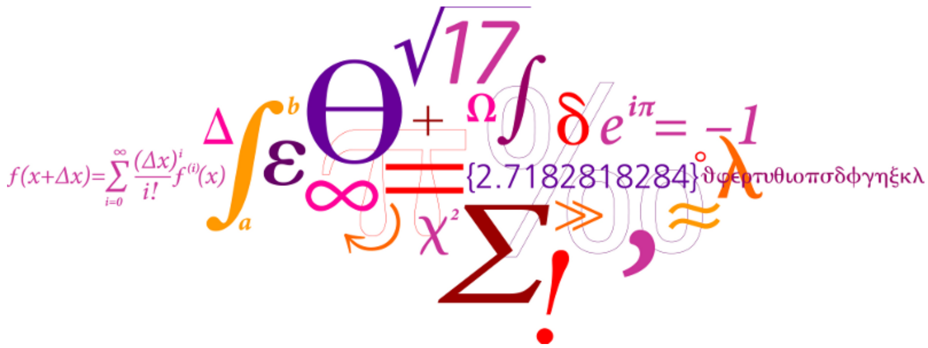
31761 - Renewables in Electricity Markets



Exercise session 4

Market participation for renewables

1 Problem 1: Calculating revenues in one-price and two-price imbalance settlement

1.1 What is the overall revenue of this solar power plant operator under a one-price imbalance settlement?

The overall system is in surplus of 130 MWh. There is a need for down regulation due to the excess production. The solar power plant has to buy back energy at the balancing stage.

Day-Ahead stage: 7 MWh $\cdot$ 41 DKK/MWh = 287 DKK
Balancing stage: 2 MWh $\cdot$ 32 DKK/MWh = 64 DKK
Total: $287 - 64 = 223$ DKK

1.2 What is the overall revenue of this solar power plant operator under a two-price imbalance settlement?

The overall system is in surplus of 130 MWh. There is a need for down regulation due to the excess production. The solar power plant has to buy back energy at the balancing stage.

In this type of market design, only wanted deviations (i.e., from dispatchable producers) opposite in sign from the system imbalance are rewarded financially with a balancing market price that is more favorable than the day-ahead price. On the contrary, deviations from stochastic producers are either settled at the day-ahead price (if opposite to the system imbalance) or, just like in a one-price market, at the less favorable balancing market price (if in the same direction as the system imbalance).

Since such a deviation, opposite in sign to the overall system imbalance, is involuntary, the less favorable day-ahead market price is charged, resulting in the negative revenue (payment).

Day-Ahead stage: 7 MWh $\cdot$ 41 DKK/MWh = 287 DKK
Balancing stage: 2 MWh $\cdot$ 41 DKK/MWh = 82 DKK
Total: $287 - 82 = 205$ DKK

1.3 Under these two imbalance settlement approaches, compare these revenues to those obtained if having perfectly predicted that power production was going to be 5MWh, and having used that value as an offer. Is one of the settlement approaches yielding better revenues?

In both imbalance settlement approaches, the revenue in case of offering 5 MWh is the following:

Total: 5 MWh $\cdot$ 41 DKK/MWh = 205 DKK

1.4 Now consider that actual energy generation is of 8MWh, while the overall system is in surplus of 130MWh. Answer again 1.1-1.3 for such conditions.

The overall system is in surplus of 130 MWh. There is a need for down regulation due to the excess production. The solar power plant has to sell energy at the balancing stage.

1.1)
Day-Ahead stage: $7 \text{ MWh} \cdot 41 \text{ DKK/MWh} = 287 \text{ DKK}$
Balancing stage: $1 \text{ MWh} \cdot 32 \text{ DKK/MWh} = 32 \text{ DKK}$
Total: $287 + 32 = 319$ DKK

1.2) Since the deviation has the same sign as the overall system deviation, the balancing price applies, resulting in the following revenue.

