Stochastic Unit Commitment at Scale: Cost Savings Analysis for ISO-NE

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Any many others…

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SunShot U.S. Department of Energy

arpa·e

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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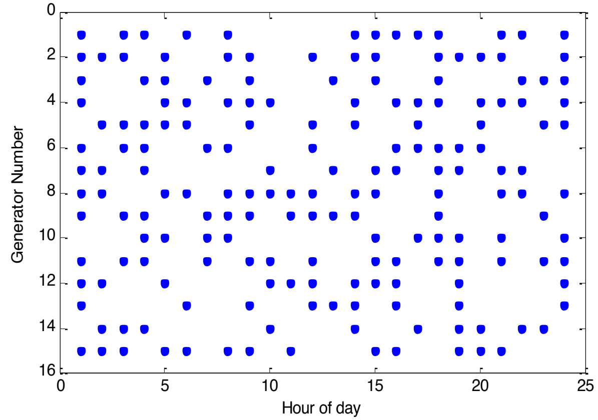
The General Structure of a Stochastic Unit Commitment Optimization Model

Objective: Minimize expected cost



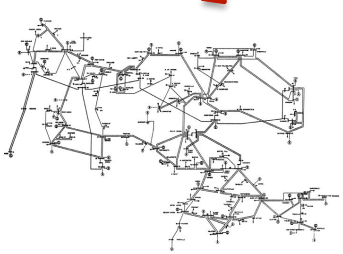
First stage variables:

- Unit On / Off

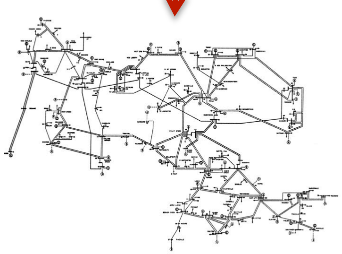
Nature resolves uncertainty

- Load
- Renewables output
- Forced outages

p_1 p_2 … p_N

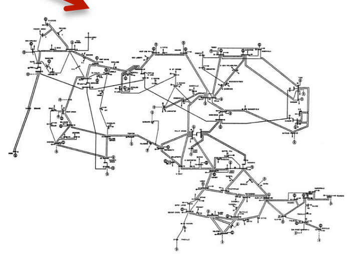


Scenario 1



Scenario 2

…



Scenario N

Second stage variables (*per time period*):

- Generation levels
- Power flows
- Voltage angles
- …

(Some) Historical Barriers to Adoption of Stochastic Unit Commitment

- ***We can't create sufficiently accurate sets of scenarios to capture load and renewables uncertainty***

- ***Even if we could create accurate sets of scenarios, the resulting models are too difficult to solve***

- ***Even if we could solve the resulting models, it would require significant HPC resources – which is a major impediment to industrial adoption***

