Overcoming Computational Challenges on Large Scale Security Constrained Unit Commitment (SCUC) Problems – MISO and Alstom's Experience with MIP Solver

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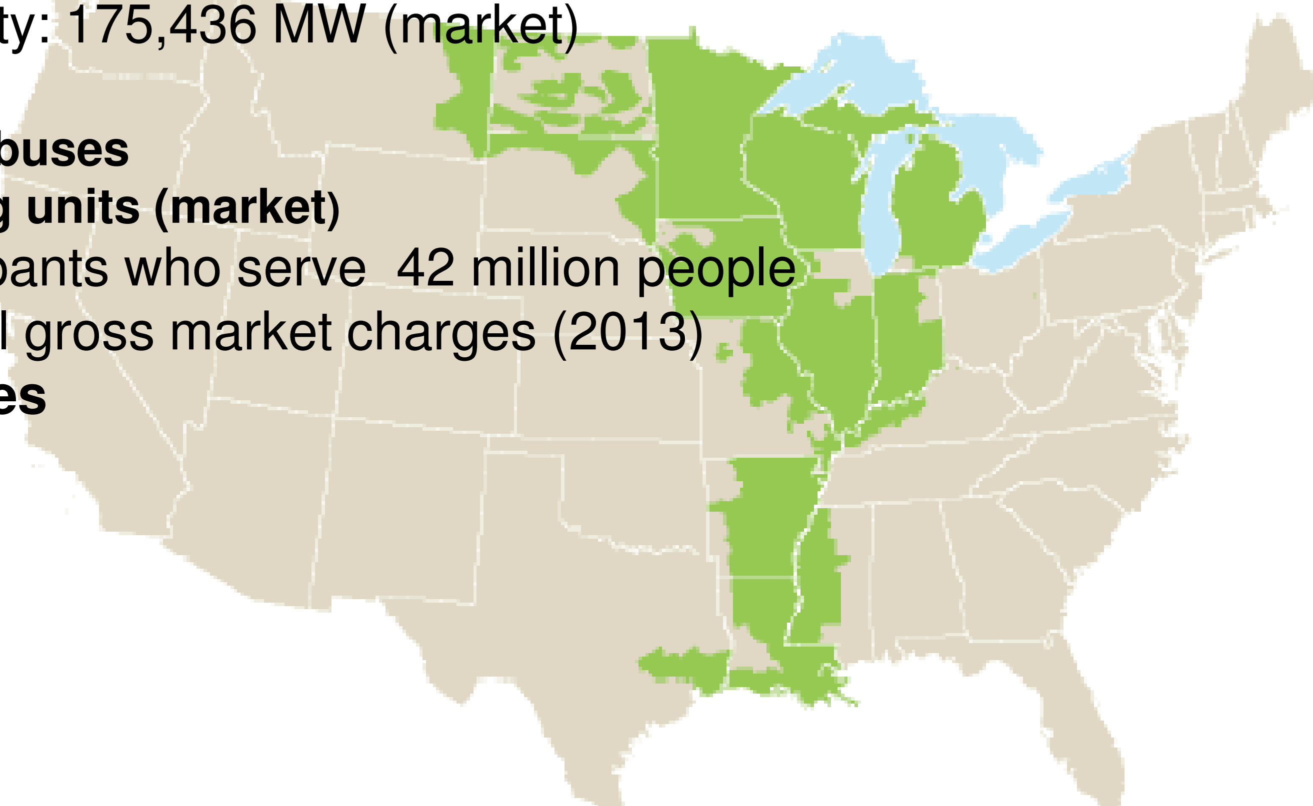
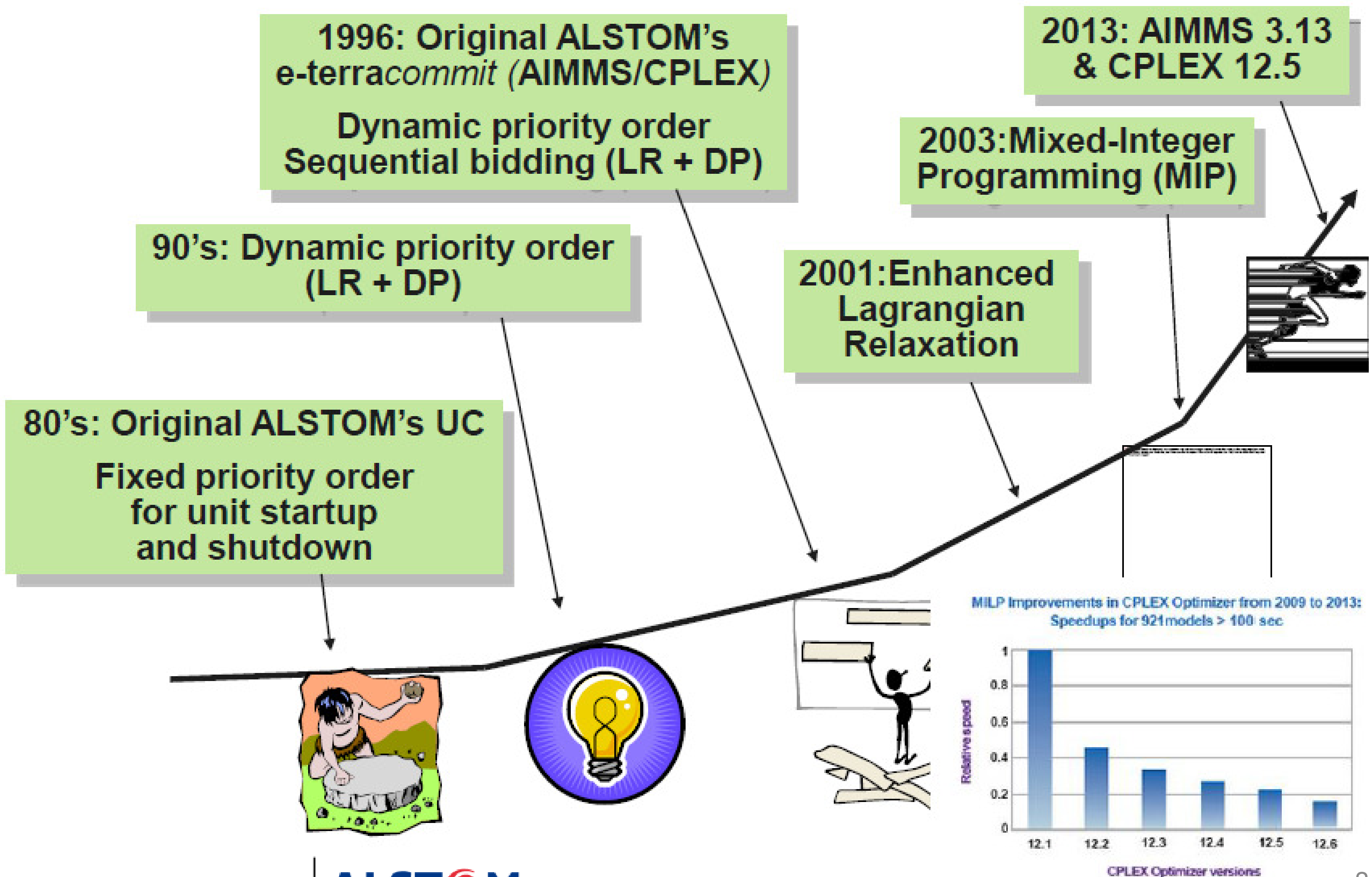
MISO Facts

