MISO R&D on Improving Market Clearing Software for Future Market Enhancements

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Overview of MISO R&D on future market clearing software

Resource modeling and mathematical formulation

- Enhanced hybrid combined cycle modeling
- Startup and transition trajectories
- Future resource analysis: storage, hybrid plants, DER, VPP, etc.
- Improve computational performance as well as price efficiency through tighter mathematical formulation
- Study on market clearing and pricing under future resource portfolio

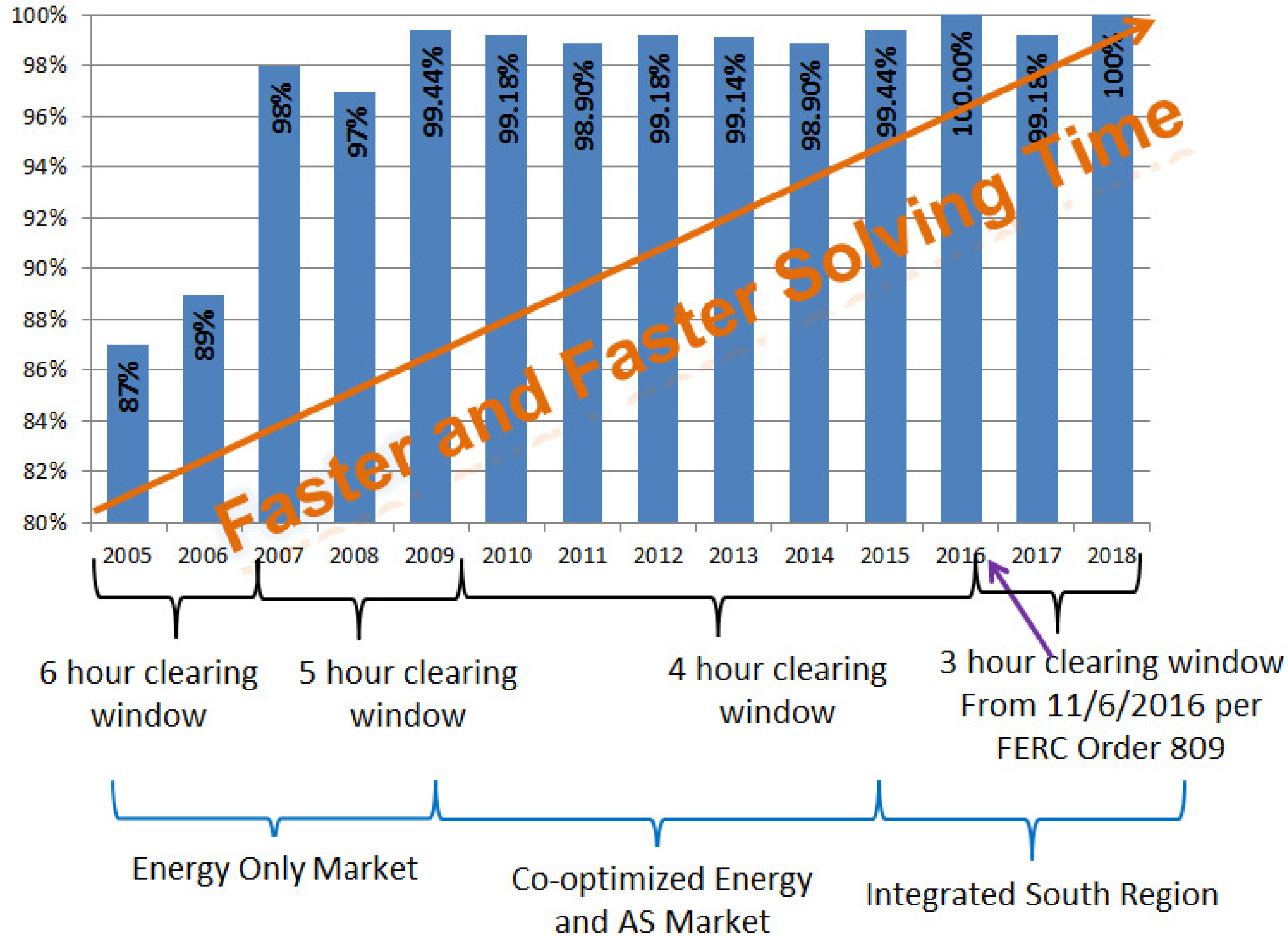
Deliverability for energy and reserves & uncertainty management

