Optimal Unit Commitment under Uncertainty in Electricity Markets

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With help from Brad Wagner at LRCA
Opening remarks

• We describe a new way to think about Unit Commitment (UC) under uncertainty
  – We describe optimal commitment strategies not just optimal unit commitment
  – This talk is about concepts, not algorithms

With better technology, can we solve a better problem?
Our objectives

• To show that conventional UC does not lead to optimality under uncertainty
  – We use a trivially simple example
  – Optimality requires *strategies*, not schedules
• To outline a modified LR solution method
  – Options not considered include modifications to Mixed Integer Programming (MIP) methods
Stochastic Unit Commitment

• Consider using Lagrangian Relaxation (LR)
  – Since energy and reserve prices are outputs of UC, start with initial guesses of prices and their probability distributions

• Refine price estimates and their probability distributions until convergence is reached
Uncertainty matters: an example

• A 4-generator energy-only 2-scenario case

• Compare three UC methods
  1. Deterministic commitment using expected values
  2. Commitment based on Monte Carlo scenarios
  3. Stochastic dispatch
The example

• Three future time periods $t=1, 2, 3$
• Four generators (next slide)
• Demand*: 146 MW, 181 MW, 146 MW
• Commitment decisions to be made at $t=0$
  – Find optimal commitment and dispatch strategy at $t=0$ to minimize expected total cost over all periods and all scenarios

*) In this example the demand is certain
Example generator features

- Generator B, 100 MW, fixed schedule
- Generator G, 15-40 MW, $33/MWh, startup $650, minimum up time 2 periods, initially offline
- Generator P, 60 MW, $50/MWh
- Generator W, 10 or 50 MW, negative $25/MWh*
  - W capability is perfectly correlated, i.e., it can produce up to either 10 MW or 50 MW across all periods
    - But we must wait for t=1 to find out…

(*) The capability of W is uncertain at t=0
1. Deterministic commitment

• Assume W produces 30 MW all 3 periods
• Dispatch is:
  – Period 1: B=100, G=16, P=off, W=30. Price: $33
  – Period 2: B=100, G=40, P=11, W=30. Price: $50
  – Period 3: B=100, G=16, P=off, W=30. Price: $33
• Solution commits G at t=0 (wrong)

What happens when W=10 or when W=50?
2. Monte Carlo Scenarios

• For $W = 10$:
  – $G = [36, 40, 36], P = [0, 31, 0], W = [10, 10, 10], p = [33, 50, 33]$

• For $W = 50$:
  – $G = [0, 0, 0], P = [0, 31, 0], W = [46, 50, 46], p = [-25, 50, -25]$
    • $G$ does not start because its 2 hour minimum up time;
      losses in either period 1 or 3 negate profits in period 2

• Monte Carlo done this way is incorrect
  because for each scenario, the future is certain

$B = 100$ all 3 periods, either scenario
3. Optimal Commitment Strategy

- At t=0, do not commit G
- At t=1, commit G conditionally
  - If W=10 at t=1, commit G: G=[0,40,36], W=[10, 10, 10], P=[36,31,0], p=[$50, $50, $33]
  - If W=50 at t=1, do not commit G: G=off, W=[46, 50, 46], P=[0,35,0], p=[-$25, $50, -$25]

B=100 all 3 periods, either scenario
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Correlation between periods need not be 100% for solution to be valid
Verifying the Solution

- Optimize G’s profits given two equally probable price forecasts at t=0:
  - Either price = [$50, $50, $33] or price = [-$25, $50, -$25]
- If G commits at t=0
  - G’s dispatch would be [40, 40, any] for scenario 1 and [15, 40, 0] for scenario 2
  - Profits = $710 for scenario 1 and -$840 for scenario 2; thus, expected profits are negative
  - Therefore it is not optimal for G to commit at t=0
Comments about the example

• The optimal commitment is a *strategy that is conditional on the state of the world*

• Many random scenarios can be handled (we use the trivially simple case of two scenarios)
  – Scenarios should consider demand uncertainty, correlation between output of wind between time periods, forced generator outages, etc.
Stochastic Unit Commitment: Possible Approaches

• Brute force Monte Carlo

• Modified Lagrangian Relaxation (LR)
  – Or perhaps modified Mixed Integer Programming (MIP) – not explored here
Stochastic Unit Commitment by LR