Day-Ahead stage: $7 \text{ MWh} \cdot 41 \text{ DKK/MWh} = 287 \text{ DKK}$
Balancing stage: $1 \text{ MWh} \cdot 32 \text{ DKK/MWh} = 32 \text{ DKK}$
Total: $287 + 32 = 319$ DKK

1.3) In both imbalance settlement approaches, the revenue in case of offering 8 MWh is the following:

Total: $8 \text{ MWh} \cdot 41 \text{ DKK/MWh} = 328 \text{ DKK}$

1.5 If you knew in advance that the overall system would have a surplus, what would be your optimal offer under these two imbalance settlement approaches? Do you actually need to know any of the prices (day-ahead and balancing) to decide on these offers?

In the one-price imbalance settlement, the optimal offer would be to bid the total capacity in the day-ahead market, if knowing in advance that the overall system would have a surplus. This strategy will result in the highest revenues for the producer.
In the two-price imbalance settlement, the optimal offer can be derived by the quantile of the power production distribution corresponding to a probability equal to the down-regulation penalty divided by the sum of the up-regulation and down-regulation penalties. When the overall system is in surplus, there is a need for down regulation. In this case, any bid in the day-ahead market that will be above the final real production (i.e., the producer produces below its day-ahead dispatch) will result in the same revenue as bidding the perfect prediction of the power production.
The prices do not affect the decision of the offers, keeping in mind that they are restricted such that

$$\lambda^{\mathrm{B}}_{\mathrm{DW}} \leq \lambda^{\mathrm{S}}$$

$\lambda^{\mathrm{B}}_{\mathrm{UP}} \geq \lambda^{\mathrm{S}}$

at all times.

1.6 As in 1.5, consider you could know in advance all prices, and that there could be a probability of 0.4 that the system is in surplus (therefore a probability of 0.6 it is in deficit), what is you optimal offer to maximize your expected revenue under one-price imbalance settlement?

The expected revenue under one-price imbalance settlement is given by the following formula,

$$ER = \pi_1 \cdot P_+ + \pi_2 \cdot P_-$$
$$P_+ = \lambda^{\mathrm{S}} \cdot E^* + \lambda^{\mathrm{B}}_{\mathrm{DW}}(\widetilde{E} - E^*)$$
$$P_- = \lambda^{\mathrm{S}} \cdot E^* + \lambda^{\mathrm{B}}_{\mathrm{UP}}(\widetilde{E} - E^*)$$

where $\widetilde{E}$ is the realization and E^* the offer of the stochastic production. The probabilities of having the system in surplus is π_1 and in deficit is π_2.

After replacing the values of the prices and the probabilities, the formula is transformed to:

$$ER = 0.4 \cdot (41 \cdot E^* + 32 \cdot \widetilde{E} - 32 \cdot E^*) + 0.6 \cdot (41 \cdot E^* + 47 \cdot \widetilde{E} - 47 \cdot E^*) = 41 \cdot \widetilde{E} \text{ DKK}$$

In this particular case any offer is optimal, as the expected profit is not a function of the offer.

1.7 To better understand that phenomenon, write the function for the expected revenue and and the derivative function with respect to your offer.

The derivative function of the expected revenue is given below,

$$\frac{\partial ER}{\partial E^*} = \pi_1 \cdot (\lambda^{\mathrm{S}} - \lambda^{\mathrm{B}}_{\mathrm{DW}}) + \pi_2 \cdot (\lambda^{\mathrm{S}} - \lambda^{\mathrm{B}}_{\mathrm{UP}}) = \lambda^{\mathrm{S}}(\pi_1 + \pi_2) - \lambda^{\mathrm{B}}_{\mathrm{DW}} \cdot \pi_1 - \lambda^{\mathrm{B}}_{\mathrm{UP}} \cdot \pi_2 \overset{\pi_1+\pi_2=1}{=} \lambda^{\mathrm{S}} - \lambda^{\mathrm{B}}_{\mathrm{DW}} \cdot \pi_1 - \lambda^{\mathrm{B}}_{\mathrm{UP}} \cdot \pi_2 \overset{\pi_1=1-\pi_2}{=} \lambda^{\mathrm{S}} - \lambda^{\mathrm{B}}_{\mathrm{UP}} + \pi_1(\lambda^{\mathrm{B}}_{\mathrm{UP}} - \lambda^{\mathrm{B}}_{\mathrm{DW}}).$$

1.8 Find the necessary relationship between probabilities of being in surplus and deficit, resulting in all potential offers being optimal.