- Co-optimized formulation for reserve deliverability
- Uncertainty management

Solution approaches

- Enhance the interaction with existing commercial solvers
- Develop high-performance computing based next generation optimization engine under the ARPA-E HIPPO project

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



R&D has contributed greatly to advancing the market clearing software performance and overall market efficiency

R&D has been addressing Day Ahead computational challenges

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

MISO is preparing for the future …

Current

- **System**
  - Centralized power plants over high voltage transmission system
    - Relatively **sparse** transmission flow matrix with generators
      - Distributed virtual transactions that may increase the **density**
  - **Non-convex resource model**
    - Scheduling and pricing challenges
- **Applications**
  - Simplification with DC-OPF
  - Deterministic SCUC/SCED
    - *Day-ahead SCUC is the most computationally challenging application*
    - **Techniques: advanced modeling and commercial MIP solver**

Future

- **System**
  - Portfolio changes
    - Potentially more, **smaller-size distributed resources**
    - More renewable and gas resources
    - More **complicated configurations** (Combined Cycle, Storage, VPP)
  - **Non-convexity + density + uncertainty**
    - Low marginal cost
    - Scheduling and pricing challenges
- **Applications**
  - ***Centralized, or hierarchical, or distributed optimization?***
  - ***DC-OPF sufficient?***
  - ***Existing tools scalable?***
  - ***Multi-scenario / stochastic?***

Enhancements in Resource Modeling

- The most complicated existing resource model: configuration-based combined cycle
  - Dedicated R&D on DA performance from 2013-2016[1,2]

SCUC formulation improvement
- Convex envelope cost function
- Condensed transmission matrix modeling
- Tighter and more compact ECC model

→

- 30% reduction in production MIP solving time
- 37% reduction in DA one-pass solving time
- 66% reduction on MIP with prototype ECC model

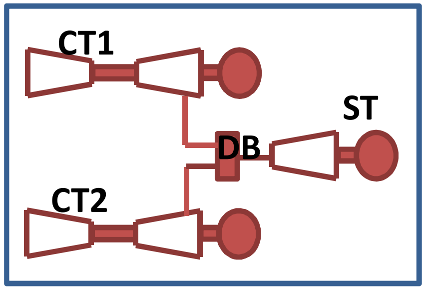
  - Estimated $34 million annual benefit
  - On-going Enhanced Combined Cycle Task Team on Conceptual Design for implementation

1. Yonghong Chen, Fengyu Wang, MIP Formulation Improvement for Large Scale Security Constrained Unit Commitment with Configuration based Combined Cycle Modeling, Journal of Electric Power Systems Research, Vol. 148, July 2017
2. Yonghong Chen, Aaron Casto, Fengyu Wang, Qianfan Wang, Xing Wang, and Jie Wan, Improving large scale Day-ahead Security Constrained Unit Commitment Performance, IEEE Transactions on Power Systems, Volume: 31, Issue: 6, Nov. 2016

Further research on combined cycle

- Hybrid configuration and component model[3]
  - Most constraints can be properly modeled on the configuration level (e.g., 1CT+1ST, 2CT+1ST+DB)
  - Mapping between configurations and components to allow constraints such as minimum run time, minimum down time to be modeled on physical component (e.g., CT, ST or DB)

➔Better reflect physical constraints and supported by participants



Developed with Clarkson University and GE

3. Chenxi Dai, Yonghong Chen, Fengyu Wang, Jie Wan, Lei Wu, A Tight Configuration-Component Based Hybrid Model for Combined-Cycle Units in MISO Day-Ahead Market, IEEE Transactions on Power Systems, under review. Available online: https://arxiv.org/ftp/arxiv/papers/1708/1708.06413.pdf

Further research on combined cycle *(Cont.)*

Tighter formulation to improve SCUC performance and ELMP approximation

- Multi-interval integer relaxation to approximate full ELMP
  - Multi-interval ELMP (future pricing design improvement option)
  - Single interval approximation (near term ECC design option)
- Single interval approximation
  - How to amortize transition cost? How to properly handle transition?

