MISO R&D on Improving the Efficiency of Market Clearing Software

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Overview of MISO R&D on improving the efficiency of market clearing software

Market clearing optimization software performance

- Exiting commercial solver performance improvement through warm start and distributed solution process
- Development of high performance distributed and parallel computing based Security Constrained Unit Commitment (SCUC) and Security Analysis software (SFT) under ARPA-E HIPPO project (>4X improvement and aiming to 10X)

Price efficiency

- Developing full ELMP solution through resource convex hull formulation

Enhancing future resource modeling and clearing process

- Pumped storage hydro (DOE grant)
- DER and storage aggregation

Deliverability for energy and reserves & uncertainty management through stochastic approaches

- Co-optimized formulation for reserve deliverability
- Stochastic look ahead commitment: ARPA-E project

Commercial solver options [1]

Commercial Solvers, settings and SCUC model options

- Solver: CPLEX / Gurobi
- Solution method: Cold start / Warm start
- Design options: Production / Enhanced combined cycle configuration (ECC)

Warm Start includes two techniques:

- "MIP start": Use repaired initial commitment solutions (e.g. repaired previous day commitment) as the first incumbent solution
- Lazy Constraints: set unlikely to bind constraints as lazy to speed up MIP

Distributed SCUC: best_4

CPLEX-Cold | Gurobi-Cold | CPLEX-Warm-from-InitUC | Gurobi-Warm-from-InitUC | ...

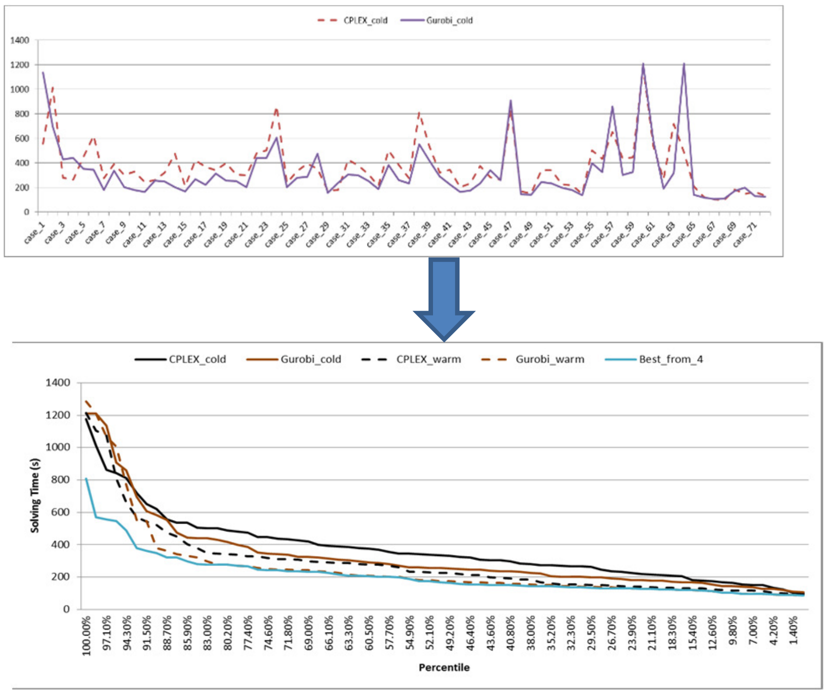
↓

The first reaching tolerance or the best at the time limit

SCUC performance benchmark

Large set of sample cases

- Sample T1: solving time from method 1,
- Sample T2: solving time from method 2



Developed statistic performance comparison index

Average performance improvement (**k-factor**)

- Sort T1 and T2 to get quantile distribution profile
- Compute k so that the confidence of the following test is ">97%"
  - $H(k):\ k \cdot T_1\ (p) - T_2(p) > 0$

Risk factor for bad cases

- Index to measure number of cases stopped at different time limits (1200s-1800s)
- High risk if high gap at time limit

