Experience and Future R&D on Improving MISO DA Market Clearing Software Performance

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Overview

- MISO continues to improve Day Ahead Market solve times while growing in size and complexity
- The Day Ahead Market Clearing Process is complex and several areas of improvement have been implemented to meet reduced Day Ahead clearing time
- MISO continues to collaborate with vendors and research entities on new solutions to further improve computational efficiency
- Broader future market platform evaluation to better position for future market growth and industry development

Size and complexity of MISO's system and markets create unique challenges to computational efficiency

Large network and market model with diverse resources and equipment types

Large number of pricing nodes and market activities

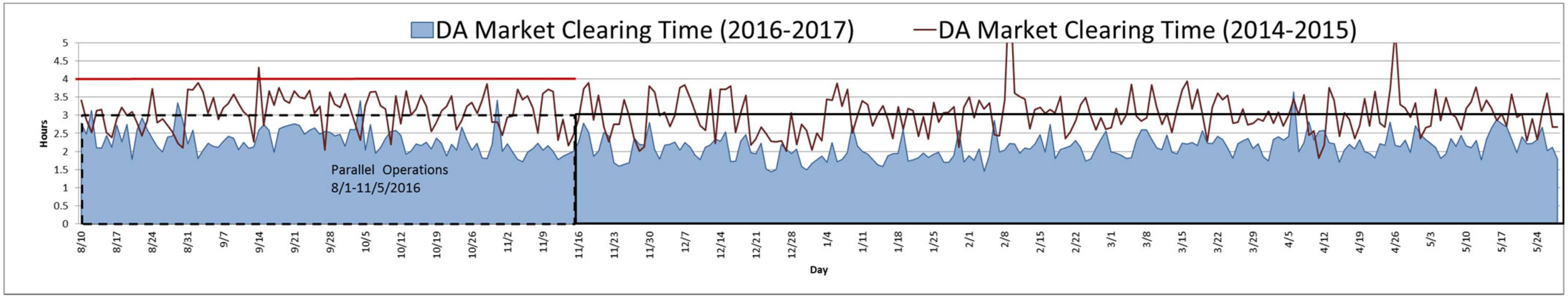
Managing higher level of uncertainties

Wind, loop flows, transactions, etc.

Tight market clearing window

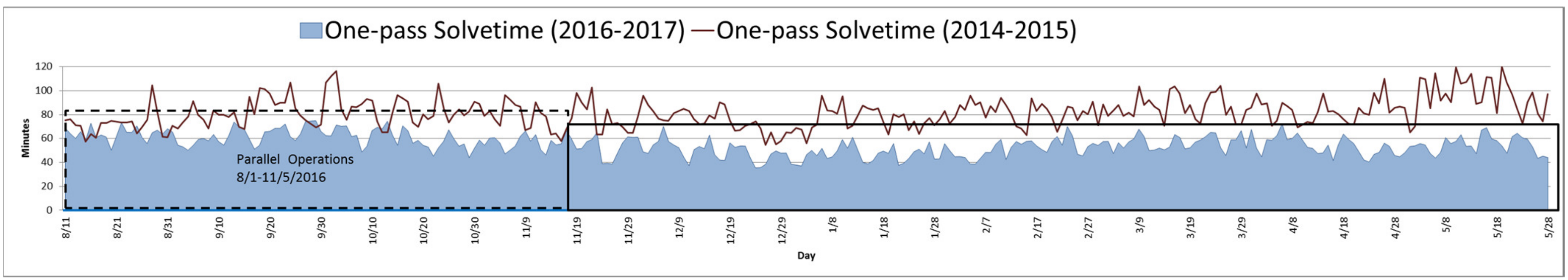
MISO strives for earlier posting of market clearing results as we continue to grow in size and complexity

Reduced DA market clearing time from 4 hours to 3 hours in Nov. 2016, per FERC Order 809