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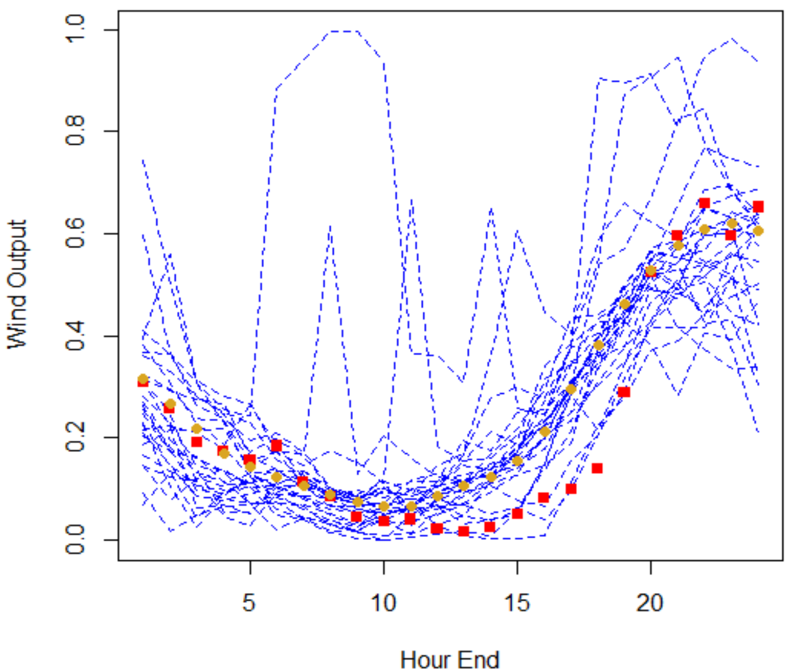
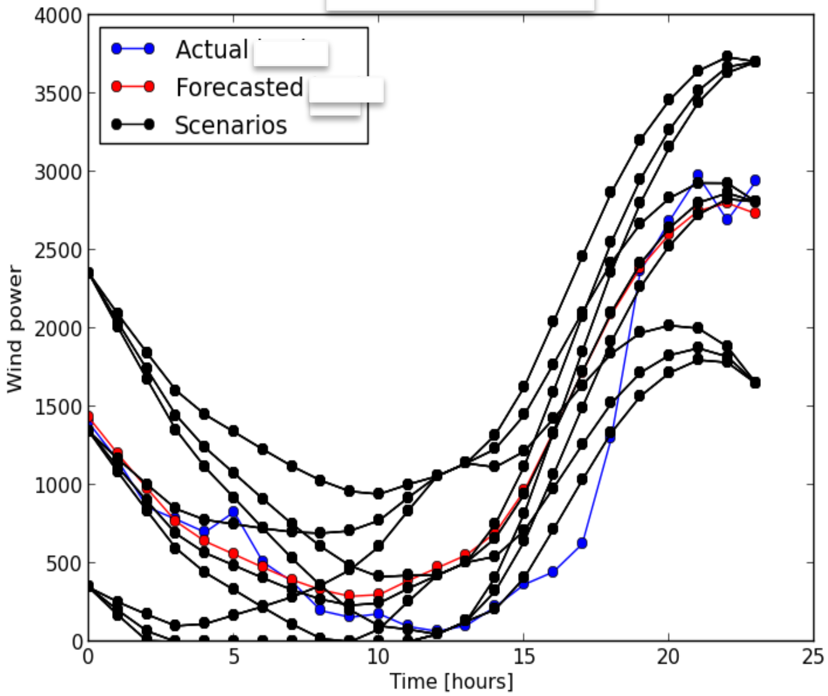
Wind Scenario Generation: BPA

Scenarios generated using Pinson et al. method



Scenarios generated using our epi-spline approach



Note: Real wind profiles show significant ramps, but not as extreme as those obtained using (e.g.,) the Pinson et al. method

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Progressive Hedging Results: WECC-240++

Table 7 Solve time (in seconds) and solution quality statistics for PH executing on the *WECC-240-r1* instance, with $\alpha = 0.5$, $\mu = 6$, and $\gamma = 0.025$

# Scenarios	Convergence Metric	Obj. Value	PH L.B.	# Vars Fx.	Time	Latest…
64-Core Workstation Results						
3	0.0 (20 iters)	64213.397	63235.381	4080	508	166
5	0.0 (in 18 iters)	62642.531	61767.253	4079	674	119
10	0.0 (in 35 iters)	61396.553	60476.604	4066	648	167
25	0.0 (in 22 iters)	60935.040	59992.622	4066	761	212
50	0.0 (in 15 iters)	60625.149	59631.839	4034	1076	280
100	0.0 (in 25 iters)	61155.387	60014.571	4080	1735	315
Red Sky Results						
50	0.0 (in 16 iters)	60623.343	59779.813	4007	404	
100	0.0 (in 25 iters)	61120.943	60275.744	4080	549	

ISO-NE results are obtained on Red Sky on average in 10 minutes, 20 minutes in the worst case (with 100 scenarios)

Improved UC Formulations?