K-factor example

Sorted CPLEX_cold solving time T_1

Sorted Gurobi_warm solving time T_2

DT=K*T_1-T_2

CPLEX_cold	*0.7553*	Gurobi_warm	*0.7553*CPLEX_cold-Gurobi_warm*
1177	889.0349286	1284.516	-395
1013	765.4021375	1211.687	-446.2848625
864	652.2725482	1068.266	-415.9934518
841	635.4202946	1004.969	-369.5487054
812	613.5400089	769.922	-156.3819911
718	542.4708107	551.281	-8.8101893
653	493.1164875	545.328	-52.2115125
622	469.6666884	377.282	92.3846884
555	418.9558464	362.172	56.7838464
536	404.8649696	340.016	64.8489696
534	403.3181152	329.859	73.4591152
504	380.4937045	320.609	59.8847045
502	379.3260107	295.766	83.5600107
501	378.594125	276.828	101.766125
487	368.0085955	275.078	92.9305955
480.078	362.6029134	268.422	94.1809134
475.484	359.1330652	268.11	91.0230652
447.265	337.8192545	256.156	81.6632545
446	336.9582125	248.047	88.9112125
437	330.0781848	245.406	84.6721848
433	326.7850768	245	81.7850768
427	322.7963375	242	80.7963375

$H(k): K*T_1 - T_2 > 0$

Adjust K so that the probability of the average of K*T_1-T_2>0 is greater than 97% (α=0.03)

$$\underline{k_{21}}^{\alpha} = \inf\{k \mid p\left(\overline{k \cdot T_1(p) - T_2(p)} > 0\right) > 1 - \alpha\}$$

With 97% confidence that Gurobi_warm takes less than **75.53%** of the time used by CPLEX_cold

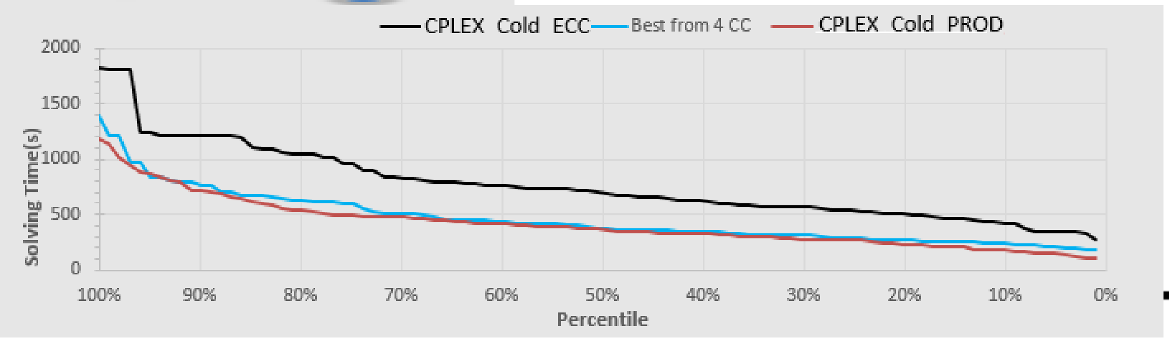
With 97% confidence that Gurobi_warm is 24% faster than CPLEX_cold on average

Comparing ECC prototype to existing production with commercial solver options (99 sample cases)

CPLEX_cold_ECC:
- 1.91x to solve compare to production "no ECC"
- High risk (4 cases at 99% gap in 1800s)

Best_4_ECC:
- 1.12x compared to production "no ECC"
- Much lower risk factor
  - no large gap at time limits

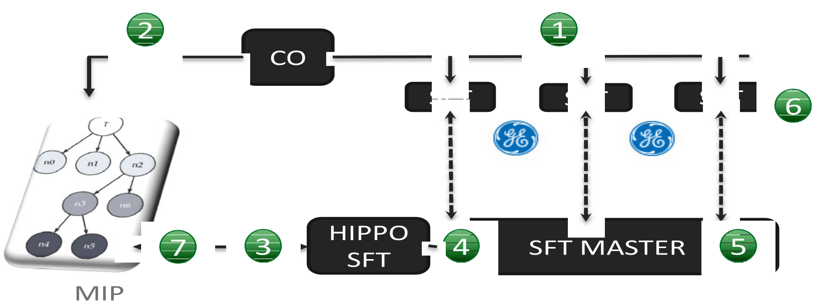
Scenario	1	6	10
Method	CPLEX_Cold_PROD	CPLEX_Cold_ECC	Best_4_ECC
$\bar{x}_j$ Sample mean	415.23	770.29	457.11
$\bar{x}_j/\bar{x}_1$ Sample mean ratio	1.00	1.86	1.10
$\underline{k}_{j1}^{0.03}$ K-factor		1.91	1.12
# of cases at 1200s (X1)	0	10	2
# of cases between 1200s and 1800s (X3)	0	0	1
# of cases with large gap at 1800s (X100)	0	4	0
Risk Index	0	410/99	5/99