Reduced one-pass solving time with narrower standard deviation

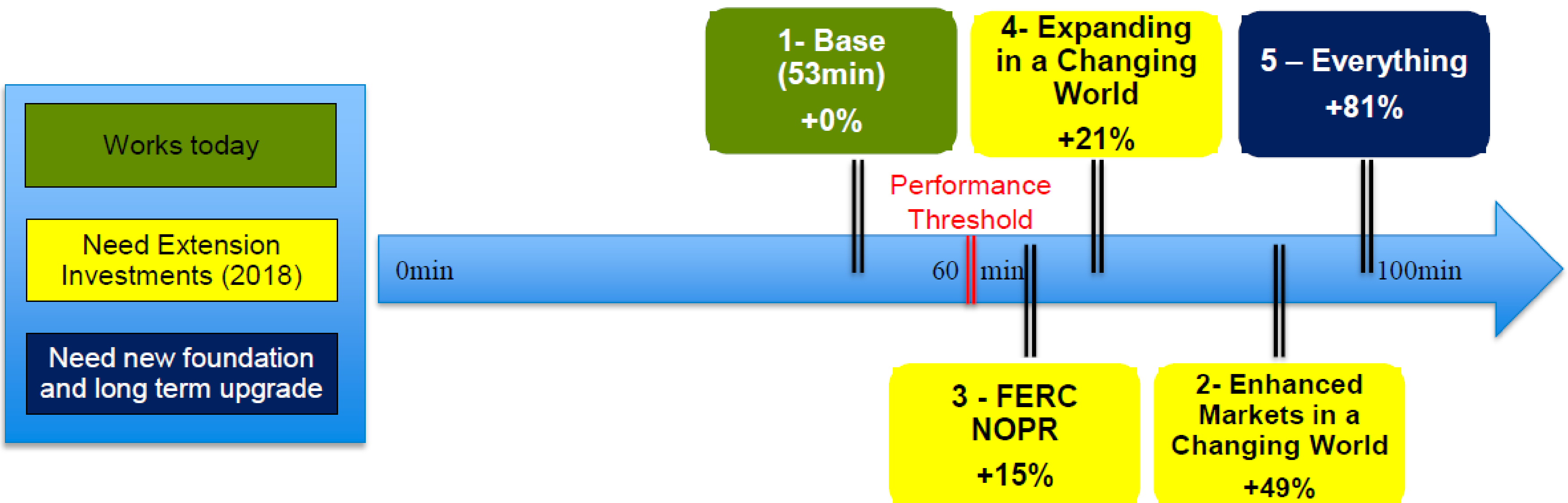
	DA Clearing time in hours (08/10-5/28)		One-pass solving time in minutes (08/10-5/28)		Average number of virtuals per hour (08/10-5/28)	
	2014-2015 (before improvement)	2016-2017 (after improvement)	2014-2015 (before improvement)	2016-2017 (after improvement)	2014-2015 (before improvement)	2016-2017 (after improvement)
Average	3.06	2.19	82	55	8706	12020
STDEV	0.54	0.35	13	9	1424	2180
Min	1.81	1.44	54	36	4890	5671
Max	6.86	3.64	123	75	11603	17143



MISO Market System Evaluation[1]

- Identify bottleneck areas under existing and future scenarios
- Recommendation on market platform investment

Market Performance
Day Ahead Market Solution Time



MISO developed R&D plan and worked with vendors and research partners to address computational challenges

a. Delivered; b. Upcoming delivery; c. POC with vendors; d. ARPA-E project

Delivered enhancements to address some of these bottlenecks in the DA Market Clearing Process

Optimization Engine Enhancements [2]

- Feasibility check to resolve input conflicts and improve optimization solution quality
- New heuristic solving methods
- **Polishing module**
  - Incremental solving capability
  - Commit reason identification and solution polishing

Enhancement on Optimization Formulation [4]

- Tighter piece-wise linear energy offer curve modeling (convex envelope PWL formulation)
- Group variables with same impact on transmission constraints to significantly reduce non-zeros
- Developed tighter and more compact MIP formulation for configuration based combined cycle modeling

Network & Security Analysis Enhancements

- Improved parallelization on security analysis on large system
- Incorporate more efficient sparse matrix techniques
- Improved iteration process between optimization and security analysis

Operator & IMM Case Adjustments

- Incorporating VLR constraints to reduce out-of-market commitment and provide systematic commitment reason identification [3]
- IMM process improvement

MIP: Mixed Integer Programming
VLR: Voltage and Local Reliability

DA-SCUC formulation improvement [4]

