Proper Security Criteria Determination in a Power System with High Penetration of Renewable Resources

Mojgan Hedayati, Kory Hedman, and Junshan Zhang

School of Electrical, Computer, and Energy Engineering

Arizona State University

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Outline

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Motivation

- A power system is subject to inevitable uncertainties such as:
    - Load forecast errors
    - Unscheduled outage of the generators
- More uncertainty due to the integration of large-scale renewable energy resources
- Schedule sufficient reserve to overcome the uncertainties
- Increasing interest in applicable approaches for determining the amount of required reserve for secure operation of the system.

N-1 security criterion

- The fundamental principle of power system security:
  A system should always be operated in such a way that no contingency could trigger cascading outages or other forms of instability
- Typical assumption: the probability of two or more independent faults or failures taking place simultaneously is too low.
- Most security rules call for the system to be able to withstand the loss of any single component, i.e. to be "N-1 secure".
- What would the proper security criteria be in presence of renewable generation?

Discrete vs. continuous uncertainty

Two uncertainty categories:

1- Low probability discrete events (contingencies).

e.g. Generator's failure

Represented as a discrete event with an associated probability.

2- The uncertainty of parameters that can vary continuously within a range.

e.g. The uncertainty of demand or the available wind generation

Described as a set of probability distributions for the uncertain parameters.

Wind uncertainty model

- Assumption behind N-1 reliability criterion: Independent discrete events are not likely to happen simultaneously.
- Not true for continuous uncertainty
- It is quite common for nearby wind farms to experience a ramp event at the same time
- Proposed approach: Employ robust optimization to hedge against both continuous and discrete uncertainties in the unit commitment framework.
- The uncertain parameters are defined using deterministic uncertainty sets

Uncertainty model

- The maximum aggregate deviation for two wind farms is proportional to their correlation coefficient.

Continuous uncertainty set (wind generation):

$$W := \{P_{wt} \in \mathbb{R}^{N_w \times T} : \widehat{W}_{it} - dw_{it} \leq P_{wt} \leq \widehat{W}_{it} + dw_{it},$$

$$\sum_{i \in N_w} \frac{dw_{it}}{\widehat{W}_{it}} \leq \Delta^t, \left|\frac{dw_{it}}{\widehat{W}_{it}} + \frac{dw_{jt}}{\widehat{W}_{jt}}\right| \leq \frac{\Delta^t}{2} + \frac{\Delta^t}{2} cor_{i,j}, \forall\, i, \forall j \ \in N_w \}$$

- As the budget of uncertainty increases, a more conservative unit commitment solution is achieved.

Discrete uncertainty set (Single generator contingencies)

$$Z := \{z_{cg} \ \in \{0,1\}^{N_g} : \sum_{g} z_{cg} \geq N_g - 1\}$$

Robust Unit Commitment formulation

- The day-ahead SCUC model used here is a multi-period unit commitment model with a DCOPF formulation.
- The objective function has two parts, representing the two stages of the problem.

$$min_{u,v,p}\left(\sum_t \sum_g c_g^{SU} v_{gt} + c_g^{NL} u_{gt} + c_g P_{gt} + max\ \ min \sum_n c_c^n (LS_{nt}^{+} + LS_{nt}^{-})\right)$$

- The first part is the unit commitment cost. The second part is the worst-case second stage load shedding penalty cost.

Solution method

- Second stage problem:

$$max \ min \sum_{n} c_c^n (LS_{nt}^{+} + LS_{nt}^{-})$$

S.t. : second stage constraints

- Formulate the dual problem of the inner problem.
- Combining these two maximization, the second stage problem will be equivalent to a bilinear problem.

Solution method(cont.)

- Two types of nonlinear terms

1- The bilinear terms including the product of a binary and a continuous variable

Can be linearized using a big M reformulation

2- The bilinear term including the product of two continuous variables
Can be linearized around intermediate solution points (using an outer approximation algorithm)

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Solution method(cont.)

- The problem is solved using a two-stage algorithm.
- The first stage master problem and the second stage dual problem are solved in an iterative manner until the convergence.
- In the second stage the decision variables passed from the master problem are fixed. The dual subproblem is solved using an outer approximation algorithm.
- A Benders' decomposition method is employed to add new constraints to the master problem using the information obtained from the inner subproblem.

Case study

- IEEE-118 bus test case
- The test system is modified by integrating three 250 MW wind farms at buses 4, 27, and 59.
- 15% of the total system-wide generation capacity

Correlation coefficients between wind generators		
	W2(bus 27)	W3(bus 59)
W1(bus 4)	0.51	0.15
W2(bus 27)		0.17

- The performance is tested against a set of 100 generated wind farm outputs.
- Compared to that of a deterministic reserve adjustment

Results

	Average costs for the robust formulation and the reserve adjustment approach					
	Robust formulation			Reserve adjustment approach		
Δ^t	Commitment cost (M$)	Penalty cost (M$)	Total cost (M$)	Commitment cost (M$)	Penalty cost (M$)	Total cost (M$)
0	2.805	0.285	3.090	2.805	0.285	3.090
0.1	2.841	0.245	3.086	2.851	0.251	3.102
0.2	2.859	0.024	2.883	2.860	0.041	2.901
0.3	2.818	0.011	2.829	2.862	0.041	2.903
0.4	2.833	0.099	2.932	2.865	0.067	2.932
0.5	2.853	0.073	2.926	2.867	0.214	3.081
0.6	2.780	0.275	3.055	2.872	0.21	3.082
0.7	2.867	0.390	3.257	2.881	0.202	3.083
0.8	2.853	0.039	2.892	2.887	0.201	3.088
0.9	2.917	0.012	2.929	2.921	0.168	3.089

- If the budget of the uncertainty is adjusted properly, the robust solution has lower average commitment and penalty costs

Conclusions and future work

- A robust optimization framework is proposed to account for both discrete and continuous uncertainties.
- The correlation coefficient of wind farms has been used to address the impact of continuous uncertainty
- Numerical studies demonstrate the effectiveness of the methodology when integrating wind farm generation
- A set of extreme events along with their probabilities (using the historical data related to the extreme ramping events) can be employed in offline simulation studies to test the output of the robust unit commitment and adjust the uncertainty budget level

Questions?

Thank you!