Demand and wind uncertainty in day-ahead power system scheduling

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Outline

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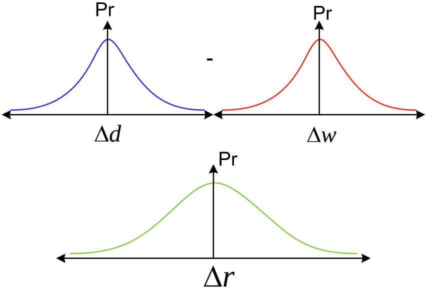
Day-ahead operations planning (unit commitment)

- Schedule the day-ahead on/off status and generation output
- Securely
- Reserve or flexibility:
  - Demand realizations different from expected value
  - Equipment failure
- In this talk we will focus on modeling demand and wind power uncertainty

Residual demand uncertainty

- Demand forecast error
- Wind forecast error
- Residual demand forecast error



$$E\{r\} = E\{d\} - E\{w\}$$
$$\Delta \mathbf{d} = \mathbf{d} - E\{d\}$$
$$\Delta \mathbf{w} = \mathbf{w} - E\{w\}$$
$$\sigma_r^2 = \sigma_d^2 + \sigma_w^2$$

Outline

Deterministic approach

- Optimize based on expected values
- Impose power balance after any contingency or scenario k

$$\min \sum_i C_i(g_i^0, \Re_i^{\mathrm{up}}, \Re_i^{\mathrm{dn}})$$

subject to:

$$\sum_i g_i^k = r^k$$

$$g_i^k - g_i^0 \leq \Re_i^{\mathrm{up}} \qquad \forall i, k$$

$$g_i^0 - g_i^k \leq \Re_i^{\mathrm{dn}} \qquad \forall i, k$$

$$f_i(g_i^k, \Re_i^{\mathrm{up}}, \Re_i^{\mathrm{dn}}) \leq 0 \qquad \forall i, k$$

Residual demand

- Residual demand uncertainty is modeled through 3 scenarios

$$r^0 = E\{d\} - E\{w\} \qquad \sum_i g_i^0 = r^0$$

$$r^{\text{high}} = r^0 + 3\sigma_r \qquad \sum_i g_i^{\text{high}} = r^{\text{high}}$$

$$r^{\text{low}} = r^0 - 3\sigma_r \qquad \sum_i g_i^{\text{low}} = r^{\text{low}}$$

Limitations of the deterministic approach

- Does not consider the likelihood of events
- It is usually conservative
- It does not measure quantities such as:
    - Expected load not served
    - Cost of reserve deployment

Stochastic approach

- Include within the formulation the probability of events
- Limit the *Loss of Load Probability* (LOLP), or the *Expected Load Not Served* (ELNS) (Gooi et al. and Bouffard et al.)
- Penalize ELNS (Wang et al. and Bouffard et al.)
  - Model the involuntary load shedding
- Their main disadvantage is the computational complexity

Outline

Objectives

- Capture the probabilistic behavior of demand and wind power while maintaining the simple nature of the deterministic problem
- Include the reserve target as a variable that can be optimized
- Compute different risk measures within the scheduling problem
    - LOLP
    - ELNS

Mathematical formulation

$$\min \sum_i C_i(g_i^0, \Re_i^{\mathrm{up}}, \Re_i^{\mathrm{dn}})$$

subject to:

$$\sum_i g_i^k = r^k$$

$$g_i^k - g_i^0 \leq \Re_i^{\mathrm{up}}, \quad \forall i, k$$

$$g_i^0 - g_i^k \leq \Re_i^{\mathrm{dn}}, \quad \forall i, k$$

$$f_i(g_i^k, \Re_i^{\mathrm{up}}, \Re_i^{\mathrm{dn}}) \leq 0, \quad \forall i, k$$

Deterministic approach

$$r^0 = E\{d\} - E\{w\}$$

$$r^{\mathrm{high}} = r^0 + 3\sigma_r$$

$$r^{\mathrm{low}} = r^0 - 3\sigma_r$$

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Mathematical formulation

$$\min \sum_i C_i(g_i^0, \Re_i^{\mathrm{up}}, \Re_i^{\mathrm{dn}})$$

subject to:

$$\sum_i g_i^k = r^k$$

$$g_i^k - g_i^0 \leq \Re_i^{\mathrm{up}}, \quad \forall i, k$$

$$g_i^0 - g_i^k \leq \Re_i^{\mathrm{dn}}, \quad \forall i, k$$

$$f_i(g_i^k, \Re_i^{\mathrm{up}}, \Re_i^{\mathrm{dn}}) \leq 0, \quad \forall i, k$$

Hybrid approach

- Define the r^{high} and r^{low} scenarios as variables

$$r^0 = E\{d\} - E\{w\}$$

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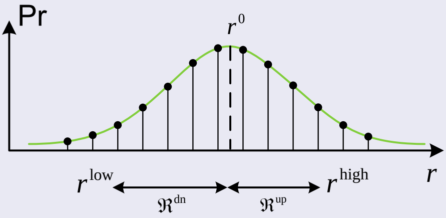
Reserve target