- Morales-Espana et al. (2013)
  - Extends prior tight formulation by Ostrowski et al.
- Shows off advantage of PH, in that improved deterministic models immediately impact stochastic solve times
- Results

Table 10 Solve time (in seconds) and solution quality statistics for PH executing on the *WECC-240-r1* instance, with $\alpha = 0.5$, $\mu = 3$, and the MTR deterministic UC model.

# Scenarios	Convergence Metric	Obj. Value	PH L.B.	# Vars Fx.	Time
		64-Core Workstation Results			
3	0.0 (in 36 iters)	64141.771	64109.021	4080	237
5	0.0 (in 23 iters)	62628.532	62499.212	4080	161
10	0.0 (in 26 iters)	61384.016	61327.734	4080	215
25	0.0 (in 41 iters)	60927.903	60850.717	4080	366
50	0.0 (in 11 iters)	60617.311	60470.956	4044	318

- ISO-NE results drop to 15 minutes maximum (10 average)

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Our Hardware Environments

- Our objective is to run on commodity clusters
  - Utilities don't have, and don't want, supercomputers
  - But they do or might have multi-hundred node clusters
- Sandia Red Sky (Unclassified Segment) – 39th fastest on TOP500
  - Sun X6275 blades
  - 2816 dual socket / quad core nodes (22,528 cores)
    - 2.93 GHz Nehalem X5570 processors
    - 12 GB RAM per compute node (1.5 GB per core) << IMPORTANT!
  - For us, the interconnection is largely irrelevant
  - Red Hat Linux (RHEL 5)
- Multi-Core SMP Workstation
  - 64-core AMD, 512GB of RAM
  - For only $17K from Dell….

On HPC and Stochastic Unit Commitment…

- We observe that stochastic unit commitment solvers ***do not*** require HPC for execution on industrial scale problems
  - Commodity clusters are sufficient for many analyses
  - Execution on the cloud (e.g., Gurobi with Amazon EC2) is feasible

- There is little evidence that hundreds of thousands to millions of scenarios are required for stochastic unit commitment
  - Approximation of stochastic process models can avoid scalability issues associated with Monte Carlo approaches

So Is All of This Machinery Worth It?

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- ***Now that we can solve stochastic unit commitment at scale…***
  – Does it provide any quantiative benefits?

Cost Savings Analysis: ISO-NE Wind (1)

- Eastern Wind dataset from NREL
  - Approximates locations from EWITS study (within ISO-NE)
  - Wind from 2004-2006
  - AWS Truepower NWP simulation used to develop actuals
- Impose site selection from Eastern Wind data set to mirror site selection corresponding to EWITS scenario 2
  - Emphasizes on-shore sites
- Forecasts
  - Obtained from AWS Truepower tool – SynForecast
  - Proprietary – "Uses actual forecasts and observed plant output to develop a set of transition probabilities that are then applied stepping forward in time…" (aka, a Markov Chain)
- Recently updated for use in the ERGIS project study

Cost Savings Analysis: ISO-NE Wind (2)

- Through the NREL wind toolkit we can obtain EWITS scenario forecast data
- The WIND dataset is a new dataset that has approximately 120,000 wind turbine production time series including 2011
  - There is no mapping from EWITS sites to WIND turbines
  - EWITS Scenarios 2 and 3 sites were matched to WIND dataset turbine locations based on geographical proximity (closest)
  - Matching WIND wind power production time series were scaled to match the installed capacity of their corresponding EWITS sites

Experimental Methodology (1)

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- 2004 Eastern Wind data
- 50 wind scenarios per day
  - Generated using our tool chain based on epi-splines
  - (Simulated) actual taken from NREL database
- 1 load scenario per day
  - Expected load computed using our epi-spline tool chain
  - Models fit using historical ISO-NE 2011 data
  - Actual taken from actual ISO-NE 2011 data
  - "Platinum" standard simulation, i.e., rolling horizon
- Run deterministic UC with fixed reserves (10%)
  - Also variant with NREL reserve rules
- Run stochastic UC with fixed reserves (2%)
  - Also variant with no reserves

