Factors Impacting Large-scale Security Constrained Unit Commitment Performance and Day-Ahead Market Software Design

Boris Gisin, Qun Gu, Jim David
PowerGEM LLC
www.power-gem.com

FERC Technical Conference
Increasing Real-Time and Day-Ahead Market Efficiency
through Improved Software
June 26, 2017

Why is Day-Ahead (DA) SCUC Performance Critical?

- ISOs want to reduce DA SCUC run time
  - 2-3 hours to post results, often several reruns are needed
  - ISOs desire to add many more features

  https://www.misoenergy.org/Library/Repository/Communication%20Material/Market%20Enhancements/Market%20Roadmap/MISO%20Market%20Roadmap.pdf
- Sometimes market design decisions are made based on available DA software performance

- What factors have the largest impact on SCUC performance now?

PowerGEM acknowledges multi-year support of PJM and MISO

PowerGEM Experience With Market Applications

- Working on large scale SCUC for over 15 years
  - PROBE – PowerGEM implementation of SCUC
- Main PROBE applications:
  - DA - day-ahead clearance and financial markets analysis
  - RAC - reliability assessment commitment, single and multiple days
  - RT - Real-time market performance analysis
  - Outage analysis, market assessment/design, off-line studies and more
- Two flavors
  - PROBE for ISOs – customized version **per ISO**
    - Experience with PJM, MISO, ISONE, NYISO, CAISO
  - PROBE LT is a general purpose non-ISO specific version
    - Long term (future year simulation) and Short term (DA and sub-hourly)

PROBE for ISOs

- Customized version per ISO
  - Model specific ISO rules and applications, takes years to implement
  - Development “never stops” - due to market rules and other changes
- Focus of this presentation is on PJM and MISO applications that are currently in production
- PJM applications
  - DA – since 2005, daily, 12+ years
  - RAC – 6+ years
  - PD (Perfect Dispatch) – RT Simulator. Since 2008, PJM estimated overall savings over $1.3 billion

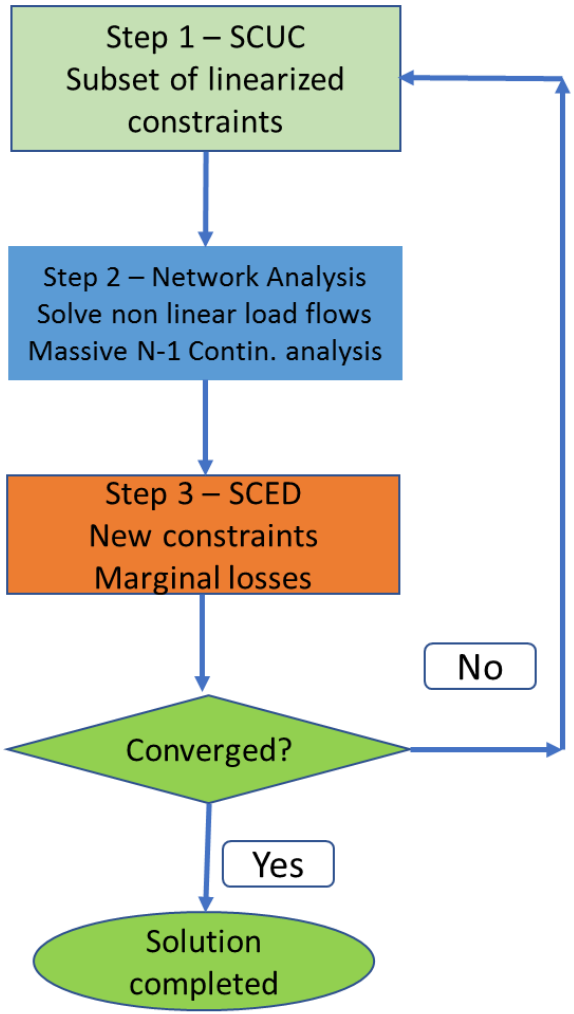
http://www.pjm.com/~/media/committees-groups/committees/mc/20170517/20170517-item-09b-operations-report.ashx

  - Outage acceleration - runs monthly, require 1000+ DA simulations
- MISO applications
  - DA, pre-DA run, single day RAC and multi-day FRAC (forward RAC)

Day-Ahead Model Statistics (PJM and MISO)

