Technical University of Denmark

# 46750 - Optimization in Modern Energy Systems
# Assignment 2
# Deadline: December 1st, 2023 (10:00pm)

**Instructions:** This assignment evaluates the topics covered in **Lectures 1 - 13** as well as programming and writing skills. It should be carried out in groups. Each group should provide a single submission, including the following:

- A concise project report (10 - 14 pages), detailing the mathematical models developed and presenting and analysing the main results. An appendix can be included (outside of page limit).
- A participation table accompanying the report, detailing the participation of each group member (as provided in Lecture 1)
- A working and well-documented code in the programming language of your choice.
- Additional relevant files and data.

All relevant files should be uploaded on DTU Learn. This assignment will count towards 50% of the final grade. The assessment will be based on the grading guide provided.

1. **Stochastic Economic Dispatch**

   We consider the following power system, based on a modified IEEE 24-node reliability test system, including 12 conventional generating units, 6 wind farms of 300 MW each (at nodes $n_3$, $n_5$, $n_7$, $n_{16}$, $n_{21}$, $n_{23}$), 17 demands, and 34 transmission lines, as illustrated in Figure 1.

   Data on the techno-economic characteristics of the generating units, transmission lines, and load profiles is provided in [1]. The commitment and ramping constraints and costs of all generators can be neglected. You can assume that the dispatch, reservation, and adjustment costs of the wind farms are very small compared to the costs of all other generators. The wind production can be dispatched and curtailed between 0 (minimum production) and its maximum available power in a given hour. 100 scenarios of *normalized* available wind power[1] over 44 hours are provided in the accompanying files in [2]. All loads are considered inflexible, however, a load-shedding variable (one for each load) can be introduced, considering a load-shedding cost sufficiently high compared to the production costs of the generators.

   The realized available wind power of each wind farm can only be observed in real-time (time of delivery). Therefore, other controllable generators may need to adjust their production in order to compensate for imbalances caused by wind production deviations. These flexible generators have costs associated with real-time upward and downward adjustment of their dispatch.

   Therefore, the system operator aims at finding the optimal day-ahead and real-time decisions that minimize the day-ahead and expected real-time operating costs of the system,

[1] defined as available wind power divided by wind farm capacity

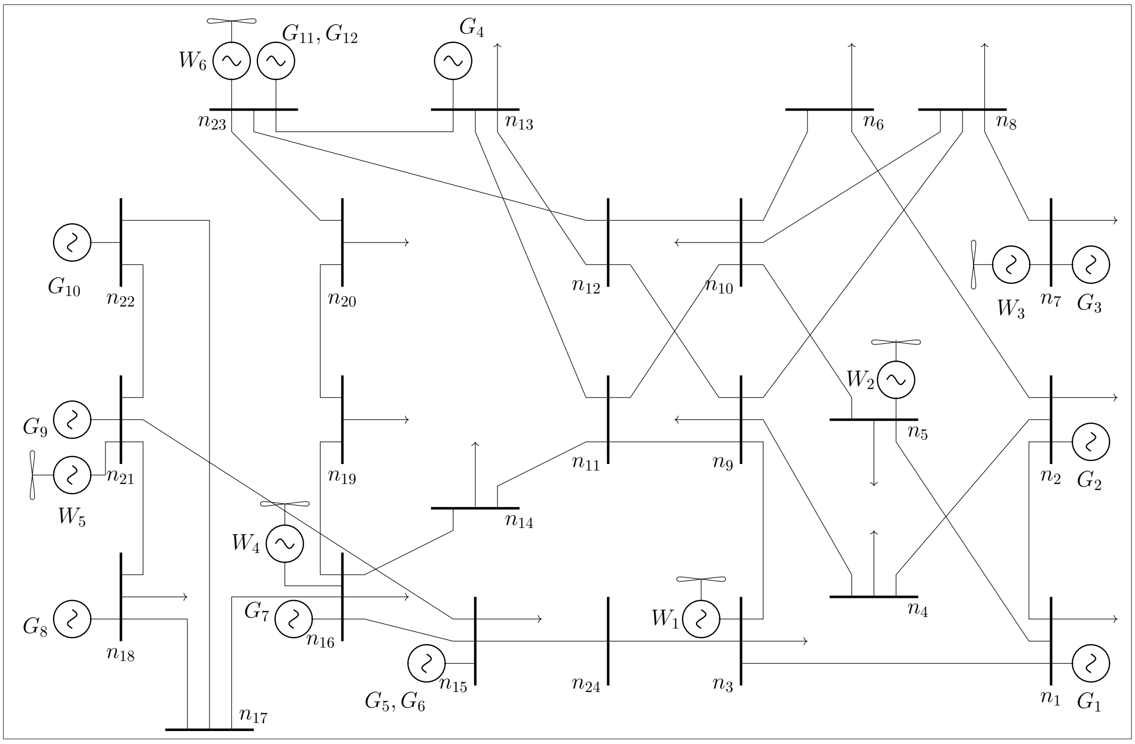


Figure 1: Modified IEEE 24-node electricity system with 6 wind farms

while ensuring feasible day-ahead and real-time operating conditions over all scenarios of available wind power.