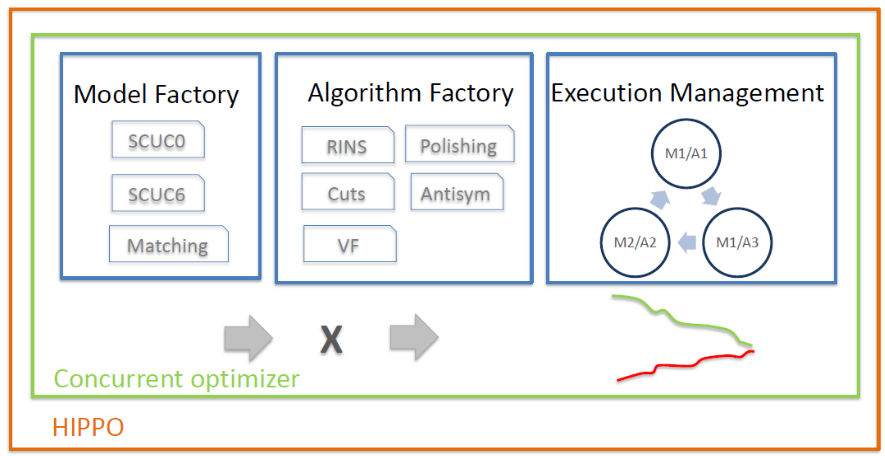


HIPPO Software Developed Under ARAP-E Project: Next Generation Clearing Engine*

Highlights

- Fast concurrent MIP with extremely fast SFT
- Configurable concurrent optimizer
- Executable in desktop and high performance computer.
- Data module, formulation factory, Algorithm Factory, Configuration Scripts.
- Python Programming Language
- Achieve >4X and aiming at 10X for median to hard cases.

