AN APPLICATION OF HIGH PERFORMANCE COMPUTING TO TRANSMISSION SWITCHING

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Transmission Switching

- It changes the topology of the network (by opening and closing certain lines)
- It is used as a control method to increase the economic efficiency of the network
- It is based on DCOPF
- Optimal Transmission Switching (MIP)
  - Computational challenging

Generic DCOPF (TXLP)

$$\text{Min} \sum c_g P_g$$

s.t.

$$\theta_n^{min} \leq \theta_n \leq \theta_n^{max} \; \forall n \qquad (1)$$

$$P_{ng}^{min} \leq P_{ng} \leq P_{ng}^{max} \; \forall n, g \qquad (2)$$

$$\sum_d p_{nd} = \sum_g p_{ng} + \sum_k p_{nk} \; \forall n \qquad (3) \qquad [LMP_n]$$

$$P_k^{min} \leq P_k \leq P_k^{max}, \; k \epsilon \widehat{K} \qquad (4) \qquad [F_k^-, F_k^+]$$

$$P_k = [B_k(\theta_n - \theta_m)], \; k \epsilon \widehat{K} \qquad (5) \qquad [S_k]$$

$$0 \leq P_k \leq 0, \; k \epsilon \overline{K} \qquad (4') \qquad [f_k^-, f_k^+]$$

$$P_k = 0, \; k \epsilon \overline{K} \qquad (5') \qquad [s_k]$$

$\widehat{K}$: Set of transmission lines in service

$\overline{K}$ Set of transmission lines out of service

Optimal Transmission Switching(TX_MIP)

$$z_k = \begin{cases} 0 & when\ line\ k\ is\ out\ of\ service \\ 1 & when\ line\ k\ is\ in\ service \end{cases}$$

$$\text{Min} \sum c_g P_g$$

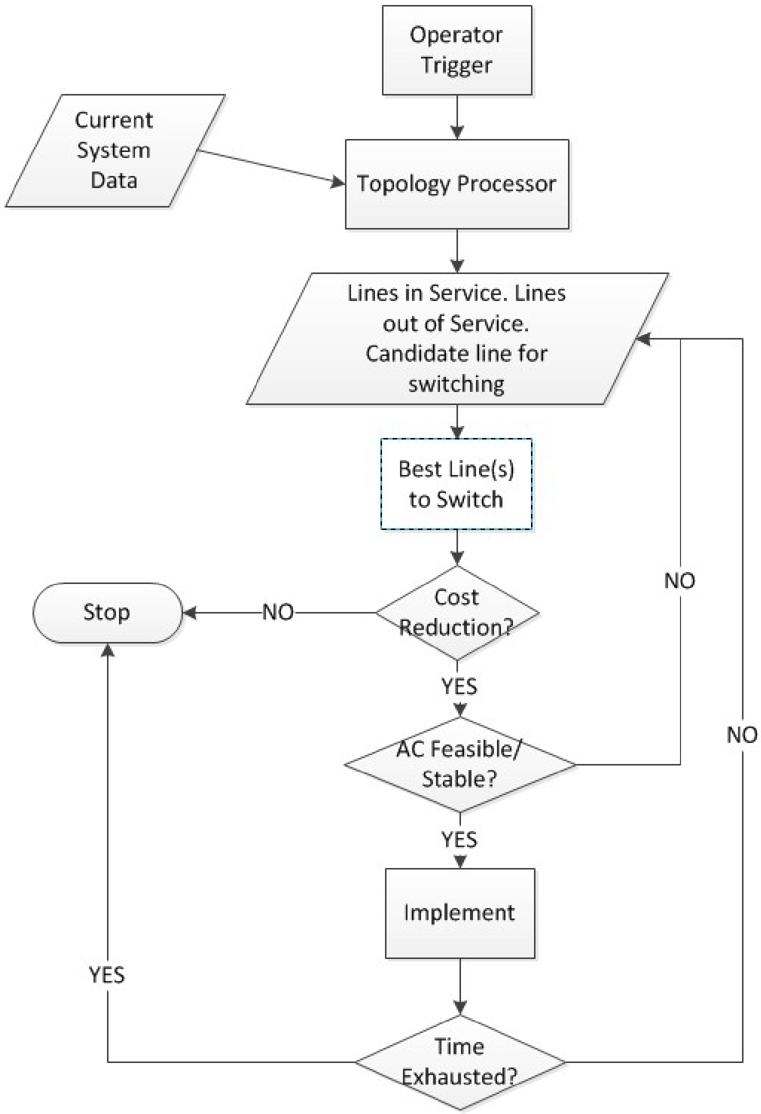
s.t.

