Variants of Stochastic Unit Commitment

Daniel Kirschen
Close Professor of Electrical Engineering
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Unit commitment

- Given a load profile for the next 36 hours
- Given a set of units available
- When should each unit be started, stopped and how much should it generate to meet the load at a minimum cost?

Objective: find the optimal combination of unit status and power output
Generation scheduling under uncertainty

actual load – uncontrolled renewable generation
= net load
= controllable generation

To be scheduled
Uncertainty on the Net Load

Net Load

Time

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What could happen?

Less wind

More wind

Smaller net load

Higher net load

More wind

Smaller net load

Faster increases in net load

Faster decreases in net load

Inefficient operation

Corrective actions

Shed load

Spill wind

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What are we trying to achieve?

• Minimize cost
  – Cost of scheduled generation
  – Cost of corrective actions

• Maintain feasibility
  – Avoid having to take drastic actions
    • Shed load
    • Spill wind
    • Spill sunshine
Stochastic optimization

- Scenario-based Stochastic Unit Commitment – SUC
- Interval Unit Commitment – IUC
- Improved Interval Unit Commitment – IIUC
- Robust Unit Commitment - RUC

<table>
<thead>
<tr>
<th></th>
<th>Stochastic</th>
<th>Interval</th>
<th>Robust</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uncertainty</strong></td>
<td>Scenarios</td>
<td>Uncertainty range</td>
<td>Uncertainty range</td>
</tr>
<tr>
<td><strong>Objective</strong></td>
<td>The expected cost of the scenarios considered</td>
<td>The cost of the most likely wind forecast</td>
<td>The highest cost among all realizations</td>
</tr>
<tr>
<td><strong>Robustness</strong></td>
<td>Increases with the number of scenarios</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Computation time</strong></td>
<td>Higher</td>
<td>Lower</td>
<td>Depends on the worst scenario searching process</td>
</tr>
</tbody>
</table>
Scenario-based Stochastic Unit Commitment - SUC

Net Load

Time
Scenario-based Stochastic Unit Commitment - SUC

• Represent the possible evolution of the net load over the optimization horizon by a finite set of scenarios

• Attach a probability to each of these scenarios

• Determine the generation schedule that minimizes the expected cost over this set of scenarios while meeting the constraints for each scenario

• **Commitment** decisions are the same for all scenarios

• **Dispatch** decisions depend on the scenario
Interval Unit Commitment - IUC

Feasibility along upper bound

Optimality along central forecast

Feasibility along lower bound

Feasibility of transitions
Feasibility along upper bound

Optimality along central forecast

Feasibility along lower bound

Feasibility of transitions
Robust Unit Commitment

- Objective function:

\[
\min \sum_{t \in T} \sum_{i \in I} \left[ SC_{i,t} \cdot y_{i,t} + F_i \left( p_{i,t}^{wc} \right) + EENS^t_{wc} \cdot VLL + WC_t^{wc} \cdot VCW \right]
\]

- Deterministic uncertainty set: “uncertainty budget”

- Solution
  - Feasible over the entire deterministic uncertainty set
  - Minimizes the cost of the worst case realization within the uncertainty set

- Tends to be conservative

- Uncertainty budget defined as the number of nodes where net load deviates from central forecast

Publicly available software

• GAMS implementation of these algorithms + test data:
  http://www.ee.washington.edu/research/real/gams_code.html

• Comparison of the algorithms:
Applications

• How can these algorithms be used in actual system operation?
  – More detailed modeling of system operation

• Development of better operation strategies
  – Better balance between cost and risk
  – Integration of larger amounts of renewables

• Modeling of system operation for planning purposes
Supplemental Slides
Scenario-based Stochastic Unit Commitment - SUC

Net Load

Time
Scenario-based Stochastic Unit Commitment - SUC

- Represent the possible evolution of the net load over the optimization horizon by a finite set of scenarios
- Attach a probability to each of these scenarios
- Determine the generation schedule that minimizes the expected cost over this set of scenarios while meeting the constraints for each scenario
- Commitment decisions are the same for all scenarios
- Dispatch decisions depend on the scenario
Scenario-based Stochastic Unit Commitment - SUC

- Objective function:

$$\min \sum_{t \in T} \sum_{i \in I} \left[ SC_{i,t} \cdot y_{i,t} + \sum_{s \in S} \pi_s \cdot F_i(p_{t,i,s}) \right]$$

- $SC_{i,t}$: Startup cost of unit $i$ at time $t$
- $y_{i,t}$: Binary variable: 1 if unit $i$ starts at interval $t$; 0 otherwise
- $\pi_s$: Probability of scenario $S$
- $p_{t,i,s}$: Active power output of unit $i$ at interval $t$ under scenario $S$
- $F_i(.)$: Running cost function of unit $i$
Scenario tree

- Scenarios must be:
  - Discretized
  - Reduced

- Issues:
  - Loss of information
  - Effect of reduction method
  - Low probability scenarios
  - Availability of data
  - Probabilities
Scenario tree

Shed load?

High probability scenarios

Spill wind?
Scenario-based Stochastic Unit Commitment - SUC

- Modified objective function:

\[
\min \sum_{t \in T} \sum_{i \in I} \left[ SC_{i,t} \cdot y_{i,t} + \sum_{s \in S} \pi_s \cdot F_i(p_{t,i,s}) \right] \\
+ \sum_{t \in T} \sum_{s \in S} \pi_s \cdot \left( EENS_{t,s} \cdot VLL + WC_{t,s} \cdot VCW \right)
\]

\(EENS_{t,s}\)  Expected Energy Not Served at interval \(t\) under scenario \(S\)

\(VLL\)  Value of Lost Load

\(WC_{t,s}\)  Wind curtailment at interval \(t\) under scenario \(S\)

\(VCW\)  Value of Curtailed Wind
Interval Unit Commitment - IUC

Feasibility along upper bound

Optimality along central forecast

Feasibility along lower bound

Feasibility of transitions
Improved Interval Unit Commitment - IIUC

Feasibility along upper bound

Optimality along central forecast

Feasibility along lower bound

Feasibility of transitions

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Improved interval UC
Robust Unit Commitment

- Objective function:

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Test system

- IEEE RTS 96
- 73 buses, 96 generators
- Added 19 wind farms
- Two types of wind profiles
  - Correlated and anti-correlated with the load
- Two sets of generator data
  - Different flexibility parameters
- 10-50% wind penetration levels
Test system
Comparison of the various schedules
Validation

- What happens when these generation schedules are implemented?
- Estimated cost of a schedule ≠ actual cost
- Must consider the cost of the corrective actions that may be required
Monte Carlo simulation

Load scenarios for Monte Carlo Simulations

Wind scenarios for Monte Carlo Simulations
Test case results – flexible generators

Favorable wind profile

Unfavorable wind profile
Test case results – inflexible generators

Favorable wind profile

Unfavorable wind profile
Computation time comparison (s) – flexible generators (1% gap)