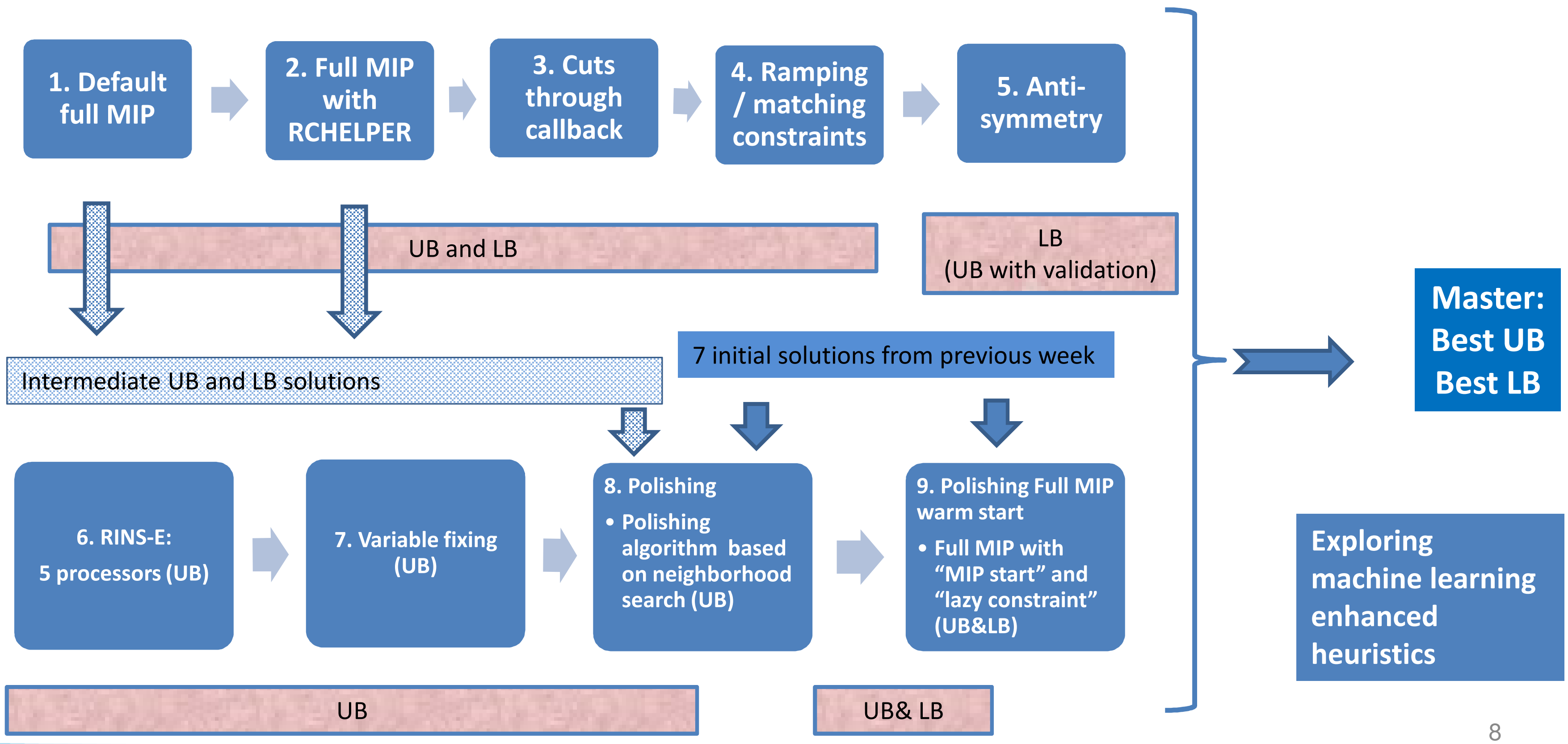




Presentations:
1) Feng Pan, Yonghong Chen, Jesse Holzer: HIPPO: A Concurrent Optimizer for Solving Day-ahead Security Constrained Unit Commitment Problem
2) Jesse Holzer, Yonghong Chen, Feng Pan, Edward Rothberg, Arun Veeramany, Fast Evaluation of Security Constraints in a Security Constrained Unit Commitment Algorithm

HIPPO Concurrent Optimizer MIP Solution Configuration

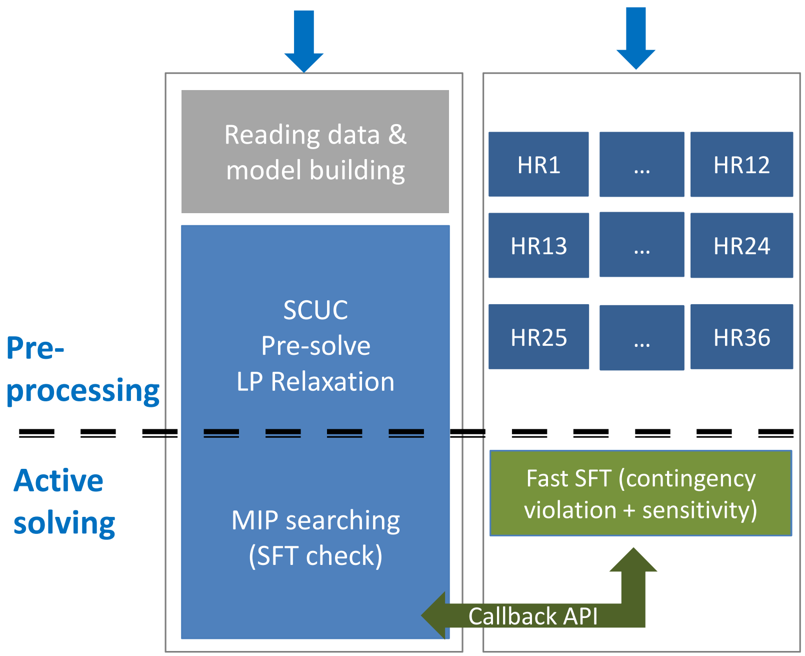
Gurobi full MIP with different settings:
Using customized **Gurobi8.1.0** with variable fixing fork-off



Fast HIPPO SFT

- Parallel processing; Configurable across nodes;
- Solve 36 intervals with 1000 contingencies and 10,000 monitored branches in less than 10s!

SFT matrix preparation runs in parallel with SCUC preparation



- SFT preparation for 36 large matrices can be a bottleneck and require >3 nodes.
- On-going work to process single large matrix and 35 delta
- 1,000 contingencies are processed as small delta to the base matrix

- 36 interval SFT in <10s on single node
- Allow using MIP callback to checks SFT and adds new constraints for each new incumbent solution

HIPPO fast SFT allows efficient communication between SFT & MIP through callback API. No need for SCUC-SFT iterations.

