MOBILIZING GRID FLEXIBILITY FOR RENEWABLES INTEGRATION THROUGH ENHANCED COMPUTATION

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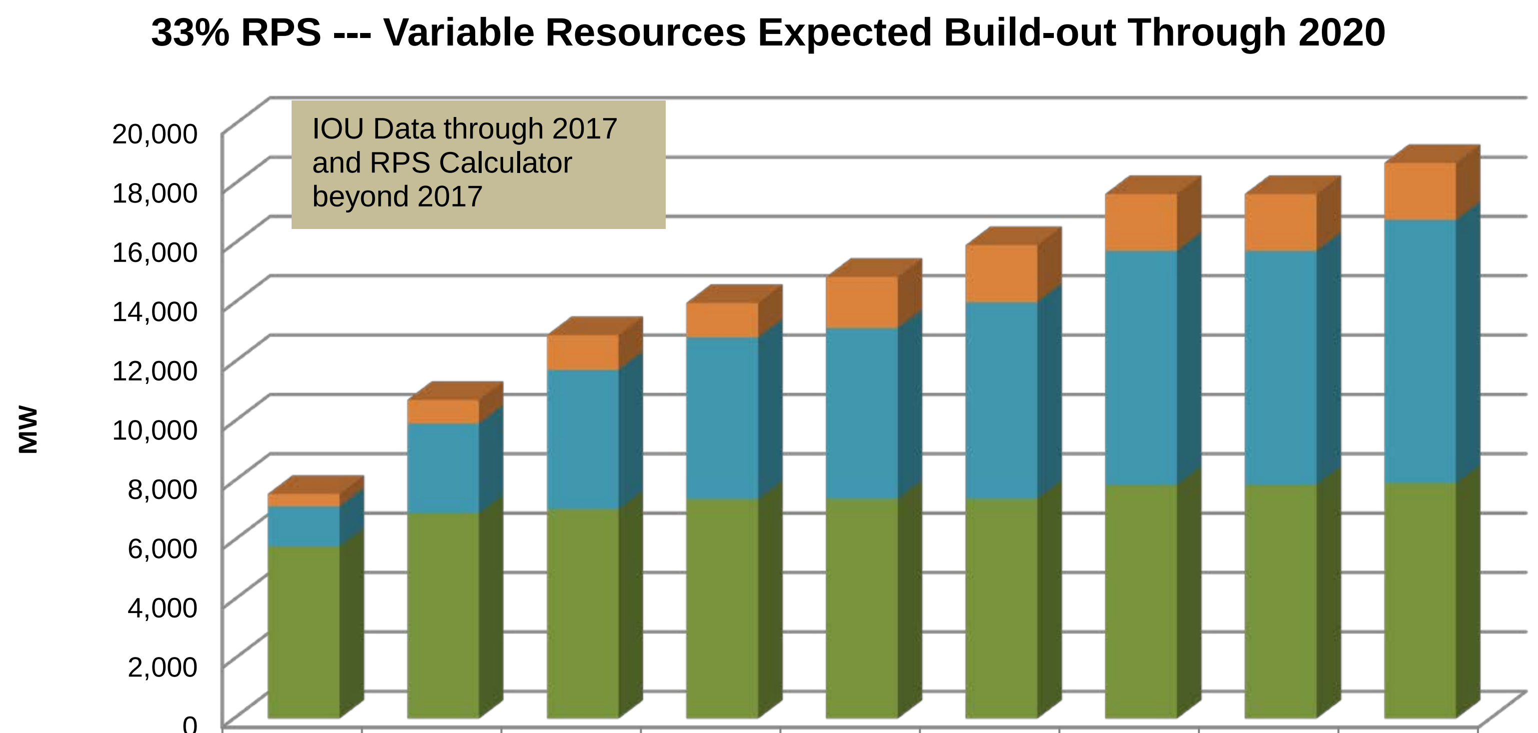
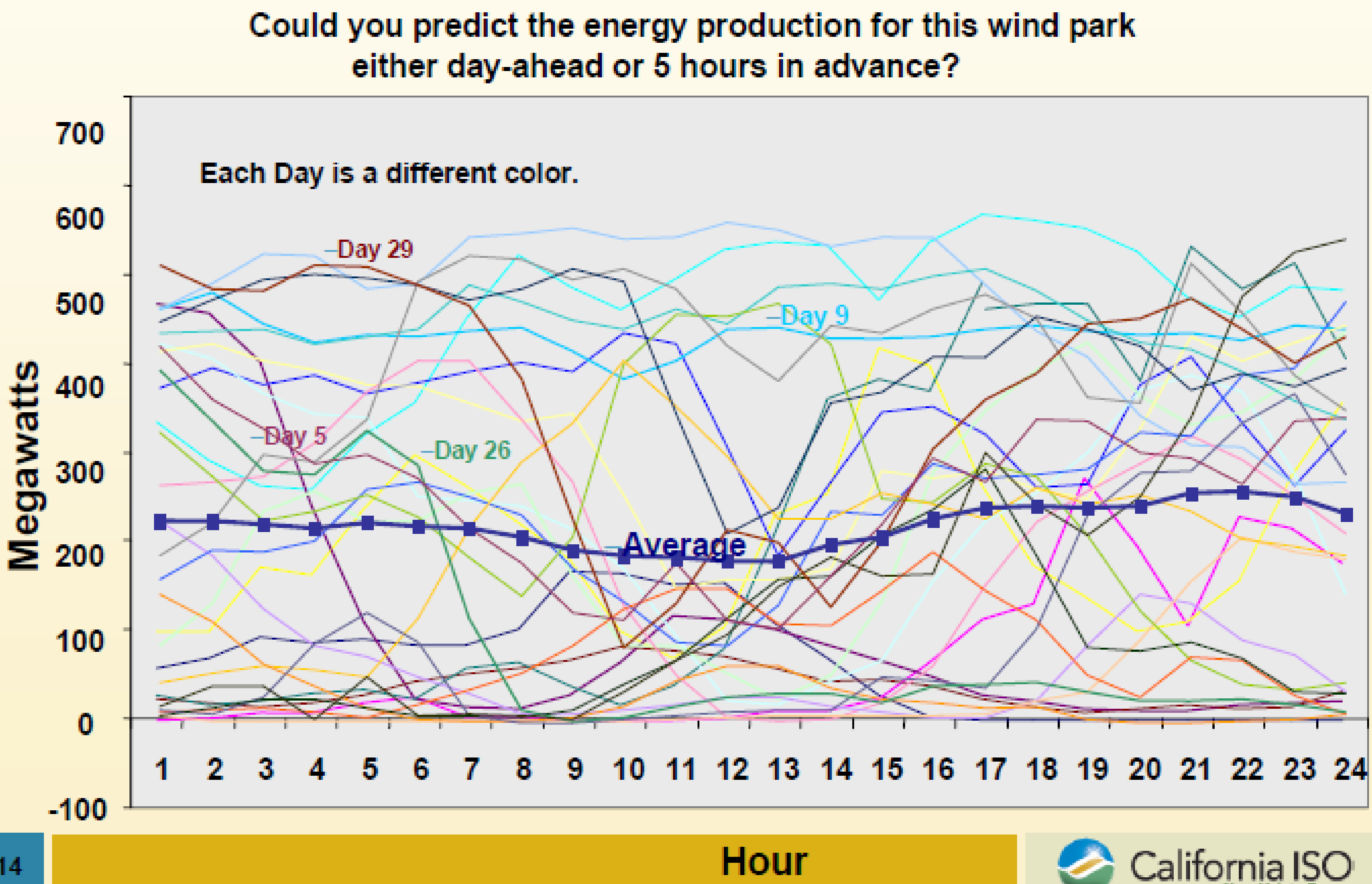
33% RPS - Cumulative expected VERs build-out through 2020



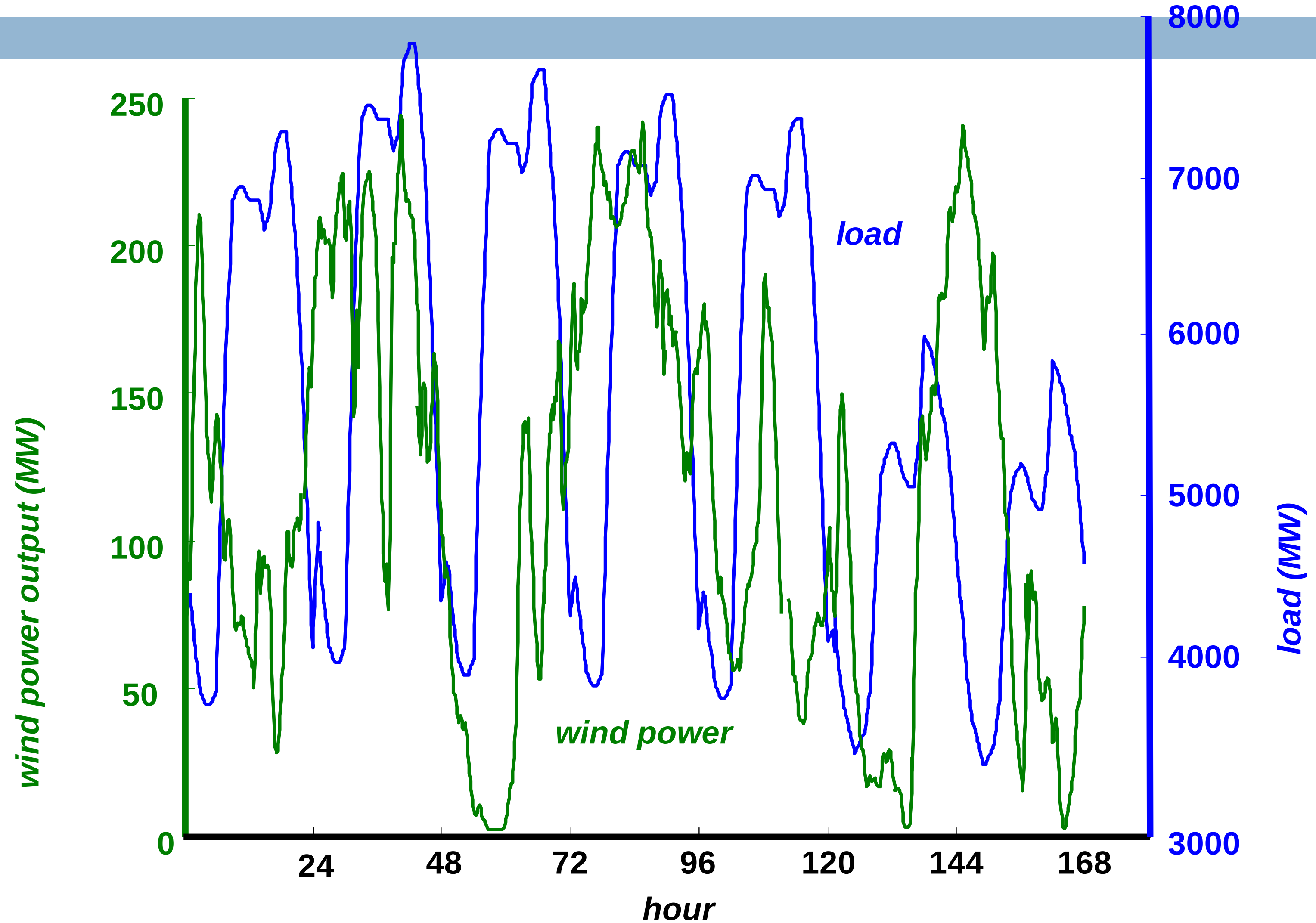
	2012 Existing	2013	2014	2015	2016	2017	2018	2019	2020
Solar Thermal	419	792	1,167	1,167	1,717	1,917	1,917	1,917	1,917
Solar PV	1,345	3,022	4,693	5,445	5,756	6,628	7,881	7,881	8,872
Wind	5,800	6,922	7,058	7,396	7,406	7,406	7,877	7,877	7,934

Source: CAISO

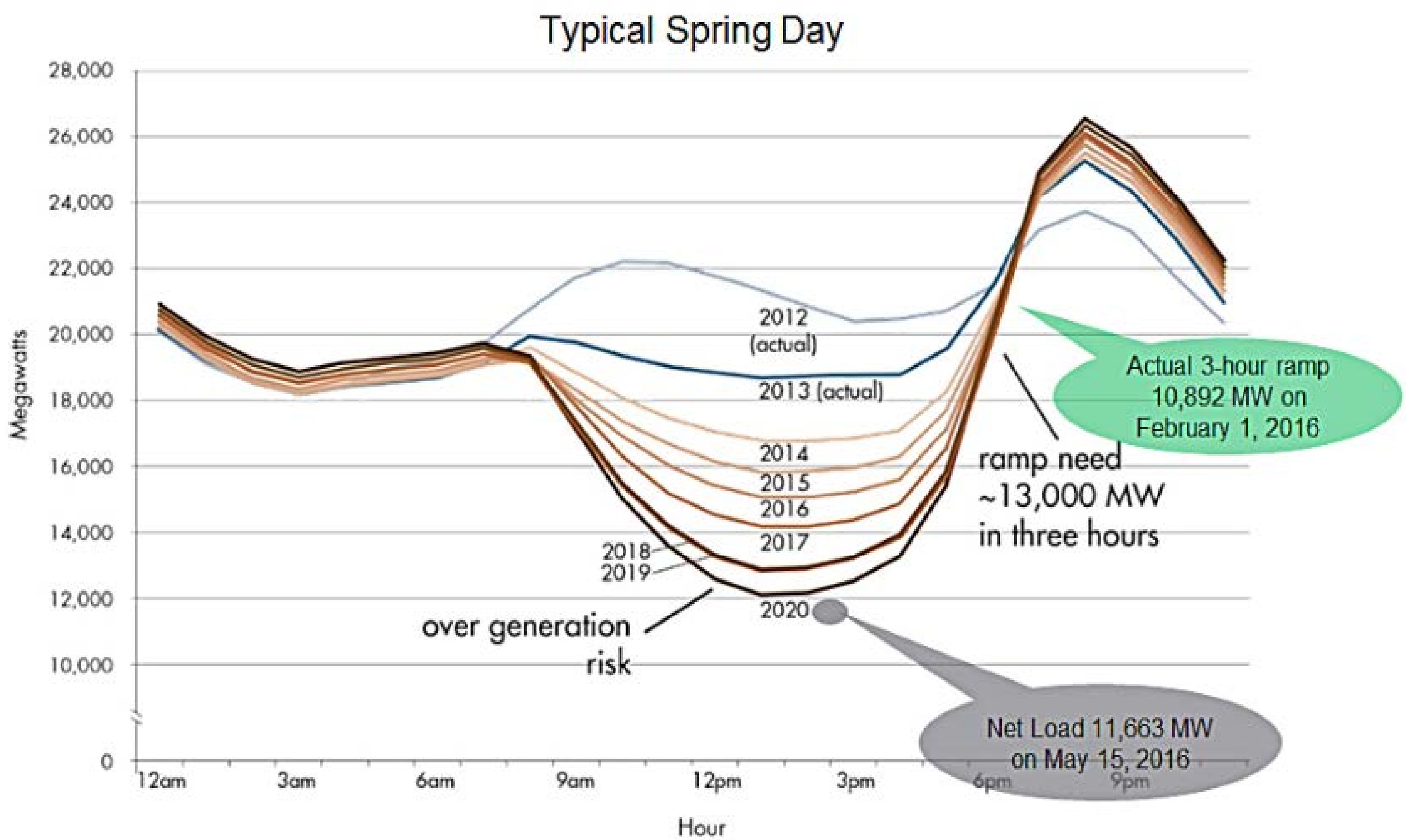
Tehachapi Wind Generation in April – 2005



Negative Correlation with Load



The “Duck Curve”



https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Introduction

- New Challenges

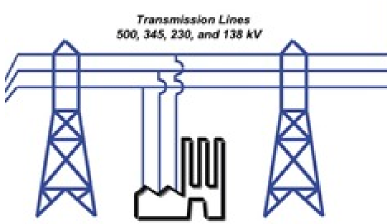
The ISO needs **a flexible resource mix** that can react quickly to adjust electricity production to meet the sharp changes in electricity net demand.