(a) For a chosen hour, please write the stochastic economic dispatch problem, considering uncertainty on the wind production. Detail the sequence of decisions (first- and second-stage variables, and realization of uncertainty).

(b) Please, select an appropriate number of wind power scenarios ($K \leq 99$), and solve this optimization problem with these scenarios. Present and analyse the most important in-sample results obtained. Can all generators recover their costs (in each scenario and in expectation) in this framework?

(c) Please, select an appropriate value for the available wind power of each wind farm, and solve the deterministic economic dispatch problem with this value. Present and analyse the most important results obtained.

(d) With the day-ahead decision variables fixed to their optimal values from Question b and Question c, please solve the real-time re-dispatch problem for each remaining wind power scenario from the original dataset used in Question b (out-of-sample). Present and analyse the most important results.

(e) Please, discuss in your own words the limitations of this sample average approximation approach, and potential solutions to mitigate them.

2. **Decomposition of Stochastic Economic Dispatch**

We consider the single-time step stochastic economic dispatch over the modified IEEE 24-node electricity system with 6 wind farms in Question 1.

(a) Please, discuss whether the structure of this optimization problem can be decomposed, and if so, in how many subproblems.

(b) If this problem can be decomposed, please select a suitable decomposition algorithm. Provide an outline of the proposed algorithm, and a detailed formulation of the different steps. If multiple decomposition approaches can be implemented, justify the chosen approach.

(c) Please solve the original optimization problem using the selected decomposition algorithm. Present and analyse results about the convergence, and computational tractability of the algorithm for various numbers of scenarios.

3. **Risk-Aware Reserve Dimensioning**

We consider the modified IEEE 24-node electricity system with 6 wind farms described in Question 1.

The realized available wind power of each wind farm can only be observed in real-time (time of delivery). Therefore, other controllable generators may need to adjust their production in real-time in order to compensate for imbalances caused by wind production deviations. We consider that the upward and downward balancing capacity of these flexible generators must be reserved in advance in order to provide upward or downward adjustments in real-time. Besides, these generators have costs associated with their reserved capacity (regardless of whether it is activated in real-time), as well as for their realized real-time energy adjustment.

Therefore, for a given (single) hour, the system operator aims at finding the optimal day-ahead dispatch and capacity reservation decisions, as well as real-time adjustment policies which ensure feasible day-ahead operating conditions and limit the risks of violations of real-time operating constraints.

(a) Please, chose a suitable approach and formulate the reserve dimensioning problem, under uncertainty on wind production. Justify the chosen approach and chosen formulation of the input parameters, decision variables, objective function, and constraints.

(b) Depending on the chosen approach, and the 100 scenarios of the normalized available wind power at 6 wind farms provided in the accompanying files, please propose a suitable representation of the uncertain input parameters, i.e., (i) define a robust uncertainty set which encompasses all the scenarios of normalized available wind power provided, and includes an upper bound on the total wind power deviation compared to its expected value; **or** (ii) fit a joint (multivariate) Normal distribution of the normalized available wind power at all wind farms by computing the mean and covariance of the dataset (i.e. 100 scenarios of a 6-dimensional random variable).

(c) Please, solve this optimization problem based on the chosen approach. Present and analyse the results. How do the chosen input parameters impact the optimal solutions?

(d) Please, discuss in your own words the limitations of the chosen approach, and potential solutions to mitigate them.

## References


[1] C. Ordoudis, P. Pinson, J. M. Morales, and M. Zugno, "An updated version of the ieee rts 24-bus system for electricity market and power system operation studies," *Technical University of Denmark*, vol. 13, 2016.

[2] L. Mitridati, J. Kazempour, and P. Pinson, "Heat-and-electricity-market-coordination-a-scalable-complementarity-approach - online appendix," 2016. [Online]. Available: https://doi.org/10.5281/zenodo.1346213