- Power balance constraints

$$\sum_i g_i^{\text{high}} = r^{\text{high}}$$

$$\sum_i g_i^{\text{low}} = r^{\text{low}}$$

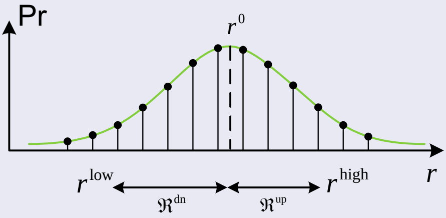
Residual demand probability distribution



Risk metrics

- Select r^{high} and r^{low}
- Meet the reliability criterion
- Express ELNS and LOLP linearly

Residual demand probability distribution

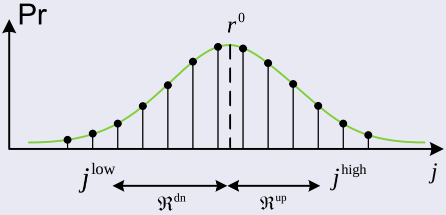


Risk metrics

$$
\begin{aligned}
LOLP &= prob\{\mathbf{r} > r^{\text{high}}\} \\
&= 1 - \sum_{-\infty}^{j^{\text{high}}} (Pr_j)
\end{aligned}
$$

$$
\begin{aligned}
ELNS &= E\{\mathbf{r}/\mathbf{r} > r^{\text{high}}\} \\
&= \sum_{j^{\text{high}}}^{\infty} (Pr_j)(r_j)
\end{aligned}
$$

Residual demand discrete probability distribution



Outline

Illustrative example

$$\min \sum_i (C_i(g_i^0) + \pi_i \Re_i^{\text{up}})$$

subject to:

$$\sum_i g_i^k = r^k \quad k \in \{0, \text{high}\}$$

$$g_i^k - g_i^0 \leq \Re_i^{\text{up}} \quad \forall i, k$$

$$\Re_i^{\text{up}} \leq \Re_i^{\text{up}-\max} \quad \forall i$$

$$u_i g_i^{\min} \leq g_i \leq u_i g_i^{\max} \quad \forall i$$

1. $r^{\text{high}} = r^0 + 3\sigma$
2. $LOLP \leq \epsilon$

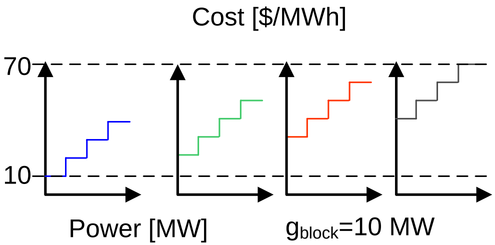
4-unit case

$$E\{d\} = 91.5MW \qquad \sigma_d = 2.5\%$$

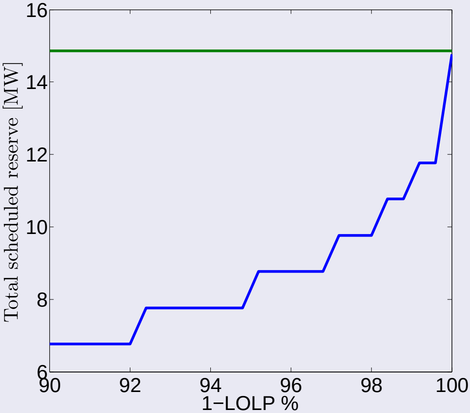
$$E\{w\} = 32.6MW \qquad \sigma_w = 13.0\%$$

$$3\sigma = 14.5MW$$

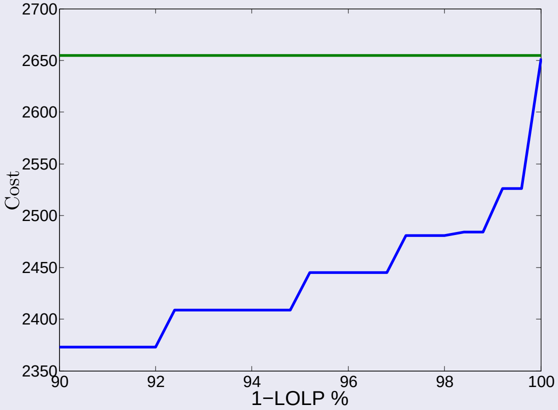
$$\mathfrak{R}^{\text{up}-\text{max}} = 15.0\% \qquad \pi_i = a_i$$



Reserve vs. 1-LOLP



Cost vs. LOLP

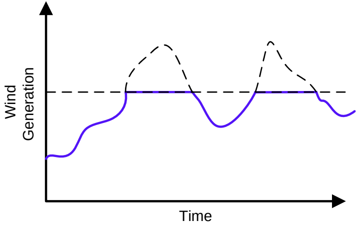

2700
2650
2600
2550
2500
2450
2400
2350
Cost
90
92
94
96
98
100
1−LOLP %

Concluding remarks

- A reserve requirement of 3σ of the residual demand prediction error implies a LOLP close to 0%
- The operating cost of integrating wind generation is sensitive to the risk metrics and security used in the day-ahead scheduling
- Preliminary results suggest that the inclusion of additional quantities such as the expected deployed reserve could help better characterize schedules that maximize social welfare

Outlook

- Define risk metrics that define the amount of down reserve $\mathfrak{R}^{\text{dn}}$
- Compare different approaches to include risk measurements into the scheduling problem
  - Limit LOLP and ELNS vs. penalizing ELNS
- Include wind curtailment or spillage as a strategy to reduce wind power uncertainty



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Questions