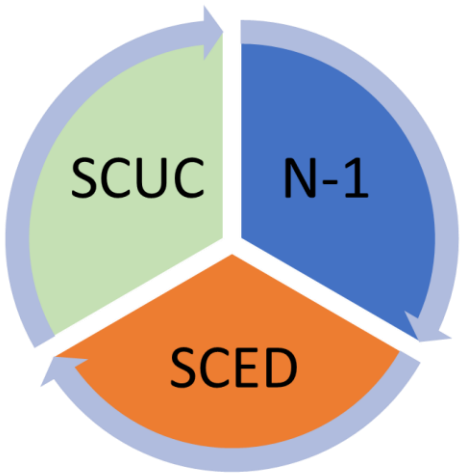
- ~1,500 generators optimized, 100,000-180,000 MW capacity
  - Ancillary services (ASM) co-optimization
- Advanced unit models
  - Pump storage and limited energy generators
- Large volume of financial bids
  - 10,000-25,000 bids per hours – PJM
- Large scale EMS based transmission model
  - Reduced MISO LF case has 50,000-70,000 buses
  - Each hour may have different topology
  - Non linear load flow model with marginal losses
  - Constraints – 3,000 – 8,000 monitored branches, but … not all
  - Contingencies – up to 1,000, but … still less than a full EMS contingency list

Typical SCUC Solution Sequence



- General SCUC implementation can be presented based on this iterative diagram
- Implementation differs by vendor
- Steps 1,2,3 can be implemented as separate applications or as a single combined solution
  - Vendor specific with no industry standard convergence criteria
  - Step 2 LF model with local controls (phase shifters) may be different from steps 1 and 3

PROBE Implementation Overview



PowerGEM doesn't decouple SCUC, SCED and N-1

It is a single integrated application

- SCUC calls SCED and N-1 CA internally many times until converged
- Numerous heuristics and constraint relaxation during SCUC search
  - depending on how close to the solution
  - At different stages of the search may relax ramp rate, econMin …
- Little value in refining UC solution until all N-1 constraints enforced and flows are computed via non linear load flow near final solution

- **SCED is based on dual simplex LP**
- **Not using third party MIP solvers, everything is coded in C/C++**

Key Design Considerations

- Active list of constraints in SCED/SCUC grows dynamically
  - Do not precompute linearization factors (DFAX) for majority of constraints
  - Active constraint flows are updated via incremental DC load flow solutions and compensation methods for post contingency constraints
  - 10,000+ active “watch list” constraints may be monitored per hour with little impact on performance – routine number in PROBE LT
- SCUC runs many incremental SCEDs (10,000+ times)
- Efficient memory management
  - All load flow models per each solved time interval are explicitly allocated in RAM
  - Share load flow models and DFAX memory whenever possible
  - No I/O between SCUC, SCED, and network analysis

Performance Analysis Objectives and Criteria

- High solution quality
  - No violations or violations minimized
  - Lower objective BPC – (Bid Production Cost)
  - Accurately represent physical system (Constraint flow, Losses)
- Faster performance without sacrificing high quality solution
- "Start to end" performance analysis
  - ***Looking at just one component like SCUC is misleading***
  - All modeling features considered at the same time
  - The worst performance is due to the presence of several factors at the same time

PROBE PJM DA performance today

- Typically PROBE solves in 5 -15 minutes
  - Single day, 24 time intervals
  - Single core I7 CPU, commodity hardware
  - Tough cases may take 30-60 minutes
  - Difficult to predict and varies a lot

	Normal Run Time Hr:Min:Sec	
20161215	**1:00:55**	Worst day last year
20170119	05:01	
20170317	04:25	
20170427	05:05	
20170517	12:28	

Top factors with the largest impact – PJM DA

- Large number of virtual UTC bids
- Pump storage and limited energy bids
- Ancillary services co-optimization
- Iterative model with marginal losses (ML)
- Automated market power mitigation based on TPS
- Phase shifters modeling - not discussed here

Performance Test below - remove one factor and rerun PROBE

Market Day	Normal Run		No UTC	No Pump	No ASM	No ML	No TPS
20161215	**1:00:55**		05:19	34:08	21:30	14:32	26:26
20170119	05:01		05:00	02:35	03:45	10:53	03:50
20170317	04:25		03:22	02:49	03:23	05:49	03:21
20170427	05:05		06:52	02:24	04:46	07:32	04:12
20170517	12:28		08:56	07:38	06:44	15:18	10:11

Large Volume of Virtual/UTC bids at PJM

- Types of PJM virtual bids – INC, DEC and UTC
  - INC, DEC (injection bids) - modest impact on performance
- UTC - bilateral **U**p **T**o **C**ongestion transactions
  - Scheduled based on the LMP difference
  - Large volume in number of bids– may be 20,000 bids per hour
  - Total MW offered may exceed demand
  - Small fraction is cleared in DA
  - Since 2011. See link below for more info

http://www.pjm.com/~/media/committees-groups/committees/mc/20170517/20170517-item-09a-markets-report.ashx

UTC impact on performance

- Increase the number of LP iterations and the number of binding constraints
- More than 80% of all marginal bids are UTC bids
  - per Monitoring Analytics 2016 PJM SOM Report, table 3-7
- Impacts convergence
  - Iterative load flow solutions may not solve
  - Cause marginal losses oscillations and more SCUC reruns
- Interaction with other advanced models like pump optimization
- Actively monitoring performance and many improvements were added over last 5 years