- Enhanced convex envelope piece wise linear (PWL) energy offer curve (SOS2 version: more compact)

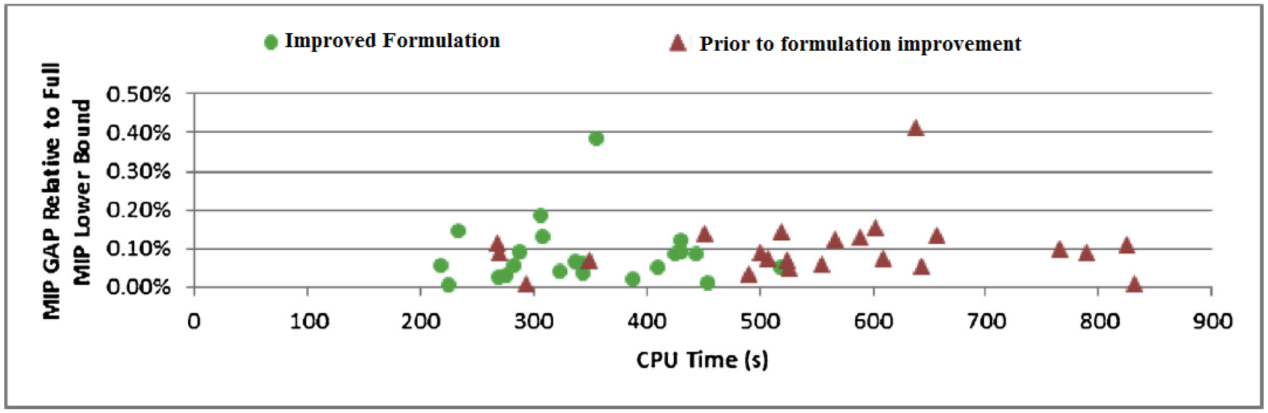
Revised PWL results in tighter MIP model

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

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

- Aggregate variables with the same impact on transmission constraints together when formulating transmission constraint
  - Significantly reduce non-zeros
- Tighten formulation for configuration based combined cycle modeling (prototype)

- **Improved formulation resulted in ~30% MIP solving time reduction**



- **Lead to the possibility of implementing configuration based combined cycle modeling (CCG)**

# of CC	20		40	
	MIP gap at 1200s	Time to <3% gap (s)	MIP gap at 1200s	Time to <3% gap (s)
C-1	64%	3561	65%	2458
C-2	64.76%	2387	48.65%	2026
C-3	**0.89%**	**738**	**0.60%**	**835**

C-1: prototype before improvement
C-2: formulation from literature
C-3: improved formulation [3]

- Current system about 40 CC groups
- Market System Evaluation study on future 96 CC groups with 351 configurations
  - ~13% increase in solving time ➔performance acceptable

Other potential applications of the improved formulation

MISO implemented single interval ELMP

- ELMP from current production formulation result in a convex under estimator of the total energy cost curve
  - To reflect fixed cost into pricing
  - May not be the highest convex under estimator

Tighter SCUC formulation may also improve production ELMP [4][7]

- Convex envelope PWL formulation can result in the highest convex under estimator of the total energy cost curve under single interval ELMP (see example)
  - Meet the original intention of convex hull pricing under single interval implementation
  - More efficient price signal
- Investigating applying tighter ramp constraints under single interval ELMP
  - To address the issue that fast unit may not be able to set price below minimum limit due to ramp down constraints.

Further research on the approximation of full convex hull pricing with convex primal formulation

Example of better ELMP results with improved PWL formulation

G1: Pmin=35MW, Pmax=65MW, No load cost $100/h

[0,30MW] $1/MWh [30, 50MW] $5/MWh [50, 65MW] $9/MWh

G2: Pmin=0MW, Pmax=60MW, All costs are 0

- Existing production ELMP formulation is in different PWL version but equivalent to the following SOS2 version:

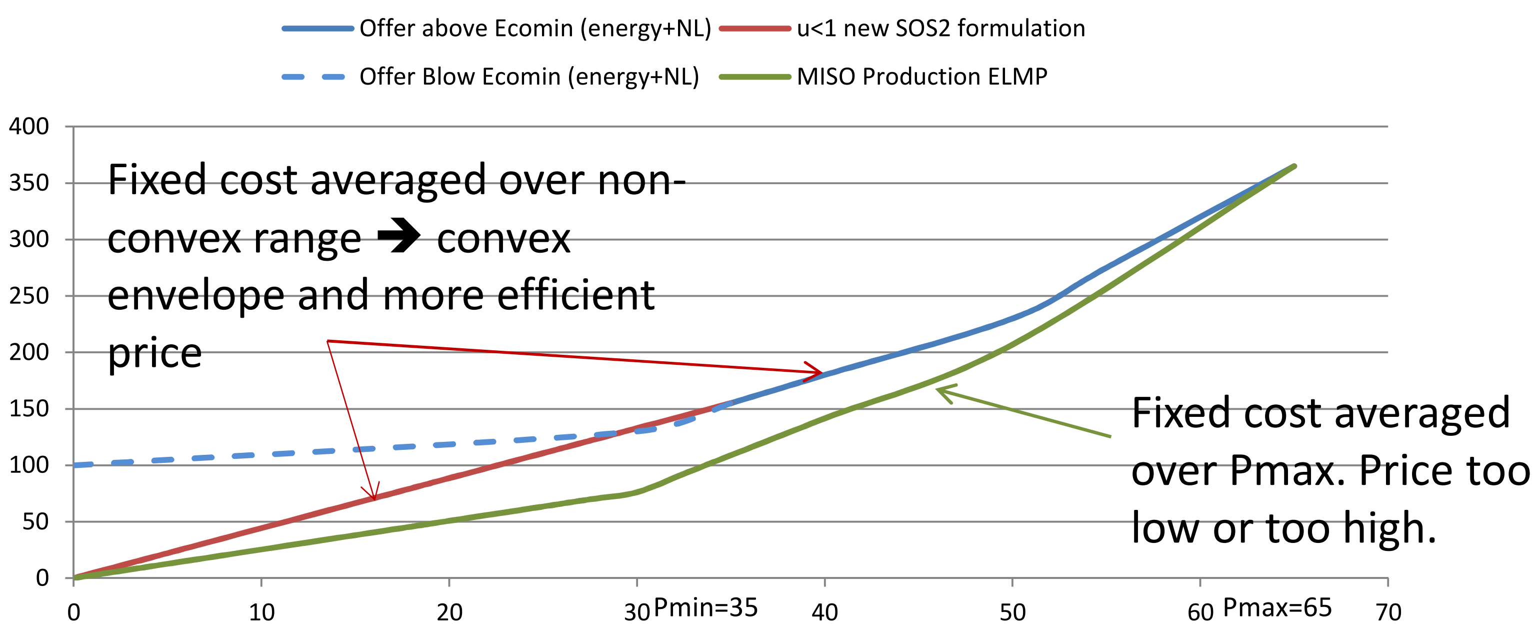
$$\gamma_{j_1} + \cdots + \gamma_{j_m} \leq 1$$
$$p_{j,t} = \gamma_{j_1} \cdot P_{j_1,t} + \cdots + \gamma_{j_m} \cdot P_{j_m,t}$$
$$C_{j,t}^{P}(p_{j,t}) = \gamma_{j_1} \cdot C_{j,t}^{P}(P_{j_1,t}) + \cdots + \gamma_m \cdot C_{j,t}^{P}(P_{j_m,t})$$
$$u_{j,t} \cdot \underline{P}_{j,t} \leq p_{j,t} \leq u_{j,t} \cdot \overline{P}_{j,t}$$

- Convex envelope formulation (SOS2 version)

