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Using High Performance Computing to Solve Unit Commitment Problem

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Electricity Infrastructure – Analytics, Operation Research

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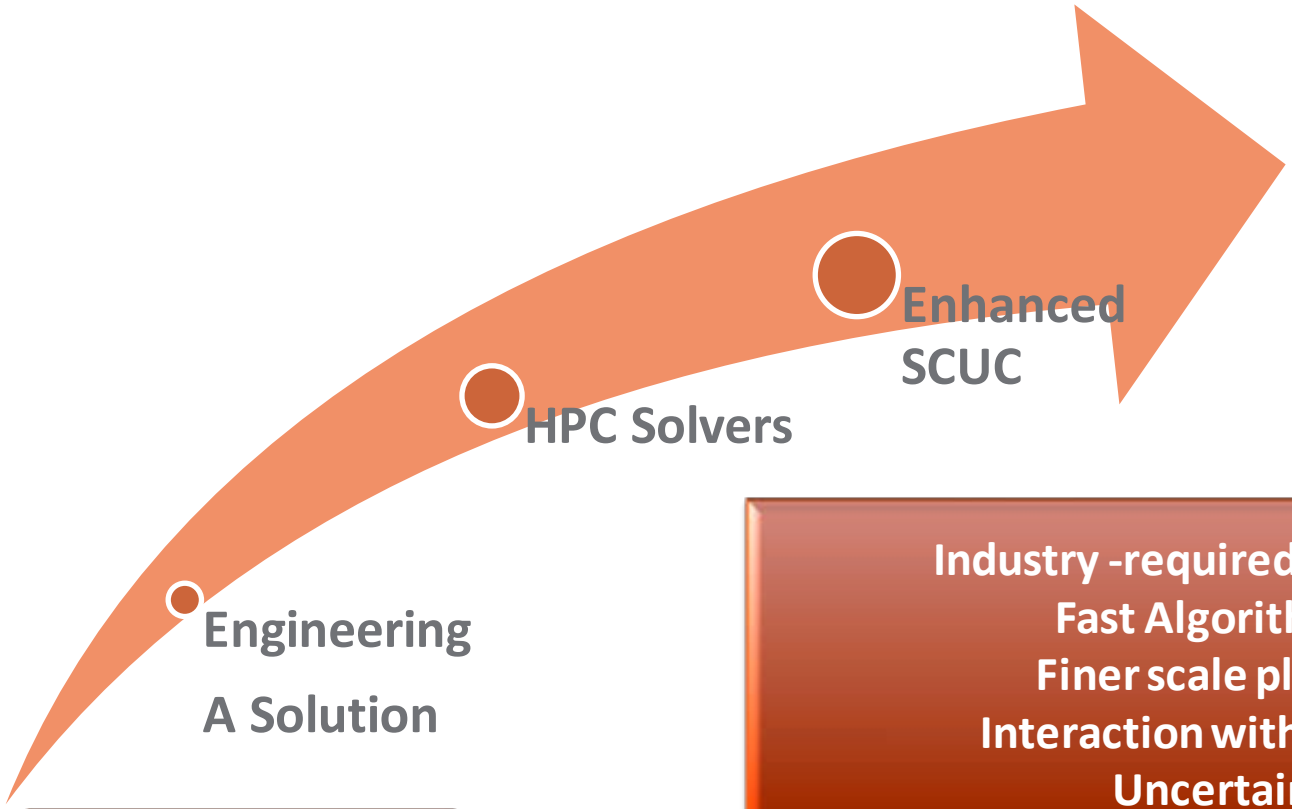
U.S. DEPARTMENT OF ENERGY

Overview of HPC-based Solution



ISO
Efficient and Reliable Operation

Industry -required capabilities
Fast Algorithm for
Finer scale planning
Interaction with operator
Uncertainty
Based on ACOPF

Unit Commitment
ACOPF

Unit Commitment

- **Unit commitment problem** - define the trajectory for the daily operation in a power system
  - Ideally, smaller interval (5-minute). Currently, hourly interval.
  - Ideally, iterations between UC and other tools. Currently, a few iterations.
  - Ideally, incorporate uncertainties. Currently, maybe/some.
  - Ideally, AC power based. Currently, based on DC power flow.
  - Challenge – **Fast algorithms to solve deterministic UC**.

ACOPF

- **AC power flow model** – master equations of the power system
  - Individual voltage, current, power, angle at buses and their interdependence
  - Steady state
  - Frequency not included
- **AC optimal power flow** – minimum feasible generation dispatch
  - Active research area, but not widely used in the industry
  - DCOPF is used with validation from AC power flow model
  - ACOPF is computationally hard and cannot be solved fast enough
- Value for industry – replacing DC with fast ACOPF solvers

Research in ACOPF and Unit Commitment

IEEE Publications

- **OPF (1968-) 2329**

Top 25 most cited:

  - Survey
  - Software
  - Newton, interior,
  - Distributed
  - Security constrained
  - Stability
  - Heuristic
  - Zero duality
  - Market product
  - Real-time

- **Unit commitment (1966-) 1726**

Top 25 most cited:

  - Survey
  - MIP formulation
  - Renewable integration
  - Lagrangian relaxation
  - Decomposition
  - Heuristics (genetic, SA, priority list)

Make Unit Commitment Decisions

- Making unit commitment decisions is more than solving UC as a MIP.
- System and business requirements and new technologies will affect the problem size, density of non-zeroes, even types of constraints.
  - Some can be solved by problem specifications
  - Some can be solved by using engineering and system knowledge
  - Some need advances in algorithms
- HPC enabled software connected with industry tool.
- Fast solution will enable better models.