- South region integration in December 2013
- 15 states
- 65,787 Miles of Transmission
- Generation Capacity: 175,436 MW (market)
- Network Model
  - **43,962 network buses**
  - **1,390 generating units (market)**
- 394 Market Participants who serve 42 million people
- $20.3 billion annual gross market charges (2013)
- **2,413 pricing nodes**



Alstom’s Unit Commitment Solution Methodology Evolution

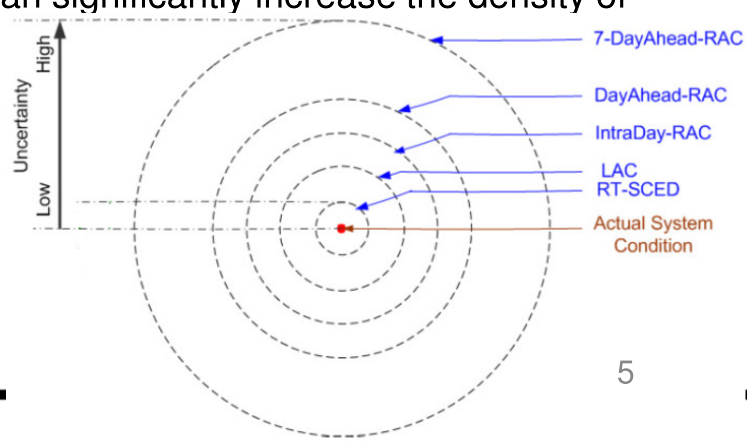


MISO SCUC

- Energy only market started in 2005
  - Lagrangian Relaxation (LR) based SCUC from Alstom
- Co-optimized energy and ancillary service market launched in 2009
  - Transition to SCUC using CPLEX MIP solver
- Commercial solver has made the efficient market expansion and market enhancement possible
  - Focus more on developing good mathematic models and formulations to reflect market rules and meet business needs
    - Launch of co-optimized energy and ancillary service market
    - Integration of south region
    - Market enhancement projects implemented, e.g.
      - Look-ahead commitment (LAC)
      - Post zonal reserve deployment transmission constraints to address reserve deliverability issues
      - Performance based regulation compensation (FERC Order 755)
    - Market development prototypes, e.g.
      - Configuration based combined cycle model
      - Robust optimization based LAC
- MIP solver can solve very well within required time limits for most cases. However, for a very small percentage of cases, it may have difficulty to find good solutions and require longer time to solve.