  - Ramping requirements
  - Flexible resources
  - Over generation mitigation

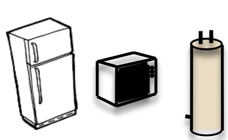
Integration of Renewable Generation

Flexibility

Flexible Generation

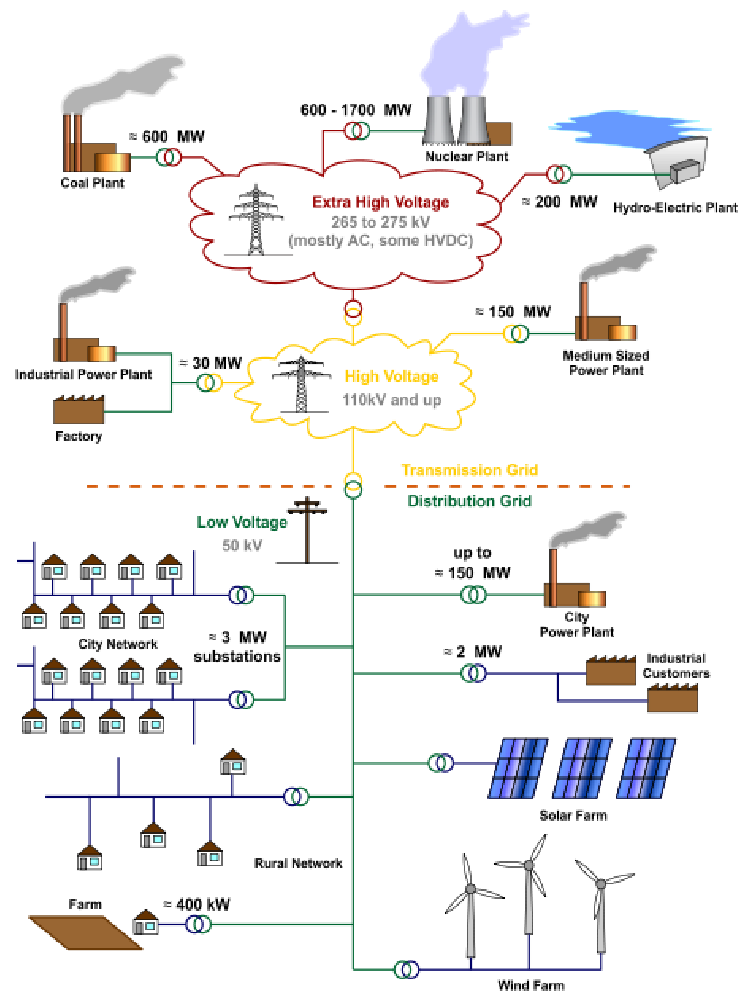


Flexible Transmission (Topology Control)



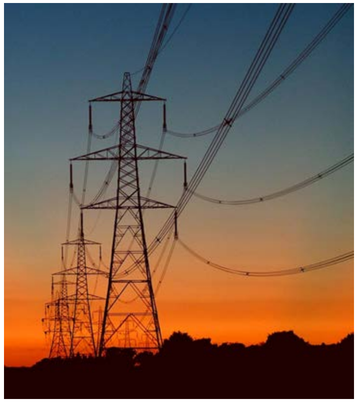
Demand Response

Storage



Flexible Transmission Network Control

- Topology Control
  - Switch on/off lines
- Flexible Line Rating
  - Include choosing proper line ratings as decisions
- FACTS



Topology Control

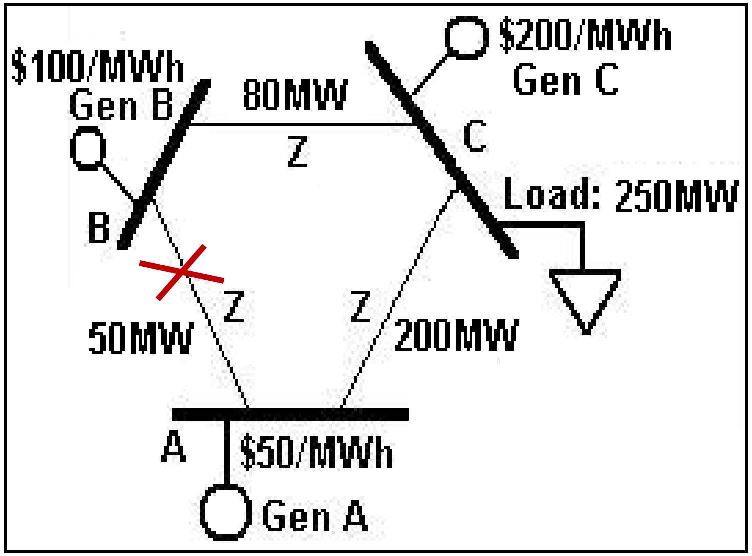
- Topology control has been studied to:
  - Relieve abnormal conditions[1]
  - Reduce system loss[2]
  - Reduce operating cost (Optimal Transmission Switching)[3]
- Utilize existing assets required by normal operating conditions. No additional cost other than the wear of breakers is incurred.

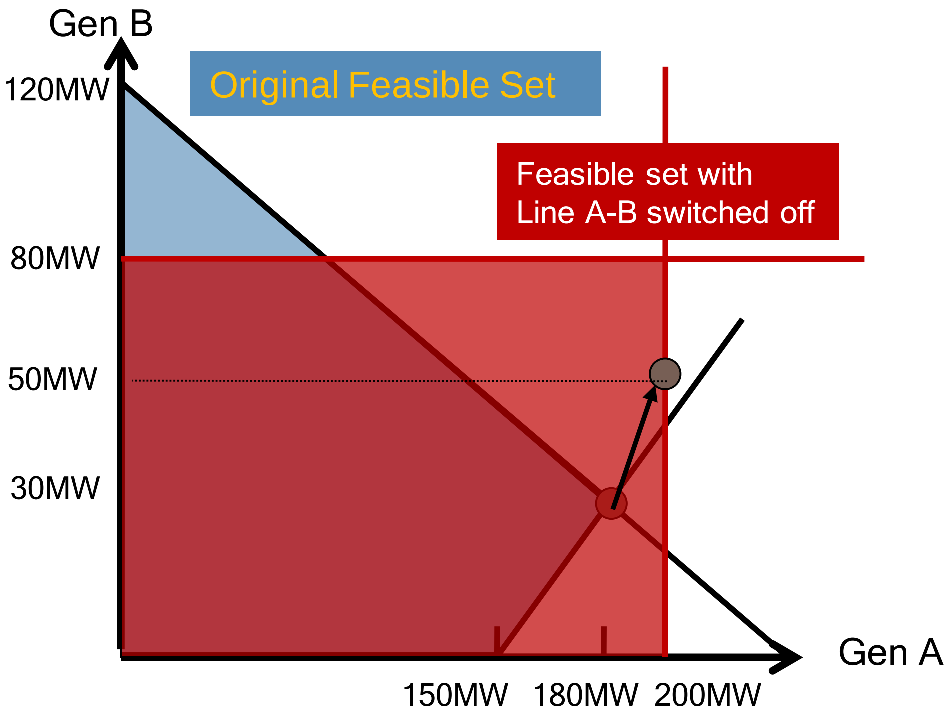
[1] A. G. Bakirtzis and A. P. Sakis Meliopoulos, “Incorporation of switching operations in power system corrective control computations,” *IEEE Transactions on Power Systems*, vol. PWRS-2, no. 3, pp. 669–675, 1987.
[2] R. Bacher and H. Glavitsch, “Loss reduction by network switching,” *IEEE Transactions on Power Systems*, vol. 3, no. 2, pp. 447–454, 1988.
[3] E. Fisher, R. O’Neill, and M. Ferris, “Optimal transmission switching,” IEEE Transactions on Power Systems, pp. 1–10, 2008.

Operating Cost Reduction

Original Optimal Cost: $20,000 (A=180MW,B=30MW, C=40MW)

Open Line A-B, Optimal Cost: $15,000 (A=200MW, B=50MW)





Topology Control in Practice

- Topology Control in Practical Power System Operations
  - PJM Manual 03: Transmission Operations

> PJM uses the following techniques to control contingency or system violations:
> - ...
> - switching transmission facilities in/out of service
> - ...

  - ISO New England Operating Procedure No . 19 - Transmission Operations

    In the operating procedure, transmission circuit switching is listed as one of EMERGENCY system actions.

> Where it is clear that opening a transmission facility will alleviate a problem existing for a specific emergency situation, consideration will be given to opening such facility.
> ...

RATC
ROBUST ADAPTIVE TOPOLOGY CONTROL

arpa·e
Advanced Research Projects Agency • ENERGY

4) Green Electricity Network Integration (GENI)

Texas A&M Engineering Experiment Station (University of California Berkeley, Arizona State University, Lawrence Livermore National Laboratory, Tennessee Valley Authority, Telcordia, Oak Ridge National Laboratory)	$4,910,031	College Station, TX	**Robust Adaptive Topology Control (RATC)** Historically, the electric grid was designed to be passive, causing electric power to flow along the path of least resistance. The Texas Engineering Experiment Station team will develop a new system that allows real-time, automated control over the transmission lines that make up the electric power grid. This new system would create a more robust, reliable electric grid, and reduce the risk of future blackouts, potentially saving billions of dollars a year.

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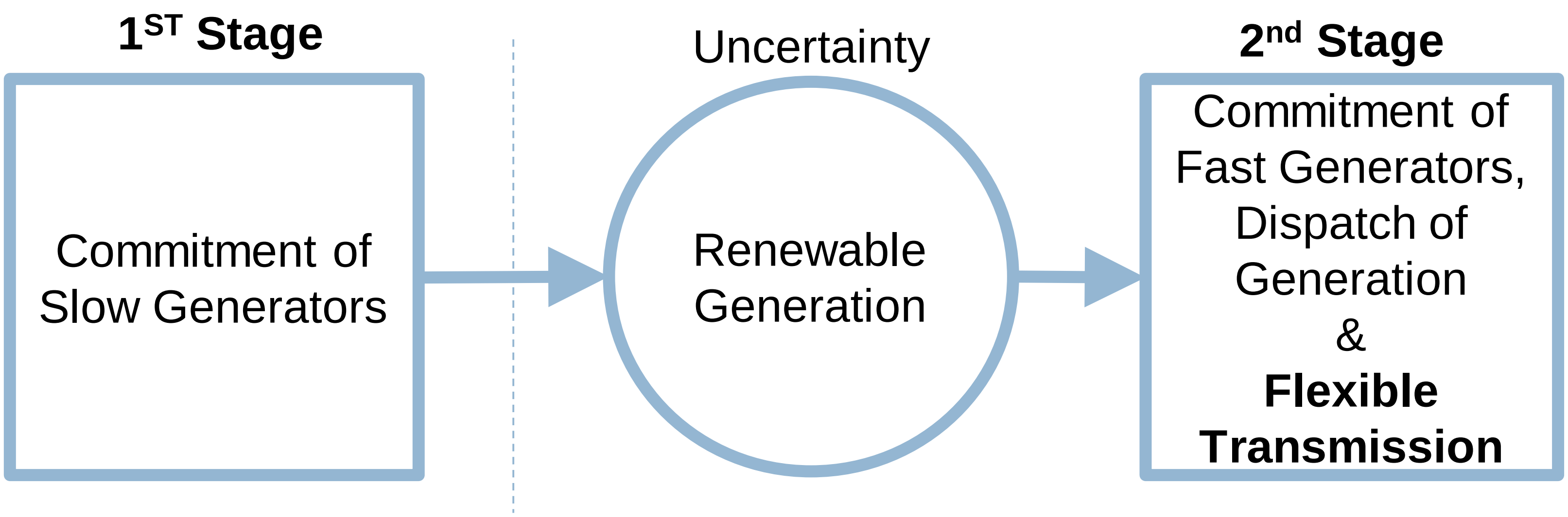
Topology Control as Recourse

- In deterministic unit commitment, topology control can reduce the generation cost[4] and mitigate post contingency violations
- In stochastic unit commitment, topology control as a recourse action may leverage the grid controllability and mitigate the variability of renewable generation.

[4] K. Hedman and M. Ferris, and et al. "Co-optimization of generation unit commitment and transmission switching with N-1 reliability," *IEEE Transactions on Power Systems* vol. 25, no. 2, pp. 1052–1063, 2010.

Two-stage Stochastic Unit Commitment

- Objective : minimize the expected operating cost
- Decision variables:



Formulation: Constraints

- System-wide constraints
  - Market clearing
  - DC power flow
  - Line capacity
  - Number of lines that can be switched off
- Generator constraints
  - Generation capacity
  - Ramping up/down
  - Min up/down time
  - On/off transition

Topology Control Formulation

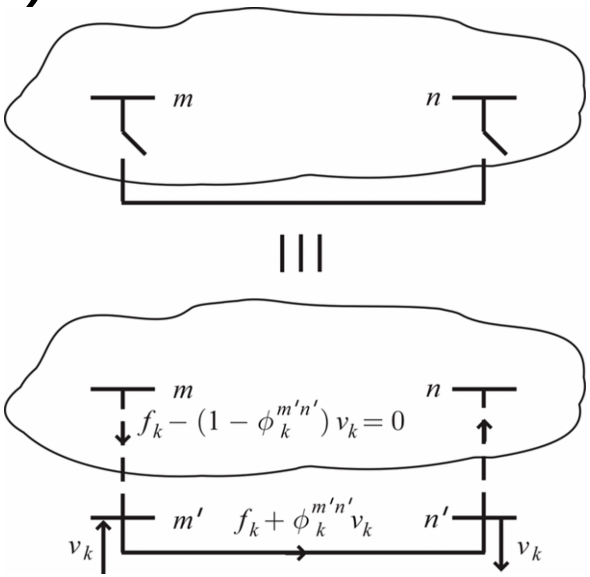
- **Bθ** Formulation

$$-M_{ij}\left(1-r_{ij,t,s}\right) \le F_{ij,t,s} - B_{ij}\left(\theta_{i,t,s}-\theta_{j,t,s}\right) \le M_{ij}\left(1-r_{ij,t,s}\right), \quad \forall i,j \in N_z, t \in T, s \in S$$

$$-r_{ij,t,s}F_{ij}^{\max} \le F_{ij,t,s} \le r_{ij,t,s}F_{ij}^{\max}, \forall i,j \in N_z, t \in T, s \in S$$

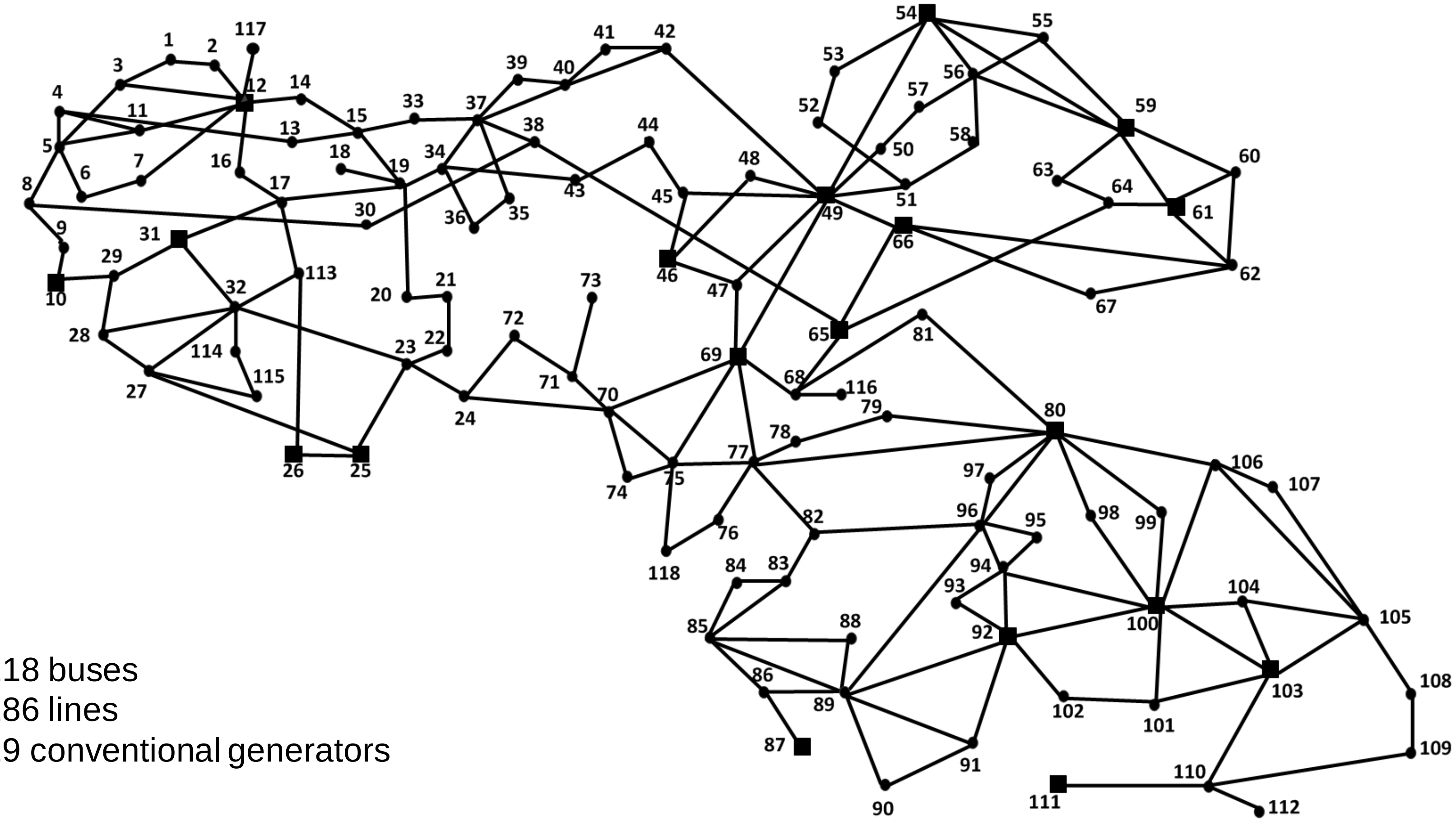
- PTDF Formulation(Ruiz, 2012)

$$\begin{aligned}
&\min_{\mathbf{p},\mathbf{v},\mathbf{z}} \mathbf{c}'\mathbf{p} \\
&\textit{subject to} \\
&\mathbf{1}'(p-1) = 0 \\
&\underline{\mathbf{p}} \le \mathbf{p} \le \overline{\mathbf{p}} \\
&\underline{\mathbf{f}}_\tau^{\mathcal{M}} \le \Psi_\tau^{\mathcal{M}}(\mathbf{p}-1) + \Phi_\tau^{\mathcal{MS}}\mathbf{v}_\tau \le \overline{\mathbf{f}}_\tau^{\mathcal{M}}, \quad \forall\tau \\
&\underline{\tilde{\mathbf{F}}}_\tau^{\mathcal{S}}\mathbf{z} \le \Psi_\tau^{\mathcal{S}}(\mathbf{p}-1) + (\Phi_\tau^{\mathcal{SS}} - I)\,\mathbf{v}_\tau \le \overline{\mathbf{F}}_\tau^{\mathcal{S}}\mathbf{z}, \quad \forall\tau \\
&-M(1-\mathbf{z}) \le \mathbf{v}_\tau \le M(1-\mathbf{z}), \quad \forall\tau \\
&z_\ell \in \{0,1\}, \quad \forall\ell
\end{aligned}$$