Our Approach

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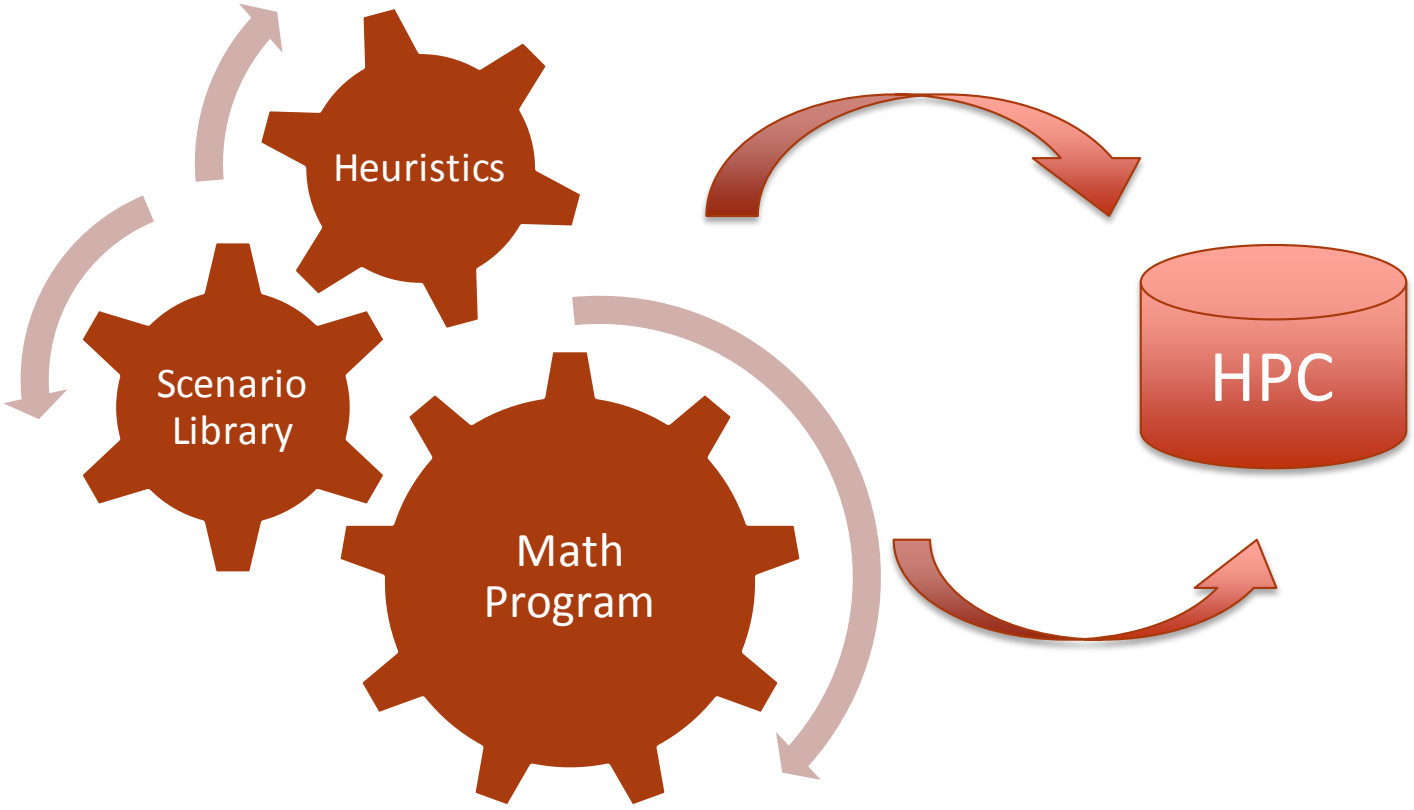
Engineer fast algorithms to solve UC with 5-minute interval