Pump storage impact on performance

- Reservoir storage model in PROBE, used for over 10 years
  - Unit bids in reservoir initial and final desired water level plus efficiency factor
  - Three state model – generation, pumping and offline. Has to be offline for at least one hour before switching between generation and pumping
- PJM Bath County pump storage is the largest storage in the world with Pmax ~3000 MW

  https://en.wikipedia.org/wiki/Bath_County_Pumped_Storage_Station
  - In congested area, large dispatchable range, two owners bidding separately
- Major impact on performance for only 3-4 pump bids in PJM
  - Concerned that performance will degrade with more storage bids

Pump storage impact on performance

- Two SCED designs/solution methods
- Global multi-period optimization – used for many years (2006-2015)
  - Solves 24 hours as a single SCED problem
  - Performance degraded with the “explosion” of UTCs and higher ASM MCPs
- Sequential SCED - used in production since 2015
  - Faster decomposition model - developed recently
  - Limiting pump dispatch change per incremental LP solution due to interaction with congestion
  - Much faster than global solution and less sensitive to the model size

Limited Energy Generation (LEG)
MISO experience

- Max Energy that can be provided during the day. Model:
  - Generation part of Pumped Storage Unit, pumping is self-scheduled
  - Hydro, gas or other fuel limited generators
  - Could be for environmental reasons
- LEG model as compared to Pump
  - Two state model – on and off
  - Some LEGs have limited dispatchable range and thus LEG constraint…
    - Sum(Pgen) <= MaxMwHr, can never be binding
  - More LEG units than pump units
- So far LEG bids have less impact on the performance
  - Smaller MW volume and do not interact with local congestion

Energy and Ancillary Service (ASM) Co-optimization

- Adds large number of optimized controls
- Adds many “Local unit” constrains
  - Pgen+Reg+Spin+Supp<=RegMax, Pgen+Spin+Supp <=EconMax
  - If regMax<econMax –three state model - Offline, OnEnergyOnly, and OnEnergyRegulation
  - Number of “local unit” binding constraints exceed transmission constraints many times
- ASM requirements can be sophisticated
  - MISO zonal ASM deliverability - ASMFlow +EnergyFlow <=Limit
- Impacts more PROBE MISO performance than PROBE PJM due to larger number of ASM products procured in DA
- Combination of UTC, Pump and ASM Interaction had the major impact at PJM

Nonlinearity of Load Flow Model

- Several iterations between linearized SCUC and non-linear load flows
- PROBE uses non-linear load flow solution
  - "MW only" iterative load flow, similar to AC load flow assuming Vmag=1PU, only voltage angles change
- Marginal loss (ML) factors are computed iteratively
  - PROBE updates ML in the outer SCED loop – 3-5 times
- Iterative solutions don't guarantee convergence
  - Many iterations may be not acceptable for performance
- Removing marginal losses typically improves performance
  - Not always, may actually slow down solution

Loss Performance Impact Study

Counterintuitive – removing ML slows down solution

- Sample day (01/19/2017), No ASM and no TPS

	UTC	No UTC
With ML	0:09:21	0:03:00
No ML	0:21:34	0:02:36

- UTC are responsible for the solution time increase when losses are not modeled
  - Market participants tune UTC bids based on DA/RT historical performance. Running without losses results in more congestion and binding constraints
  - Solution degeneracy – many bids with the same $bid. No losses to serve as a tie-breaker. Increase number of LP iterations with no objective change

Multiple-Schedule Optimization and TPS

- Units may have multiple schedules (mode of operation) for various reasons
  - Price schedule (submitted bid) vs. cost schedule
  - Multiple fuel units
  - Unit may have limited fuel and need to change fuel during the day
- PJM DA market power mitigation
  - TPS - Three Pivotal Suppliers test
  - PROBE runs in two passes
    - Pass 1 - SCUC1 with submitted bids. Find units that failed TPS test
    - Pass 2 – SCUC2 – second pass. Unit schedule can be changed by SCUC to minimize BPC

Multi-day Optimization – Beyond Day-Ahead

- Today DA solves for 24 hourly intervals
- Current Multi-day PROBE applications
  - Commitment of long lead units with (minRun+minDown) > 24 hours
  - PROBE MISO multi-day FRAC – 3-5 days - 72-120 hourly time intervals
- Other applications with more than 24 time intervals
  - PROBE PJM Perfect Dispatch uses 48-96 time intervals
- Future potential applications
  - MISO considering multi-day financial commitment
  - Weekly pump storage optimization and hydro requiring longer time window
  - Solving DA with 30 minute time step
- Sequential SCED is more scalable than global SCED

Summary

- Focus on “Start to end” performance analysis is important
  - Looking at just unit commitment is misleading
- All modeling features considered at the same time
  - Worst performance is due to several critical factors at the same time
- Dependent on market conditions – need to test many days
- Performance will continue being critical in the near future and will be an area of further research in foreseeable future
  - ISOs want to add more features
  - Users always want to run more studies than can be done