SFT configuration	3node*12processor	1node *12 processor	1node*36processor	6node*6processor
Pre-processing #Matrix/Node	12	12	36	6
#nodes	3	1	1	6
#Matrix	36	12	36	36
SFT check time | end time | #violation	40.22 | **195.70** | 252	39.85 | **197.47** | 252	418.73 | **572.77** | 252	5.82 | 161.28 | 252
	4.46 | 203.47 | 7	8.82 | 209.61 | 7	7.88 | 583.93 | 7	3.88 | 168.44 | 7
	4.34 | 237.23 | 1	8.73 | 248.44 | 1	7.84 | 620.60 | 1	3.84 | 201.45 | 1
	4.35 | 260.45 | 0	8.70 | 276.21 | 0	7.73 | 646.93 | 0	3.83 | 224.04 | 0
	4.40 | 276.81 | 0	8.23 | 296.49 | 0	7.42 | 666.12 | 0	3.80 | 239.68 | 0
	4.36 | 294.97 | 1	8.60 | 319.35 | 1	7.85 | 687.60 | 1	3.75 | 257.12 | 1
	4.35 | 312.84 | 1	8.70 | 341.97 | 1	7.65 | 708.68 | 1	3.77 | 274.27 | 1
	4.36 | 328.24 | 0	8.29 | 361.73 | 0	7.74 | 727.39 | 0	3.85 | 289.09 | 0
Total Time	419	452	816	378

SFT pre-processing 36 full matrix on 1 node is long

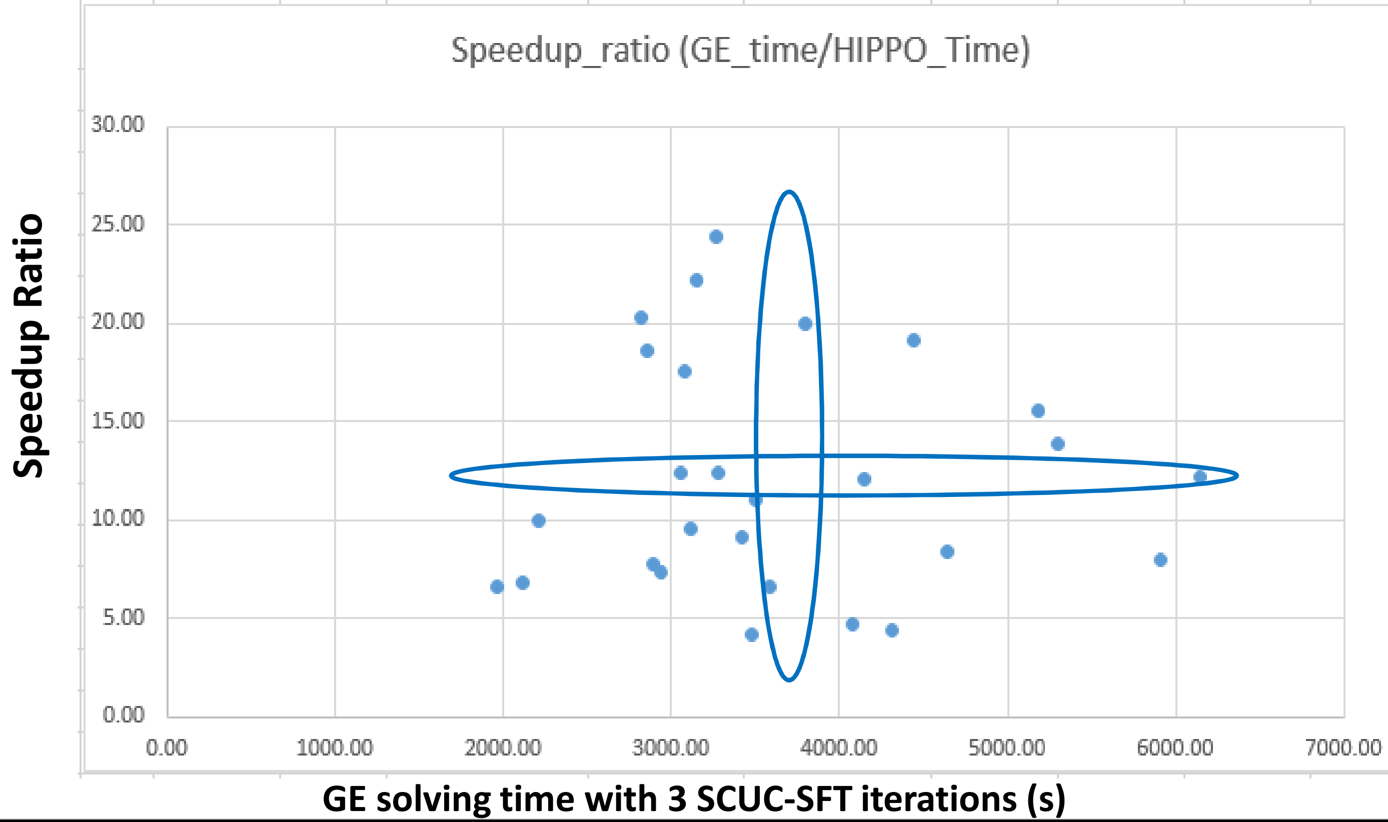
Existing approach with 3 SCUC-SFT iterations:

