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

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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

- 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

<table>
<thead>
<tr>
<th>Date</th>
<th>Normal Run Time Hr:Min:Sec</th>
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<td>1:00:55 Worst day last year</td>
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<tr>
<td>20170119</td>
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<td>20170317</td>
<td>04:25</td>
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<tr>
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<td>05:05</td>
</tr>
<tr>
<td>20170517</td>
<td>12:28</td>
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</table>
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

<table>
<thead>
<tr>
<th>Market Day</th>
<th>Normal Run</th>
<th>No UTC</th>
<th>No Pump</th>
<th>No ASM</th>
<th>No ML</th>
<th>No TPS</th>
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</thead>
<tbody>
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</tbody>
</table>
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 Up To Congestion 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 $P_{max} \approx 3000$ 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 \( V_{\text{mag}} = 1\text{PU} \), 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

<table>
<thead>
<tr>
<th></th>
<th>UTC</th>
<th>No UTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>With ML</td>
<td>0:09:21</td>
<td>0:03:00</td>
</tr>
<tr>
<td>No ML</td>
<td>0:21:34</td>
<td>0:02:36</td>
</tr>
</tbody>
</table>

• 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