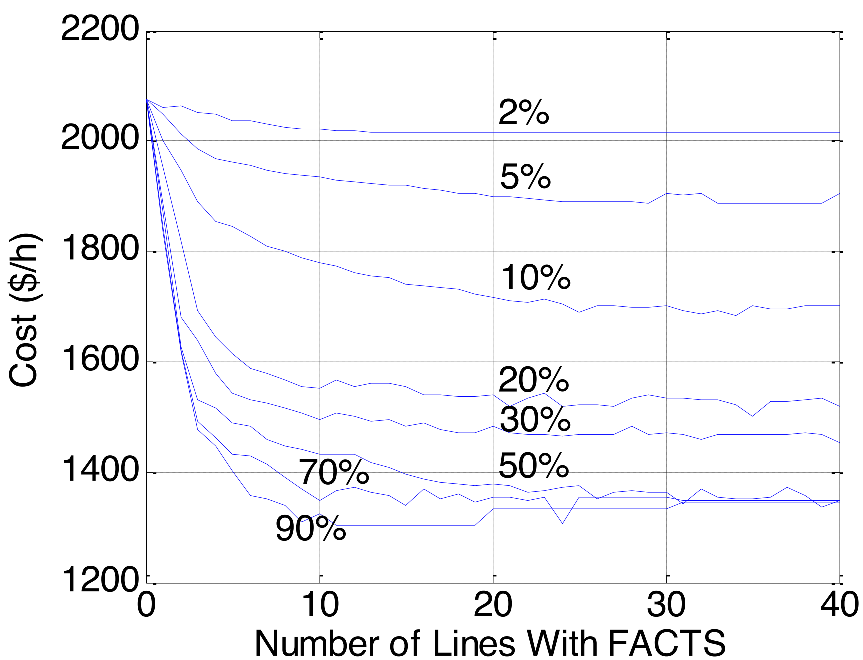
Optimality is not guaranteed!