Incorporate transition curve into SCUC, SCED and pricing

On going R&D with University of Texas – Austin (see presentation on this topic for details)

Commitment

	hr=1	hr=2
1X1	1	0
1X1-DB	0	1

$transition^{1x1 \rightarrow 2X1} = 1$

Pricing

	hr=1	hr=2
1X1	1	**0.8**
1X1-DB	0	**0.2**

$transition^{1x1 \rightarrow 2X1} = \mathbf{0.2}$

- ELMP would be driven by:
  - Transition cost
  - "From configuration" incremental energy cost
  - "To configuration" incremental energy cost
- Transition trajectory may have bigger impact on commitment, dispatch and pricing

Research on future resource modeling

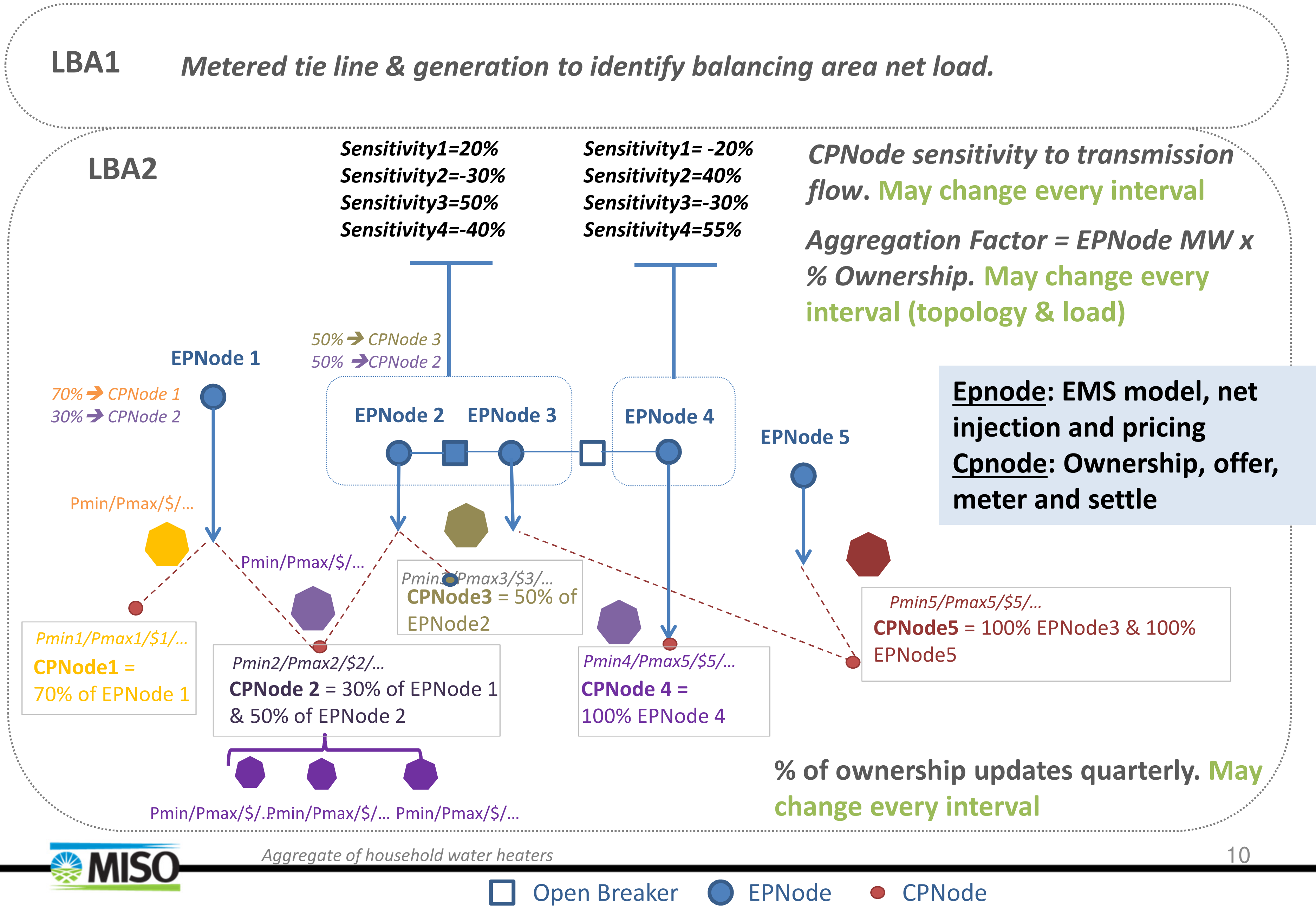
MISO uses 8% performance tolerance in part to account for inaccurate resource modeling