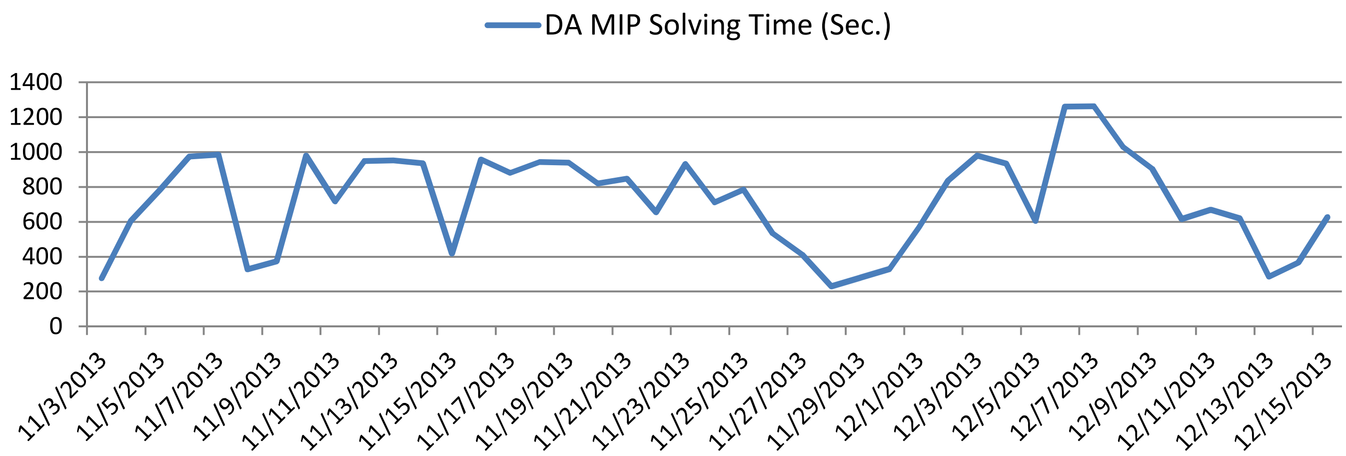
MISO SCUC Model

- Identified factors that drive MIP performance challenges
  - Number of binary and continuous variables
  - Number of transmission constraints
  - Density of matrix
  - Required solving time
- MISO has one of the largest and most complicated unit commitment problems in the real world
  - Commitment process
    - 7-day Forward Reliability Commitment (RAC)
      - Large number of binary variables
    - Day-ahead market commitment
      - Virtual offers and transmission constraints can significantly increase the density of the matrix
    - Day-ahead Forward RAC
    - Intra-day RAC
    - Look ahead commitment



MIP Solver based SCUC

- MIP solvers
  - "Branch & bound" + "heuristics"
  - Solution and lower bound
    - MIP gap to indicate the quality of the solution
- Observations
  - MISO SCUC problems are mostly solved with heuristics at the root node
  - Uncertainty of solving time depending on when the heuristics are triggered



MIP Solver based SCUC (Cont.)

- Day-ahead case
  - Without transmission constraints, MISO DA cases can solve in ~100s
    - Number of binaries is not the single contributor of performance challenge
  - Transmission constraints and continuous virtual variables can cause very dense matrix and drive performance challenge
    - DA SCUC requires longer time to solve with large number of continuous variables and dense matrix
      - Longer time to solve root relaxation LP
      - Longer time to solve each LP problem during the MIP searching process
    - MIP may not solve faster even if it is fed with a better initial binary solution
    - Uncertainty of solution quality at the time limit
- FRAC case
  - With no virtuals, the challenge is primarily driven by number of binaries
    - Especially for 7-day FRAC cases under load increasing pattern, i.e. requiring more commitment for future days
  - Primarily consider commitment cost with near zero incremental energy and reserve cost can cause the problem to be harder to solve
  - Multi-thread and parameter tuning can help improve the performance

MIP Solver based SCUC (Cont.)

- Example of DA case
  - Several participants submitted "≤1MW" virtuals on every pnodes
    - 18,1474 rows, 48,9155 columns, and **10,585,477 nonzeros** and 54,245 binaries
    - Production DA settings: single thread, 1200s time limit, 0.1% MIP relative gap

CPLEX12.5	Root relaxation	MIP Gap with 1200s time limit	Objective	Lower Bound	Major MIP gap reduction	MIP Gap with 1800s time limit
Thread=1	454s	40.18%	1.69a	1.01a	1484s: 40% to 2.85%	0.80%
Thread=8	279s	99.99%	7650a	a	1697s: 14.11% to 1.08%	1.00%

  - Remove all virtuals "≤1MW" by freezing the corresponding continuous virtual variable (reduced model)
    - 179,509 rows, 26,9991 columns, **1,956,112 nonzeros** and 54,245 binaries
      - Much more reduced matrix density with the number of nonzeros to be only 18% of the full model
      - With 1 thread, root relaxation (LP): 182s
      - At 431s, solved with 0.15% gap with an objective of 6.79a for the reduced model

MIP Solver based SCUC (Cont.)

- After getting the solution from the reduced model, putting back small virtuals
  - Using the binary solution from the reduced model to solve LP of the full model results in an objective of 1.05a

    ➔ **The reduced model can find a pretty good binary solution for the full model in 431s**

  - Let MIP solve the full model staring from the good binary solution

    ➔ **It takes another 1200s for MIP only to justify that its gap is 4.91% for the full model**

Root relaxation solution time = 463.07 sec.				
Node	Nodes Left	Best Integer	Best Bound	Gap
* 0+	0	1.05a	-11.7a	---
0	0	1.05a	0.96a	8.88%
0	0	1.05a	Cuts: 4263	4.91%