Test Case

- IEEE 118 system



118 buses
186 lines
19 conventional generators

Wind Modeling

- Wind Generation Simulation
  - In our test, wind speed and wind power data of three locations in Wyoming are obtained from NREL Western Wind Resources Dataset .
  - 1000 wind generation scenarios are generated using the method described in [5].
  - To reduce the computational complexity, we adopt the scenario reduction technique introduced in [6].

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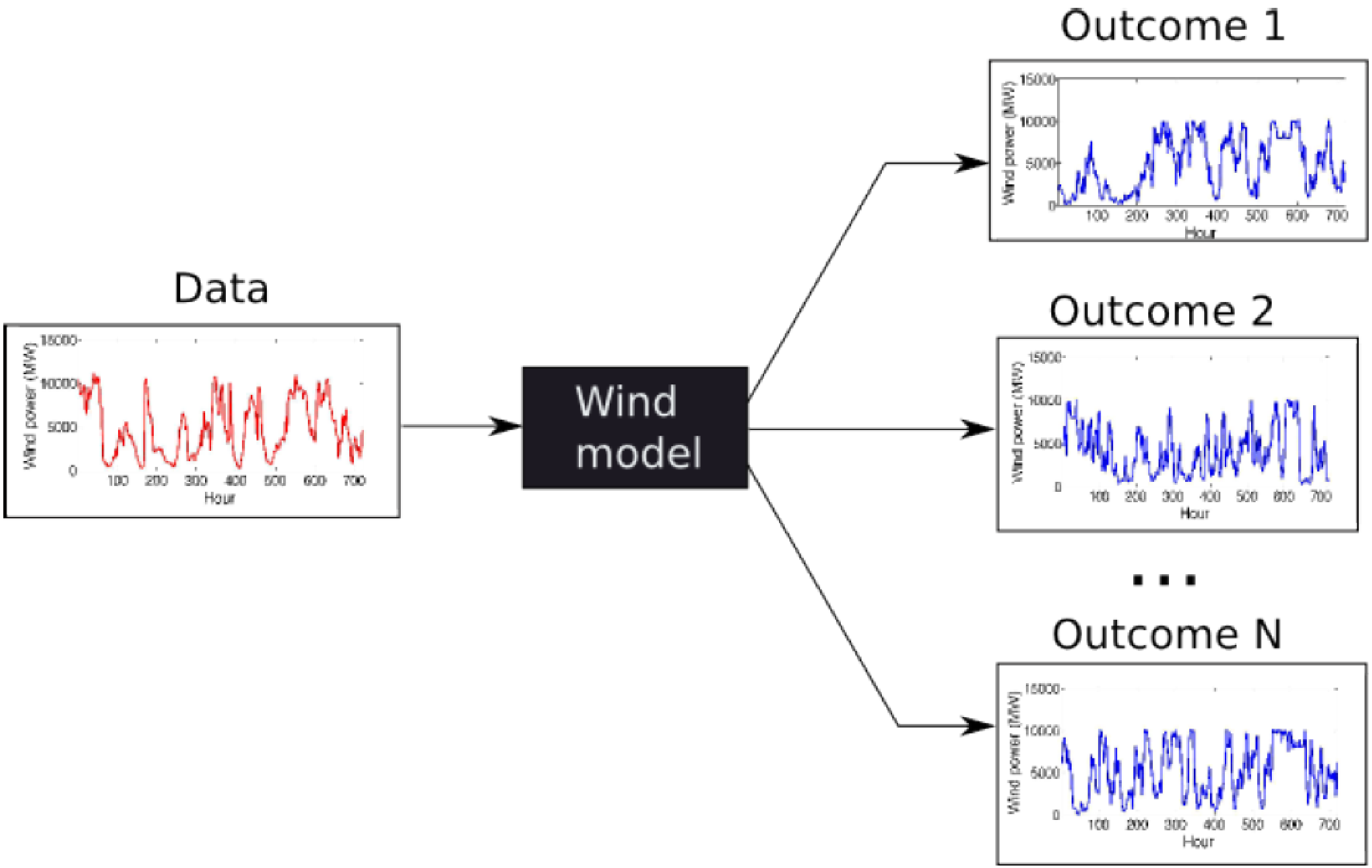
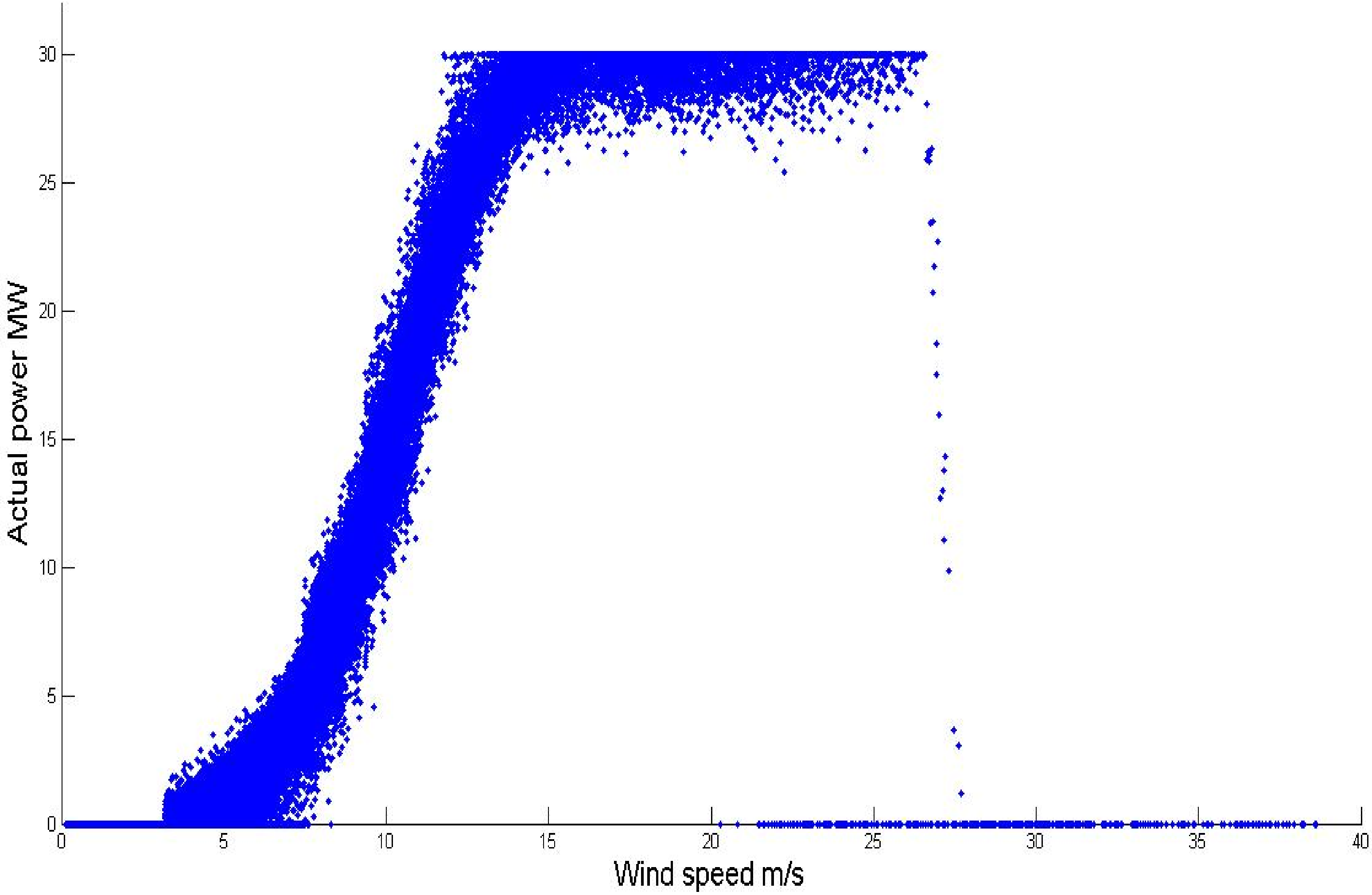
[5] A. Papavasiliou and S. S. Oren, “Multiarea stochastic unit commitment for high wind penetration in a transmission constrained network,” Operations Research, vol. 61, no. 3, pp. 578–592, 2013.
[6] N Growe-Kuska, H Heitsch and W Romisch, “Scenario Reduction and Scenario Tree Construction for Power Management Problems”. IEEE Power Tech Conference, Bologna 2003.

Wind Speed Scenario Generation



Power Curve

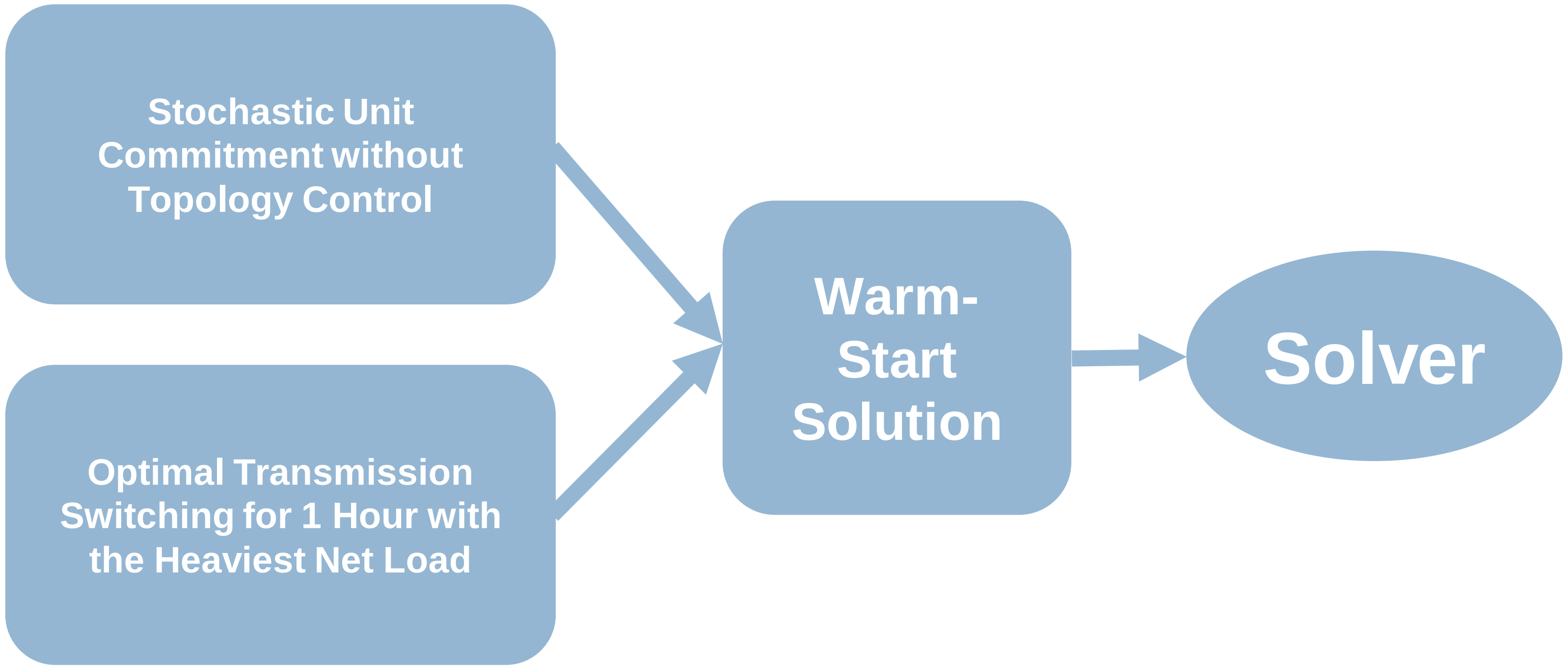

Actual power MW
0
5
10
15
20
25
30
0
5
10
15
20
25
30
35
40
Wind speed m/s

Test Results

- Solving the problem—Branch and Bound
  - 48,336 binary variables, 80,352 continuous variables.
  - The problem is solved on a laptop: 2.6GHz CPU, 12G RAM.
  - When the MIP gap tolerance is 5%, using the default setting of CPLEX the program does not terminate after 8 hours.
  - The automatic tuning tool of CPLEX does not work for this problem. Appropriate parameters are not found after over 8 hours.

Warm Starts

- Solving the problem—Branch and Bound
  - Using CPLEX MIP warm-start



Warm Start Heuristic

- Solving the problem—Branch and Bound Using CPLEX MIP
  - Unit Commitment Decisions
    - The warm-start values for unit commitment decisions are obtained from solving a stochastic unit commitment problem with no topology control recourse.
    - In practice, system operators can use the commitment decisions of previous days with similar loading conditions to construct warm-up values for commitment decisions.

Warm Start Heuristic

- Solving the problem—Branch and Bound Using CPLEX MIP
  - Topology Control Decisions
    - Topology control warm-up values are obtained from solving an optimal transmission switching problem for the highest load hour (no wind).
    - The warm-start values for switching decisions are the same for different hours and scenarios.