If we set $\frac{\partial ER}{\partial E^*} = 0$, in order to find the optimal offer, then the relationship between the probability and the prices is given by,

$\pi_1^* = \frac{\lambda^{\mathrm{S}} - \lambda^{\mathrm{B}}_{\mathrm{UP}}}{\lambda^{\mathrm{B}}_{\mathrm{DW}} - \lambda^{\mathrm{B}}_{\mathrm{UP}}}.$

By replacing the prices given,

$\pi_1 = \frac{41-47}{32-47} = 0.4$,

which is also the probability given in Question 1.6 and that resulted in all potential offers to be optimal.

1.9 Deduce a set of simple rules permitting to find an optimal offer as a function of these probabilities, as well as day-ahead and balancing prices.

If $\pi_1 < \pi_1^*$ then it is preferable to offer zero volume.
If $\pi_1 > \pi_1^*$ then it is preferable to offer the nominal capacity.

2 Problem 3: Comparing 3 alternative strategies for market participation

3.1 What is the overall revenue of the wind farm operator is directly using the deterministic forecast as an offer?

The overall system is in deficit of 78 MWh. There is a need for up regulation due to the excess consumption. The wind farm operator has to buy back energy at the balancing stage.

Day-Ahead stage: 20 MWh $\cdot$ 35 DKK/MWh = 700 DKK
Balancing stage: 8 MWh $\cdot$ 47 DKK/MWh = 376 DKK
Total: $700 - 376 = 324$ DKK

3.2 Deduce unit regulation costs (for up and down regulation) based on the provided price forecasts.

The unit regulation costs are given below:

$\psi^{\mathrm{UP}} = \lambda^{\mathrm{B}}_{\mathrm{UP}} - \lambda^{\mathrm{S}} = 12\mathrm{DKK/MWh}$
$\psi^{\mathrm{DW}} = \lambda^{\mathrm{S}} - \lambda^{\mathrm{B}}_{\mathrm{DW}} = 4\mathrm{DKK/MWh}$

3.3 What is the nominal level of the quantile that would permit to maximize expected revenues?

The unit regulation costs are given below.

$\frac{\psi^{\mathrm{DW}}}{\psi^{\mathrm{UP}}+\psi^{\mathrm{DW}}} = \frac{4}{4+12} = \frac{1}{4}$

3.4 Calculate the overall revenue for that strategy based on offering the best quantile from the probabilistic forecast.

The best offer based on the calculated quantile from the probabilistic forecast is 15 MWh. The wind farm operator has to buy back energy at the balancing stage.

Day-Ahead stage: 15 MWh $\cdot$ 35 DKK/MWh = 525 DKK
Balancing stage: 3 MWh $\cdot$ 47 DKK/MWh = 141 DKK
Total: 525 − 141 = 384 DKK

3.5 Compare these revenues with that one would obtain by offering the perfect forecast.

If the perfect forecast was offered, it would be 12 MWh.

Total: 12 MWh $\cdot$ 35 DKK/MWh = 420 DKK

3.6 The optimal quantile strategy defined in Lecture 10 and used here overlooks the probabilities of being in situations with overall system surplus and deficit. Would you be able to generalize the quantile strategy to the case for which these probabilities are also predicted?

The generalization of optimal quantile strategy for the case that the probabilities of being in situations that the overall system is in surplus or deficit are predicted, is given based on the following nominal level of the quantile,

$$\frac{\pi^{\mathrm{DW}} \cdot \psi^{\mathrm{DW}}}{\pi^{\mathrm{UP}} \cdot \psi^{\mathrm{UP}} + \pi^{\mathrm{DW}} \cdot \psi^{\mathrm{DW}}}$$

where the probabilities are embodied in the formula. More can be found in [1].

References

[1] Zugno, M. and Jónsson, T. and Pinson, P., "Trading wind energy on the basis of probabilistic forecasts both of wind generation and of market quantities," *Wind Energy*, vol. 16, no. 6, pp. 909–926, 2013.