Knowing the direction would reduce the complexity to a LP

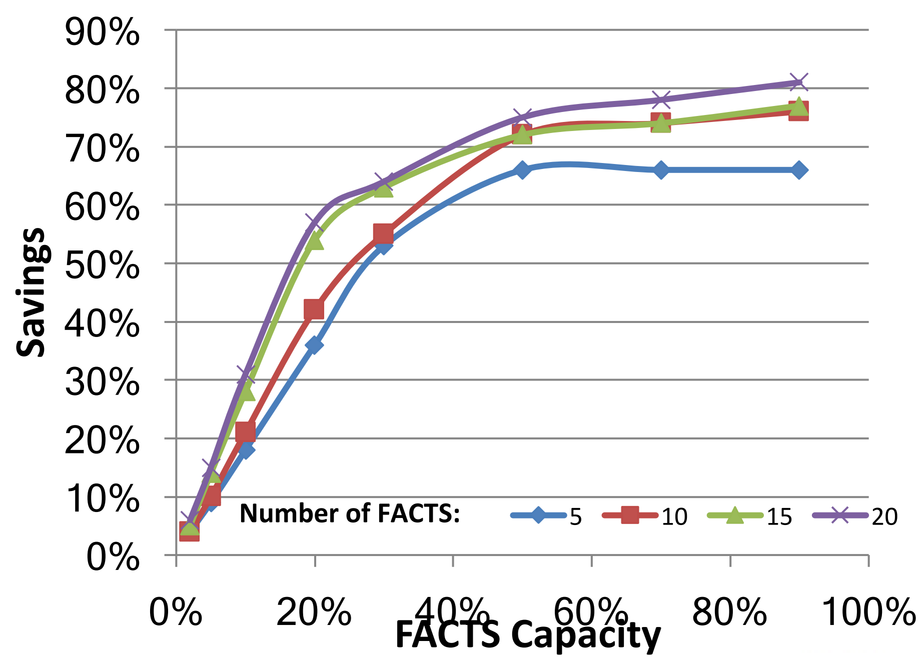
SCED Cost Savings—IEEE 118-Bus System

Savings are calculated compared to a transportation model

Optimal FACTS Placement:
>98% Optimal



Located on More Heavily Utilized Lines: 100% Optimal