MIP1 (s)	SFT1 (s)	SFT_AddConstr_1	MIP2 (s)	SFT2 (s)	SFT_AddConstr_2	MIP3 (s)	SFT3 (s)	SFT_AddConstr_3
398	1212	211	623	764	10	731	768	5
Total Time (s)	4496							

MISO

HIPPO_Concurrent versus GE (with SFT)

	HIPPO_time (s)	GE_time (s)	SpeedupRatio
max	972.64	6146.93	24.41
min	133.68	1961.14	4.17
median	326.01	3417.93	11.04



HIPPO at MISO

Evaluate path for production implementation

- Development to further align with production and evaluate near term market enhancement
- Software and hardware configuration

R&D prototype tool to study new market rule and market system design options

- Future resource project
- Future DER scenarios and evaluation of market rules and software performance
- DER aggregation T&D integration
- Renewable study - 15-min DA case
- Watchlist constraint pre-screening
- Enhanced combined cycle and pumped storage optimization
- Pricing study
- Historical data / machine learning
- Case library with over 120 historical cases can be used for future studies

Improving price efficiency: applying convex envelope formulation on single interval ELMP (near term) [2][3]

Convex envelope of the energy cost function

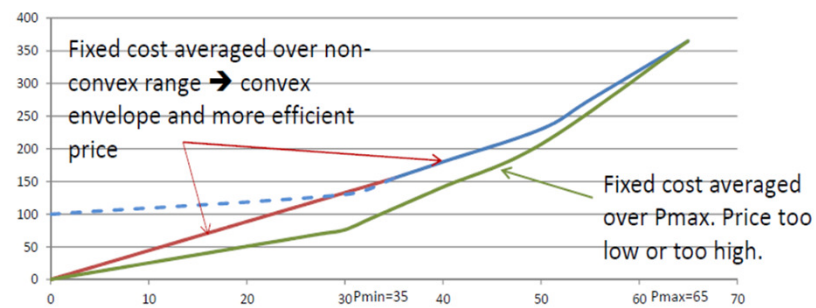
- MISO's Day-Ahead unit commitment piece wise linear formulation implemented in 2017 that contributed to the reduction of its solving time from 4 to 3 hours
- Can also improve single interval ELMP approximation

Simulation show modest price impacts on single interval ELMP approximation [5]

- Resulting prices can be higher, lower or equal to production ELMP
- Overall uplift reduced with higher prices helping to reduce make-whole payments and lower prices helping to avoid lost opportunity cost
- Planning for near term implementation

$$\gamma_{j_1} + \cdots + \gamma_{j_m} \leq u_{j,t}$$
$$p_{j,t} = \gamma_{j_1} \cdot P_{j_1,t} + \cdots + \gamma_{j_m} \cdot P_{j_m,t}$$
$$C_{j,t}^{P}(p_{j,t}) = \gamma_{j_1} \cdot C_{j,t}^{P}(P_{j_1,t}) + \cdots + \gamma_m \cdot C_{j,t}^{P}(P_{j_m,t})$$
$$u_{j,t} \cdot \underline{P}_{j,t} \leq p_{j,t} \leq u_{j,t} \cdot \overline{P}_{j,t}$$

where $u_{j,t}$ is the binary commitment variable



MISO

Improving price efficiency: solution for full convex hull pricing[4]

Solving full convex hull pricing through LP relaxation

- Developing convex envelop and convex hull formulation for individual generator
- Under the condition of “convex envelop” and “convex hull” formulation on individual resource