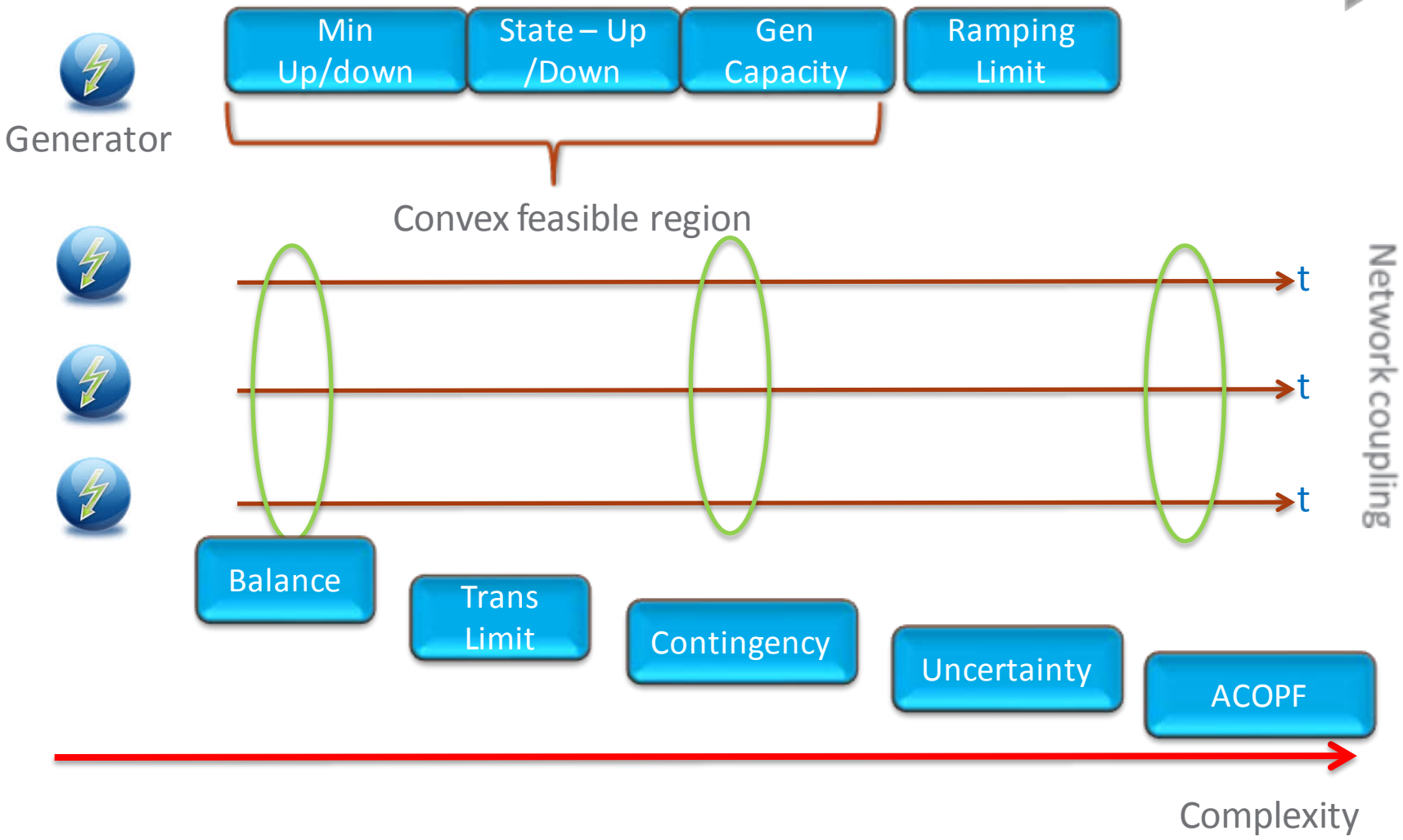


Optimization + System & Market Knowledge

Preliminary Study

- Understand characteristics of UC solutions.
- Large amount of time is spent at root node.
- Difference between a MIP solution and a LP solution.
- Understand the performance of heuristics.

Unit Commitment



Unit Commitment

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Min Up/down

$$\sum_{k=t-T_i^U+1}^{t} v_{ik} \leq u_{it} \quad \forall i, t \in [T_i^U, T]$$

$$\sum_{k=t-T^D+1}^{t} w_{ik} \leq 1 - u_{it} \quad \forall i, t \in [T_i^D, T]$$

State – Up /Down

$$u_{it} - u_{it-1} = v_{it} - w_{it} \quad \forall i, t$$

Gen Capacity

$$p_{it} + r_{it} \leq (\bar{P}_i - \underline{P}_i)u_{it} - (\bar{P}_i - S_i^U)v_{it} \quad \forall i \in N^1, t$$

$$p_{it} + r_{it} \leq (\bar{P}_i - \underline{P}_i)u_{it} - (\bar{P}_i - S_i^D)w_{it+1} \quad \forall i \in N^1, t$$

$$p_{it} + r_{it} \leq (\bar{P}_i - \underline{P}_i)u_{it} - (\bar{P}_i - S_i^U)v_{it} - (\bar{P}_i - S_i^D)w_{it+1} \quad \forall i \notin N$$

Convex Feasible Region

Ramping Limit

$$p_{it} + r_{it} - p_{it-1} \leq R_i^U \quad \forall i, t$$

$$-p_{it} + p_{it-1} \leq R_i^D \quad \forall i, t$$

Separable

Balance Reserve

$$\sum_{i \in N} \underline{P}_i u_{it} + p_{it} = D_t - l_t \quad \forall t \in T$$