(1),(2),(3)

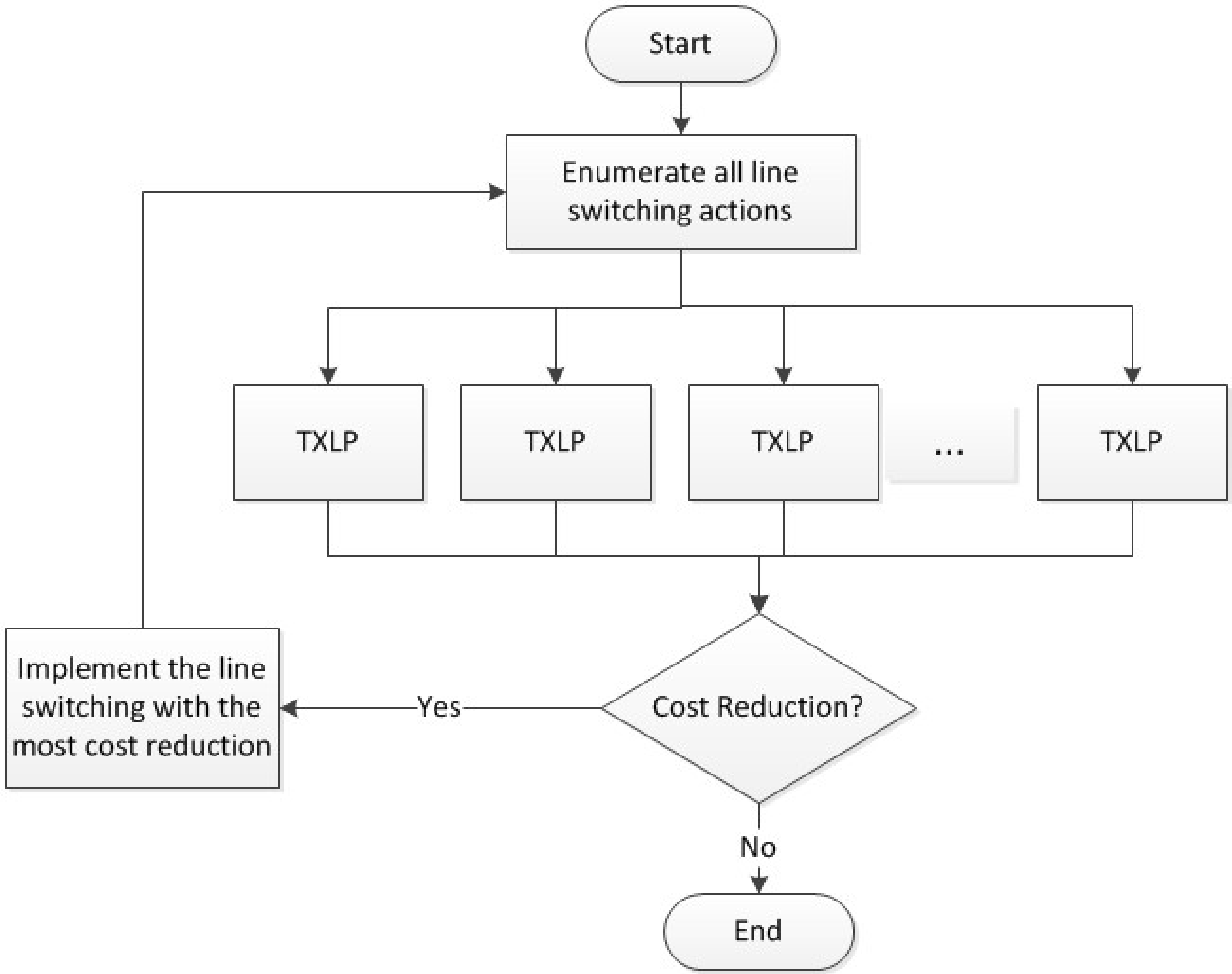
$$P_k^{min} z_k \le P_k \le P_k^{max} z_k, \qquad (6)$$

$$P_k = [B_k(\theta_n - \theta_m) z_k] \qquad (7)$$

General Heuristic Procedure



Enumeration of All Lines



DCOPF with Line Switching

$$\text{Min} \sum c_g P_g$$

s.t.

