Scheduling and Pricing under Variable and Uncertain Power Systems

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Variability and Uncertainty

• Variability: issues can occur at time resolutions the system is not prepared for.
  • The scheduling model is not prepared for it. For example, a 5-minute dispatch cannot correct 1-minute variability.
  • The system resources are not prepared for it. For example, resources ramp rates and start-up times are too low to handle 5-minute variability even if it is known to occur.

• Uncertainty: issues can occur that were not explicitly anticipated.
  • When scheduling toward one realization and another realization occurs.
Variability and Uncertainty

**Variability:** Wind and solar generator outputs vary on different time scales as the intensity of their energy sources (wind and sun)

**Uncertainty:** Wind and solar generation cannot be predicted with perfect accuracy

**Variability:** load varies throughout the day, conventional generation can often stray from schedules

**Uncertainty:** Contingencies are unexpected, load forecast errors are unexpected
## Variability and Uncertainty

<table>
<thead>
<tr>
<th>Sources of V and U</th>
<th>Impacts of V and U</th>
</tr>
</thead>
<tbody>
<tr>
<td>System demand (V and U)</td>
<td>Active power imbalance</td>
</tr>
<tr>
<td>Variable generation (V and U)</td>
<td>Frequency excursions</td>
</tr>
<tr>
<td>Conv. gen behavior (V)</td>
<td>Area control error</td>
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<tr>
<td>Conv. gen outages (U)</td>
<td>Line flow exceedance</td>
</tr>
<tr>
<td>Transmission outages (U)</td>
<td>Reactive Power Imbalance</td>
</tr>
<tr>
<td>Fuel prices (V and U)</td>
<td>Voltage violations</td>
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<tr>
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<td>Angle instability</td>
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<tr>
<td></td>
<td>Changes in production costs</td>
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<td></td>
<td>Changes in generator cycling</td>
</tr>
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<td></td>
<td>Changes in software solution times</td>
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Variability and Uncertainty

- Understanding of variability and uncertainty impacts requires more than characteristics of variable and uncertain variables, it requires understanding of the mitigation strategies being used to accommodate these impacts.
- Ex: A system with very large uncertainty, can have zero uncertainty reliability impacts as dispatch resolution $\rightarrow 0$, minimum capacities and start-up times $\rightarrow 0$, and ramp rates $\rightarrow \infty$.
## Mitigation Strategies

<table>
<thead>
<tr>
<th>Variability</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster Ramp Rates</td>
<td>Faster Ramp Rates</td>
</tr>
<tr>
<td>Faster Start-up times</td>
<td>Faster Start-up times (shut-down times)</td>
</tr>
<tr>
<td>(shut-down times)</td>
<td></td>
</tr>
<tr>
<td>Greater power output ranges</td>
<td>Fewer Commitment Constraints (min on, off, etc.)</td>
</tr>
<tr>
<td></td>
<td>Better Forecasting</td>
</tr>
</tbody>
</table>
### How to model variability and uncertainty?

<table>
<thead>
<tr>
<th>Type of Model</th>
<th>Mathematical</th>
<th>Explicit Secure</th>
<th>Full Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty</td>
<td>Operating reserve</td>
<td>Security constrained</td>
<td>Stochastic optimization</td>
</tr>
<tr>
<td>Variability</td>
<td>Operating reserve</td>
<td>Maximum movement ramp constrained</td>
<td>Faster interval resolution</td>
</tr>
</tbody>
</table>

Longer Horizons

Computation Time and complexity

Improved Efficiency and Reliability?
## Current Strategies

<table>
<thead>
<tr>
<th>V/U</th>
<th>Issue</th>
<th>Cause</th>
<th>Modeling Mitigation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty</td>
<td>Imbalance</td>
<td>Conventional Trip</td>
<td>Contingency Reserve</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Imbalance</td>
<td>VG Forecast error</td>
<td>Reserve (other)</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Imbalance</td>
<td>Load Forecast error</td>
<td>Reserve (other)</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Power flow</td>
<td>Conventional Trip</td>
<td>Locational reserve requirements</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Power flow</td>
<td>VG Forecast error</td>
<td>Nothing</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Power flow</td>
<td>Branch failure</td>
<td>Security-constrained</td>
</tr>
<tr>
<td>Variability</td>
<td>Imbalance</td>
<td>VG/load variability (slow)</td>
<td>5-min dispatch</td>
</tr>
<tr>
<td>Variability</td>
<td>Imbalance</td>
<td>VG/load variability (fast)</td>
<td>Reserve (AGC)</td>
</tr>
</tbody>
</table>
Incentives

- Issue #1: With increasing amounts of variability and uncertainty on the system, we need to find a way to incentivize the resources that accommodate this variability and uncertainty.