Experimental Methodology (2)

- Wind is *not* modeled as must-take
  - Per advice from NREL
  - In practice, there are days at these penetration levels in which it is impossible to use net load formulations w/o shedding
- Note
  - Load shedding does not imply delivery will not occur
    - Rather, actions outside the simulator will be taken to secure generation
  - Same holds for reserve margin shortfalls

Cutting to the Chase: Cost Savings (1)

- Computed in terms of relative cost increase of deterministic over stochastic
  - Yes, this implies that stochastic does win (but)…
- Results in terms of percentages
  - Q1: 1.52%
  - Q2: 1.31%
  - Q3: 0.89%
  - Q4: 1.23%
- Not as significant as we would have anticipated, given the large wind penetration levels in EWTIS scenario 2
  - Possible reasons to be discussed in subsequent slides

Cutting to the Chase: Cost Savings (2)

- Translating percentage savings into dollars…
  - Q1: ~$4M per month
  - Q2: ~3M per month
  - Q3: ~$12M per month
  - Q4: ~$2.5M per month
- Overall, the savings in 2011 “would have been” $64.5M
- That is real money, but is it accurate?
  - As we argue in subsequent slides, this should be viewed as a lower bound on the potential cost savings

Reliability Results

- We did not report load shedding and/or reserve shortfalls in the previous cost savings statistics
  - Placing arbitrary penalty values on these quantities is not useful
  - Distinct reporting allows more insight into system behaviors
- Stochastic UC
  - One load shedding event – peak day in July
  - Incurred due to particularly bad load forecast
- Deterministic UC
  - Five load shedding events – including the peak day in July
  - Additionally incurs reserve margin shortfalls on approximately 10% of all days in 2011
- Summary
  - Stochastic UC, despite lower reserve margins, is more reliable