$\theta_n^{min} \leq \theta_n \leq \theta_n^{max}\ \forall n$	(1)	
$P_{ng}^{min} \leq P_{ng} \leq P_{ng}^{max}\ \forall n, g$	(2)	
$\sum_d p_{nd} = \sum_g p_{ng} + \sum_k p_{nk}\ \forall n$	(3)	$[LMP_n]$
$P_k^{min} z_k \leq P_k \leq P_k^{max} z_k,\ \mathrm{k} \epsilon \widehat{K}$	(6)	$[F_k^-, F_k^+]$
$P_k = [B_k(\theta_n - \theta_m) z_k],\ \mathrm{k} \epsilon \widehat{K}$	(7)	$[S_k]$
$P_k^{min} z_k \leq P_k \leq P_k^{max} z_k,\ \mathrm{k} \epsilon \overline{K}$	(6')	$[f_k^-, f_k^+]$
$P_k = [B_k(\theta_n - \theta_m) z_k],\ \mathrm{k} \epsilon \overline{K}$	(7')	$[s_k]$
$z_k = 0,\ \mathrm{k} \epsilon \overline{K}$	(8)	$[\gamma_k^{os}]$
$z_k = 1,\ \mathrm{k} \epsilon \widehat{K}$	(9)	$[\gamma_k^{is}]$

$\widehat{K}$: Set of transmission lines in service

$\overline{K}$ Set of transmission lines out of service

Generic DCOPF (TXLP)

$$\text{Min} \sum c_g P_g$$

s.t.

$$\theta_n^{min} \leq \theta_n \leq \theta_n^{max} \ \forall n \qquad (1)$$

$$P_{ng}^{min} \leq P_{ng} \leq P_{ng}^{max} \ \forall n, g \qquad (2)$$

$$\sum_d p_{nd} = \sum_g p_{ng} + \sum_k p_{nk} \ \forall n \qquad (3) \qquad [LMP_n]$$

$$P_k^{min} \leq P_k \leq P_k^{max}, \ \mathrm{k} \epsilon \widehat{K} \qquad (4) \qquad [F_k^-, F_k^+]$$

$$P_k = [B_k(\theta_n - \theta_m)], \ \mathrm{k} \epsilon \widehat{K} \qquad (5) \qquad [S_k]$$

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$\widehat{K}$: Set of transmission lines in service