- Issue #2: With different modeling strategies to mitigate the variability and uncertainty, we have to ensure there are no adverse ways in which the incentive programs are structured.
Incentives Today

- Various operating reserves are paid today to providers of capacity of those services.
- Prices are the marginal cost to provide capacity.
- Reserves are co-optimized with energy.
- Price of reserve reflect the lost opportunity cost to provide energy or other reserve.
- Prices of reserve reflect pricing hierarchy so higher valued services contain the lower valued services price.
- Some mechanisms include utilization payments.
  - FERC Order 755 for Regulating Reserve
Pricing for operating reserve, the main mechanism for accommodating variability and uncertainty seems to work OK. But what about moving to other strategies???
Operating Reserve Categorization

Non-event

Regulating Reserve
- Automatic
- Within optimal dispatch

Following Reserve
- Manual
- Part of optimal dispatch

Event

Contingency Reserve
- Instantaneous
  - primary
  - secondary
  - tertiary

Ramping Reserve
- Non-Instantaneous
  - secondary
  - tertiary

Correct the current ACE
Correct the anticipated ACE
Stabilize Frequency
Return Frequency to nominal and/or ACE to zero
Replace primary and secondary
Replace secondary

Dynamic Operating Reserves

The need for operating reserves will likely change with time and horizon.

Operating reserve demands, and therefore prices, will not be known in advance and market participants will need to forecast.

Virtual trading of ancillary services may be helpful in convergence between day-ahead and real-time markets.

Scheduling Strategies to Improve Variability
Faster Dispatch interval

- Faster clearing of energy markets and economic dispatch can help reduce the impact of variability.
- Faster clearing will reduce the need of requiring expensive regulating reserve capacity.
- This may eliminate the premiums given to units that follow the ACE while still requiring them to move fast and follow the ACE.
- Will this reduce the incentive for resources to offer capacity as flexible in the real-time energy market?
Fast Dispatch

- Using FESTIV Model
- Perfect forecasts in all time frames, hourly day-ahead SCUC, 30-min real-time SCUC, 20% wind penetration, 6-second AGC, 24 hour simulation.

<table>
<thead>
<tr>
<th></th>
<th>Dispatch at 5-minute intervals</th>
<th>Dispatch at 1-minute intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation Reserve</td>
<td>Regulation reserve at 1% load</td>
<td>No regulation reserve</td>
</tr>
<tr>
<td>Abs ACE (MWH)</td>
<td>94</td>
<td>59</td>
</tr>
<tr>
<td>Cost ($)</td>
<td>$909,852</td>
<td>$909,878</td>
</tr>
<tr>
<td>Revenue ($)</td>
<td>$1.636M</td>
<td>$1.396M</td>
</tr>
</tbody>
</table>

- Improved reliability, same costs, but significantly less payments. Missing money?

FESTIV Model:
Scheduling Strategies to Improve Uncertainty
Most ISOs in the US will run two SCUC programs with two different purposes:

- **DAM** – purely financial, used for price certainty, hedging against volatile real-time market, insurance of side payment guarantees
- **RSCUC** – The ISO uses this to ensure a reliable system with sufficient capacity available for the day-ahead time frame

Different inputs
Different objective functions
Full Day-Ahead Procedure

Day-Ahead Market and Unit Commitment

- Ancillary Service Requirements
- Load bids
- Wind Generator bids
- Generator bids and information

Prices

ISO Load Forecast

ISO Wind Forecast

Commitments

Schedules

Reliability Unit Commitment

Updated Commitments

Transmission network, facilities, outages, contingencies, etc.
Stochastic Unit Commitment

- Higher penetrations of uncertainty result from larger penetrations of variable generation, e.g., wind
- Higher quantity of reserve or new methods of scheduling may be required.