Natural gas prices over time…

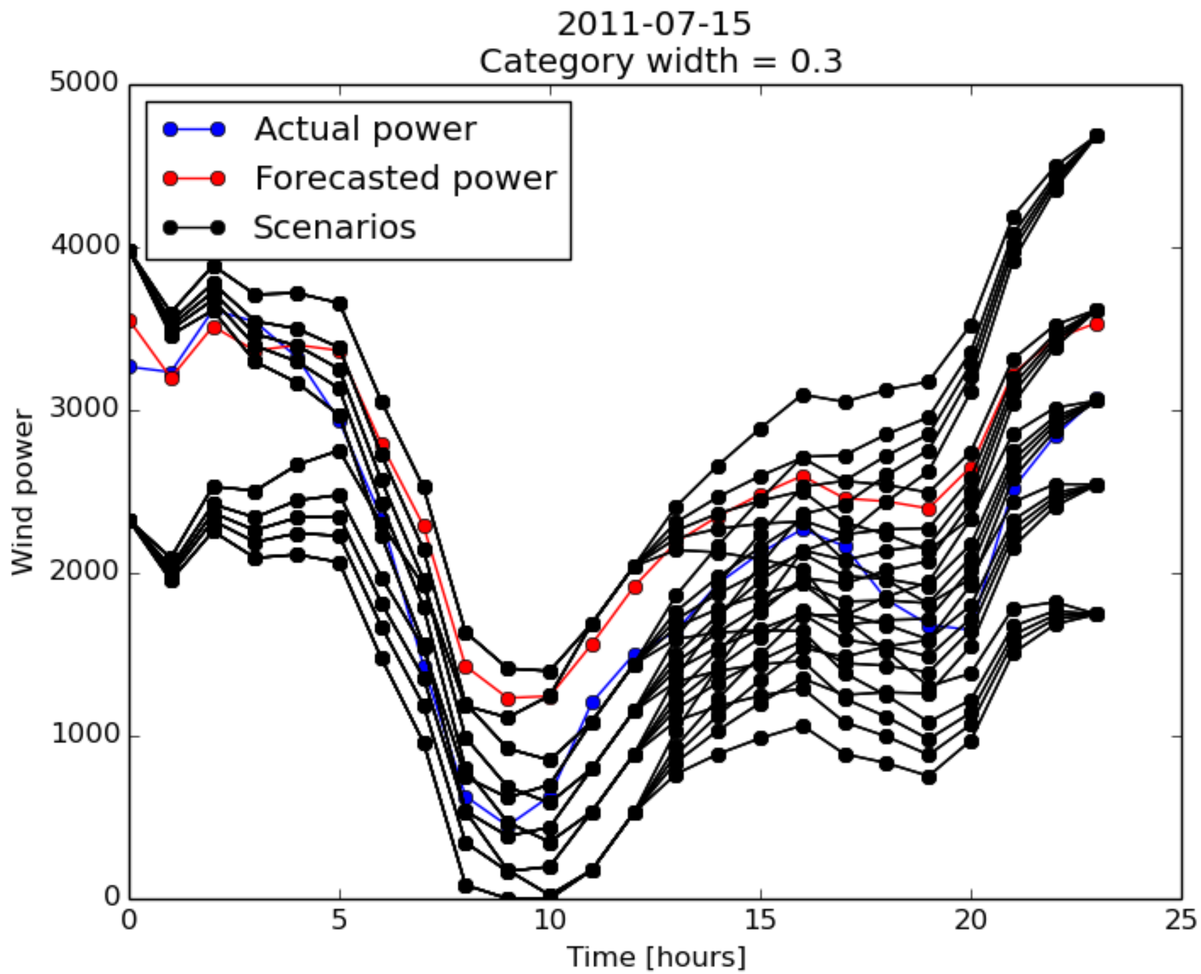
Cost Computation Issue # 2

- Stating the obvious
  - The cheap price of natural gas in 2011 *significantly* impacts the overall cost savings numbers we observe
- Most of the stochastic unit commitment literature still assumes that natural gas / peaker units drive costs when making up for discrepancies between forecasts and actuals
  - Which would be true with 2000 through 2008 natural gas prices
  - Current prices are 25% lower (at least) relative to that period
  - It now costs very little to be wrong for deterministic UC
- Almost all of the cost savings are due to natural gas units
  - Would significantly impact absolute dollar savings
  - Would impact percentages; not sure to the degree
- We are partially a victim of bad timing
  - If we had started the project in 2008…

Some Perspective

- The annual bid cost savings for PJM in the transition from Lagrangian relaxation to MIP are estimated at $60M
  - And PJM is approximately 7 times larger than ISO-NE
- Even discounting potential / likely issues causing our cost savings numbers to be low, the savings is sufficiently large that it may drive ISO adoption
  - With numerous caveats, in that the comparison is not as clean
    - Day-ahead markets and regulation complicate the interpretation

Potential Issues with Wind Scenarios (1)



The above is typical of wind scenarios generated from NREL "forecast" and "actual" data

Potential Issues with Wind Scenarios (2)

- NREL data sets are generated from NWP simulations
  - OK, but it depends on how the forecasts are generated…
- The forecasts and actuals are suspiciously correlated
  - Too correlated, in our view – the shape correlation is notable
  - We believe our forecasting technology is very good
    - But it isn't that good…
- Better-than-expected correlation between forecasts and actuals are more likely to benefit deterministic UC
  - E.g., imposing BPA wind on ISO-NE yields significantly larger savings in limited / preliminary experiments
- Using 3-Tier scenarios as actuals de-correlates the forecasts with the actuals in the WIND data
  - And also leads to larger cost savings (but is harder to defend)

Simulator Enhancements (1)