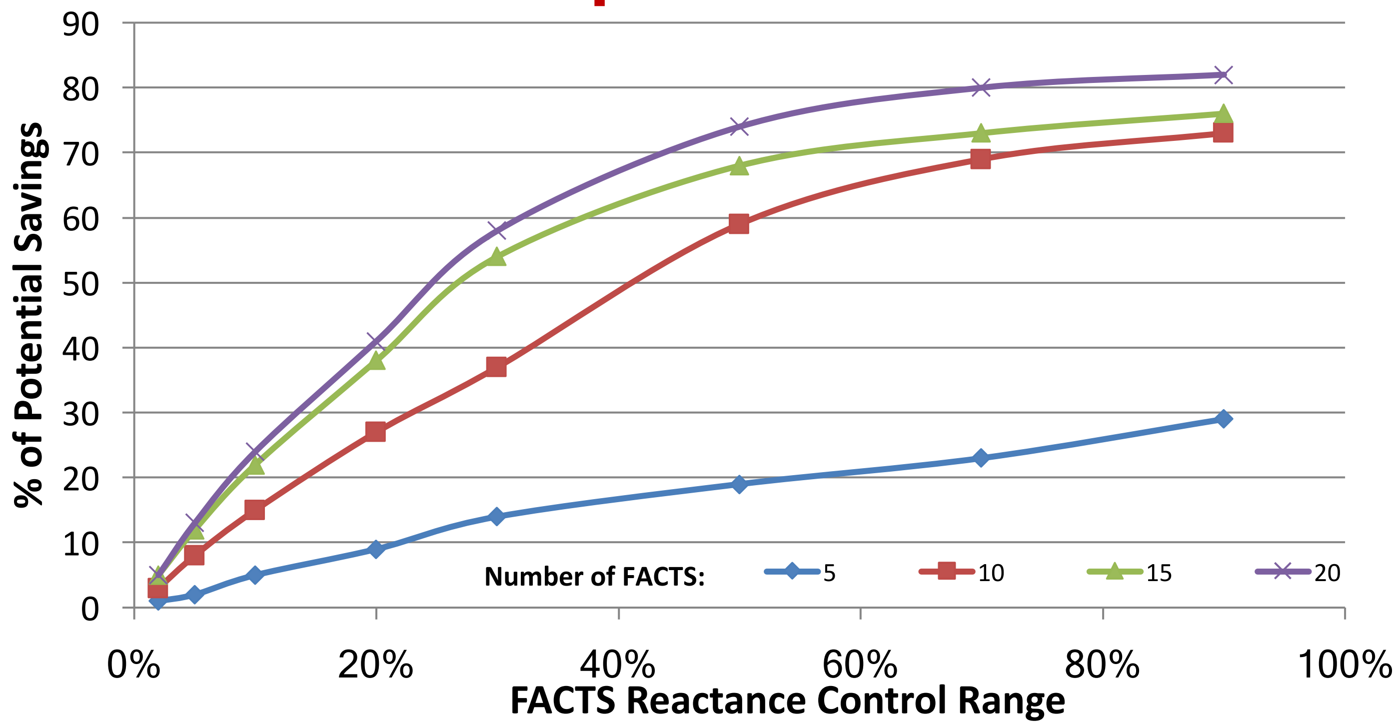


SCED Cost Savings—Polish System

Located on More Heavily Utilized Lines: 100% Optimal

~2,400 buses

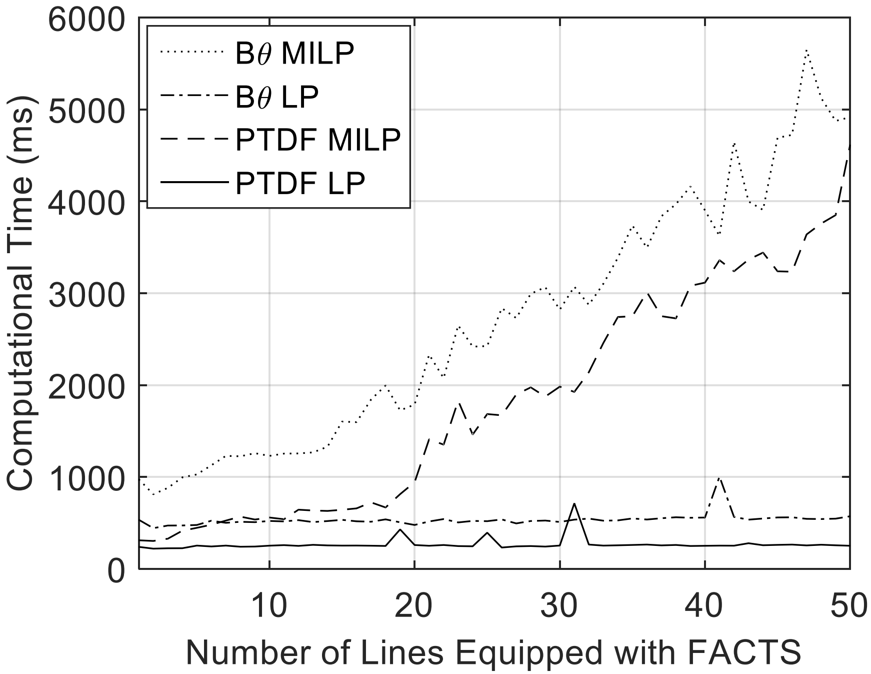
~2,900 branches



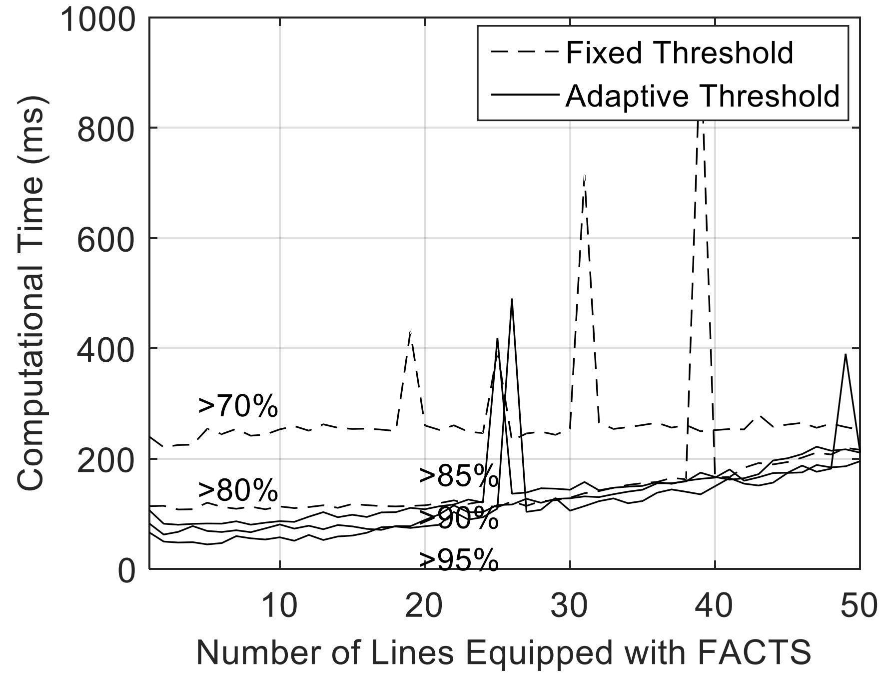
Savings are calculated compared to a transportation model