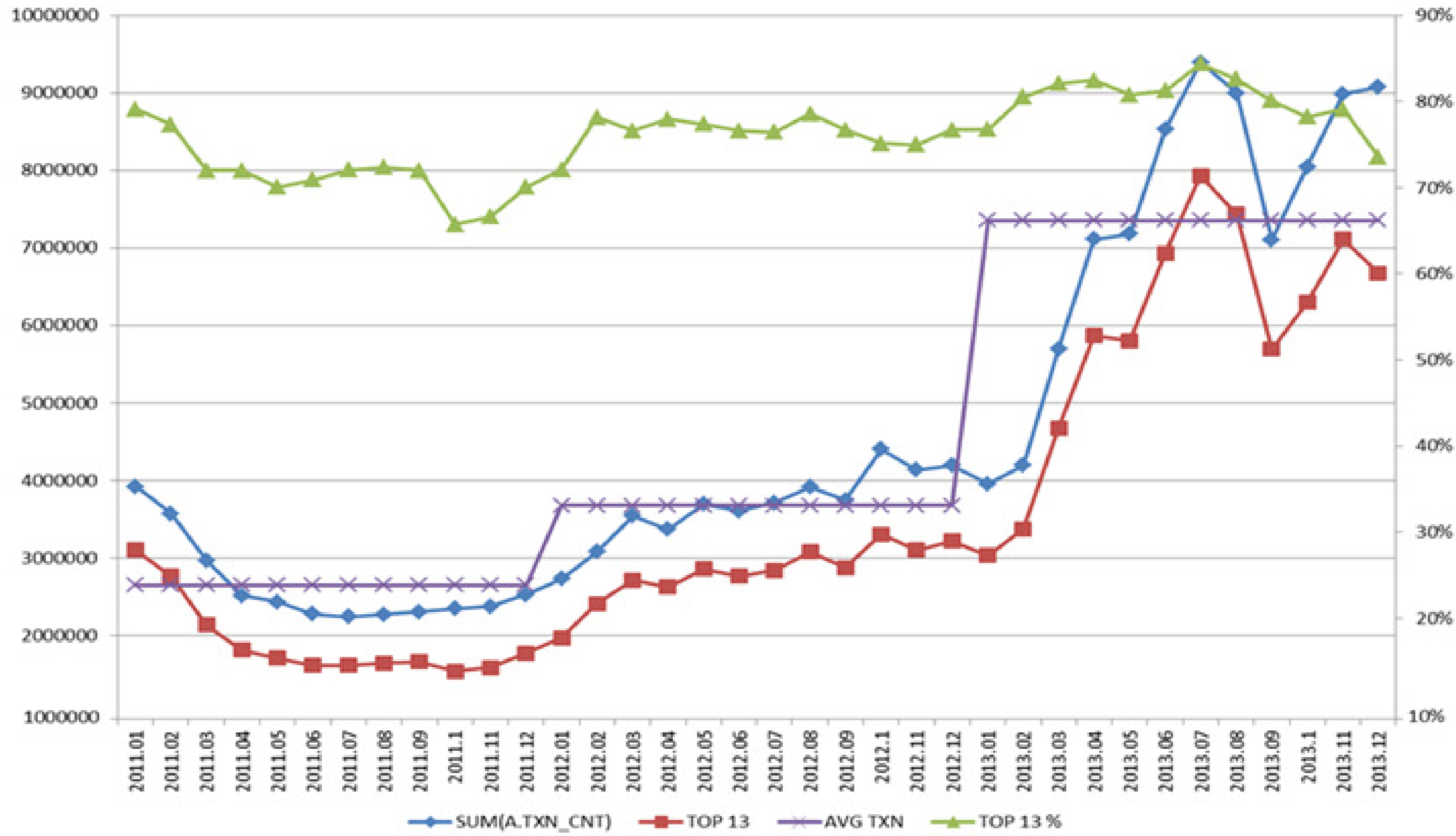
- Conclusion
  - Besides binary variables, density of the matrix can cause the problem very difficult to solve
  - MIP solving time can be very uncertain
  - Feeding MIP with better initial solution may not help solve the problem faster
  - MIP doesn't do very well for incremental solve