$$\sum_{i \in N} r_{it} \geq R_t \quad \forall t \in T$$

Other constraints

MIP vs LP – State of Generators

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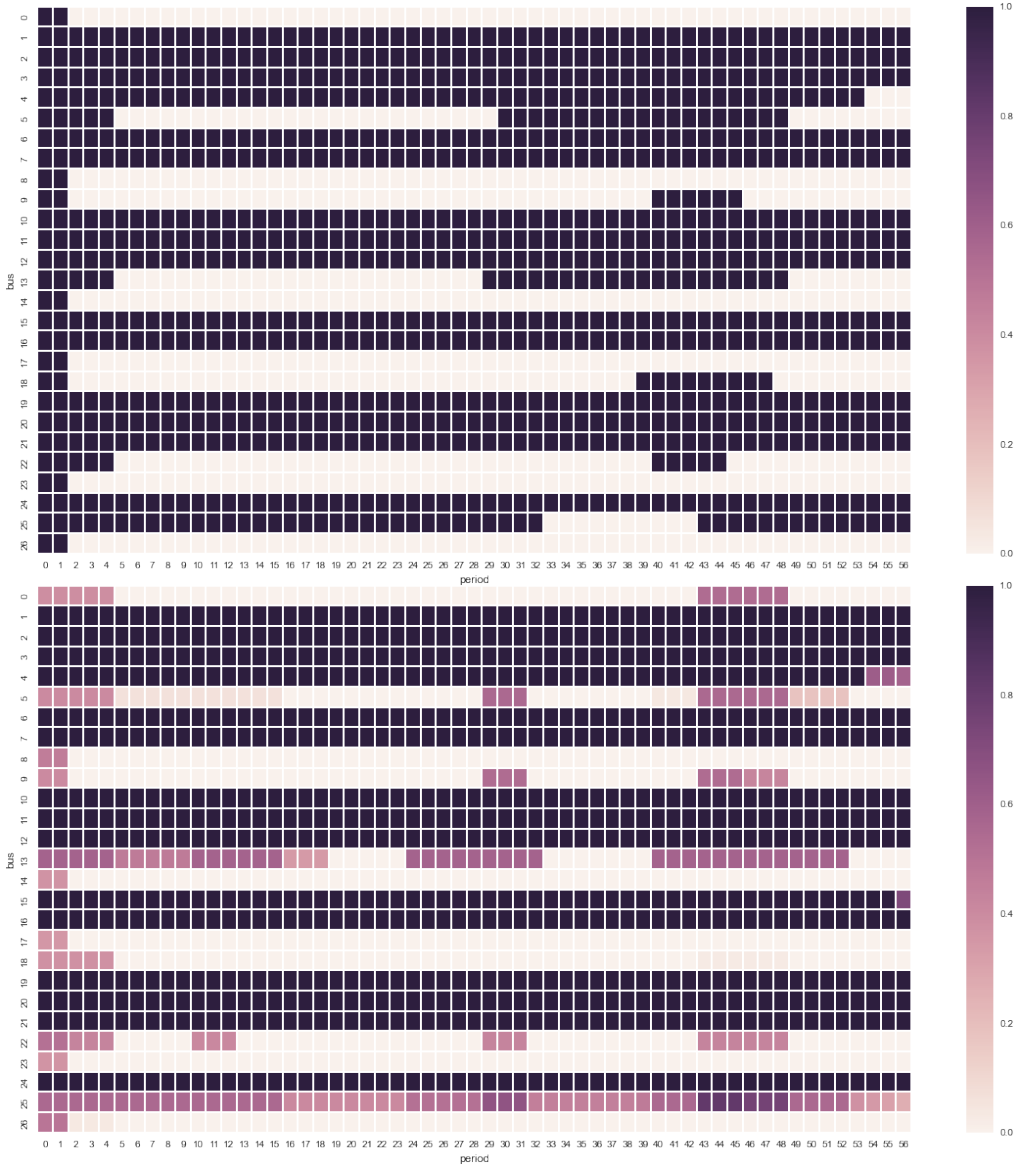
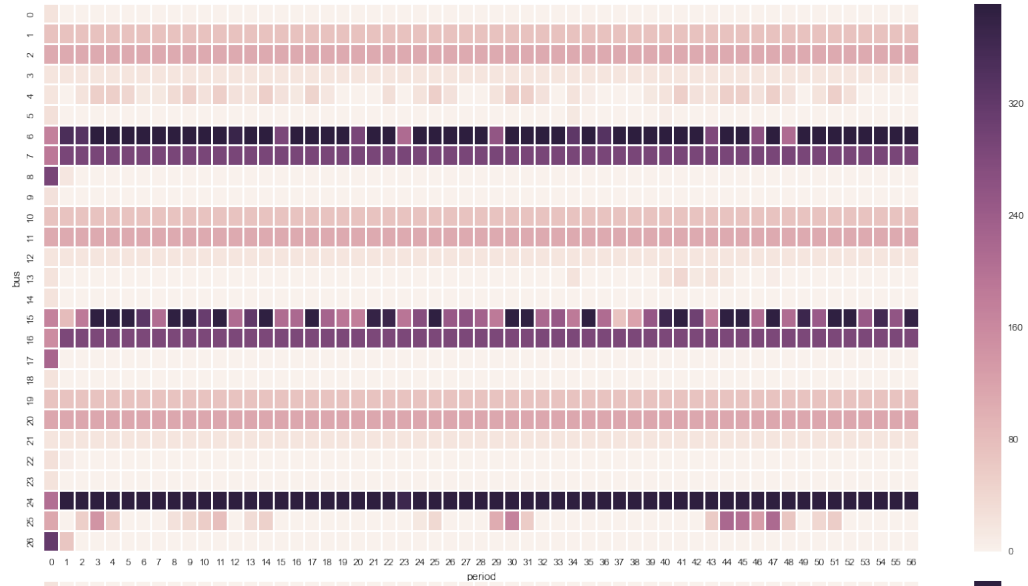
MIP