Results – Polish System

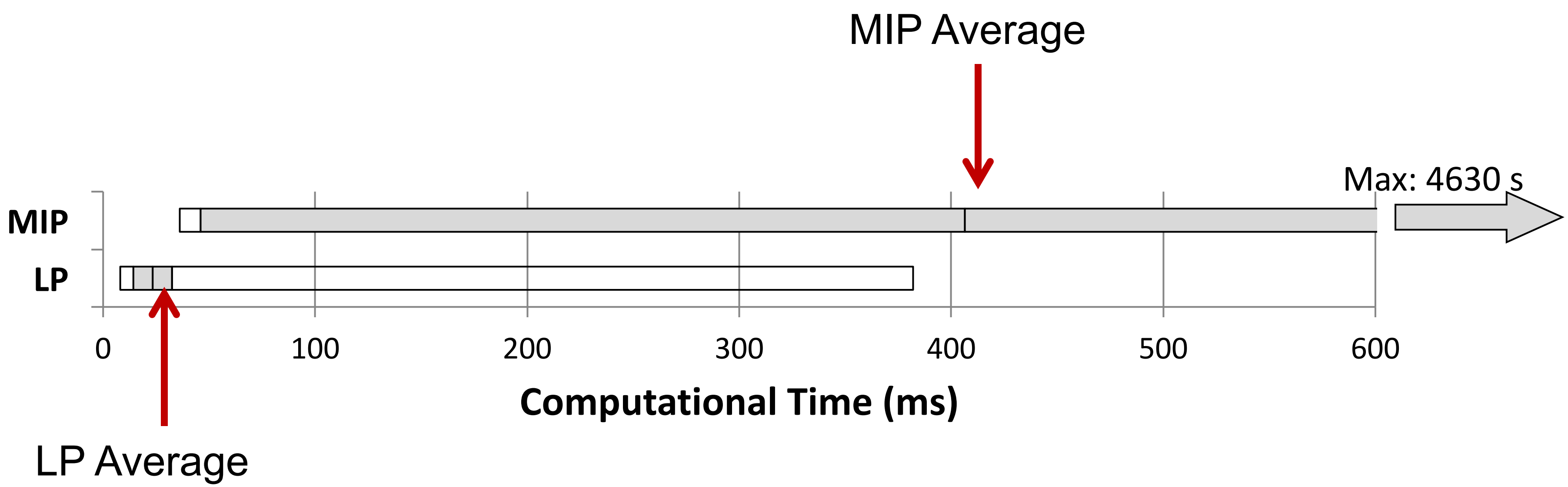
$B\theta$ versus PTDF



Fixed versus Adaptive Thresholds

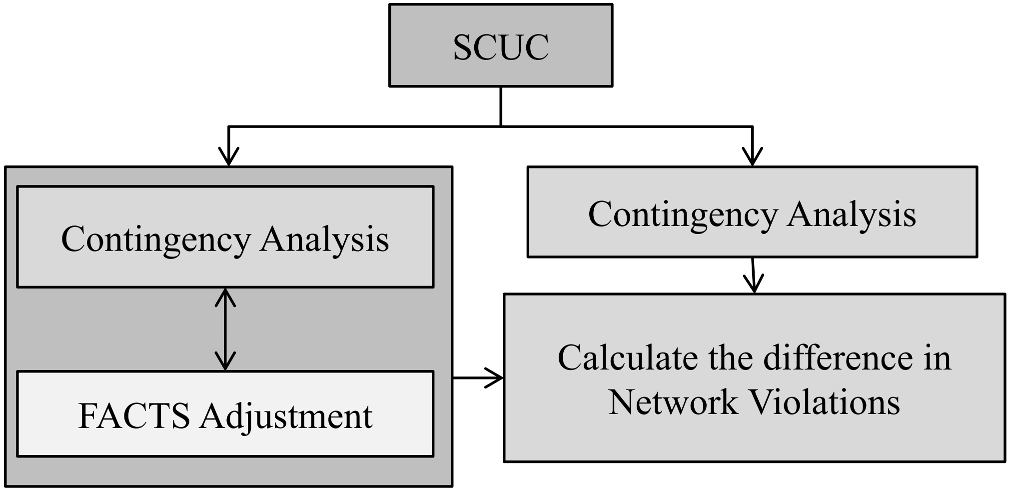


Computational Time

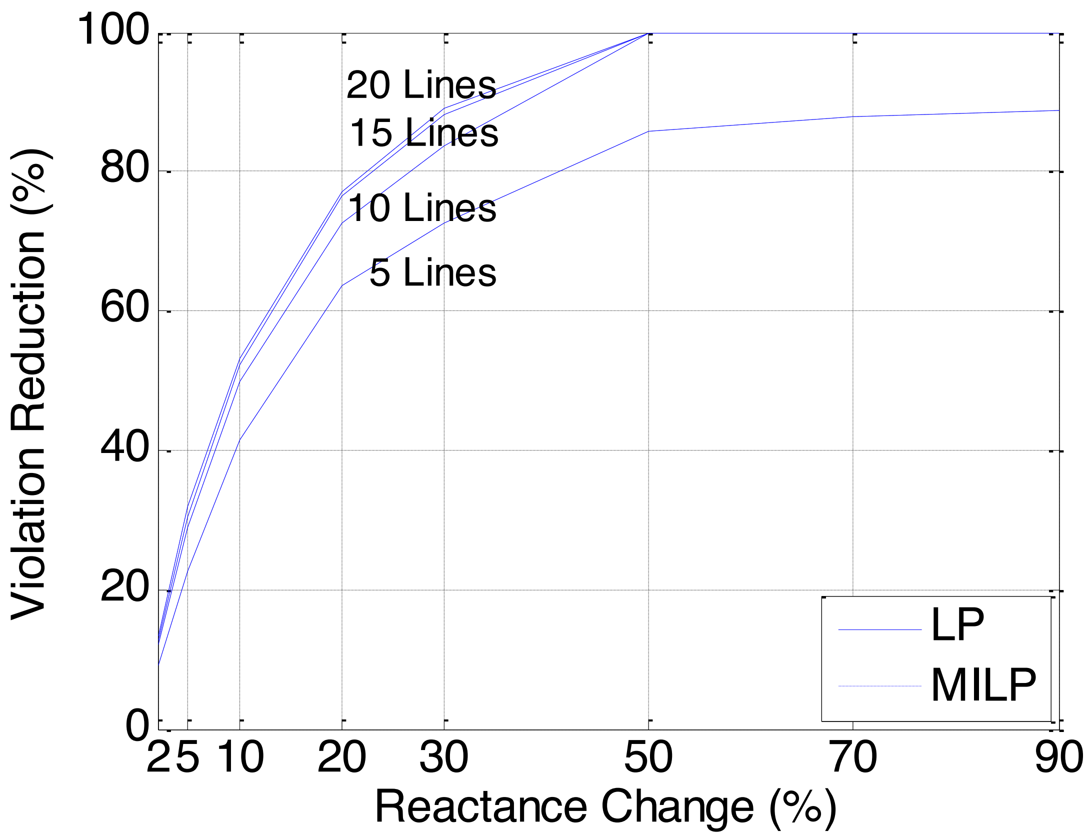


Corrective Adjustments

- In corrective adjustments we have even better insight about the direction of the power flow: pre- or post- contingency flows
- Goal: minimization of post-contingency network violations
- **Optimal utilization of FACTS in recourse state only**



Corrective Results—IEEE 118-Bus System



Located on More Heavily Utilized Lines:
100% Optimal

Conclusions

- Mathematical representation of OPF with FACTS: NLP
- We reformulated the NLP to a MILP; using our knowledge of electricity flow physics, we reformulate the problem to an LP
- The LP heuristic is extremely effective: it found the optimal solution more than 98% of the time.
- The heuristic is extremely fast (LP) and would not add to the complexity of the OPF problem

Questions?

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- M. Sahraei-Ardakani and K. Hedman, “A Fast LP Approach for Enhanced Utilization of Variable Impedance Based FACTS Devices,” *IEEE Transactions on Power Systems*
- M. Sahraei-Ardakani and K. Hedman, “Day-Ahead Corrective Adjustment of FACTS Reactance: A Linear Programming Approach,” *IEEE Transactions on Power Systems*
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- M. Sahraei-Ardakani and K. Hedman, “Computationally Efficient Adjustment of FACTS Set Points in DC Optimal Power Flow with Shift Factor Structure,” *IEEE Transactions on Power Systems*