• We suggest an adaptation of LR
• The optimal solution is characterized by prices and their probability distribution, and by generator commitment and dispatch strategy for each
• At the optimum:
  – Expected total costs (over all time periods and uncertainty scenarios) are minimized
  – For each generator, expected profits are maximized
Traditional Lagrangian Relaxation

Maximize profits over T periods

Prices
- Energy
- Regulating Reserves
- Spinning Reserves
- Supplemental Reserves
- Backup Reserves for each period 1,2,..,T

Feedback Loop to Adjust Prices
(ensure that dispatch satisfies system requirements)

Generator 1
Self-commitment (maximize profits)

Generator 2
Self-commitment (maximize profits)

Generator N
Self-commitment (maximize profits)

Aggregate Schedules
Of Energy and Reserves
- Energy
- Regulating Reserves
- Spinning Reserves
- Supplemental Reserves
- Backup Reserves for each period 1,2,..,T
Traditional LR (step 1)

• Use **prices** as intermediate variables to decouple commitment among generators
  – Given prices of energy and reserves, produce a profit-maximizing schedule for any generator using backward DP
    • Find profit-maximizing schedules for each period and for each generator
      – This yields generation schedules for each period
Traditional LR (step 2)

- If aggregate schedules from step 1 differ from energy and reserve requirements in any period, adjust prices and repeat step 1
  - The price is adjusted through gradient search
  - Caveats:
    - Convergence can be unstable
    - Dual solution may not be feasible
    - Near degeneracy of solutions
    - Issues often handled by heuristics during the final iterations
LR under uncertainty

Self-commitment Under Uncertainty

Prices and probability distribution

Optimal Generator strategy

Other Uncertain Parameters

Feedback Loop

Heuristics

Demand
The proposed modified LR

• Part 1: Self-commitment
  – Self commitment must consider uncertainty
    • “Self-commitment” can be done by the system operator
  – The result is a strategy, not a fixed schedule

• Part 2: Feedback Loop
  – Prices are not just prices, they are price distributions
  – They are adjusted based on mismatch between aggregate schedules and aggregate demand, and based on uncertainty parameters
Optimal self-commitment strategies

• There is an optimal strategy that a generator can follow to optimize its expected profits
  – A “self-commitment” optimal strategy differs from a commitment based on certainty of prices

• The problem is solved using nested backward dynamic programming

The problem can be solved by the ISO on behalf of each generator
(i.e., “self-commitment” is a bit of a misnomer)
Generator-level decision issues

- Prices are uncertain
- How much to allocate to each market?
  - *Energy or various types of reserves*
- Operational constraints
- Obtain estimates of profits and losses
Cost Characteristics

• Generator costs can include:
  – Incremental or marginal costs
  – Startup/shutdown costs
  – No-load costs
  – Ramping costs

• Cost may be non-convex because of:
  – Startup and shutdown costs
  – “Valve points”
  – Declining marginal costs
Generator Operational Constraints

• MW limits on energy and reserves
• Sum of energy and reserve MWs limits
• Inter-temporal constraints
  – Minimum up/down times
  – Startup delays
  – Multi-period emissions or energy constraints
  – Ramping rate limits
Generator-level decisions

• Generators decisions must consider profits over many periods
  – Are $expected$ revenues $> expected$ costs$? 

• For each period, decisions include:
  – Startup/Shutdown?
  – Ramp up/down next hour?
  – Offer reserves or energy?
    • Or some of each?
Reasons for price variability

• Uncertainty in demand
  – Weather and non-weather related

• Generation output uncertainty
  – Forced outages
  – Wind uncertainty

• Transmission outages
  – Contingency constraints and congestion
Handling Price Uncertainty

• Use discrete price states (*High*/*Medium*/*Low*)
• Determining optimal commitment strategy is similar to determining when to exercise an option
  – When to commit, when to sell reserves, etc.
• Price correlation issues:
  – Are prices correlated between time periods?
  – Are prices correlated between markets?
Locational factors

• Every generator sees a unique price distribution for energy (and reserves) as a result of congestion and losses

• Optimal commitment on a generator-by-generator basis optimizes every generator’s value to the system
Sample energy costs and prices
Results summary

These model results use the optimal generator commitment strategy over 10,000 Monte Carlo runs.