Strategies for Improving the Performance

- Collaboration with Operations Research community to improve the MIP solver
  - Existing MIP solvers cannot handle the DA problem caused by dense matrix very well. Have been working with the R&D experts on the solver side.
  - So far there hasn't been fundamental breakthrough
- MISO/Alstom collaboration to develop heuristics to improve SCUC performance
  - LR based approach and decomposition based approach
    - Using MIP to solve sub-problems makes it much easier to implement the heuristic approaches
  - Fundamental issue: how to justify the optimality
- MISO/Alstom collaboration to improve the entire commitment solving process
  - Improve the efficiency of DA-SCED, network analysis and software architecture
    - Phase I of the effort has reduced DA-SCED solving time by ~50%
    - Continue the effort in 2014-2016
  - Improve the capability of incremental solve
    - MIP cannot handle incremental solve very well
    - R&D prototype to use LR based approach for incremental changes

Strategies for Improving the Performance (Cont.)

- Potentially developing market rules to limit total number of virtuals
  - Virtual transaction volumes in 2013 doubled in comparison to 2012 levels and tripled compared to 2011 levels
  - Mostly driven by a small number of the top financial traders.



Strategies for Improving the Performance (Cont.)

- Possible rules to limit total number of virtuals
  - Impose administrative fees
  - Limit number of virtual offers from each participant

- Hardware/OS options
  - Current server: HP DL380Gen 8 Server Chassis; 2 Intel Xeon E5-2690 8 core CPUs; 64 GB memory
  - MIP solvers need more time to solve dense cases. More powerful hardware can potentially help.
  - Linux may give better performance over windows

Prototype Heuristic 1: LR Based Approach

- Incrementally adjust the commitment of a subset of the resources
  - Step 1: solve MIP with no transmission constraint (fast)
  - Step 2: freeze commitment variables, add all transmission constraints and solve LP (fast)
  - Step 3: Based on the prices, solve profit maximization for each resources (fast)
  - Step 4: Compare the profit between step 2 and 3, select the top ~20 resources out of the money for commitment adjustment. Freeze commitment variables of all other resources. Solve MIP for the top ~20 resources. (200s~500s).
  - Go to Step 3.
- This approach can also start from any other feasible solutions. Potential usage:
  - Backup approach to solve SCUC
  - Solution polishing when MIP gap is relatively large
  - Quickly solving commitment for increment changes

- Issue: no good indicator of the optimality gap

Prototype Heuristic 2: Decomposition Approach

- Handle transmission constraint incrementally
  - Step 1: solve MIP UC (i.e. master problem) with no transmission constraint (fast)
  - Step 2: freeze commitment variables, add all transmissions back to generate a LP (i.e. sub-problem). Solve this LP (fast)
  - Step 3: Pick (severe) violated transmissions and feed them back into the master problem; re-optimize the MIP with additional transmission constraints (600s~700s)
  - Step 4: Compare the objectives between Step 2 and Step 3. Stop the iteration if they are within the gap requirement
  - Go to Step 2.
- Usually achieve a good feasible solution (<10% gap) after two iterations.
  - Master problem grows with more transmission constraint after each iteration.
  - Final master problem MIP gap reflects global optimality if the approach converges
  - No good optimality gap indicator if the approach doesn't converge well

Example DA Case

- With CPLEX MIP

CPLEX12.5	Root relaxation	MIP Gap with 1200s time limit	Objective	Lower Bound	Major MIP gap reduction	MIP Gap with 1800s time limit
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- With LR-based approach

CPU sec	step	MIP Gap based on Lower Bound from CPLEX
92	MIP with no xmission	
26	Freeze binary; add xmission; solve LP	94.15%
27	Solving commitment under profit maximization based on price from last step; select top 20 out of the money	
123	Solving original problem for only the 20 selected resources with all other binaries fixed	20.73%
28	2nd profit maximization	
298	2nd top 20 commitment adjustment for the original problem	7.40%
28	3rd profit maximization	
528	3rd top 20 commitment adjustment for the original problem	3.20%
1150		

Example DA Case (Cont.)