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

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

		ELMP non-convex envelope formulation (equivalent to current production)						ELMP convex envelope formulation					
Total Load	P_1	u_1	γ_1	γ_2	γ_3	Objective	Shadow Price of Power Balace Equation	u_1	γ_1	γ_2	γ_3	Objective	Shadow Price of Power Balace Equation
65	5	0.077	0.17	0	0	$12.69	$2.54	0.143	0.107	0.04	0	$22.14	$4.43
77.5	17.5	0.269	0.58	0	0	$44.42	$2.54	0.5	0.375	0.13	0	$77.50	$4.43
80	20	0.308	0.67	0	0	$50.77	$2.54	0.571	0.429	0.14	0	$88.57	$4.43
85	25	0	0.83	0	0	$63.46	$2.54	0.714	0.536	0.18	0	$110.71	$4.43
87.5	27.5	0.423	0.92	0	0	$69.81	$2.54	0.786	0.589	0.2	0	$121.79	$4.43
90	30	0.462	1	0	0	$76.15	$6.54	0.929	0.643	0.21	0	$132.86	$4.43
95	35	0.538	0.75	0.3	0	$108.85	$6.54	1	0.75	0.25	0	$155.00	$4.43
100	40	0.615	0.5	0.5	0	$141.54	$6.54	1	0.5	0.5	0	$180.00	$5.00
110	50	0.769	0	1	0	$206.92	$6.54	1	0	1	0	$230.00	$5.00
125	65	1	0	0	1	$365.00	$10.53	1	0	0.333	0.667	$365.00	$9.00



Research & Development collaboration is also planned for developing future DA market clearing engine…

Proof-of-concept with Gurobi on improving solver performance with distributed and parallel computing

- Distributed hardware: a cluster of Ethernet connected computers
  - Best lower bound and best upper bound from the cluster
  - Using multiple strategies to speed up both the upper bound and the lower bound search
- Develop strategy specific for unit commitment
  - Incorporate variable hints and transmission constraint hints (lazy constraint) from the latest available unit commitment solution
  - Recognize binary variables associated with the same generator
  - Allow solving multiple MIP start in concurrent
  - Smart partition by generators

MISO polishing module:

- Start with initial commitment solution
  - Identify ~80% binary variables to be fixed
  - Identify ~80% unlikely binding transmission constraints to be excluded
  - Solve incremental MIP that can be over 50% faster than full MIP.
- Further polishing on out of money resources with commitment reason identification [2]

Proof of concept with Gurobi:

- Variable hint
  - Set ~80% binary variables to lower priority
  - Slight improvement
- Lazy constraint (3 settings)
  - Set ~80% unlikely binding transmission constraints to lazycon=2
  - Significant reduced time on root node relaxation and reduced time to reach 1% gap
- Multiple MIP starts for concurrent solve
- Variable partitions
- Concurrent solve with different settings and MIP starts
- **Time to reach 1% gap can be improved**
- **Long tail to reduce MIP gap further**

Full MIP

Small number of out-of-money units

Total Gen	Total Transmission	Full MIP onjective at **200s**	Full MIP gap at **1200s**
1134	13536	**Pre-solve and LP Relaxation**	0.23%
		Reduced MIP (fix in-the-money and remove lazy transmission)	
No. OutOfMoney	Percentage of LazyTransmission	MIP start obj relative to full MIP LB	Feasible solution at **200s relative to full MIP LB**
83	86.44%	10.04%	0.31%
80	86.61%	10.83%	2.38%
81	85.96%	10.49%	0.49%
101	86.36%	11.32%	8.67%
103	86.08%	9.80%	1.30%
102	86.37%	11.52%	8.66%
132	86.54%	17.81%	0.83%

Solving Incremental MIP with polishing can get very good solution at 200s

Large number of unlikely to bind transmission constraints

Feed in commitment from different days (after repaired for feasibility)

Explore parallel computing and utilize large number of historical commitment to speed up the polishing algorithm under the ARPA-E HIPPO project

MISO

Several proof-of-concept efforts are undergoing with vendors and research entities

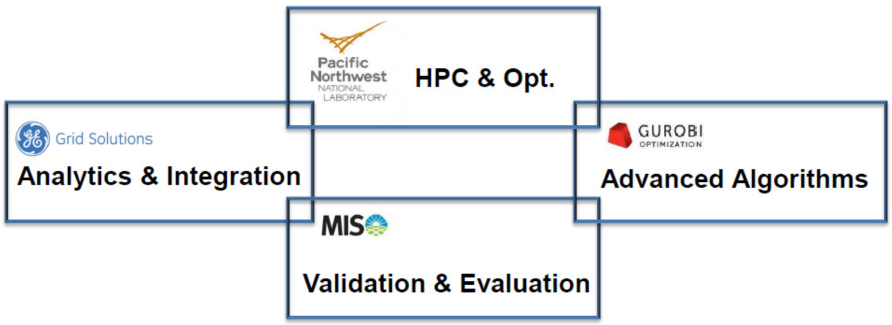
Proof-of-concept with GE to explore next generation market clearing engine