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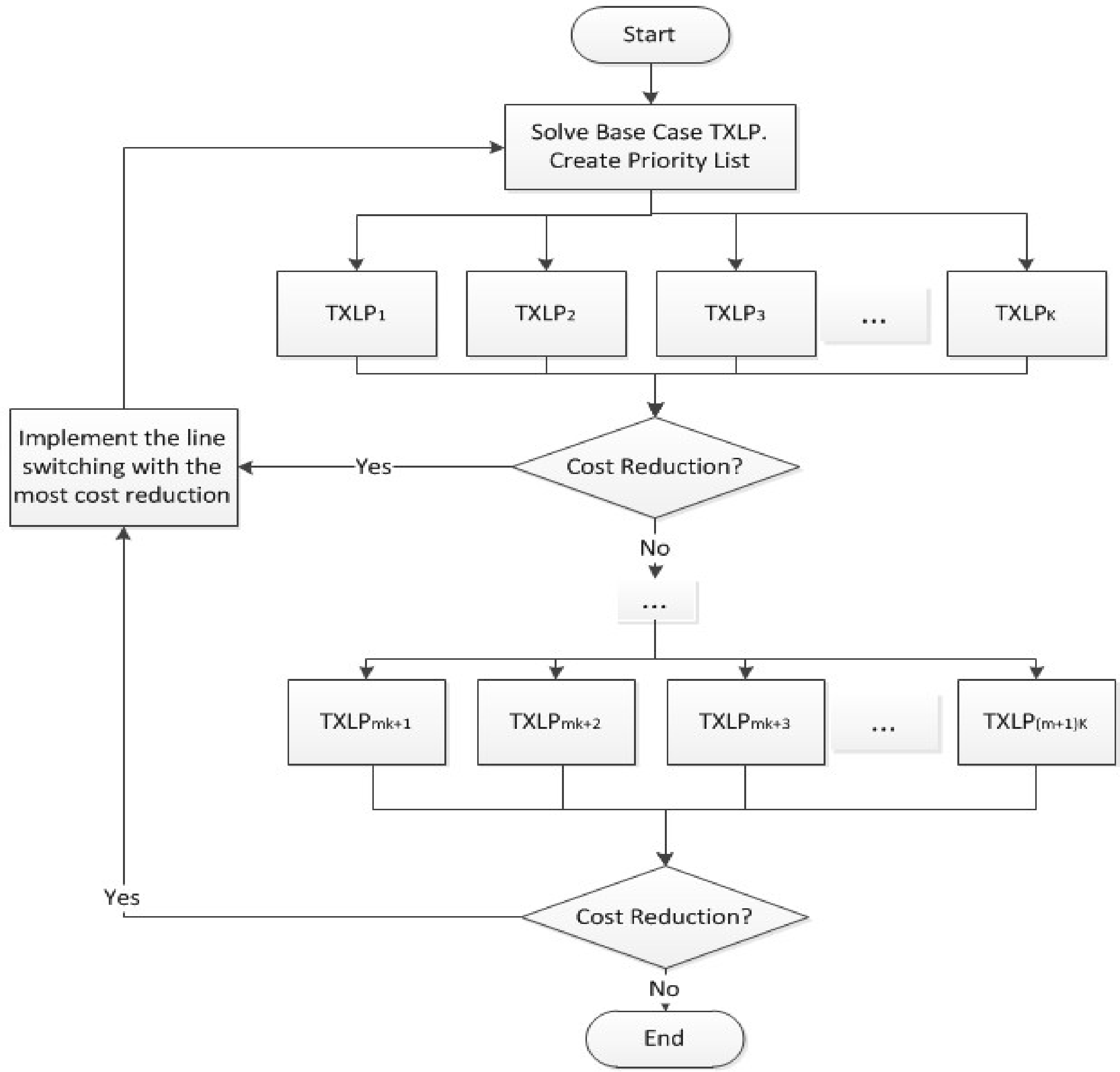
Dual Criterion

- By applying KKT conditions, one can derive a relationship for the dual variables:

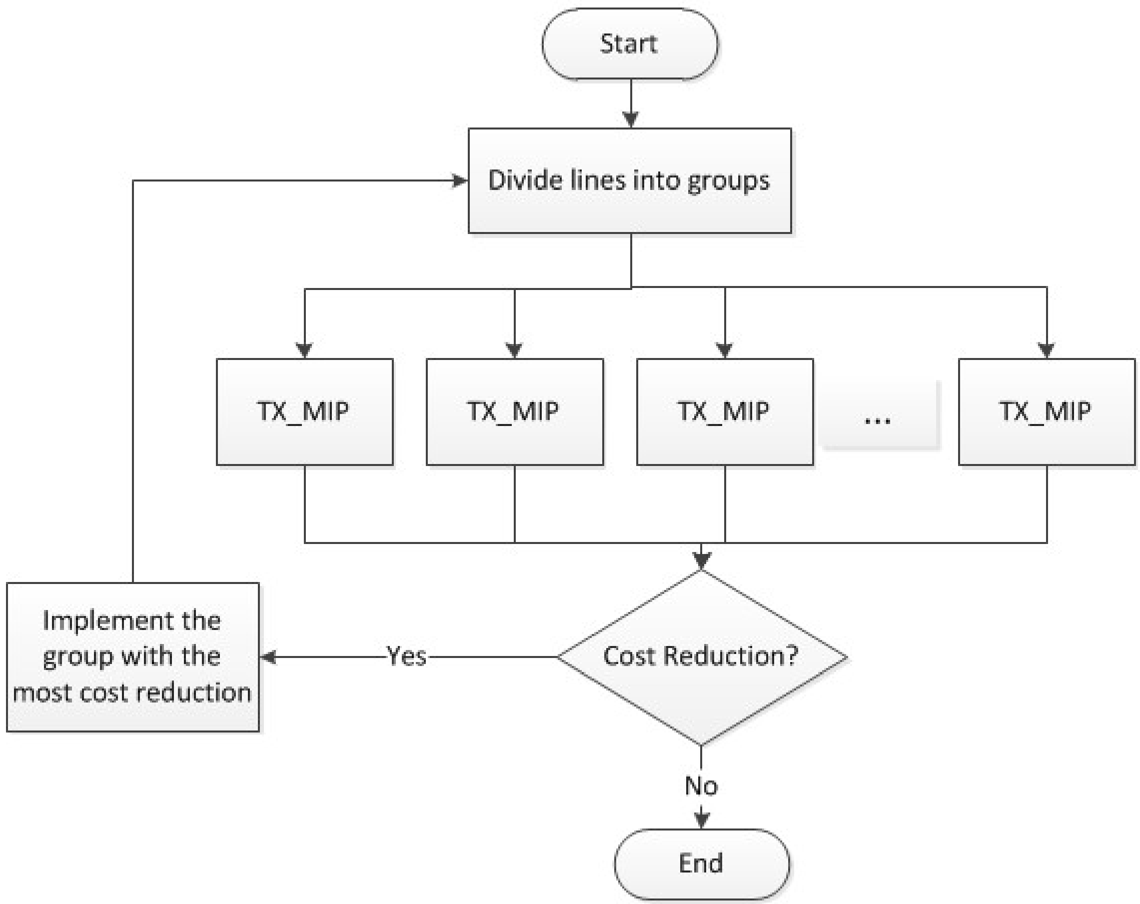
$$\gamma_k^{is} = S_k(LMP_n - LMP_m)\, P_k$$
$$\gamma_k^{os} = -P_k^{max}(f_k^{+} + f_k^{-}) + B_k\, s_k(\theta_n - \theta_m)$$