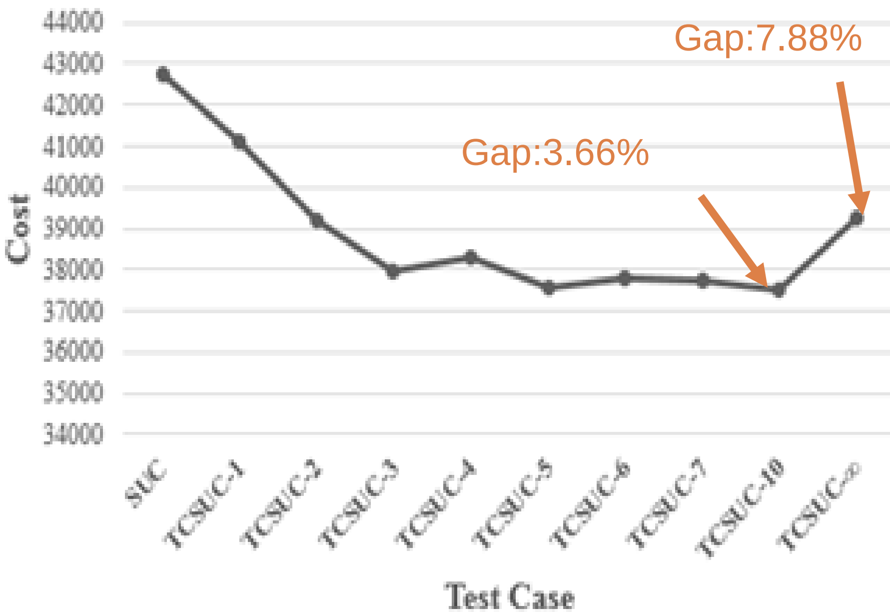
Test Results

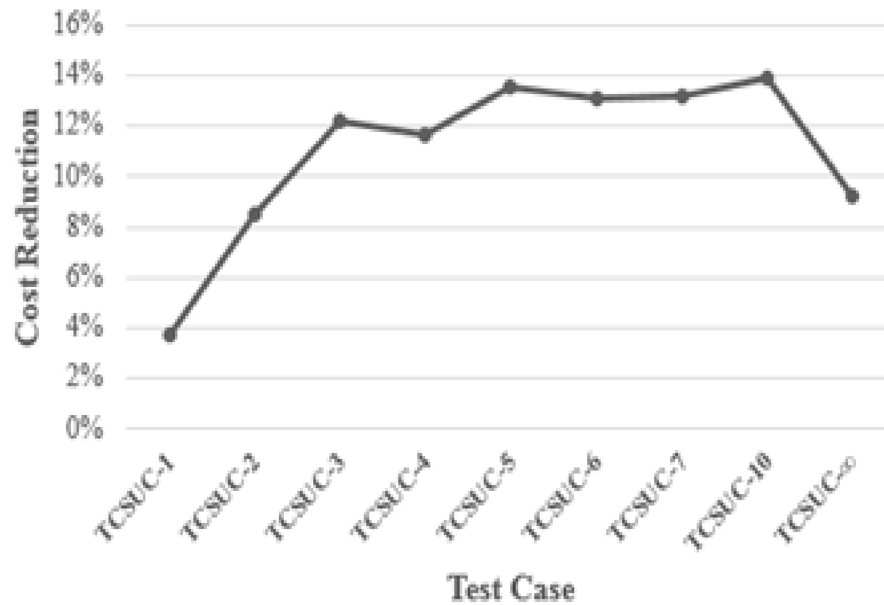
- Start Switching Solutions
  - We conducted 9 numerical tests
  - "x" in "TCSUC-x" stands for the maximum number of lines that can be switched off. ($J = x$)

Case	**Start switching solution**
TCSUC-1	132
TCSUC-2	132,136
TCSUC-3	132,136,153
TCSUC-4	132,136,153,162
TCSUC-5	132,136,151,153,163
TCSUC-6	132,136,148,153,161,162
TCSUC-7	63,132,136,148,153,161,162
TCSUC-10	126, 132, 136, 146, 151, 153, 157, 165
TCSUC-∞	1, 10, 14, 25, 28, 31, 57, 63, 66, 77, 79, 86, 96, 103, 110, 111, 132, 136, 146, 151, 153, 161, 165, 184

Test Results

Improvement over SUC with no switching





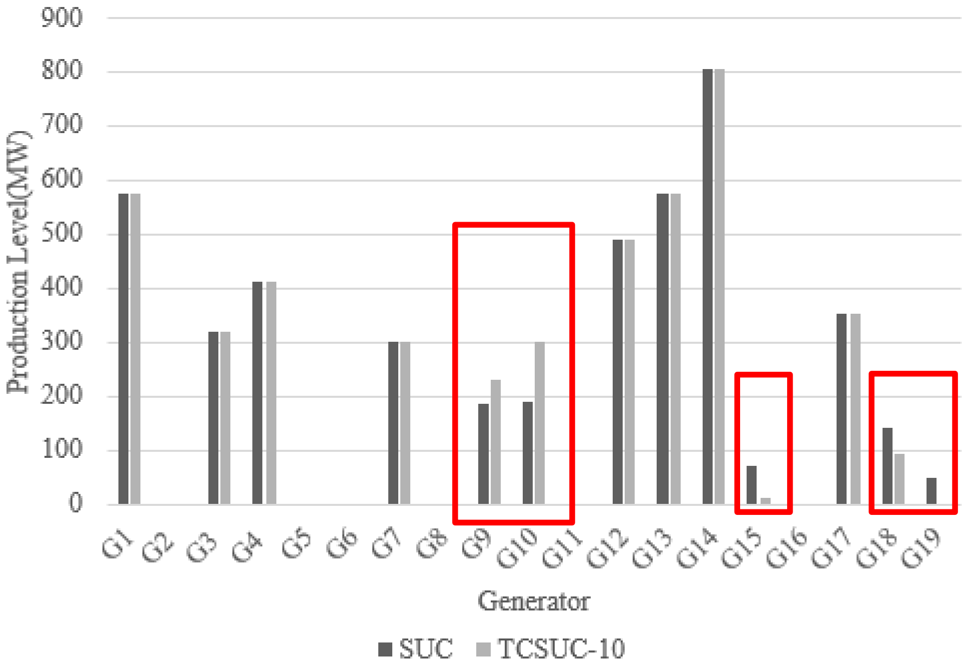
Cost Reduction: percentage of saving
Time limit: 30min
Maximum value of optimality gap: 7.88%

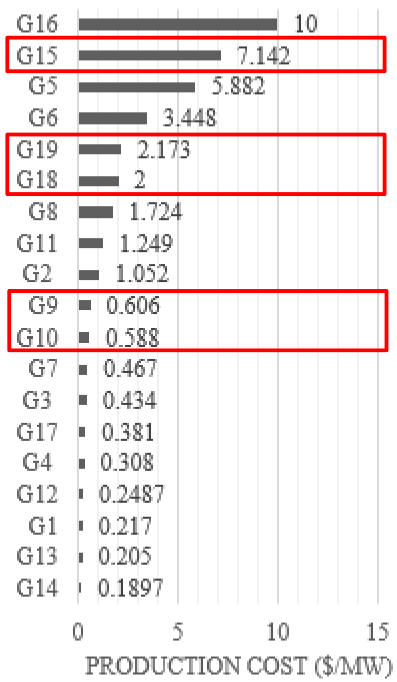
Results Analysis

- Sources of cost savings
  - Reduction of production cost
  - Reduction of start-up cost
  - Reduction of no-load cost
  - Reduction of load shedding

Test Results

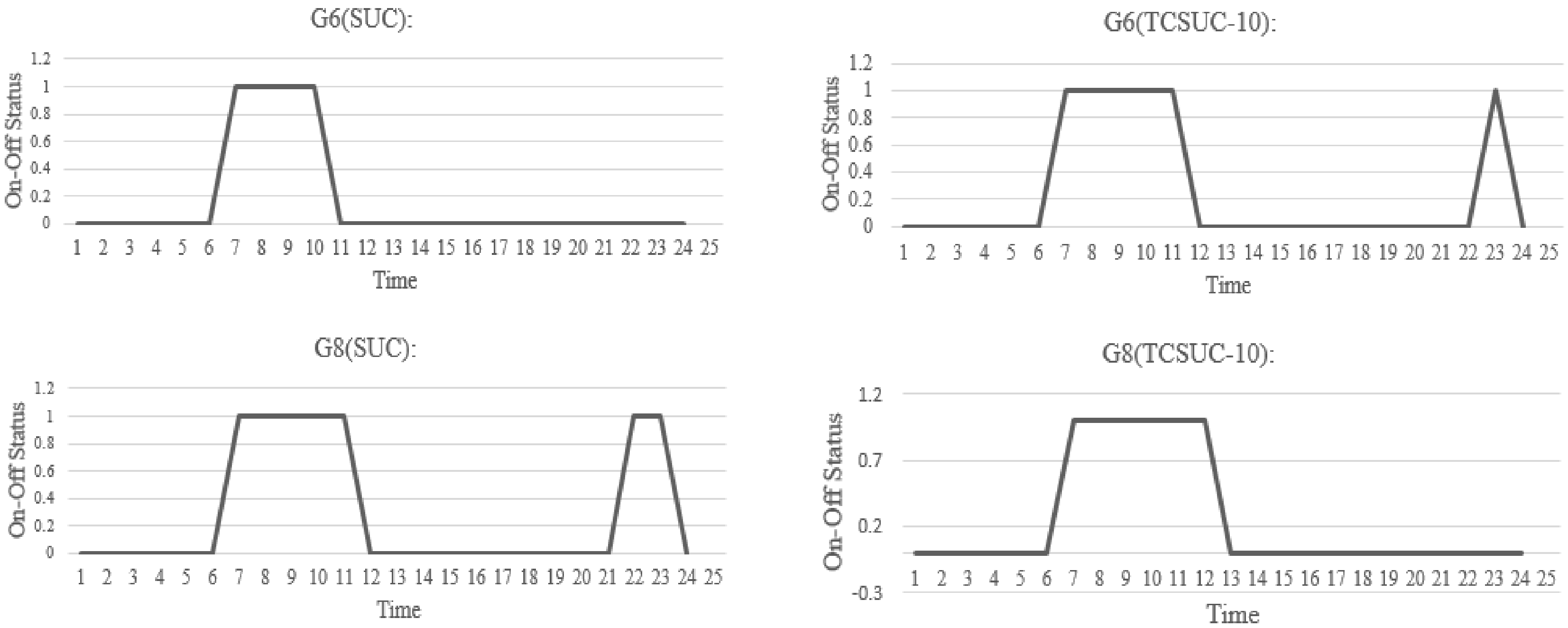
- Reduction of production cost





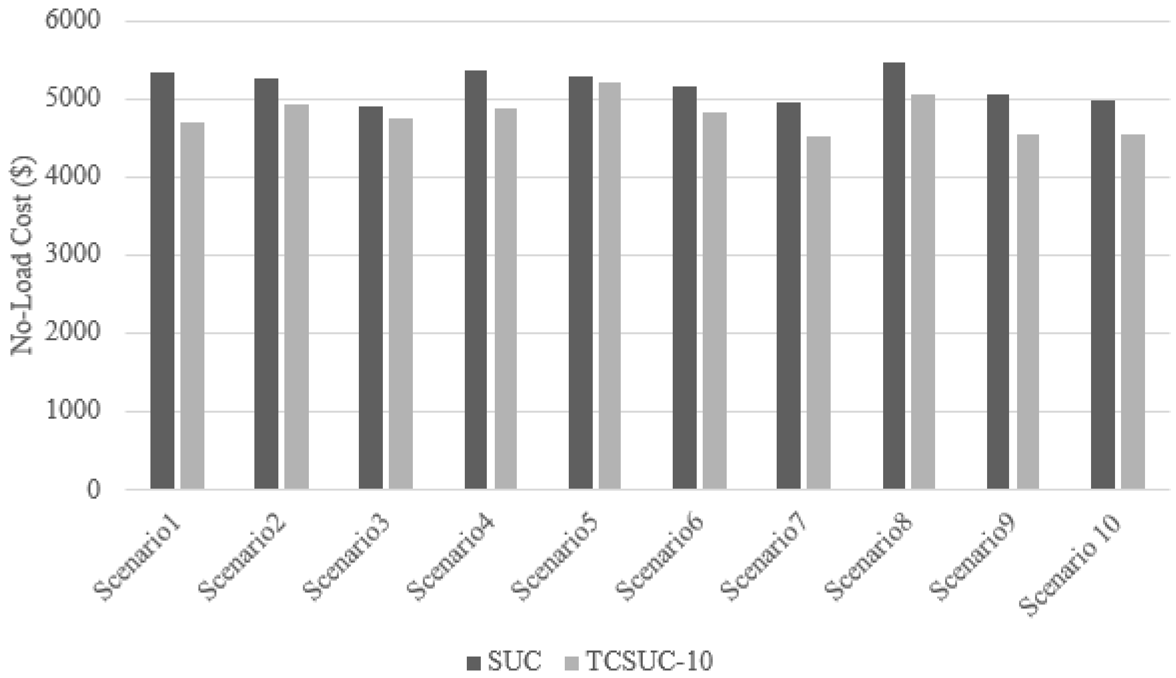
Test Results

- Reduction of start-up cost (STC6<STC8)



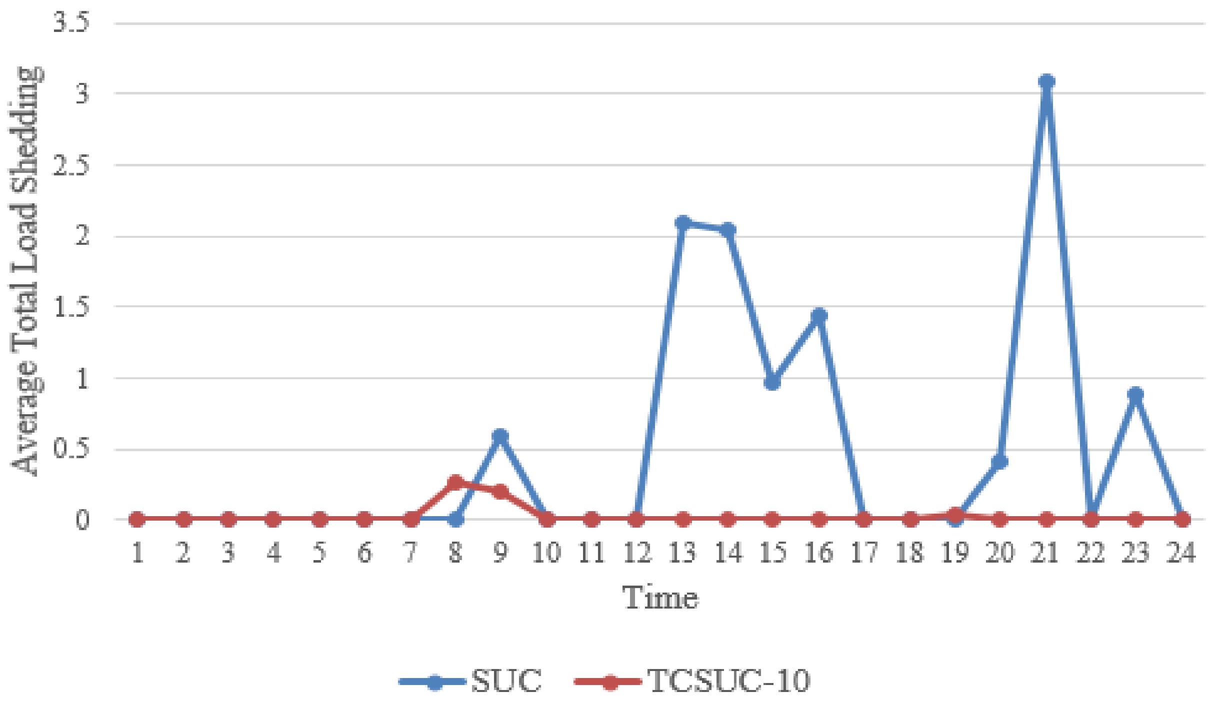
Test Results

- Reduction of no-load cost



Test Results

- Reduction of load shedding



Solving the Problem

- The optimality gap for each sub-problem is set to be 4% and the time limit for each sub-problem is set to be 6 minutes.
- The algorithm converges after 7 iterations. The estimated time for solving the problem in parallel is 42 minutes.
- The cost is reduced by 10.1% with topology control recourse.

Switching Results

- Switching solution for different scenario

Scenario	Switching solution of Hour 18 (Lines are off)
1	40, 94,109, 132, 136, 146, 151, 153, 157, 165
2	48, 88, 126, 132, 136, 146, 151, 153, 157, 165
3	116, 126, 132, 136, 153, 165
4	94, 96, 124, 132, 136, 146, 151, 153, 157, 165
5	39, 40, 63, 84, 122, 132, 136, 151, 153, 165
6	1, 83, 126, 132, 16. 146, 151, 153, 157, 165
7	45, 118, 126, 132, 136, 146, 151, 153, 157, 165
8	63, 96, 109, 124, 127, 132, 153, 163, 168
9	21, 42, 79, 132, 136, 146, 151, 153, 157, 162
10	37, 42, 59. 103, 132, 136, 146, 151, 153, 157

Evaluation

- Evaluate the robustness of the solution that was based on a reduced scenario set, under a richer uncertainty representation.
- The **commitment of slow generators are fixed as the slow generators commitment solution** of TCSUC-10.
- The **line switching decisions are optimized for each of the simulation scenarios among the set of lines in the union of lines switched in** TCSUC-10 for the 10 optimization scenarios.
- 1000 wind generation scenarios produced using Monte Carlo simulation are used in the evaluation.
- Both unit commitment and unit commitment with transmission switching are implemented to compare the cost.