- Stochastic Security Constrained Unit Commitment (STSCUC):
  - Minimization of expected costs with respect to meeting a multitude of potential scenarios reliably
  - Proof of reduced costs, limited proof of improved reliability

- 1st-stage variables fixed for all scenarios (start-up and unit status of long-start units)
Stochastic Unit Commitment

- Computationally intensive (main disadvantage)
- Scenario representation complex
- Linkage with market design not straightforward
- Can be used in RSCUC or DAM
  - RSCUC usage somewhat straightforward
  - Benefit of usage in RSCUC may not be full
- This work focuses on usage of STSCUC in DAM and linkage between the two
Issues

- For a STSCUC modeling $n$ scenarios, there will be $n$ LMP for every bus and time period.
- A unit turned on for a high net-load scenario will likely cost more than the prices that are based on the median scenario.
- A price based on median scenario may not truly reflect the schedules given.
- A price based on median scenario may not incentivize resources to provide the flexibility to provide different dispatch depending on scenario.
- The units that used to get paid for providing reserve are still providing reserve, without the reserve payment.
Payments and Costs

Payment with Deterministic Pricing

\[
Payment_{i,h} = P g_{i,h}^{DA} \times [K_{i,n}] \times LMP_{n,h}^{DA} + \left( P g_{i,h}^{RT} - P g_{i,h}^{DA} \right) \\
\times [K_{i,n}] \times LMP_{n,h}^{RT} \\
+ \sum_{r=1}^{R} RS_{i,h,r}^{DA} \times RCP_{h,r}^{DA} + \left( RS_{i,h,r}^{RT} - RS_{i,h,r}^{DA} \right) \times \hat{RCP}_{h,r}^{RT}
\]

Payment with Probability-Weighted Pricing

\[
Payment_{i,h} = \left\{ \sum_{s=1}^{NS} \pi_s \times \left( P g_{i,h,s}^{DA} \times [K_{i,n}] \times LMP_{n,h,s}^{DA} + \sum_{r=1}^{R} RS_{i,h,r,s}^{DA} \times RCP_{h,r,s}^{DA} \right) \right\} + \left( P g_{i,h}^{RT} - \sum_{s=1}^{NS} \pi_s \times P g_{i,h,s}^{DA} \right) \times [K_{i,n}] \times LMP_{n,h}^{RT} + \sum_{r=1}^{R} \left( RS_{i,h,r}^{RT} - \sum_{s=1}^{NS} \pi_s \times RS_{i,h,r,s}^{DA} \right) \times RCP_{h,r}^{RT}
\]

Cost

\[
Cost_{i,h} = SUC_{i} \times z_{i,h} + NLC_{i} \times u_{i,h} + \left\{ \sum_{k \in K_i} IC_{i,k} \times P g_{i,k,h}^{RT} \right\} + \sum_{r=1}^{R} RC_{i,r} \times RS_{i,h,r}
\]

### Using FESTIV model, 2-stage STSCUC

<table>
<thead>
<tr>
<th></th>
<th>Unit-hours with negative profit</th>
<th>Total $ of negative profit</th>
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<tbody>
<tr>
<td></td>
<td>LMP based on single scenario</td>
<td>LMP based on single scenario</td>
</tr>
<tr>
<td></td>
<td>Probability weighted LMP</td>
<td>Probability weighted LMP/RCP</td>
</tr>
<tr>
<td>August</td>
<td>77</td>
<td>-$9,252</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>-$4,180</td>
</tr>
<tr>
<td>April</td>
<td>73</td>
<td>-$6,357</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>-$4,724</td>
</tr>
</tbody>
</table>
Summary

• There are new ways to accommodate the increasing variability and uncertainty that is being introduced especially by variable generation
  • Resource flexibility
  • Enhanced modeling strategies
• The resources that provide this flexibility must be incentivized to do so regardless of modeling strategy
• New innovative methods of modeling may be introduced, and new incentive structures may have to be introduced alongside
Questions

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www.nrel.gov/wind/systemsintegration