Future work

- Evaluating the impact on high renewable / DER penetration

SCUC problem:

$$v(y) = Min_{(x,u)\in X} f(x,u)$$
$$s.t. \quad g(x) = y, \;\; u = 0,1$$

ELMP problem:

$$L = Max_{\pi} q(\pi)$$
$$s.t. \quad q(\pi) = Min_{(x,u)\in X, u=0,1}[f(x,u) - \pi(g(x) - y)]$$

SCUC integer relaxation:

$$v(y) = Min_{(x,u)\in \boldsymbol{conv(X)}} \boldsymbol{f^{**}(x,u)}$$
$$s.t. \quad g(x) = y, \;\; 0 \le u \le 1$$

$$L\_Relex = Max_{\pi} q(\pi)$$
$$s.t. \quad q(\pi) = Min_{(x,u)\in \boldsymbol{conv(X)}, 0\le u \le 1}[\boldsymbol{f^{**}(x,u)} - \pi(g(x) - y)]$$

Convex hull

Convex envelope

Preliminary results*

- Apply extended convex hull formulation
- Simplified MISO DA case
  - Energy only, no transmission, generation only, ignore must on / must off

	SCUC	SCUC Integer relation	SCUC Integer relation	SCUC Integer relation
Math problem	MIP	LP	LP	Multiple LP
Formulation	HIPPO	HIPPO	Extended convex hull on all generators	Extended convex hull on selected generators
objective	47889159	47860497	47887537	47887537
time (s)	139	18	>20000	255
gap	0%	-	-	-
Uplift	$8,999	$4,042	$1,622	$1,622

LMP

Approximate ELMP through Integer relation of HIPPO SCUC formulation

True ELMP through Integer relation of extended convex hull SCUC formulation

**Presentations:*
Yongpei Guan, Yanan Yu,, Yonghong Chen: An Efficient Algorithm for Convex Hull Pricing Problems and MISO case study

Enhancing future resource modeling and clearing process

Optimize pumped storage through multi-stage market clearing process*

- SCUC optimization: applying configuration based combined cycle modeling
  - 3 configurations: generating, pumping and offline
  - SOC optimization through energy limited constraints
- Multi-stage clearing processes
  - How to optimize through DA-SCUC, FRAC, IRAC, LAC and single interval SCED?
  - Uncertainty management
- Pricing to reflect SOC constraint through multi-stage clearing processes

DOE grant: Modeling and analyzing the role of pumped storage in asset and system optimization

- Joint work with MS&T and other R&D partners
  - https://www.energy.gov/eere/articles/funding-selections-announced-innovative-design-concepts-standard-modular-hydropower

***Presentation:**
Bing Huang, Yonghong Chen, Ross Baldick, A Configuration Based Pumped-storage Hydro Model in MISO Day-ahead Market

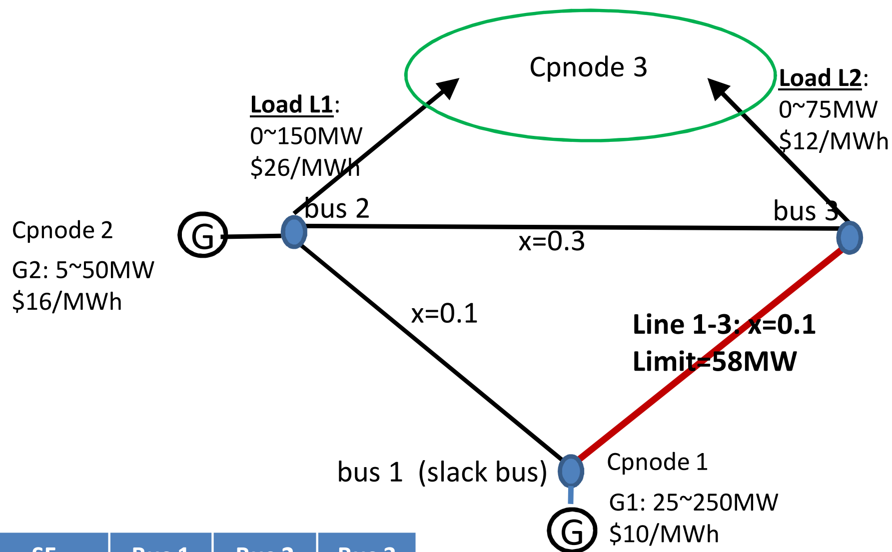
Future Resources: Initial findings summary

Out-of-market & self-responding DER	• Potential pricing oscillation: Status Quo is not a good idea!
Aggregate in large regions & update participation factors	• Potential price oscillation even when updating participation factor instantaneously. • Current information may not be a good prediction of the future.
Only aggregate resources w/ similar congestion impact	• Large number of small resources with less than 2% sensitivity approximation may result in over 100 MW flow differences. • Requires a large number of zones.

