31761 - Renewables in Electricity Markets

Assignment 2: Participation of a renewable energy producer in the electricity market

General considerations

Assignment 2 concentrates on participation in electricity markets with a portfolio of renewable energy generation. This portfolio actually consists of a single wind farm located in Western Denmark. Assignment 2 requires knowledge of both basic market concepts (day-ahead and balancing stages) and market participation aspects following the lectures, exercise sessions, games and reading material from the first 8 weeks of the course. The work to undertake involves a bit of mathematical modelling, implementation in your favourite modelling language (R/Matlab/Python/etc.), generation and discussion of results, as well as presentation of the work in a short report.

The aim of Assignment 2 is to evaluate

- your understanding of combined day-ahead and balancing markets,
- your ability to use forecasts as input to decision-making,
- your understanding of market revenues and their potential improvement,
- your ability to use real-world data as input,
- your critical analysis of the results generated.

The expected outcome of Assignment 2 includes:

- a report of maximum 10 pages (excluding appendices),
- code pasted in the appendix or delivered as supplementary material.

Asisgnment 2 is to be performed in groups, where a group optimally consist of 2 students. It is not recommended to do it alone, or with a group of more than 2, though it is possible.

The **evaluation of Assignment 2 will count for 26.7% of the final grade**.

Description of the Assignment

Wind power producers have to offer their energy generation through electricity markets, despite the variability and uncertainty in their power production. This makes that they may consider a number of alternative strategies for participating in electricity markets, which could be more or less successful. Offers are to be placed on the day-ahead market, while deviations from day-ahead contract will necessarily lead to direct or opportunity costs. Most likely, these strategies will be based on forecasts (for renewable power generation and market prices), either in a deterministic or probabilistic form. The aim of this project is therefore to simulate and analyse the situation where you would operate a wind farm of 160MW (Horns Rev in Western Denmark) and trade its energy generation through the Nord Pool, based on your various strategies. Note that all data is real, and so the money figures will be real too!

1. Set-up of our market participation problem

Here is the set-up for our market participation problem:

- The wind power forecast data for this wind farm, as well as related measurements, are made available for the whole year of 2017, at the following link. Details regarding the file contents are given in the Appendix below;

- The operator of this wind farm is to participate in the Nord Pool over the whole year of 2017, based on these forecasts (or not, if you have better ideas...). The Horns Rev wind farm is located in the price area DK1;
- This market participant is to be considered as a price-taker;
- Market data (day-ahead and regulation prices) can be obtained from the "historical market data" part of the Nord Pool website. You may want to download data for both 2016 and 2017, since data for 2017 will be used for actual participation and revenue calculation, while data for 2016 could be used to develop market insight on the dynamics of market prices;
- **No cheating!** Participation in the market should be done as if in real conditions. E.g., when placing offers on 23 March 2017 for the following day, you can only use data available at that date (and not from the future)...

2. Steps towards completion of the Assignment

2.1 Extract and analyse all necessary wind power and market data;

2.2 Formulate 3 market participation strategies: one base strategy (not using wind power forecasts), one based on deterministic wind power forecasts, and one using probabilistic wind power forecasts. For all of them, you may also want to use some market insight, e.g., some trends in day-ahead and balancing prices. For instance, a base strategy is to always offer 10MWh for each and every market time units, and a more advanced one is to derive offers based on you latest deterministic forecast just before market gate closure at noon;

2.3 Apply these various strategies and determine the revenue of the wind farm operator;

2.4 Analyse revenues on both day-ahead and balancing markets, on a daily basis and overall, and compare with the case of using perfect wind power forecasts for market participation (optimal revenue).

Structure and contents of the report to be delivered

The report for the assignment should include:

- The formulation of how market revenues are calculated, both for day-ahead and balancing markets, as well as overall
- A description of the various market participation strategies
- The calculation results for the revenues from application of the various strategies, for instance in the form of plots of cumulative revenues over the year
- A discussion on the comparison of these revenues, e.g., can you explain why some strategies seem to yield higher revenue overall, and more/less fluctuations in daily revenues?
- The code in an Appendix (if not provided separately)

Delivery of the Assignment

Assignment 2 is to be uploaded through DTU Learn before the **final deadline of 19.4.2020** (all day included). It should take the form of a zip or tar.gz archive with naming convention "31761-Assignment2-Student1-Student2.zip" (or ".tar.gz"), where "Student1" and "Student2" are the names or DTU student numbers (e.g. s093482) of the students in the group. Less (or more) students in a group obviously means less (or more) student names/ids to be used in the naming convention.

Suggested readings

Morales JM, Conejo A, Madsen H, Pinson P, Zugno M (2014). Renewable energy sources - Modelling and forecasting. Chapter 2 in *Integrating Renewables in Electricity Markets - Operational Problems*, Springer Verlag: New York (pdf) - also the references therein

Morales JM, Conejo A, Madsen H, Pinson P, Zugno M (2014). Trading stochastic production in electricity pools. Chapter 7 in *Integrating Renewables in Electricity Markets - Operational Problems*, Springer Verlag: New York (pdf) - also the references therein

Pinson P, Chevallier C, Kariniotakis G (2007). Trading wind generation from short-term probabilistic forecasts of wind power. *IEEE Transactions on Power Systems* **22**(3): 1148–1156 (pdf)

Zugno M, Jónsson T, Pinson P (2013). Trading wind energy based on probabilistic forecasts of both wind generation and market quantities. *Wind Energy* **16**(6): 909–926 (pdf)

Appendix: short description of wind power data

The file at this link include all necessary wind power forecasts and measurements for to be used in the assignment. 'NA' symbols means that for some hour, the corresponding data is not available. This hour may then be skipped. The data contents is summarized below, based on the name of the various columns of the dataset:

dato	dates (timestamps) for which a given forecast is made
dati	dates (timestamps) at which a given forecast is issued
hors	corresponding lead time of the forecast
fore	deterministic forecast from your forecast provider
meas	actual power measurement
q5	quantile forecasts for a nominal level of 5%
q10	quantile forecasts for a nominal level of 10%
q15	quantile forecasts for a nominal level of 15%
⋮	⋮
q90	quantile forecasts for a nominal level of 90%
q95	quantile forecasts for a nominal level of 95%

Note that dates are given as timestamps, e.g. 201701010100 for the 1st January 2017 at 1am.

All power values (forecasts and measurements) are in kW.

Finally, remember that a quantile forecast (with a given nominal level α) tells that there is a probability α that the wind power to be observed will be less than this value. For instance, if issuing a quantile forecast of 3.5MW, with nominal level of 10%, for tomorrow at noon, it less that there is a probability of 0.1 that wind power generation will be less than 3.5MW tomorrow at noon. All these quantile forecasts (for a given time) together can permit to describe cumulative distribution function for potential power generation at that time.