LP Relaxation

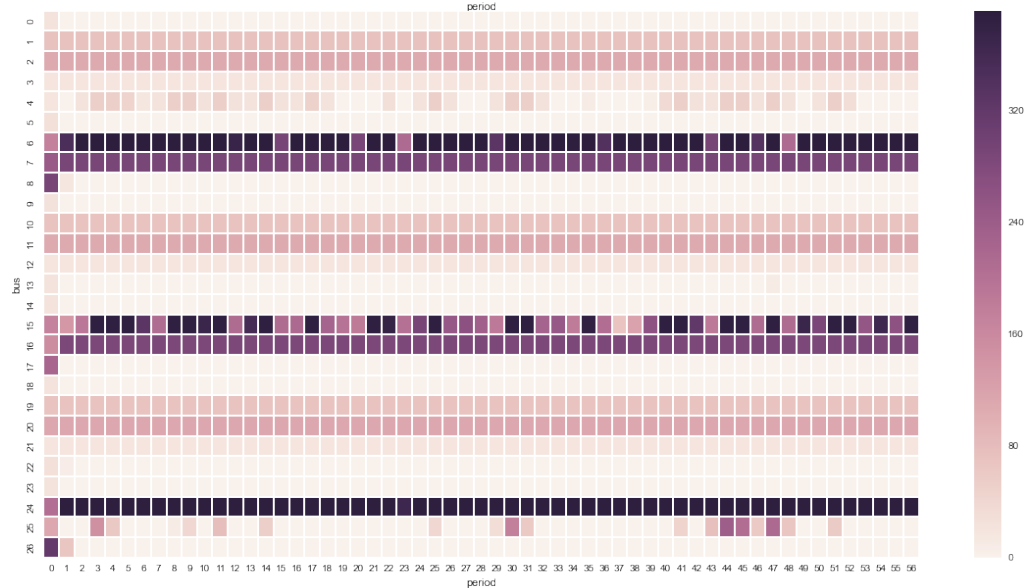


MIP vs LP – Dispatch

MIP



LP Relaxation



MIP vs LP – State and Dispatch

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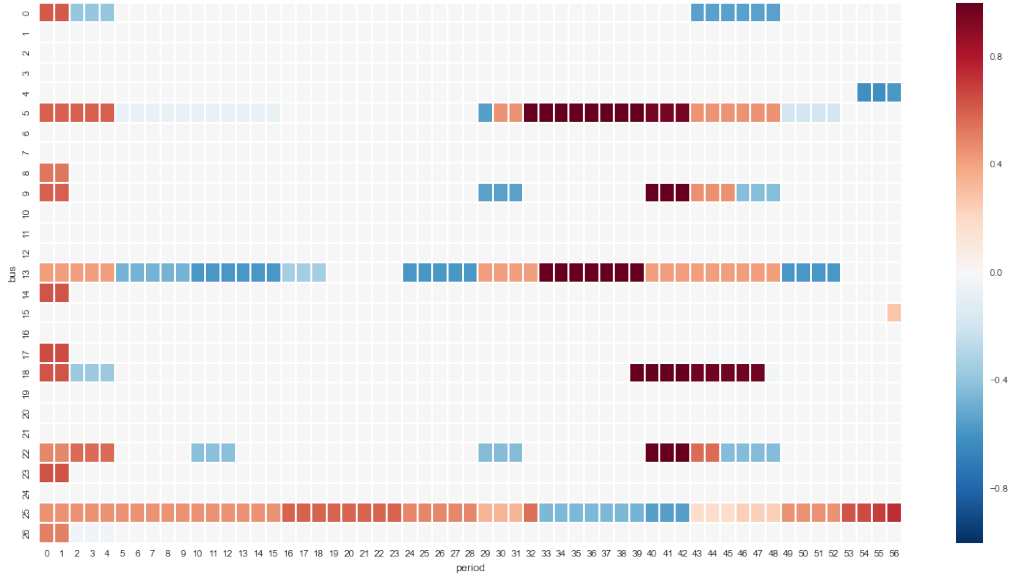
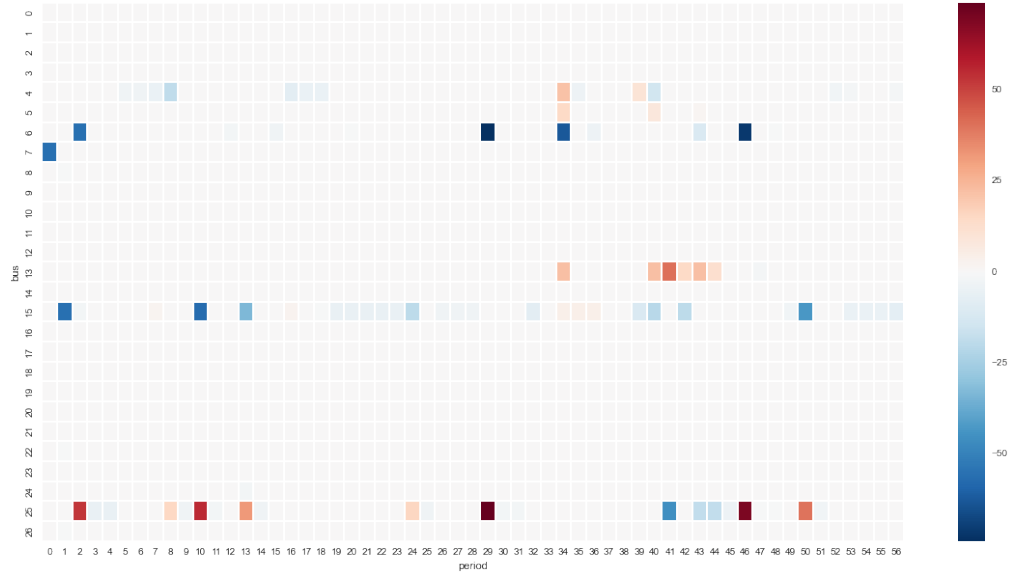
Difference in states