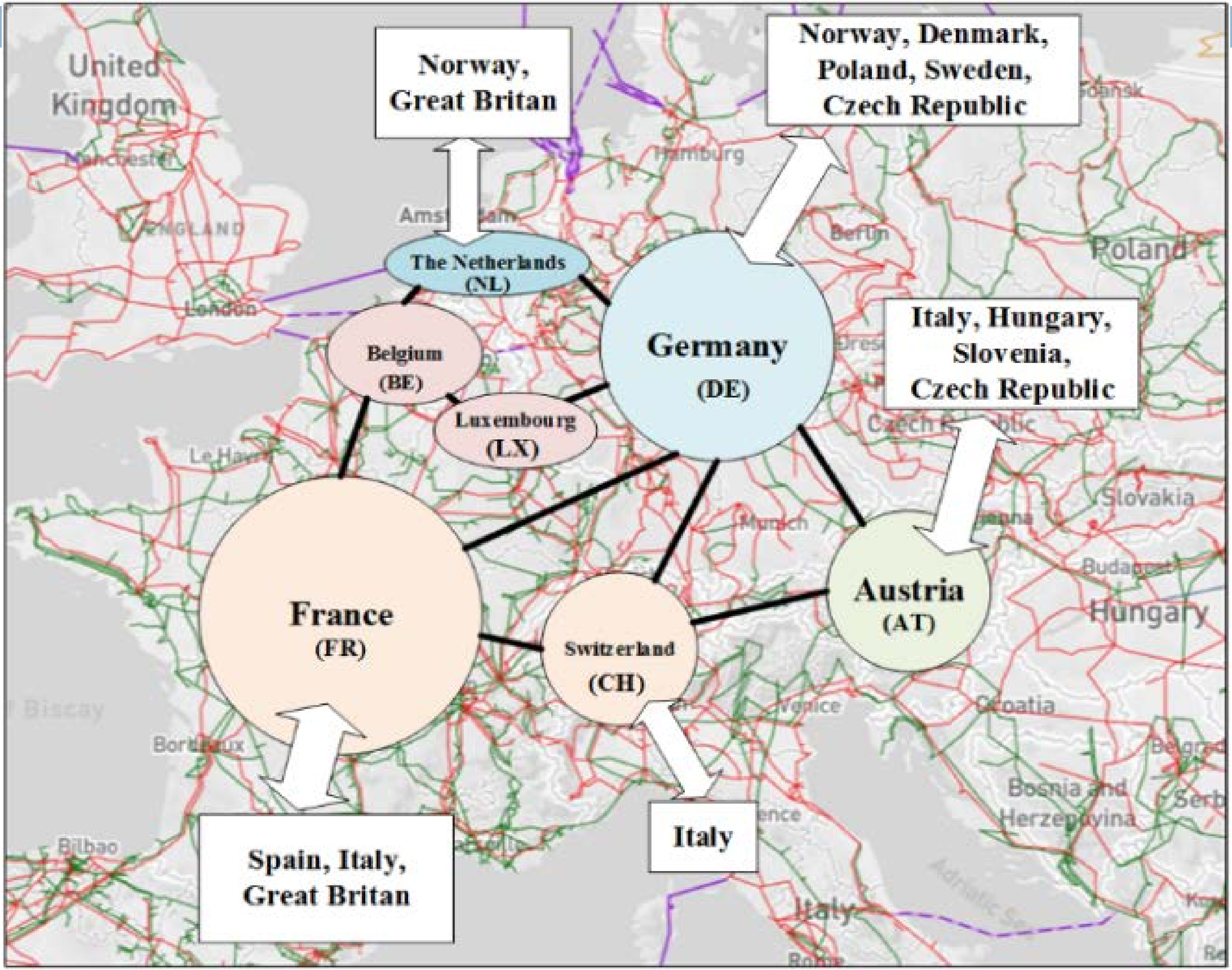
Evaluation

- In all 1000 tests, when there is transmission switching in the recourse, the total cost is less than when there is no transmission switching.
- The average total cost is reduced by 12.9% with transmission switching in the recourse.
- The simulation provides a **lower bound** of the cost reduction for the case where there is no restriction on the lines that can be switched.

Central European System Test Case

- Central European System
  - 7 Countries
  - 679 Buses
  - 1036 Lines
  - 667 Conventional Units :
    - 183 fast units and 484 slow units
  - 10 selected scenarios for renewable generation
  - Renewable Generation: 1439 units
    - Wind
    - Solar
    - Hydro

Central European Test System

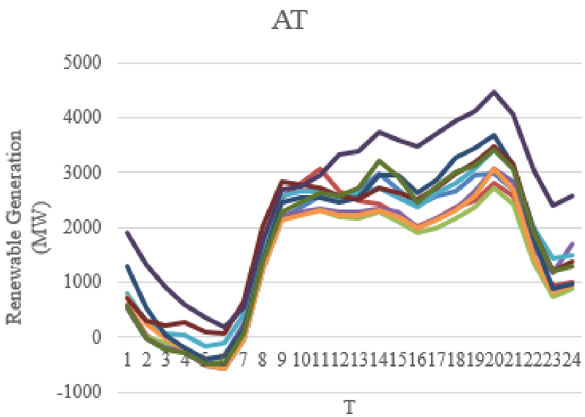


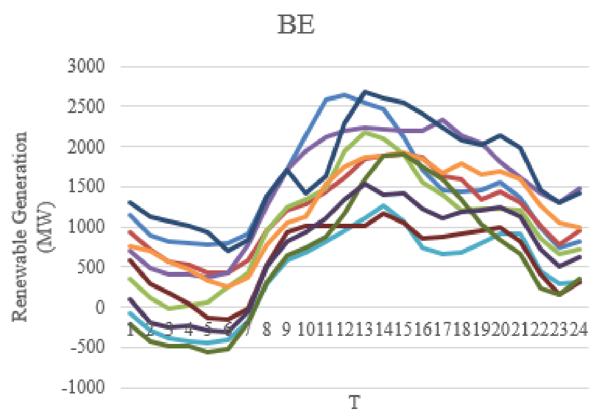
Central European Test System

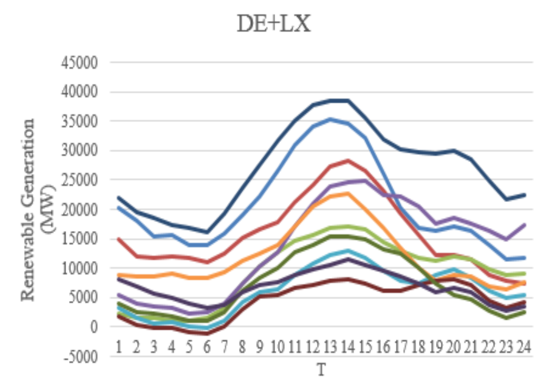
	AT	BE	CH	DE	FR	LX	NL
Buses	36	24	47	228	317	3	24
Lines	42	23	76	312	518	2	26
Fast Units	11	25	4	94	22	0	19
Slow Units	25	45	5	254	108	1	46
Peak Load (MW)	8044.9	1.3e4	7328	65018	69043	839	13959
Max. Gen. Cap. (MW)	7656.8	1.7e4	4335.1	1.1e5	9.0e4	375	24690

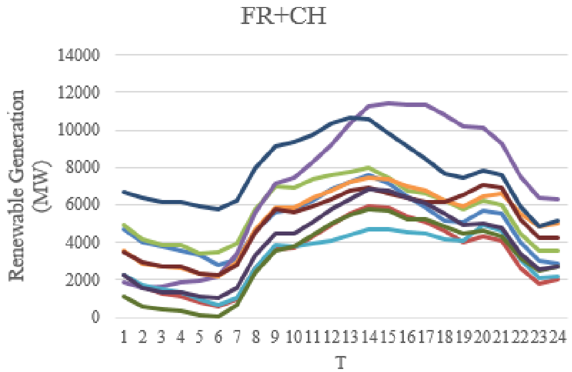
Central European Test System

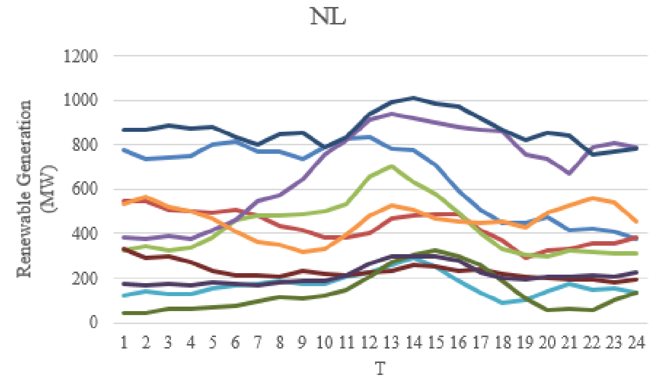
- Central European System
  - Renewable Generation Scenarios











Test Results

- Stochastic unit commitment with topology control recourse
  - With 10 scenarios, there are over 1 million continuous decision variables and over 300,000 binary decision variables.
  - The problem cannot be solved within reasonable run time just using branching and cut even without topology control.
  - For single scenario deterministic unit commitment problem when the switching decision is relaxed as a continuous variable, the cost saving for the entire system is within 5%.
  - A good warm start solution is required for tuning Progressive Hedging.

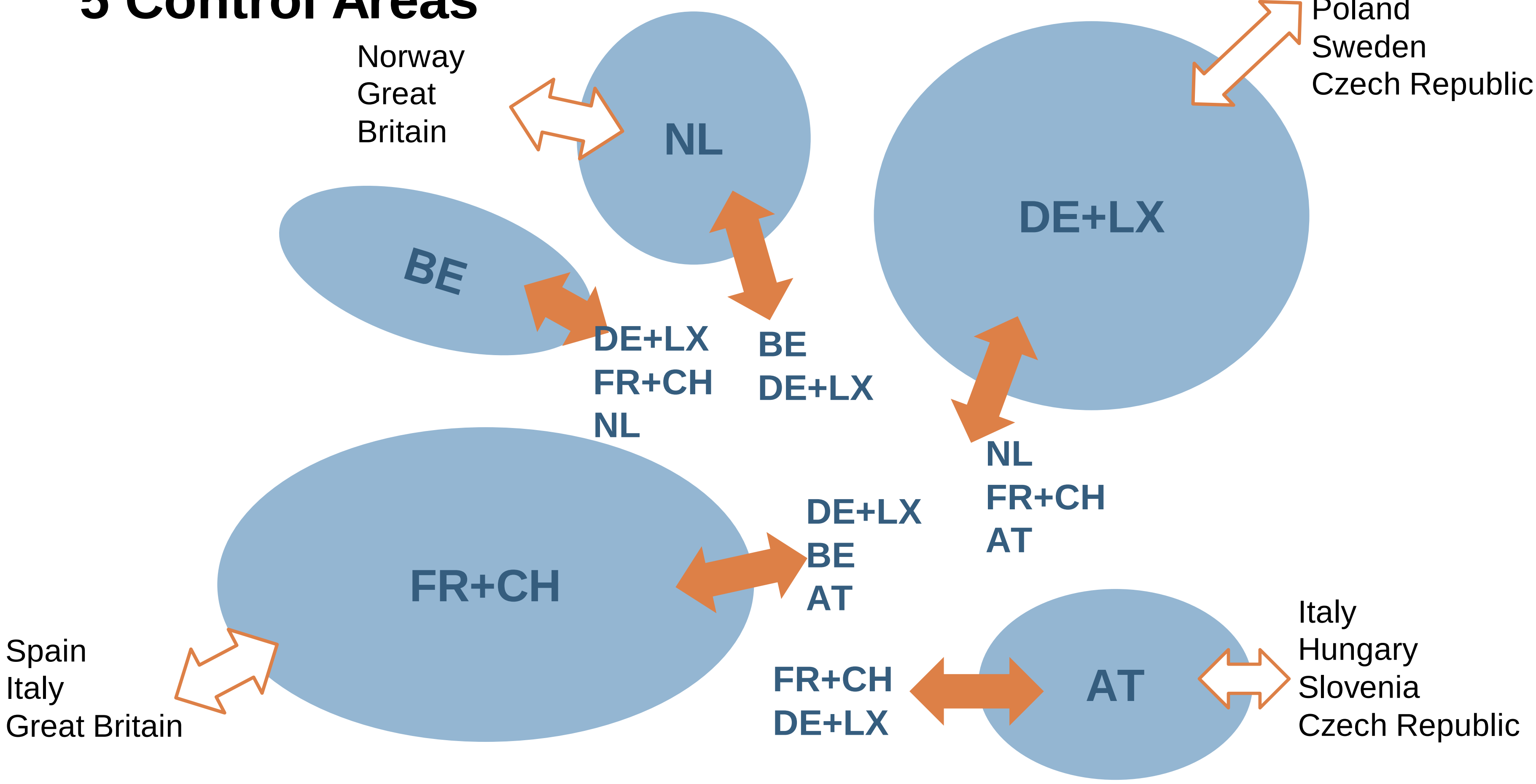
Test Results

- Proposed Method
  - Decompose the system into 5 control areas.
  - Power exchanges between areas are obtained through solving a optimal dispatching problem for the whole system.
  - Each control area solve its own SUC/TCSUC.

Test Results

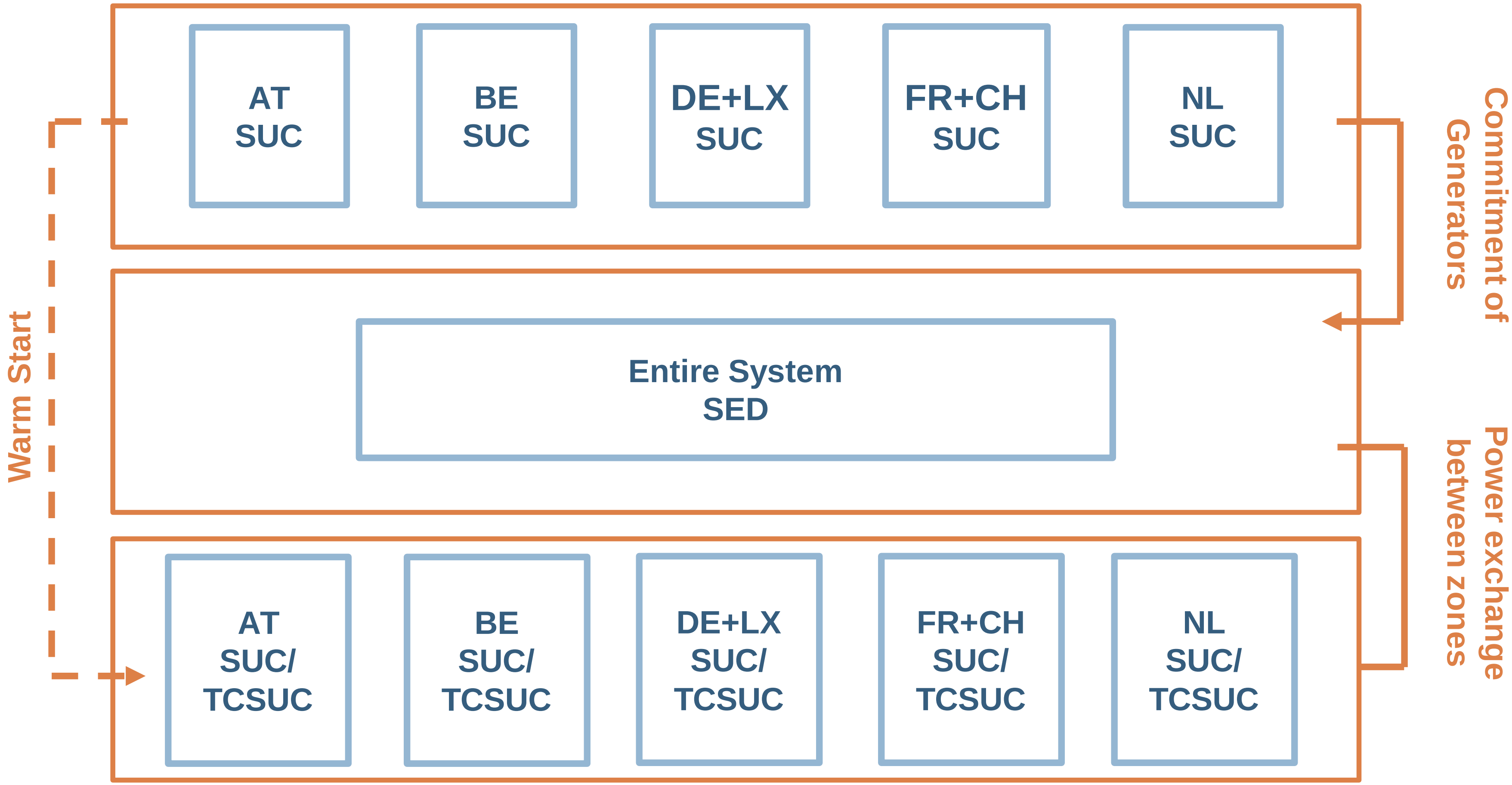
Proposed Method

5 Control Areas



Heuristic for Zonal Decomposition

- Proposed Method



Heuristic for Zonal Decomposition

- Proposed Method

  - Solve stochastic unit commitment for each control area.
  - Each control area submit commitment decisions to the second step.
  - The solution to the first step can serve as warm starts for the third step.
  - Total amount of power exchange with other control areas are penalized.