- IMM recommendation to tighten the tolerance band
- Configuration-based modeling may be expanded for pumped storage or coal units
  - Applying to too many resources can cause computational difficulty

Future resource challenges

- Resources on different size scale: optimize large generators with small DER/storage/DR
  - MIP gap issue for small resources modeled with integer variables (experience with wind)
  - Density issue for small resources only modeled with continuous variables (experience with small virtuals)
- Aggregation
  - May address small size issue
  - **Challenge with aggregated resource modeling**
  - **Challenge with transmission constraints**

Current commercial and EMS model illustration

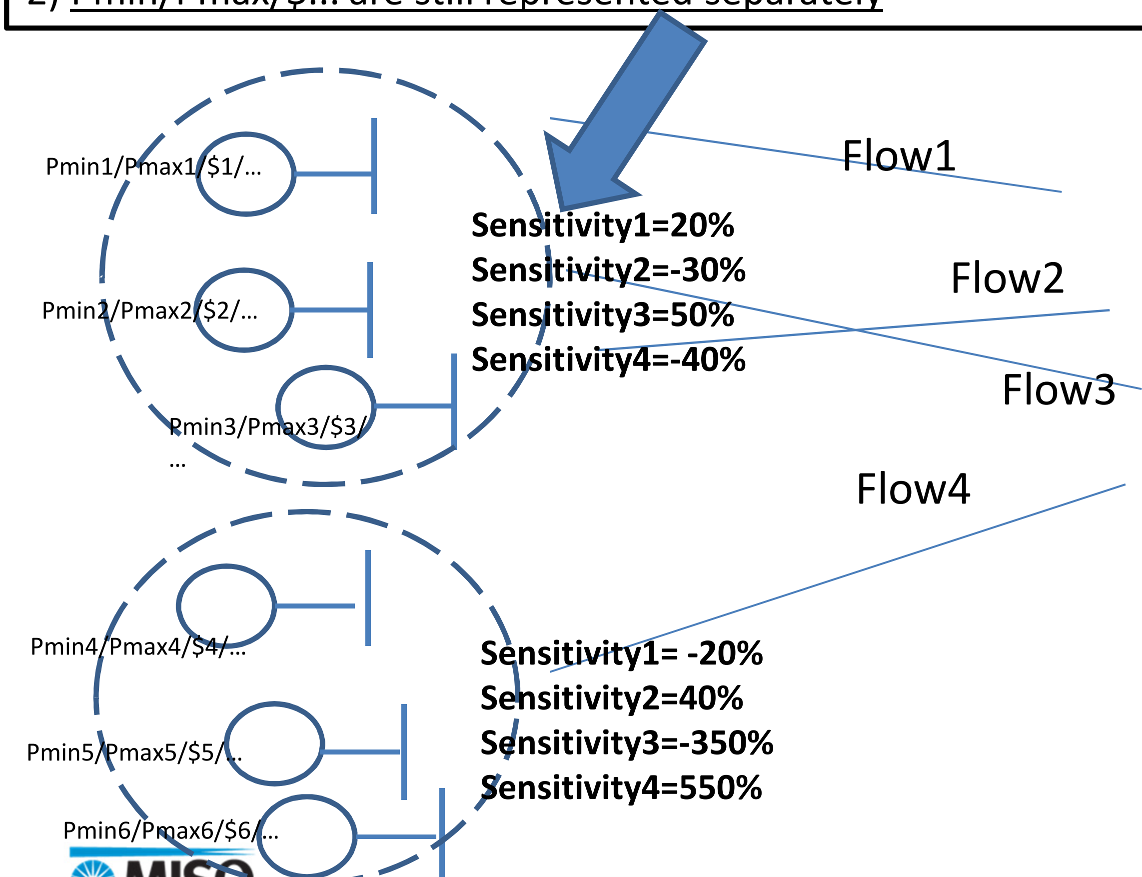


DER resource modeling and impact on transmission

"Master Pnode" aggregation formulation on transmission constraints can greatly reduce non-zeros from 10million to 2~3million [1]