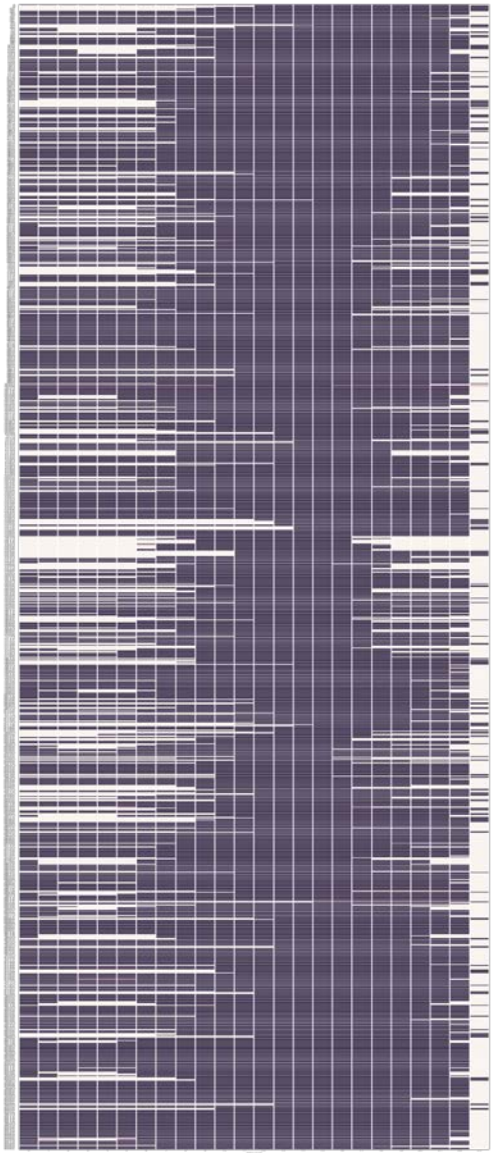


Difference in dispatch

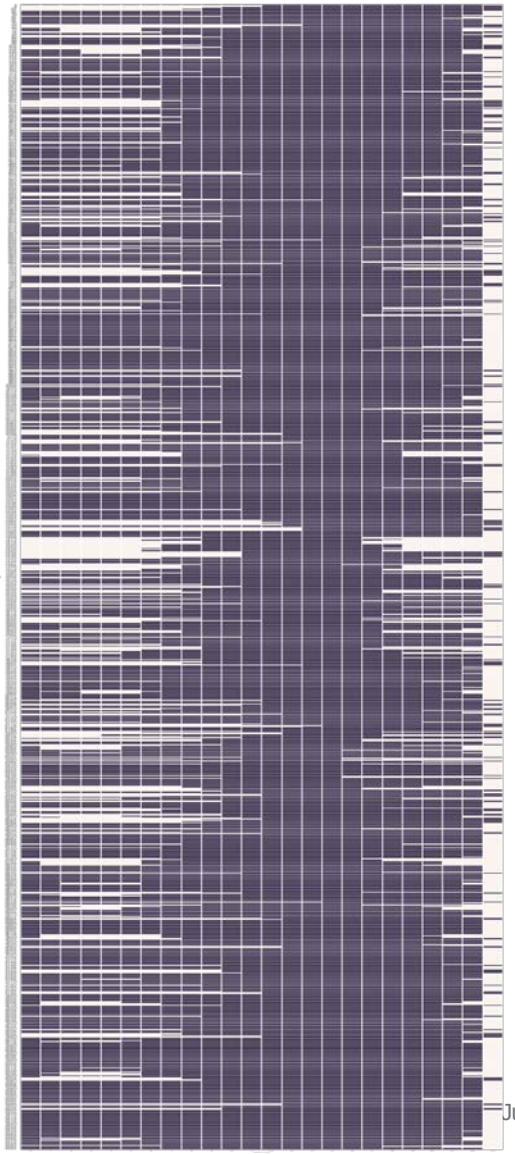


MIP vs LP – State of Generators

MIP

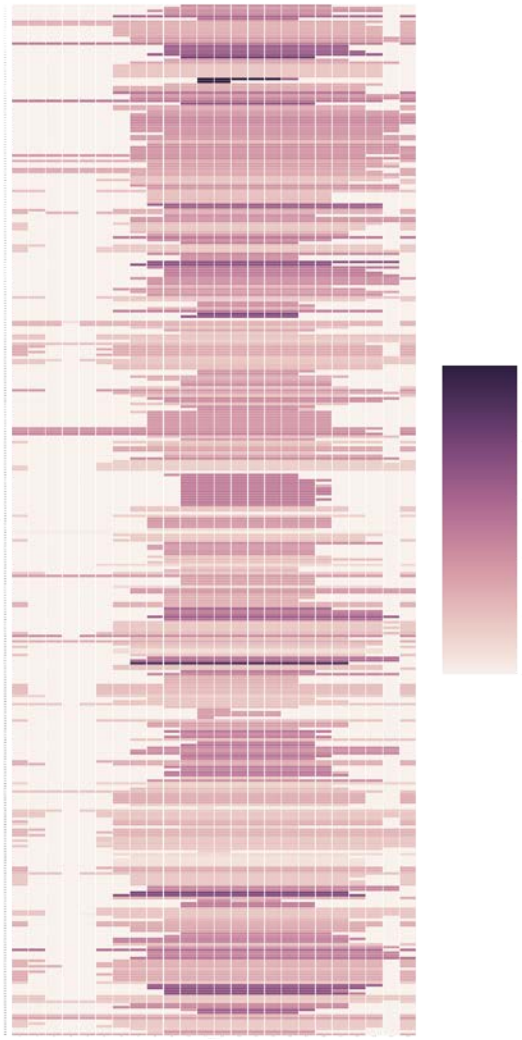


LP
Relaxation

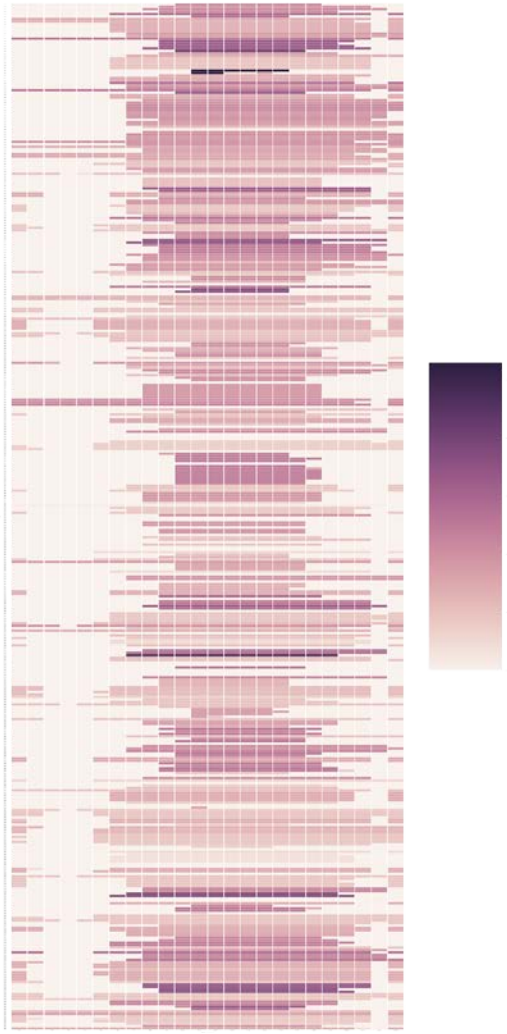


MIP vs LP – Generation Dispatch

MIP



LP
Relaxation



MIP vs LP – State and Dispatch

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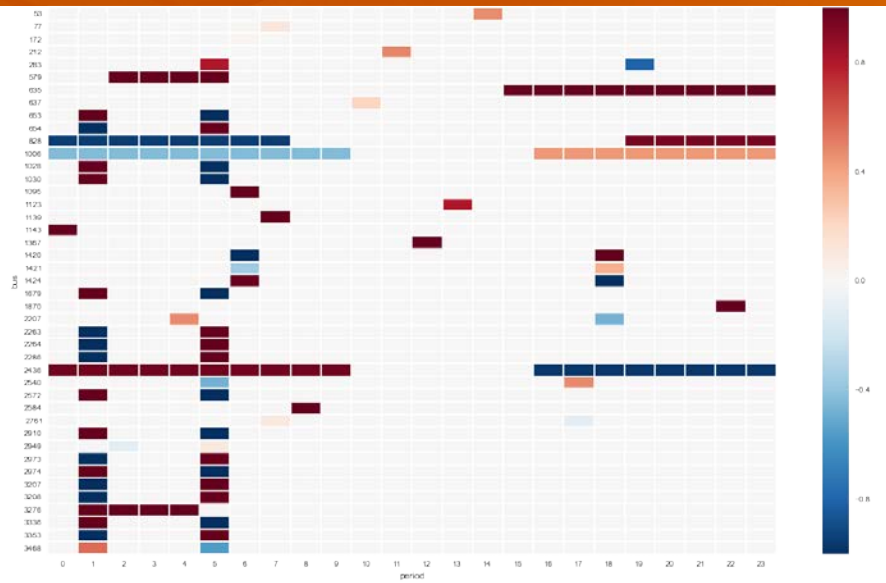
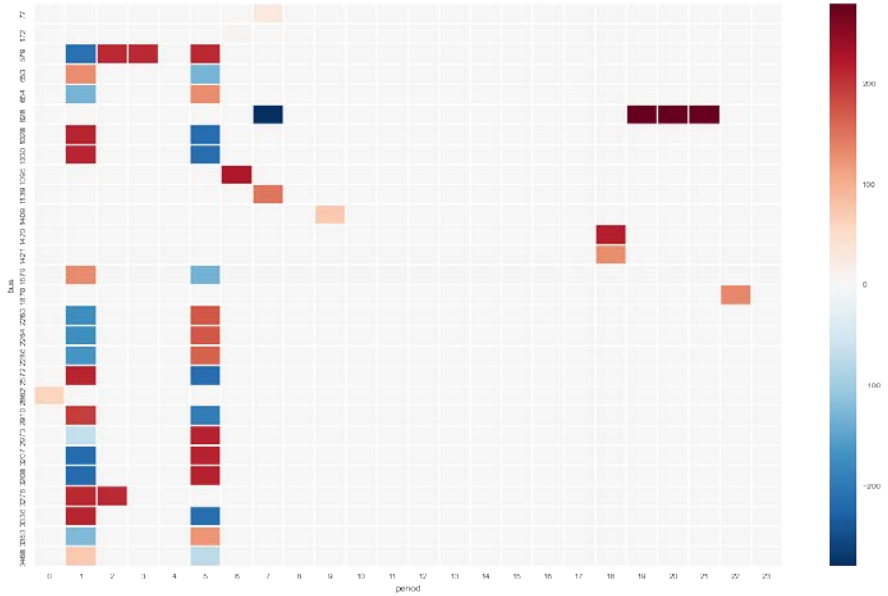