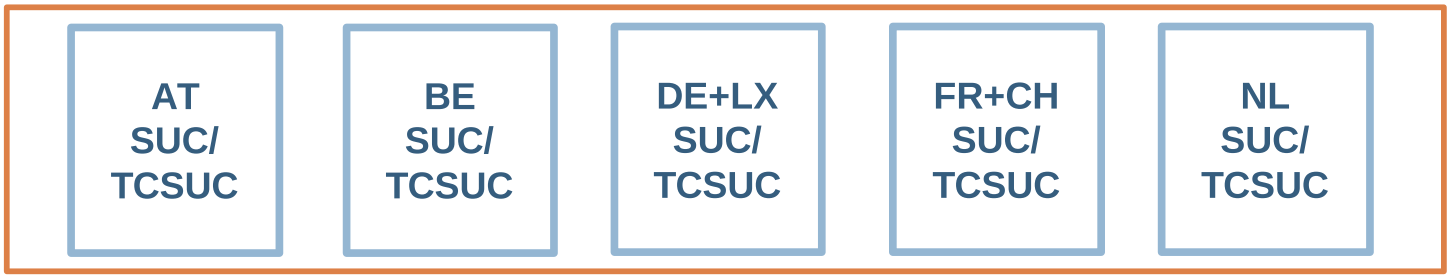
Heuristic for Zonal Decomposition

- Proposed Method

  - Solve stochastic economic dispatch for the entire system to get the power exchange between control areas.
  - Commitment of generators are fixed.
  - Power exchange between control areas are sent to each area in step 3.

Heuristic for Zonal Decomposition

- Proposed Method



  - Solve SUC/TCSUC for each control area.
  - The power exchange between control areas is given by the previous step.
  - If we combine the solution of each control area, we get a feasible solution to SUC/TCSUC of the entire system.

Test Results

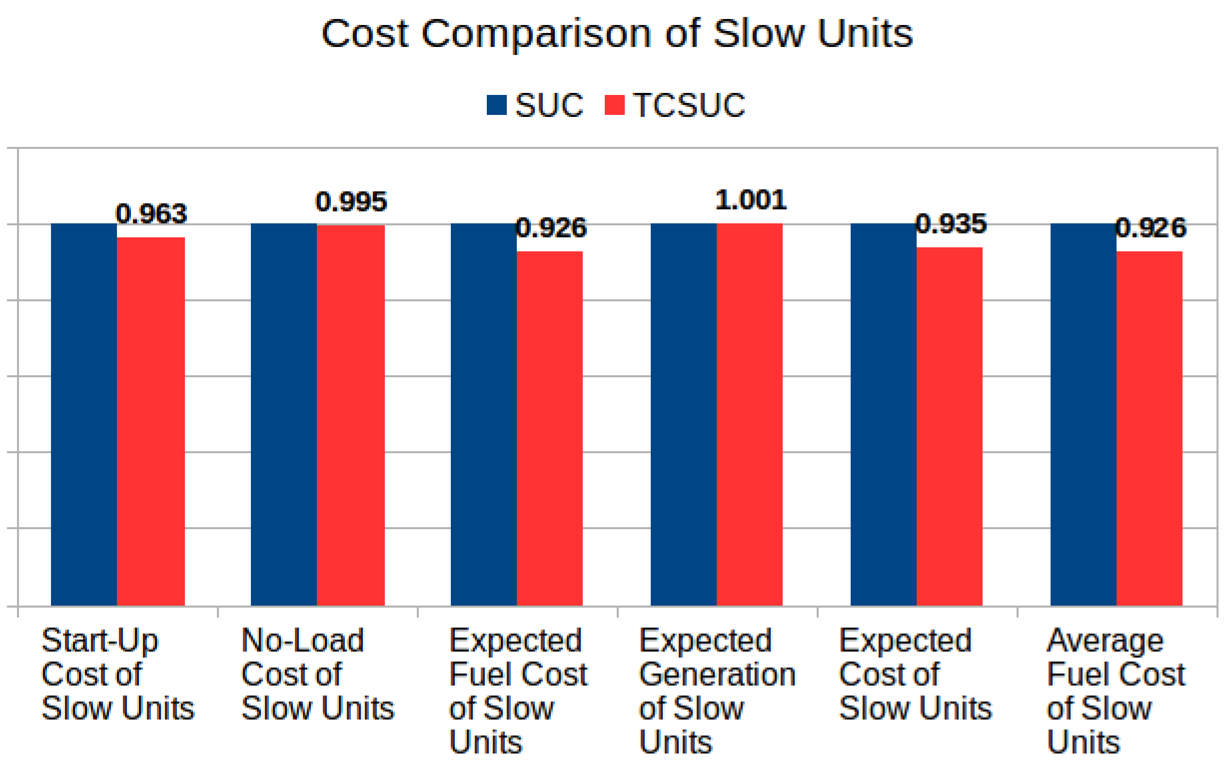
- TCSUC vs. SUC: Cost Savings

	SUC (MEUR)	TCSUC (MEUR)	Cost Saving (MEUR)
AT	7.0057	6.8244	0.1813
BE+LX	**6.2083**	**6.2083**	**0.00**
DE	14.2089	14.0540	0.1549
FR+CH	**17.3961**	**16.0753**	**1.3478**
NL	10.5475	10.3793	0.1682
Total	55.3665	53.5141	1.8521

**To solve TCSUC within reasonable time, switching decision for DE+LX and FR+CH are restricted on a preselected set.

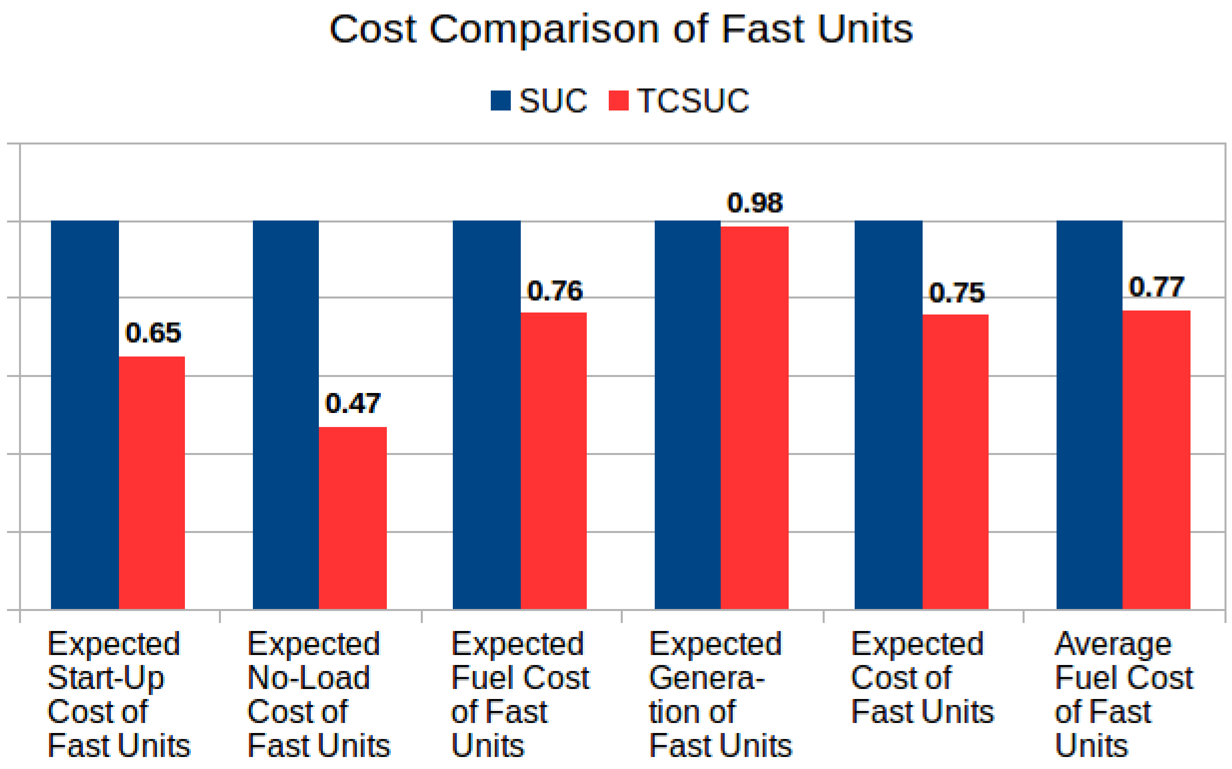
Test Results

- TCSUC vs. SUC: Result Analysis
  - Zone FR+CH



Test Results

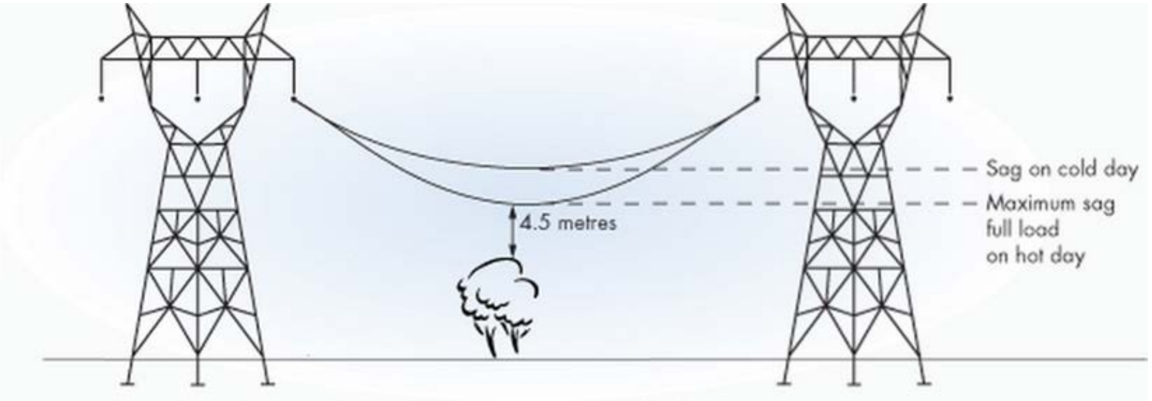
- TCSUC vs. SUC: Result Analysis
  - Zone FR+CH



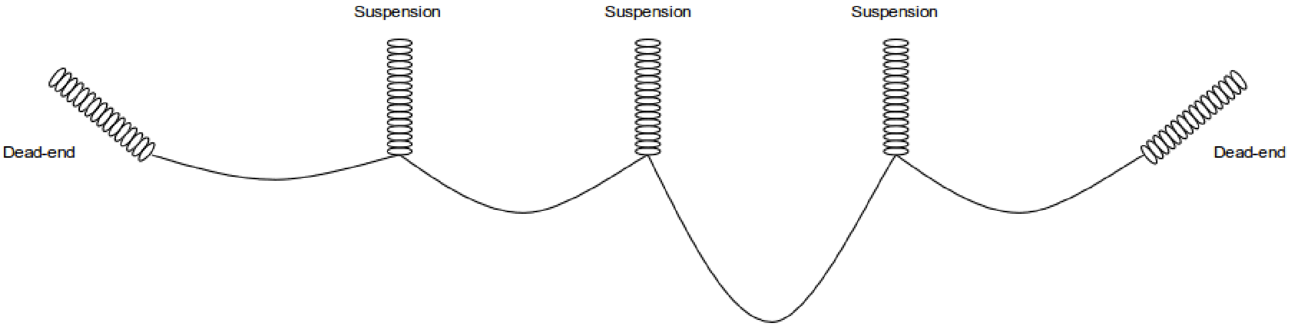
Flexible Line Rating

- Thermal Limits

Sag:



Mechanical Structure:

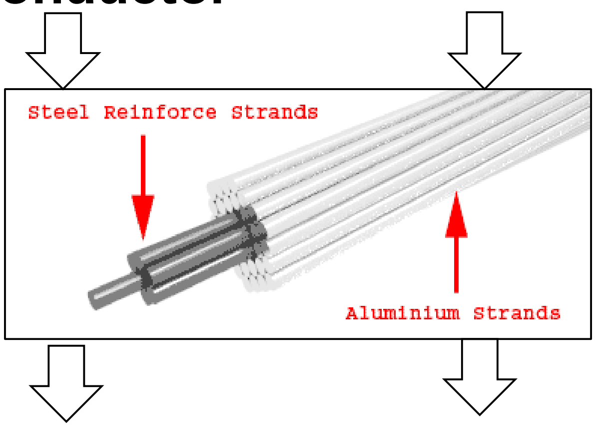


Line Rating Standards

- IEEE Std 738 -2012
- CIGRE Technical Brochure 601, 2014

Current flowing in the conductor

Solar radiation



Convection heat loss

radiation heat loss

- Heat Balance Equation(HBE)

$$q_c + q_r + mC_p \frac{dT}{dt} = q_s + I^2 R(T)$$

- Ambient conditions:
  - Temperature
  - Wind speed and direction
  - Solar radiation

Static Line Rating Adjustment

- Line Ratings in Practical Power System Operations
  - PJM Manual 03: Transmission Operations
    - Three sets of thermal limits:
      - normal limit
      - emergency limit
      - load dump limit
    - Eight ambient temperatures are used with a set for the night period and a set for the day period; thus, 16 sets of three ratings are provided for each monitored facility.

All Transmission Owners' and the PJM RTO's security analysis programs must be able to handle all 16 sets and allow operating personnel to select the appropriate rating set to be used for system operation.

ISO New England Equipment Rating, Characteristic, and Operational Data Implementation Form Transmission Line (NX-9A)

Reference	555	**Participant ID**	12345
Participant	Test Company	**ISO ID**	12345-3
Form State	Submitted	**Ckt**	1

Conductor Type	795 MCM 36/1 ACSR and 1113 ACSS 45/7 Blue Jay	**ISO EMS ID**	12345-3		
Terminal A	Station1 115kV	**Bus #**	987654	**EMS**	STATION1
Terminal B	Station2 115kV	**Bus #**	654321	**EMS**	STATION2

Cable Type Overhead **Nominal System Voltage (kV)** 115 **Conductor Length (mi.)** 12.26

Default Summer 100 F **Wind** 3 ft/s

	MVA	Limiting Device / Description	Location
Normal	208	Bus – Wire Bus	Station1
LTE	244	Breaker – 123CB	Station2
STE	261	Conductor – 1113 ACSS	Line
DAL	328	Conductor - 1113 ACSS	Line

Default Winter 50 F **Wind** 3 ft/s

	MVA	Limiting Device / Description	Location
Normal	200	Bus – Wire Bus	Station1
LTE	200	Breaker – 123CB	Station2
STE	200	Conductor - 1113 ACSS	Line
DAL	200	Conductor - 1113 ACSS	Line

Impedance Data (%) (100 MVA Base)

R 0.8507 **X** 5.4413 **B** 0.758

Revision Comments Reconductored section of the line with 1113 ACSS 45/7 Blue Jay from Structure X to Structure Y

Equipment Notes Open field available for Participant to supply pertinent information about the equipment or the manner in which it is operated.