- Rank $[\gamma_k^{is}, -\gamma_k^{os}]$ from the lowest to highest values

Line Selection with Priority Listing



MIP Heuristic



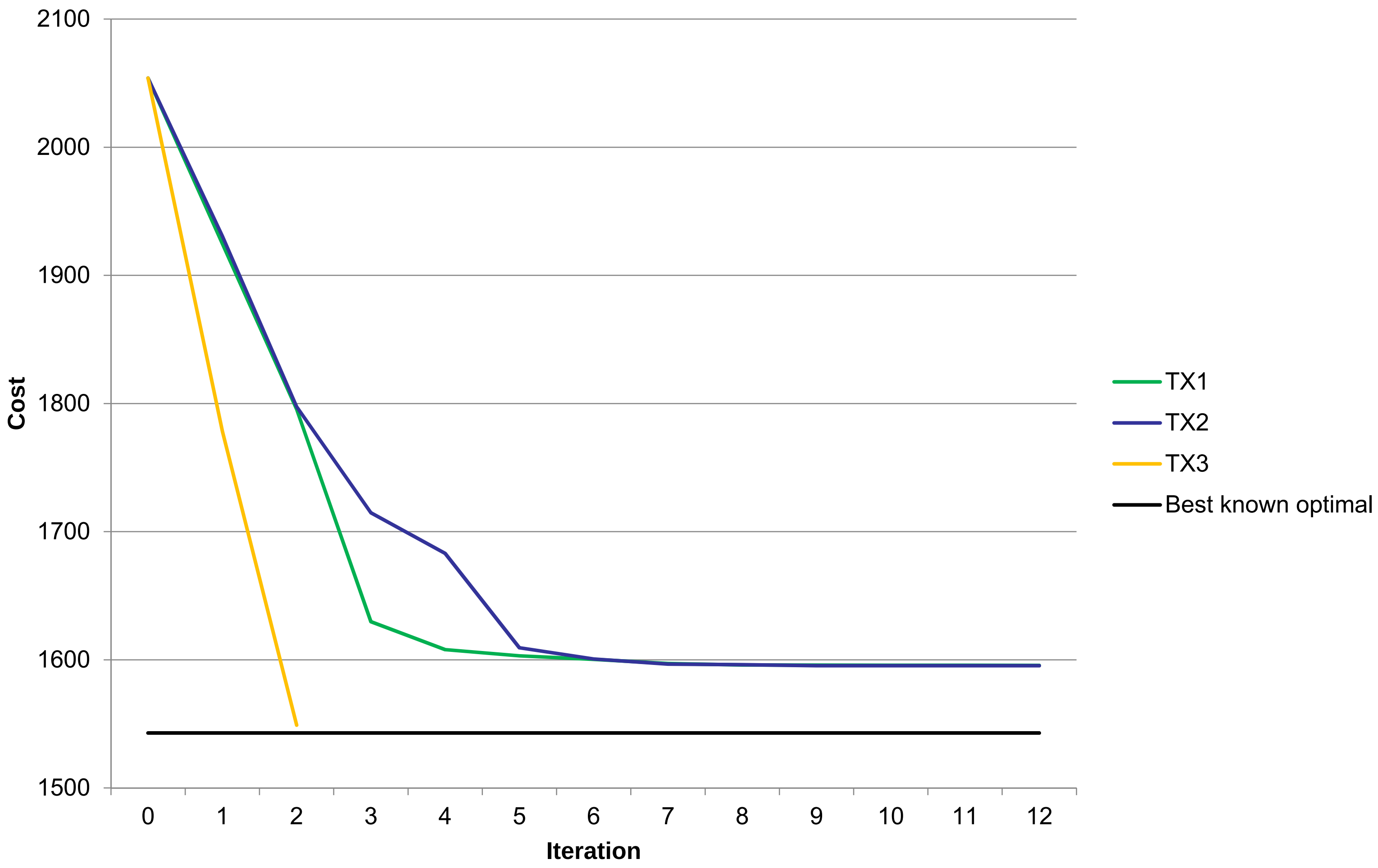
IEEE 118 Test Case

- 118 Buses
- 17 Generators
- 186 Lines
- Original cost (no line open): $2054
- With transmission switching, best found objective: $1542.89

Results

Iteration	TX1		TX2		TX3	
	Switch	Cost	Switch	Cost	Switch	Cost
1	L153	1924.5	L132	1930.6	L129,L132,L136	1778.3
2	L132	1795.5	L163	1797.5	L148,L153,L161,L162	1549.0
3	L136	1629.8	L133	1714.7		
4	L162	1607.9	L153	1683.0		
5	L37	1603.1	L151	1609.4		
6	L122	1600.3	L78	1600.6		
7	L14	1597.0	L85	1596.6		
8	L31	1595.9	L82	1596.1		
9	L19	1595.8	L96	1595.3		
10	L54	1595.6394	L45	1595.32		
11	L60	1595.6360	L48	1595.3048		
12	L68	1595.6258	L59	1595.3004		

Results



2100
2000
1900
1800
1700
1600
1500
Cost
0
1
2
3
4
5
6
7
8
9
10
11
12
Iteration
TX1
TX2
TX3
Best known optimal

Conclusion

- We presented three parallel implementations for the optimal topology control.
- Based on IEEE118 bus system, the third algorithm outperforms the second which outperforms the first, both in terms of cost improvement and computational time.
- The use of high performance computing can greatly improve the computational performance.

Current (Future) Work

FERC (PJM) MODEL

- 13867 Buses
- 1011 Generators
- 18824 Transmission Lines

- Direct implementations are computationally challenging.

- Possible solution: careful choice of parameters & warm start

Thank you

Priority List

Switching Sequence	Rank
L132	1
L163	3
L133	2
L153	14
L151	11
L78	23
L85	24
L82	31
L96	37
L45	59
L48	75
L59	77

FERC Data Preliminary Result

Iteration	TX1	Cost Improvement (%)	TX2	Cost Improvement (%)
1	L17230	0.182	L2813	0.098
2	L2913	0.353	L1831	0.2
3	L8731	0.792	L11231	0.226
4	L12031	0.991	L103	0.441
5	L7031	1.404	L7482	0.605
6	L721	1.42	L2310	0.893
7	L293	1.556	L14823	1.03
8	L7981	1.652	L5567	1.059
9	L10002	1.762	L787	1.255
10	L8310	1.86	L8313	1.268