1) Aggregate resources with the same impacts on transmission constraints together in <u>transmission constraint</u>

2) <u>Pmin/Pmax/$... are still represented separately</u>



Participants may aggregate DERs with different transmission impact together to form an aggregated off: Pmin34/Pmax34/$34

- How predictable is the aggregation factor (DA, 7-day RAC, LAC, RT-SCED)?
- How to update RTO on the aggregation factor?
- How good is the aggregated offer?
- How to reflect distribution constraints?

1. Yonghong Chen, Fengyu Wang, MIP Formulation Improvement for Large Scale Security Constrained Unit Commitment with Configuration based Combined Cycle Modeling, Journal of Electric Power Systems Research, Vol. 148, July 2017

Reserve deliverability

- With increased uncertainty, reserve can play more important role

- Existing reserve models may require improvement to properly address deliverability
  - MISO started with define reserve zones and enforce zonal reserve requirement constraints
  - Enforce reserve zone requirement constraints inside SCUC and SCED
  - Count on offline study to provide
    - Reserve zone definition (quarterly update)
    - Minimum zonal reserve requirements (three-day ahead study)

Production issues:

- Difficult to define proper zonal reserve requirements

- When there is enough capacity in a zone:
  - Energy were dispatched down in a zone to relief congestion
  - 600MW (~75%) of spinning reserve was cleared in that zone. Most of the spinning reserve would not be deliverable if deployed
  - Offline study could not predict the issue

- When there is not enough capacity in a zone:
  - In order to clear pre-set zonal reserve requirement, cleared energy in the zone had to be lowered. ➔Increase in import flow
  - Cleared zonal reserve can provide count flow when deployed. However, the post-deployment flow was not better with the pre-set zonal reserve requirement.
  - MISO had one event with zonal spin scarcity due to the pre-set zonal requirement when the requirement didn't provide any benefit to post deployment flow.

Post Zonal Reserve Deployment Transmission Constraint

- Solve co-optimized reserve zone requirements (implemented in 2011)[4]
  - To deliver reserve within transmission limits on a zonal basis
  - Solve $r_{k,t}^{REG}$, $r_{k,t}^{SPIN}$, $r_{k',t}^{SUPP}$: **zonal requirement variable for zone k'** within the optimization

- **Post-Regulating Reserve Deployment Up and Down Transmission Constraints**

$$F_{i,t}^{P}(\boldsymbol{p_t}, \boldsymbol{P_t}) + \sum_{k\in K}\{r_{k,t}^{REG} \cdot B_{i,k,t}^{REG}\} - B_{i,LC,t} \cdot R_{MKT,t}^{REG} \leq \bar{F}_{i,t} \qquad \forall i \in I \qquad (1)$$

$$F_{i,t}^{P}(\boldsymbol{p_t}, \boldsymbol{P_t}) - \sum_{k\in K}\{r_{k,t}^{REG} \cdot B_{i,k,t}^{REG}\} + B_{i,LC,t} \cdot R_{MKT,t}^{REG} \leq \bar{F}_{i,t} \qquad \forall i \in I \qquad (2)$$

Flow from Energy — *Flow from regulation deployment* — *Flow from load deviation at reference bus (0)*

- **Post-Contingency Reserve Deployment Transmission Constraints (one for each reserve zone)**

$$F_{i,t}^{P}(\boldsymbol{p_t}, \boldsymbol{P_t}) - E_{k,t} \cdot B_{i,k,t}^{TRIP} + D_{k,t}^{SPIN} \cdot \sum_{k'\in K}\{r_{k',t}^{SPIN} \cdot B_{i,k',t}^{SPIN}\} + D_{k,t}^{SUPP} \cdot \sum_{k'\in K}\{r_{k',t}^{SUPP} \cdot B_{i,k',t}^{SUPP}\} \leq \bar{\bar{F}}_{i,t} \qquad \forall i \in I, \forall k \in K \qquad (3)$$