Data Revision Number	2	**Date Created**	03/03/2014	**Prepared By**	Participant Username
Requested Effective Date	04/30/2014	**Date Received**	03/03/2014	**Approved By**	
Actual Effective Date	04/01/2014			**ISO EMS Implementation Date**	

ssion

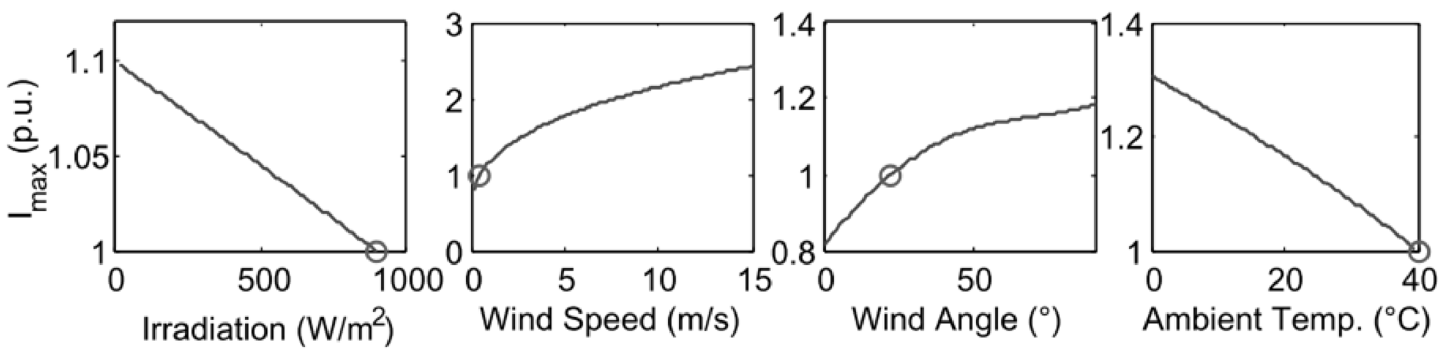
nple),

Flexible Line Rating

- Static Line Ratings
  - Steady State HBE

$$q_c + q_r + \quad 0 \quad = q_s + I^2 R(T)$$

    - CIGRE Technical Brochure 299 : Select Parameters
    - Sensitivity of the ampacity w.r.t. different meteorological conditions*:



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* M. Bucher, On Operational Flexibility in Transmission Constrained Electric Power Systems, ETH ,2016

Flexible Line Rating

- Dynamic Line Ratings

> Dynamic line ratings adapts the **prevalent weather conditions**, **real-time conductor temperatures** and **actual loading** of transmission lines.

- Dynamic Line Rating in Practical Power System Operations
  - United States: Oncor, ERCOT's security constrained economic dispatch model.
  - Europe: Currently only used for information, alarms to dispatchers and others.

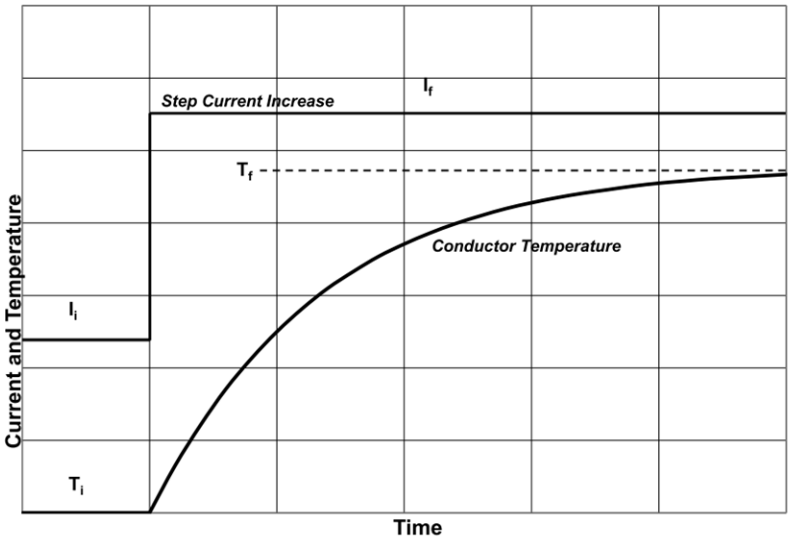
Flexible Line Rating

- Dynamic Line Ratings
  - Dynamic Line Rating in Research
    - Davis, 1977: First proposed dynamic line ratings(DLR)
    - Foss, 1990: impacts of DLR on system security
    - Michiorri, 2015; Fan, 2016: Probabilistic forecast of DLR
    - Nick,2016: HBE in unit commitment; select representative scenarios of weather conditions
    - Tschampion, 2016: DLR in N-1 secure dispatch optimization
    - Cheung, 2016: DLR in security constrained economic dispatch

Flexible Line Rating

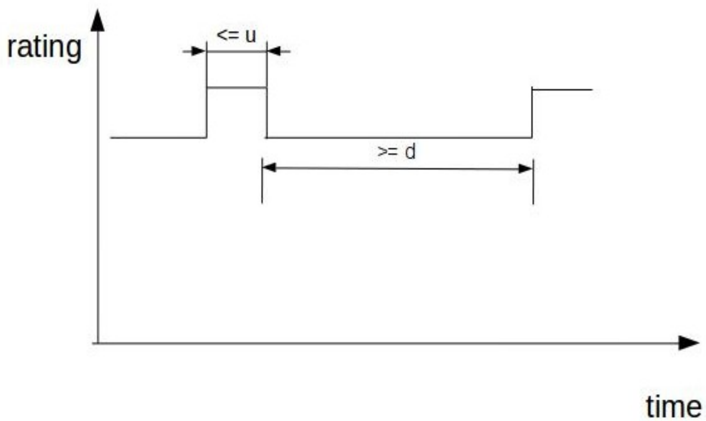
- Motivation
  - Lack of measurement/forecast of meteorological conditions in day-ahead operations.
  - HBE:thermal inertia of

$$q_c + q_r + mC_p \frac{dT}{dt} = q_s + I^2 R(T)$$



Flexible Line Rating

- Formulation



Line Status Variables:

$s^{0}_{ij,t,sc}$: 1 if line *ij* is switched off in scenario *sc* at time *t*

$s^{1}_{ij,t,sc}$: 1 if line *ij* adopts normal rating in scenario *sc* at time *t*

$s^{2}_{ij,t,sc}$: 1 if line *ij* adopts high rating in scenario *sc* at time *t*

$$s^{0}_{ij,t,sc} + s^{1}_{ij,t,sc} + s^{2}_{ij,t,sc} = 1 \quad , \forall ij,t,sc$$

Flexible Line Rating Formulation

1) line flow constraints:

$$-M(s^1_{ij,t,sc} + s^2_{ij,t,sc}) \leq e_{ij,t,sc} - B_{ij}(\theta_{i,t,sc} - \theta_{j,t,sc}) \leq M(s^1_{ij,t,sc} + s^2_{ij,t,sc})$$

2) line flow limit constraints:

$$-r^{normal}_{ij} s^1_{ij,t,sc} - r^{high}_{ij} s^2_{ij,t,sc} \leq e_{ij,t,sc} \leq r^{normal}_{ij} s^1_{ij,t,sc} + r^{high}_{ij} s^2_{ij,t,sc}$$

3) maximum time allowed to adopt high rating

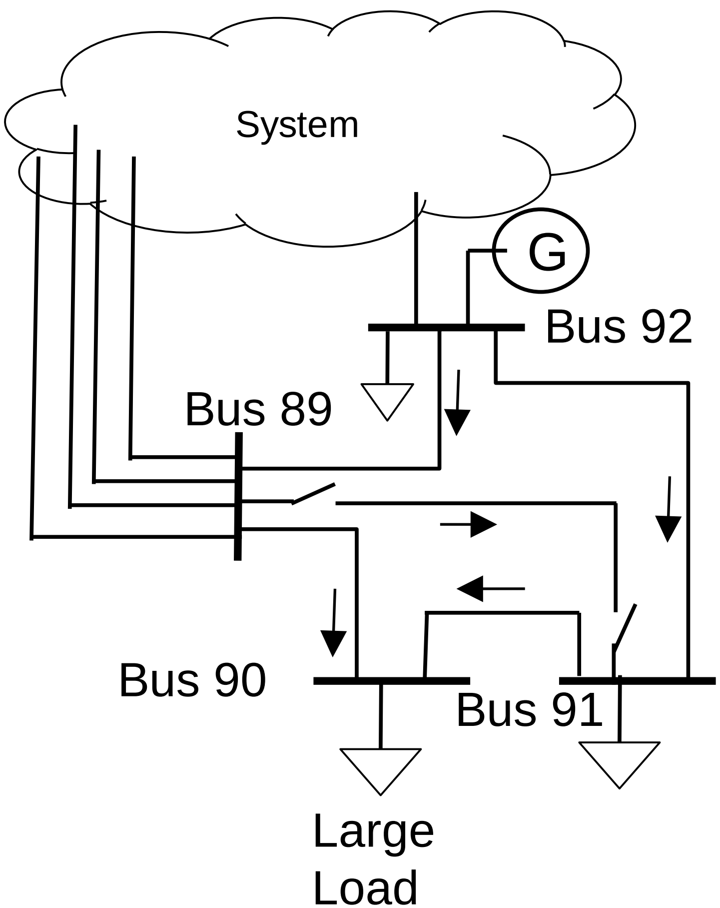
$$\sum_{t=t_0}^{t_0+u_{ij}+1} s^2_{ij,t,sc} \leq u_{ij}$$

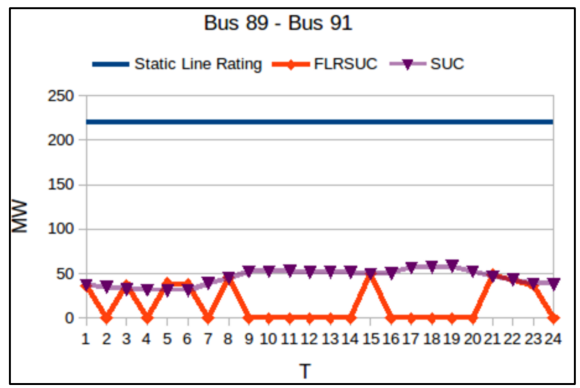
4) minimum time allowed to cool down:

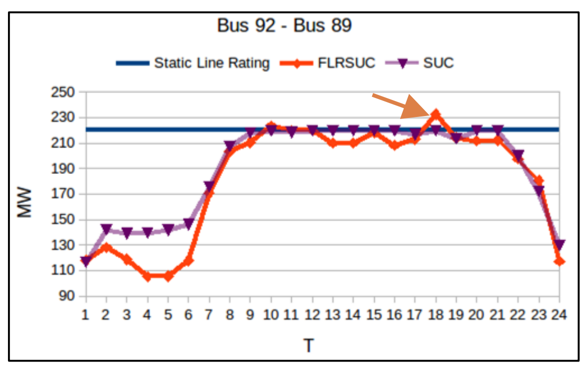
$$\sum_{t=t_0}^{t_0+d_{ij}+1} (s^1_{ij,t,sc} + s^0_{ij,t,sc}) \geq d_{ij}(s^2_{ij,t_0,sc} - s^2_{ij,t_0-1,sc})$$

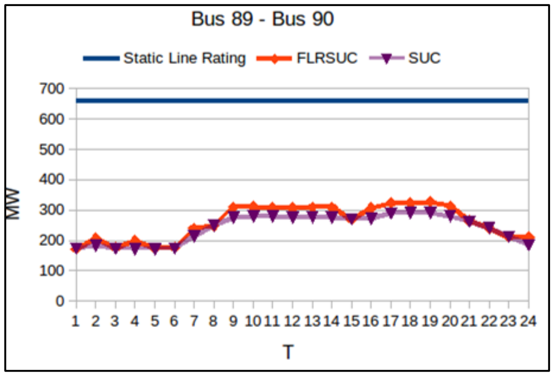
IEEE 118 System Test Results

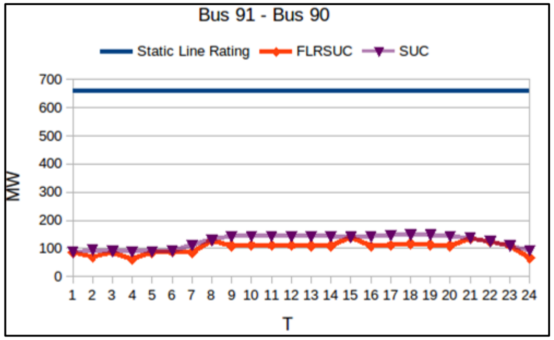
With flexible line rating (including switching), the cost of stochastic unit commitment can be reduced by 19%.

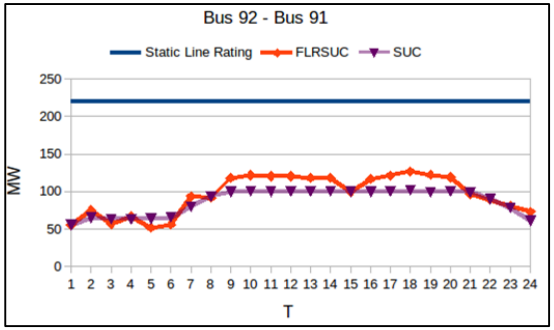






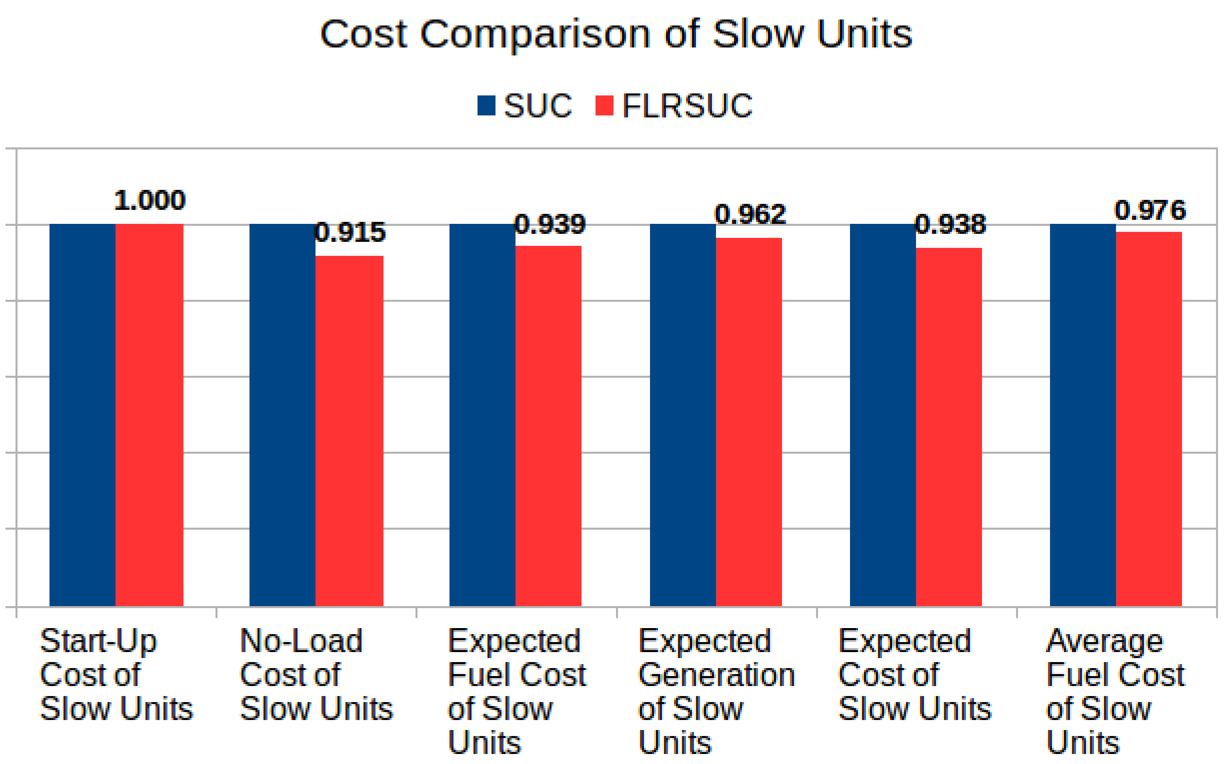






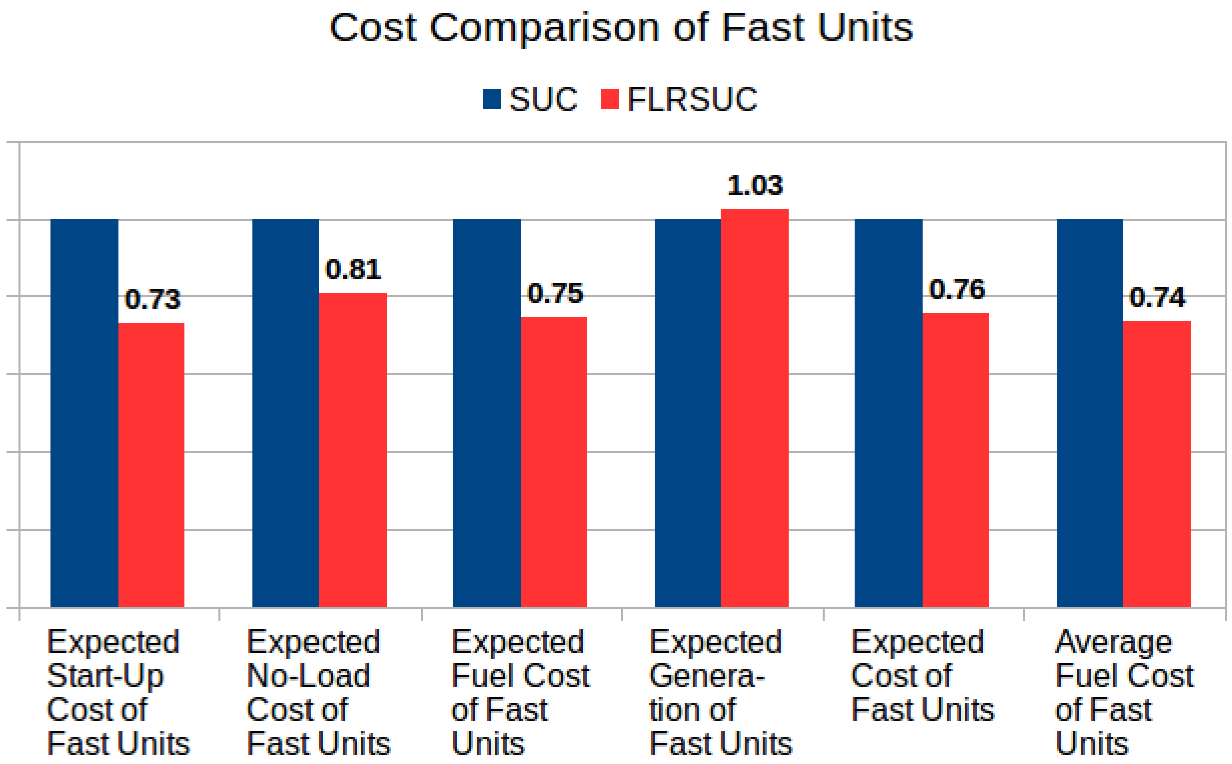
IEEE 118 System Test Results

- Results Analysis



IEEE 118 System Test Results

- Results Analysis



Model Complexity

- TCSUC
  - With 10 scenarios, there are around 1 million continuous decision variables and over 400,000 binary decision variables.
  - For a single scenario sub-problem, there are over 70,000 binary decision variables
  - In the zone of FR+CH, with 10 scenarios, there are around 170,000 binary decision variables and over 500,000 continuous variables. The solution time for this zone is within 8hr.