- Reduce overhead
- Improve parallelization
- Easy adapt to future distributed solver and high performance computing

Proof-of-concept on new formulations and solution approaches

- Surrogated LR with UConn and GE [8]
- ADMM with Stanford and Purdue
- SCUC base formulation and with combined cycle with Clarkson and GE
- ……

ARPA-E High-performance Power-Grid Optimization (HIPPO) project to explore solving SCUC with high performance computing [6]

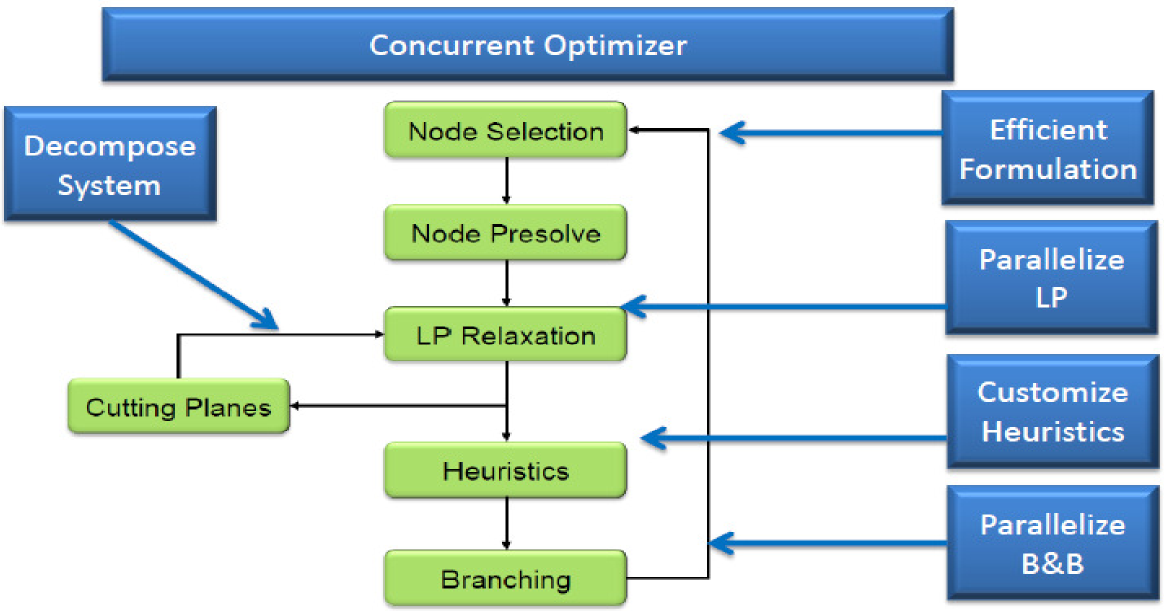


- Tasks – collaborative
- PNNL – MIP, algorithm development, HPC, implementation and testing
- GUROBI – MIP, Gurobi solver and parallel/distributed computing
- GE – market simulator, benchmark, domain knowledge, MIP and OPF
- MISO – domain knowledge, algorithm development, data, model validation, market operations, and MIP.

- PNNL
  - Feng Pan (PI, Optimization)
  - Steve Elbert (Co-PI, HPC, Optimization)
  - Jesse Holzer (Optimization)
  - Matthew Oster (Optimization)
  - Shuangshuang Jin (HPC)
  - *Daniel Duque Villarreal, Northwestern (Intern)*
- GUROBI
  - Ed Rothberg (Optimization)
  - Daniel Espinoza (Optimization)
- GE
  - Jie Wan (Optimization, Power System Application)
  - Qianli Su (Market Application)
- MISO
  - Yonghong Chen (Optimization, Analytics, Electricity Market)
  - Fengyu Wang (Optimization, Electricity Market)
  - *Bowen Hua, UT-Austin (Fellow student)*
  - *Gabriel Hackebeil, U-Michigan (Fellow Student)*

HIPPO Software

- Implemented in Python with multiple threads and MPI
- Tighten formulation, mathematical decomposition, distributed algorithms, parallel heuristics



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