Flow from Energy

Flow from largest zonal gen trip

Flow from spin deployment

Flow from supp deployment

Proportional deployment factor for largest gen trip in zone k, calculated based on "the size of the event" and "system total reserve requirement"

4. Y. Chen, P. Gribik and J. Gardner, "Incorporating Post Zonal Reserve Deployment Transmission Constraints Into Energy and Ancillary Service Co-Optimization," in *IEEE Transactions on Power Systems*, vol. 29, no. 2, pp. 537-549, March 2014

Observations and conclusions from post zonal reserve deployment transmission constraint approach

- Zonal reserve requirement resulted in **spin scarcity without improving post event flow**. **LMP didn't reflect the import congestion.**
- Co-optimized SCED can ensure 750 MW post deployment flow primarily through re-dispatch of energy
- Zonal MCP and LMP differences reflect the impact of both energy and reserve deployment on congestion.

DA 4/1 HR12	No Zonal Constraint	MinCR(z6)=84MW	MinCR(z6)=284MW	"AMISOUTH_IMPORT + Z6 Gen Trip" (Post Deployment Flow@ 750MW limit)
EnergyFlow	**351.74**	**379.73**	**408.96**	**263.20**
Zone6 GenTrip Flow	462.20	462.20	462.20	462.20
Spin Deploy Flow	**14.62**	**-13.97**	**-39.84**	**14.99**
Supp Deploy Flow	10.12	9.88	9.80	9.62
Post Deployment Flow	**838.67**	**837.84**	**841.12**	**750.00**

DA 4/1 HR12	No Zonal Constraint			MinOR(z6)=84MW			MinOR(z6)=284MW			"AMISOUTH_IMPORT + Z6 Gen		
Zone	SpinMW	SpinMCP	LMP	SpinMW	SpinMCP	LMP	SpinMW	SpinMCP	LMP	SpinMW	SpinMCP	LMP
1	432.36	$7.00	$17.06-$42.8	381.90	$7.00	$16.55-$43.48	356.16	$6.50	$16.44-$45.39	450.43	$6.77	$16.25-$44.87
2	115.00	$7.00	$18.63-$47.98	125.00	$7.00	$18.67-$47.85	115.00	$6.50	$18.68-$47.78	121.26	$7.09	$18.69-$47.77
3	176.41	$7.00	$31.86-$37.67	175.80	$7.00	$31.92-$37.76	129.79	$6.50	$31.92-$37.77	176.41	$7.09	$31.96-$37.84
4	20.00	$7.00	$32.49-$39.56	7.00	$7.00	$32.6-$39.72	2.00	$6.50	$32.61-$39.69	11.68	$6.88	$32.53-$39.77
5	130.70	$7.00	$27.26-$37.75	126.70	$7.00	$27.4-$37.92	126.70	$6.50	$27.24-$37.81	130.70	$6.75	$26.88-$37.5
6	**0.00**	**$7.00**	**$36.25-$39.65**	**84.00**	**$18.35**	**$36.44-$39.93**	**161.10**	**$1,106.50**	**$36.55-$40.39**	**0.00**	**$15.31**	**$39.88-$49.95**
7	0.00	$7.00	$34.36-$42	0.00	$7.00	$35.47-$42	0.00	$6.50	$38.01-$42.09	0.00	$6.13	$35.44-$40.3

MISO

Improvement with post zonal reserve deployment constraints

- Formulation implemented in 2011 was based on proportional contingency reserve deployment