**Expected Profit**

- Expected Revenue: $389,300
- Expected Costs: $288,837
- Minimum Profit: -$16,440
- Maximum Profit: $262,280
- Std. Dev. of Profit: $36,935

**Optimal Commitment and Dispatch**

- View the Generator Commitment Decisions Under the Optimal Strategy
- View the Optimal Dispatch Strategy Without Inter-Temporal Constraints
- View the Dynamic Program Decision Tree
Profit distribution
Expected profits and costs by hour
For more details…

• See “Optimal Bidding Strategy Under Uncertain Energy and Reserve Prices”, PSERC Publication 03-05, April 2003
  – Find optimal self-commitment strategy under uncertainty
  – Is “implemented” by GenOptimizer, a program developed by LRCA
    • GenOptimizer can be used for transmission planning, bidding strategies, generator siting analysis, etc.

Feedback Loop Description

- **Step 0:** Assume energy and reserve price distributions
- **Step 1:** Get optimal UC strategies for each generator
  - Perfect for parallel computation
- **Step 2:** Aggregate schedules and compare to energy and reserves system requirements
  - Adjust prices based on mismatch between generation and requirements
    - Use Monte Carlo applied to optimal commitment strategies
- **Go to Step 1 if not converged**

Heuristics needed to simplify computations (research required)
Impact on ISO Markets

• Most ISOs run one day-ahead UC per day
• Replace DA UC by a dynamic, rolling, 24-hour look-ahead stochastic UC run each hour
• Update commitment decisions every hour
  – This will result in changes in the DA market, but the market will produce better results
Parting comments

• We redefine Unit Commitment from “create a schedule” to “create a strategy”
  – We suggest using a rolling hourly 24-hour UC
• We suggest a modified LR method to handle price uncertainty
  – Other possibilities include modified MIP
• The approach is optimal for each generator
• It is well suited for parallel computation
GenOptimizer*: Optimal self-commitment under uncertainty

• It implements optimal self-commitment:
  – It finds profit maximizing strategies
  – It can assist in finding optimal bidding strategies
  – It can help assess transmission needs
  – It can help value generation (including wind)

• It is educational and informative

(*) Developed by Laurits R. Christensen Associates.
For more information contact Brad Wagner at LRCA (brad@caenergy.com)
Uses of GenOptimizer

• For optimal self-dispatch under uncertainty
• For transmission planning assessment
• For generator bidding strategy optimization
  – In disputes about market power behavior
• For generator valuation and siting analysis
• As part of an integrated UC under uncertainty as proposed in this talk
GenOptimizer Inputs

- Energy and reserve price forecasts
- Price volatilities
- Fuel costs
- Generator heat rate
- Minimum and maximum energy dispatch constraints
- Maximum reserve dispatch constraints
- Likelihood that offered reserve services will be called
- Start up time of a cold generator vs. a hot generator
- Minimum down time of a generator
GenOptimizer Inputs (cont.)

• Time it takes for a hot generator to become cold
• Ramping rate of the generator
• Cost to start a cold generator vs. a hot generator
• Cost to shut down the generator from a low dispatch vs. a high dispatch
• Banking costs
• No-load costs
• Ramping costs
• Planned generator outages and must-run conditions

Or just about anything an individual generator could care about
How to Model State Transitions

Time $t$

- **UP**
  - Cost = $0$

- **TRANS**
  - Cost = $1000$

- **DOWN**
  - Cost = $3500$

Time $t+1$

- **UP**
  - Cost = $0$

- **TRANS**
  - Cost = $0$

- **DOWN**
  - Cost = $0$

\[ \text{Cost} = \$0 \]
Feasible State Transitions

Use Backward DP to solve self-commitment problem
How to model ramp rates, startup times and inter-temporal constraints
GenOptimizer Execution

- Backward Dynamic Programming determines the optimal strategy in every time period, generator dispatch state, and price level
  - Considers price uncertainty and operational constraints
- Monte Carlo is used to evaluate the performance of the commitment strategy under price volatility.
- Finds the optimal energy and reserve dispatches for given price levels
GenOptimizer Outputs

• Expected revenue, costs, and profit by hour for energy and reserve services
  – Standard deviation of expected profit

• Distribution of profits
  – Minimum and maximum profit achieved over a set of Monte-Carlo runs

• Analysis of commitment and optimal dispatch strategies
Time permitting, we will do a short demonstration of GenOptimizer.