Only allow DERs to participate under EPNode (similar to DRR-2 and Generators)	• Most efficient market outcome right now
	• Size issue & computational challenges:
	  • May result in a large number of small resources under one EPNode & restrict effectiveness of aggregations by limiting diversity
	  • MIP solver may not make effective commitment decisions for small resources due to relative MIP gap size.
	  • Even if model small resources as continuous variables, may still face computational challenges due to the large number of non-zeros.

T&D coordination	• Similarity to SEAMS. We have experienced M2M flow oscillation due to limited information from the other side of SEAMS. • Lack of information & visibility between T&D can also lead to oscillation.

Small Illustration System on Price Oscillation caused by Aggregation



SF	Bus 1	Bus 2	Bus 3
Line 1-3	0	-0.2	-0.8

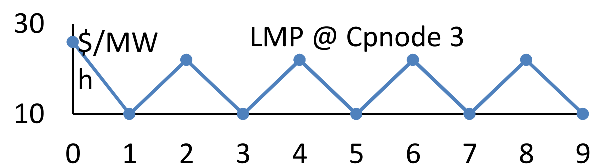
Flow limits of line 1-3:

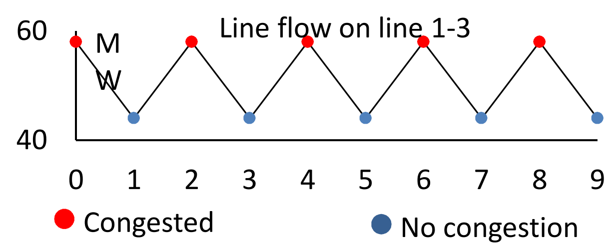
- $-58 \le SF_{Cpnode3}*(-L1-L2) + SF_{Cpnode2}*G2 \le 58$
- $SF_{Cpnode3} = SF_{L1} * LF_{L1} + SF_{L2} * LF_{L2}$
  $= -0.2*L1/(L1+L2) - 0.8*L2/(L1+L2)$

Calculated based on current load MW,
Not necessarily what the load will be

Assume aggregator disaggregates based on cost

Inconsistency causes flow and price oscillation!





Uncertainty management

Internal study on quantify uncertainty and flexibility needs*

ARPA-E Stochastic LAC project

- Input data uncertainty
  - Renewable resources; demand response; generator non-compliance;
  - Load forecast;
  - Interchange and loop flow;
  - Extreme weather; contingencies
- Application
  - Systematic scenario definition (currently: 3 LAC scenarios)
  - Decision making under multi-scenario: e.g. commitment from SLAC
  - Advisory tool for operational decision:
    - Capacity evaluation with systematic scenarios considering energy and reserve deliverability

****Presentation:***
Congcong Wang, Stephen Rose, Long Zhao, Managing Flexibility and Uncertainty in Markets and Operations - Including Near-Term Improvements to Manage Intra-Hour Flexibility

References

- [1] Yonghong Chen, Fengyu Wang, Yaming Ma, Yiyun Yao, “A Distributed Framework for Solving and Benchmarking Security Constrained Unit Commitment with Warm Start”, IEEE Transactions on Power Systems, under review
- [2] Yonghong Chen and Fengyu Wang, “MIP formulation improvement for large scale security constrained unit commitment with configuration based combined cycle modeling,” *Electr. Power Syst. Res.*, vol. 148, pp. 147-154, Jul. 2017.
- [3] B. Hua and R. Baldick, “A convex primal formulation for convex hull pricing,” IEEE Transactions on Power Systems, vol. 32, no. 5, pp. 3814–3823, 2017
- [4] Yanan Yu, Yongpei Guan, Yonghong Chen, An Integral Formulation and Convex Hull Pricing for Unit Commitment, IEEE Transactions on Power Systems, under review
- [5] MISO, ELMP III White Paper I, Jan. 2019, https://cdn.misoenergy.org/20190117%20MSC%20Item%2005%20ELMP%20III%20Whitepaper315878.pdf