- With Decomposition Approach

CPU sec	step	Gap
69.09	MIP with no xmission (Master 1)	
31.17	Freeze binary; add all xmission; solve LP (Sub 1)	95%
620.56	Master 1 with violated xmission from Sub 1; Re-optimize the new MIP (Master 2)	
18.66	Freeze binary; add all xmission; solve LP (Sub 2)	6.90%
887.04	Master 2 with violated xmission from Sub 2; Re-optimize the new MIP (Master 3)	
19.67	Freeze binary; add all xmission; solve LP (Sub 3)	0.20%
1646.19		

Improve the Capability of Incremental solve

- Operators need to make incremental solves every day
  - Add additional transmission constraints
  - IMM mitigation on offers
  - Determine commitment reasons for uplift cost allocation
- MIP cannot handle incremental solve very well
  - MIP may not solve faster even if it starts with a binary solution closer to the optimal
- LR based approach may improve the incremental solve capability
  - Example: determine commitment reason
    - Some "load pockets" in the south region requires using "N-2" limits while other parts of the system require "N-1" limits
    - Need to determine the additional commitment for "N-2" for uplift allocation purpose
    - Approach: compare commitment difference between "N-2" and "N-1". For one DA case:
      - Starting from "N-2" MIP solution, applying "N-1" limits and solve MIP: 1251s to reach 0.17% gap.
      - Starting from "N-2" MIP solution, one iteration of LR based approach can reach 0.79% gap in 231s CPU time.

Next Steps for Improving Existing SCUC Performance

- Short term
  - Solver performance option tuning and upgrade
  - Use MIP solver as the primary approach to solve the full SCUC problem
  - Use "LR based Approach" or "Decomposition Approach" as the backup approach
  - Improve the incremental solve capability and improve the entire commitment process
  - MISO operations also monitor the number of virtual transactions and request top traders to reduce the number of offers if needed
- Long term
  - Work with OR experts to
    - Incorporate the heuristics into the solver
    - Develop other new approaches
  - Better utilize multi-core hardware architecture
    - Multi-solver session in AIMMS
    - Concurrent MIP
    - Parallel SCUC sessions
  - Look at new hardware options
  - Develop market rules to better manage virtual volume

Future Market Development Depending on MIP

- Configuration based combined cycle modeling
  - Prototype case study on MISO testing cases prior to South Region integration
    - 27 CC groups; about 1150 resources
    - 36-h DA study intervals
  - Critical to tighten the binary constraints
    - MIP solving time initially increased from ~200s to ~1300s
      - The number of binary variables increased by ~70%
      - With better formulation of the optimization model, the solving time can be significantly reduced to ~500s
- Explore the possibility of combining LR based approach with MIP solver

Future Market Development Depending on MIP (Cont.)

- Virtual spread product
  - Expect significant increase of virtual volumes
- Robust optimization and stochastic unit commitment
  - Increase of continuous variables and constraints
  - Master problem becomes harder and harder to solve
  - Made good progress on robust optimization based LAC
    - MISO LAC case example

	Average Optimization Solution Time (sec.)				
	Total	Master 1	Sub 1	Master 2	Sub 2
Deterministic	26	-	-	-	-
Robust	225	33	25	141	26
Unified	121	33	28	41	26

    - The third iteration of the Master problem takes extremely long time to solve
  - RAC problem is much more challenging
    - A long way to go for production implementation

Summary

- Large scale RTO/ISO: increased societal benefit
- Requirement of advance modeling and computation on market clearing engines
  - More resource and network equipment mixes:
    - Combined cycle, HVDC, phase shifter, storage, ……
  - Increased problem size and variables
  - Increased number of transmission constraints, pricing nodes and financial activities that can drive dense matrix
  - Increased uncertainty
- Need more collaboration
  - Across multiple disciplines
  - Between industry and academia