Difference in states



Difference in dispatch



LP Solution

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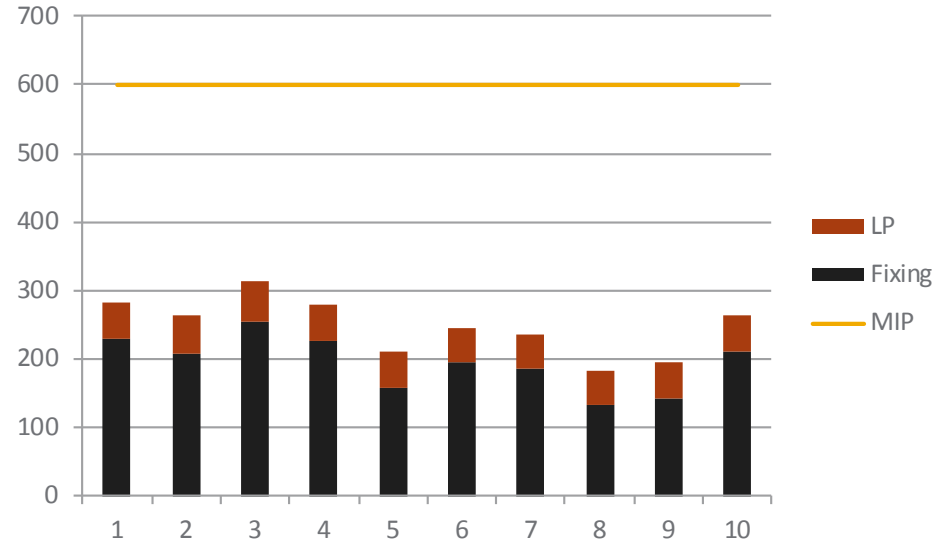
MP				LP		
State	Up	Down		State	Up	Down
1	0	0		1	0	0
1	0	0		1	0	0
1	0	0		1	0	0
1	0	0		1	0	0
0	0	1		0.433931	0	0.566069
0	0	0		1	0.566069	0
0	0	0		1	0	0
0	0	0		1	0	0
0	0	0		1	0	0
0	0	0		0.562624	0	0.437376
1	1	0		1	0.437376	0
1	0	0		1	0	0
1	0	0		1	0	0
1	0	0		1	0	0
1	0	0		1	0	0
1	0	0		1	0	0