- Nearly all existing production cost models are *prescient* with respect to economic dispatch
  - Including the original version of our simulator
  - Actual time-series are released at midnight
  - Economic dispatch proceeds with perfect foresight through the day
- (Potential) Issues
  - This obviously results in an optimistic operations environment
  - At a minimum, is completely unrealistic
  - More fundamentally, projected cost savings could be off
- One notable non-prescient production cost model is WILMAR
  - But they are prescient for 3 hours ahead
  - And execute within-sample, with a limited number of scenarios

Simulator Enhancements (2)

- Our new approach
  - Use persistence approach to computing forecast errors
  - For deterministic
    - Assume percentage error for current time relative to point forecast holds in the future
  - For stochastic
    - We have scenarios, so we'll use them
    - Compute the nearest scenario to the observed realization
    - Assume percentage error for current time relative to nearest scenario holds in the future
  - We argue these approaches are a sane and straightforward emulation of what either does or could happen in operations
- Also worth noting
  - Most production cost models consider only a single time period
  - We are cost-minimizing for one time period, maintaining feasibility for the next 24 time periods

Revisiting Wind-Only Baseline Results

- Computed in terms of relative cost increase of deterministic over stochastic
  - Yes, this implies that stochastic does win (but)…
- Results in terms of percentages
  - Q1: 1.49%
  - Q2: 1.27%
  - Q3: 0.92%
  - Q4: 1.03%
- Slightly lower than with prescient simulation model
- Penetration levels vary by season
  - Ranges from 10% to 40%
  - But 40% is when you don't need it…

Toward Higher Wind Penetration (1)

- Consider October 2011
- 26% observed penetration of wind power (in our model)
- Stochastic curtails 4.5% less wind than deterministic
- Stochastic is 1% less costly than deterministic
- No serious reserve shortfall issues
  - Although worth noting that deterministic sees reserve shortfalls in two days, while stochastic has no reliability issues

- So why isn't stochastic saving more?
  - There isn't yet enough "spread" in wind power scenario forecasts to avoid having committed generation make up the shortfall
    - In particular, relative to the total demand

Toward Higher Wind Penetration (2)

- Reconsider October 2011, but increase the penetration level
- 43% observed penetration of wind power
  - Not crazy high levels – toward the higher end of current practice
- Stochastic curtails 2.7% ***more*** wind than deterministic
- Stochastic is 7.6% ***more*** costly than deterministic
- But what about reliability?
  - Stochastic yields ~7K MWh of load shedding
  - Deterministic yields ~73K MWh of load shedding
- Summary
  - Easy to cost less and curtail less when you load shed (a lot) more!
  - Reliability issues start to dominate at ~40-50% penetration levels
  - Cost isn't an issue here – you'll need stochastic to even operate the system

Increased Deterministic Reserves?

- What if we increase the deterministic reserves from the NREL 5% to an aggressive NREL 20%?
- Stochastic curtails 2.3% ***more*** wind than deterministic
- Stochastic is 1.8% ***less*** costly than deterministic
- What about reliability?
  - Stochastic yields ~7K MWh of load shedding
  - Deterministic yields ~35K MWh of load shedding
  - Deterministic exhibits reserve shortfalls of 306K MWh
- Summary
  - Substantial increases in reserves do yield reduced load shedding
  - But the stochastic solution is both more reliable and cost-effective

(Some) References

- Toward Scalable Stochastic Unit Commitment – Part 1: Load Scenario Generation, Feng et al., *Energy Systems*, To Appear.
- Toward Scalable Stochastic Unit Commitment – Part 2: Solver Configuration and Performance Assessment, Cheung et al., *Energy Systems*, To Appear.
- Multi-Period Forecasting and Scenario Generation with Limited Data, Rios et al., *Computational Management Science*, To Appear.
- Obtaining Lower Bounds from the Progressive Hedging Algorithm for Stochastic Mixed-Integer Programs, Under Review.
- Integration of Progressive Hedging and Dual Decomposition in Stochastic Integer Programs, *OR Letters*, To Appear.

QUESTIONS