Model Complexity

- FLR
  - With 10 scenarios, there are around 1 million continuous decision variables and over 900,000 binary decision variables.
  - For a single scenario sub-problem, there are over 120,000 binary decision variables
  - In the zone of FR+CH, with 10 scenarios, there are around 450,000 binary decision variables and over 500,000 continuous variables. The solution time for this zone is around 18 hr.

Computation Platform Information

- Platform description
  - Laptop: Intel i7 CPU (2.8GHz)+ 12 GB Memory
  - Solver: CPLEX 12.5
  - Choosing Steepest-edge pricing as the algorithm for the pricing applied in the dual simplex algorithm for the linear relaxation problem at each node can significantly reduce the solution time caused by dual degeneracy.

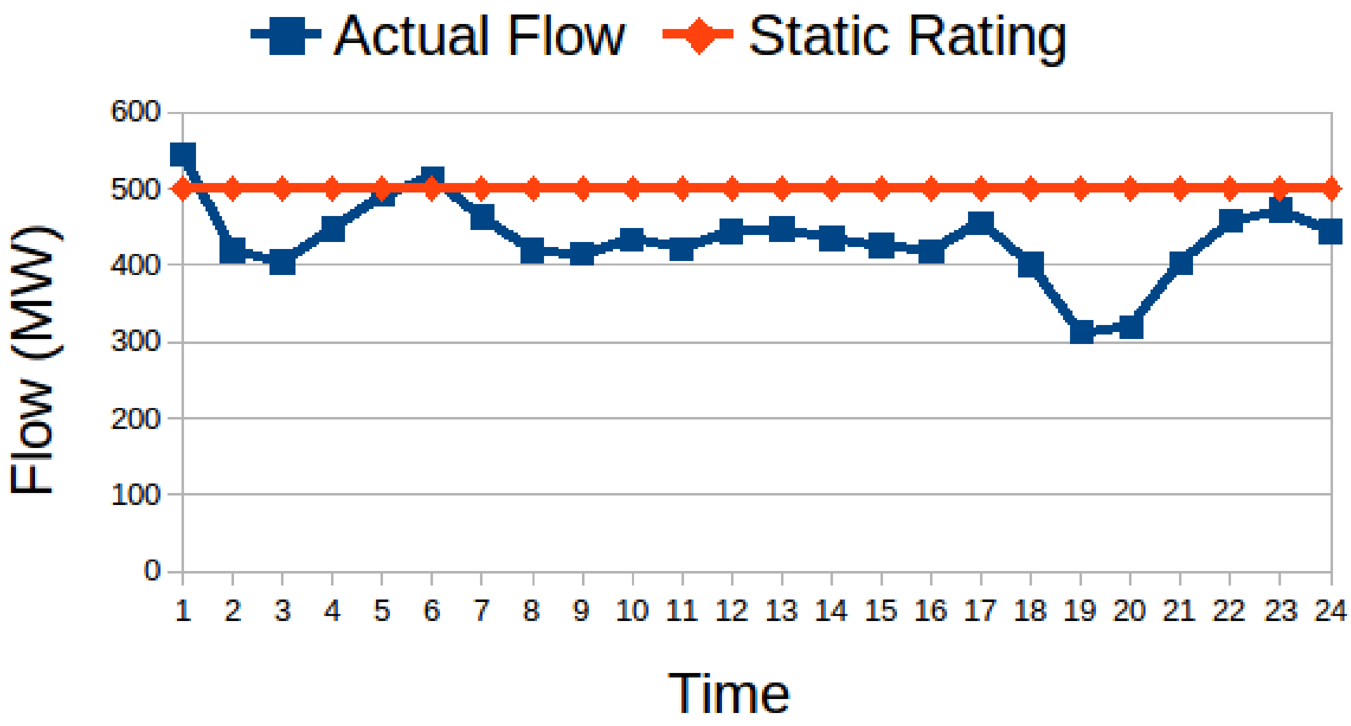
Test Results

- FLRSUC vs. SUC: Cost Savings

	SUC (MEUR)	FLRSUC (MEUR)	Cost Saving (MEUR)
AT	7.0057	6.7980	0.2077
BE+LX	**6.2083**	**6.1850**	**0.0233**
DE	14.2089	13.9496	0.2593
FR+CH	**17.3961**	**15.5977**	**1.7984**
NL	10.5475	10.3642	0.1833
Total	55.3665	52.8945	2.472

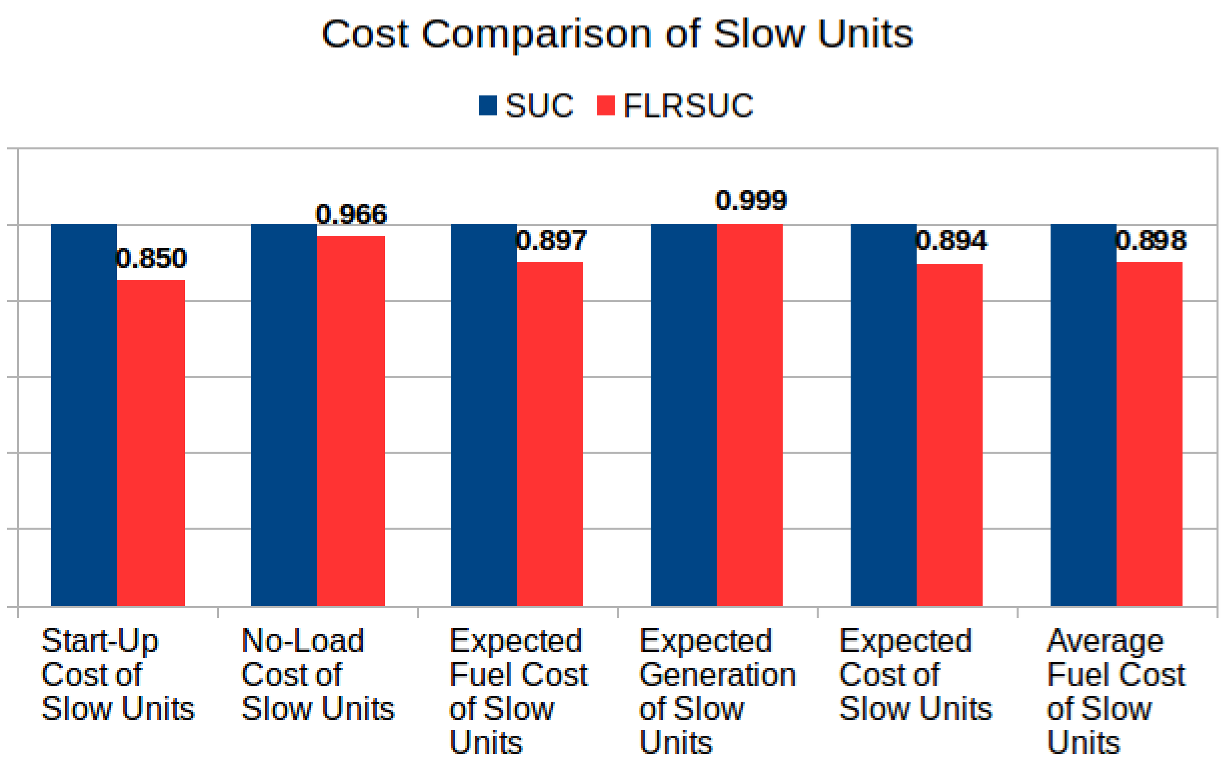
Test Results

- FLRSUC vs. SUC: Result Analysis
  - Zone FR+CH



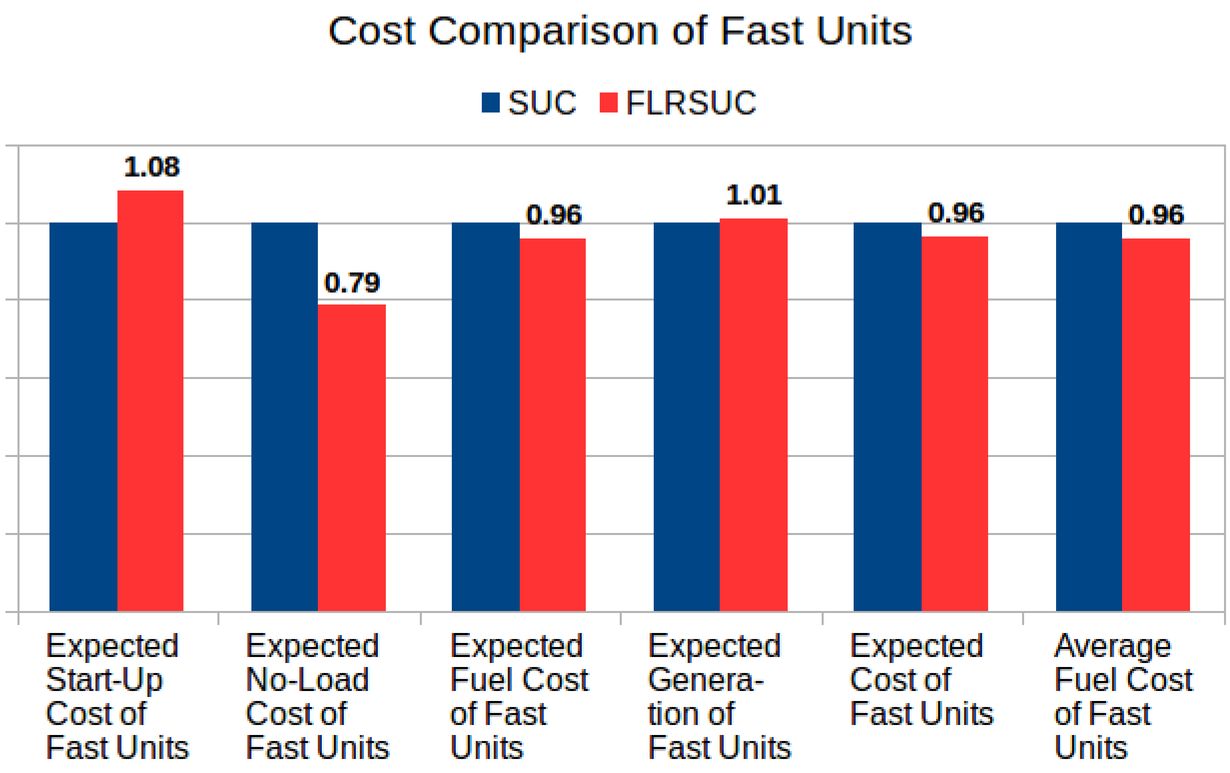
Test Results

- FLRSUC vs. SUC: Result Analysis
  - Zone FR+CH



Test Results

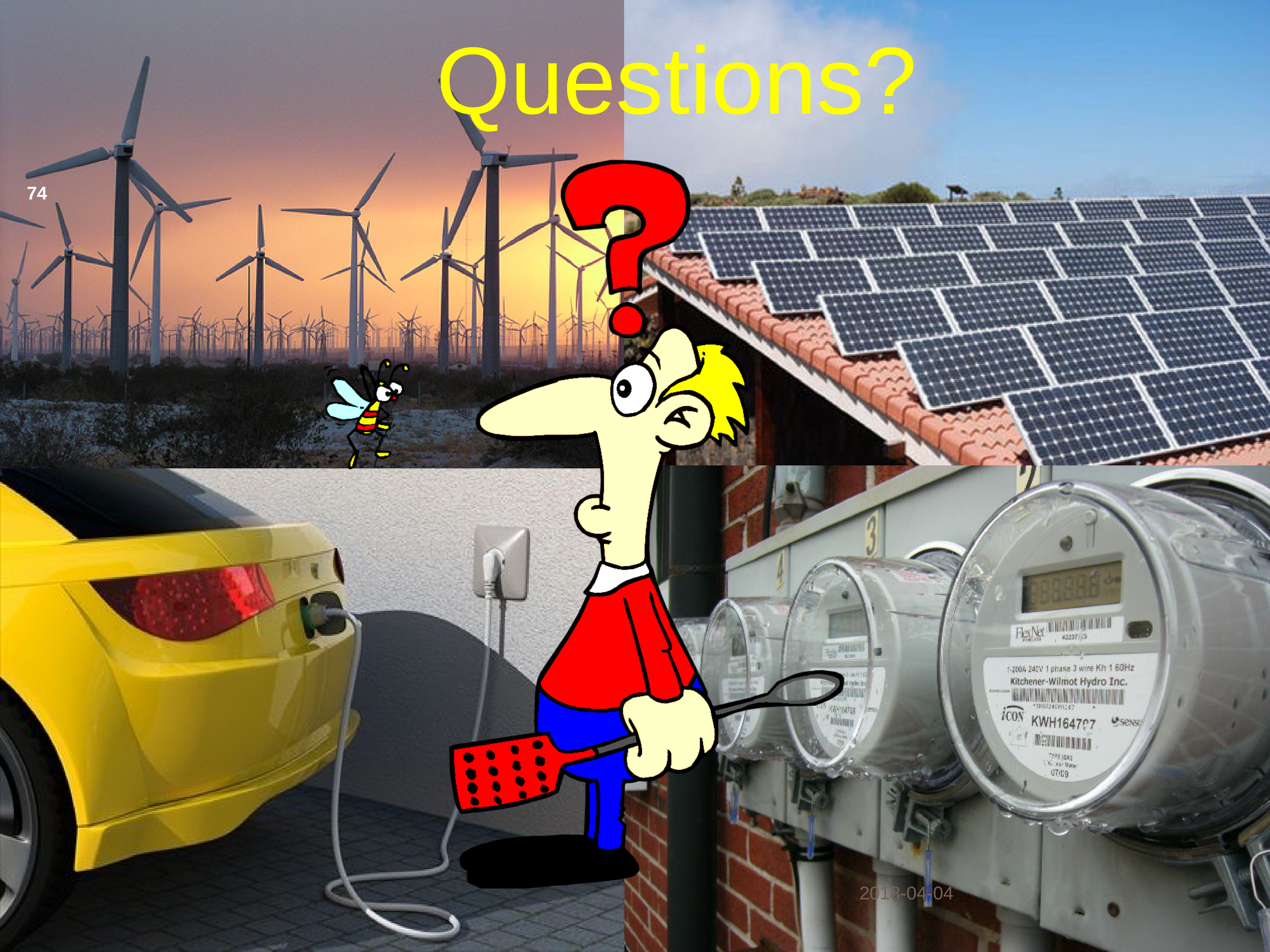
- FLRSUC vs. SUC: Result Analysis
  - Zone FR+CH



Conclusion

- Topology control and flexible line rating can both reduce the operating cost
- Flexible transmission network control can mitigate the variability of renewable generations so that cheaper slow generators can commit in the first stage.

Questions?



FlexNet
1-200A 240V 1 phase 3 wire Kh 1 60Hz
Kitchener-Wilmot Hydro Inc.