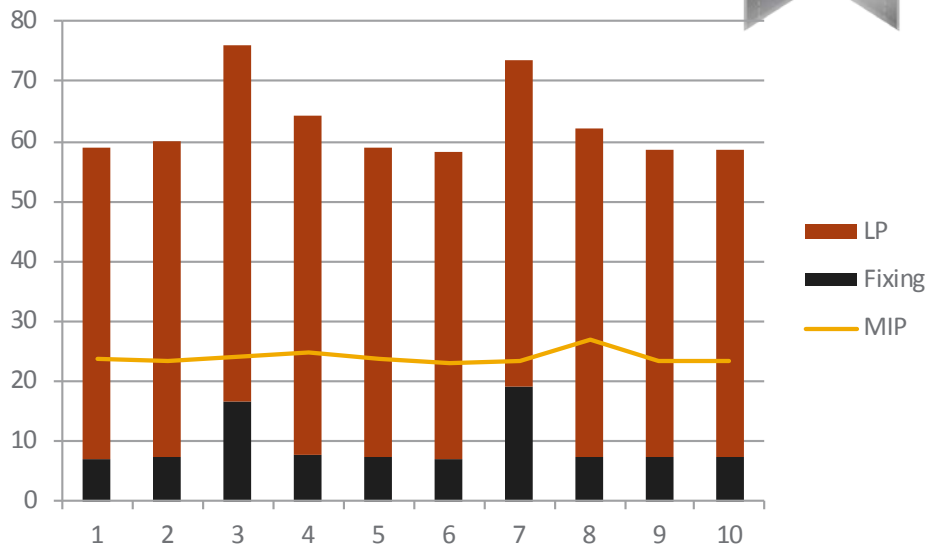
MIP			LP		
state	up	down	state	up	down
1	0	0	1	0	0
1	0	0	1	0	0
1	0	0	1	0	0
1	0	0	1	0	0
0	0	1	0.566069	0	0.433931
1	1	0	1	0.433931	0
1	0	0	1	0	0
1	0	0	0.433931	0	0.566069
1	0	0	0.4576	0.023669	0
1	0	0	0.4576	0	0
1	0	0	1	0.5424	0
1	0	0	1	0	0
1	0	0	1	0	0
1	0	0	1	0	0
1	0	0	1	0	0
1	0	0	1	0	0

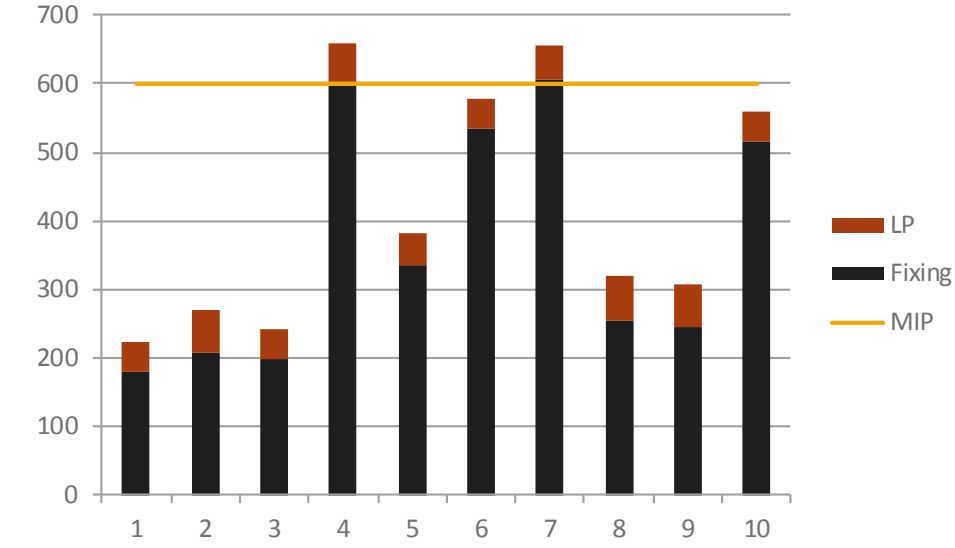
Heuristics

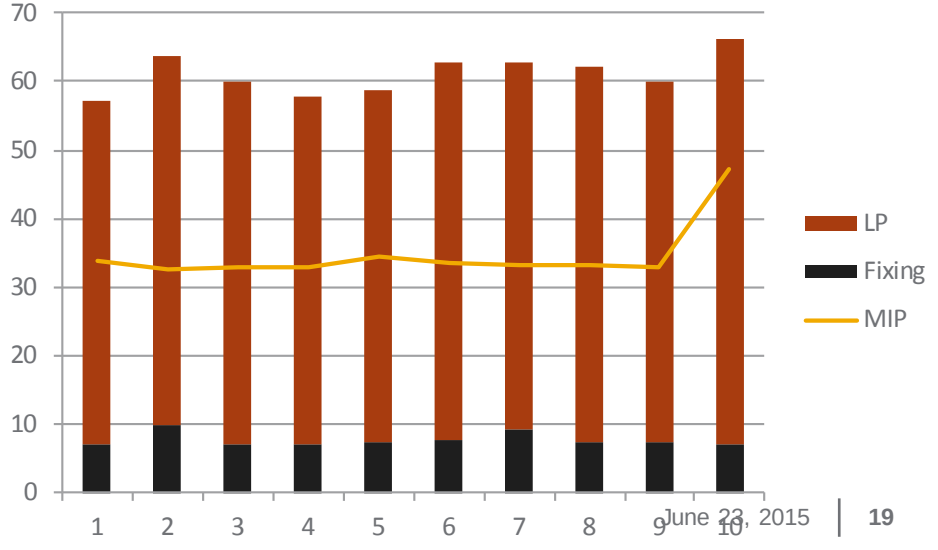
- Variable fixing
  - Solving LP relaxation (easier to parallel than MIP)
  - Fix a binary variable if fractional value is larger than a threshold
  - Solve the modified UC
- Randomized rounding
  - Solving LP relaxation (easier to parallel than MIP)
  - Fix a binary variable with probability proportional to its fractional value
  - Solve modified UC problems (parallelize many instances of randomized rounding)

Variable Fixing – Computational Time









UC Heuristics

- Observations
  - what made UC a hard problem - low loads, large range between lower and upper generation capacities.
  - "Similarity" between MIP and LP relaxation solutions.
  - Fixing 80-90% binary variables helps, but reduction in computing time is less than expected. Is there "critical" subset of binary variables making the problem hard to solve?
  - Next, we are going to explore the structure of LP solutions.

Acknowledge

- Many fruitful discussions with
  - Dr. Yonghong Chen (MISO)
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  - Dr. Edward Rothberg (GUROBI)

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Thank you