- Considering new formulation that may be extended for other reserve products (e.g., 30-min reserve)

$$F_{i,t}^{P}(\boldsymbol{p_t}, \boldsymbol{P_t}) - E_{k,t} \cdot B_{i,k,t}^{TRIP} + \sum_{k' \in K} \{ rd_{k,k',t}^{SPIN} \cdot B_{i,k',t}^{SPIN} \} + \sum_{k' \in K} \{ rd_{k,k',t}^{SUPP} \cdot B_{i,k',t}^{SUPP} \} \leq \overline{\overline{\overline{F}}}_{i,t}$$

$$\sum_{k' \in K} rd_{k,k',t}^{SPIN} = D_{k,t}^{SPIN} \cdot TotalSpin_t, \quad \sum_{k' \in K} rd_{k,k',t}^{SUPP} = D_{k,t}^{SUPP} \cdot TotalSupp_t$$

$$rd_{k,k',t}^{SPIN} \leq r_{k',t}^{SPIN}, \quad rd_{k,k',t}^{SUPP} \leq r_{k',t}^{SUPP}$$

$$\forall i \in I, \forall k', k \in K$$

$rd_{k,k',t}^{SPIN}$, $rd_{k,k',t}^{SUPP}$ Zone k' deployment variable for largest gen trip in zone k

Future research on managing deliverability and uncertainty

Deliverability

- Will modeling the largest event each zone be sufficient?
  - Multi-scenario stochastic / robust optimization?
- Nodal reserve formulation?
  - MISO defines 8 reserve zones, which only allows handling reserve deliverability for ~10 IROL and important SOL constraints on a zonal basis

Uncertainty management

- Available capacity uncertainty
- Energy deliverability uncertainty
  - More challenging to manage due to difficult to predict future / near future transmission congestions
  - Operators not only need to know the deterministic commitment/dispatch results, but also need to understand the available headroom under various scenarios
    - Better to provide probabilistic indices

Improve price efficiency

Near term: improving single interval ELMP approximation

- Apply convex envelope formulation
- Evaluate fast-start eligibility
- Evaluate regulation eligibility in pricing run

Research on future pricing design

- Renewable study
  - Pricing issues under near zero marginal cost
  - How and to what extend can current single interval ELMP help?
- Multi-interval full ELMP
  - Approximate with solving integer relaxation under convex primal formulation
  - Passing commitment costs through multi-stage processes. How to handle commitment cost incurred in early stages?
    - 7-day RAC → DA →FRAC→IRAC→LAC
    - Rolling RT (commitment from DA/RAC/LAC)
  - Reflect reliability services in the clearing and pricing (e.g., local VAR constraints)
- Other pricing mechanism ?

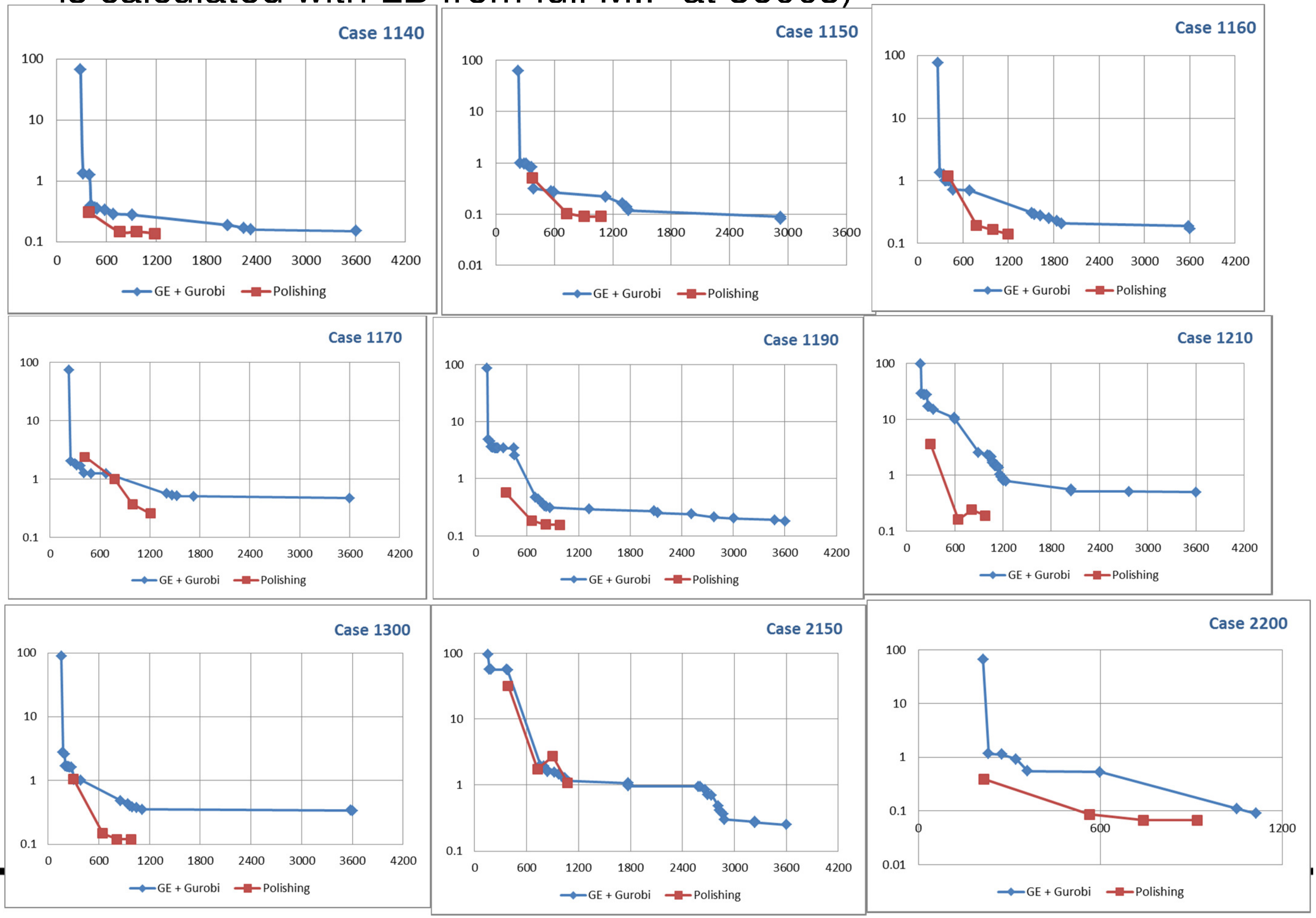
New solution approaches

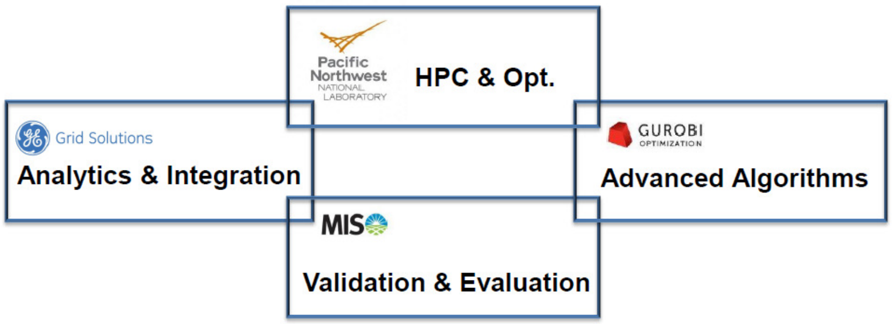
Explore parallel computing under ARPA-E HIPPO project

- HIPPO concurrent solver milestones: 2x by 09/2018 and 10x by 09/2019
- ADMM, RINS, partition, tighter formulation, strong branching… (see HIPPO presentations for detail)
  - Upper bound (UB)
    - Several promising methods to achieve 2x
  - Lower bound (LB):
    - LB directly from the MIP solver is sufficiently good for 0.5% MIP gap.
    - Need more improvement on LB in order to reduce time to reach 0.1% MIP gap

- Approach led by MISO: neighborhood search with parallel processors to generate effective hints and speed up solution process (i.e., SCUC polishing)
  - Fix binary and continuous variables
  - Set lazy constraints
  - Fast LP and MIP for solution polishing
  - Extract hints from historical solutions (possibility of using machine learning)

Polishing after 4 iterations compared to Full MIP (polishing gap is calculated with LB from full MIP at 3600s)





- 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.
- UF – Optimization, cutting planes, and integer programming
- LNNL – parallel MIP

- PNNL
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  - Arun Veeramany (Applied Math, Machine Learning)
- GUROBI
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