31761 - Renewables in Electricity Markets

Exercise session 3: Intra-day and balancing markets - [SOLUTION]

The aim of this exercise session is to appraise and better understand the basic structure of electricity markets, and most particularly its intra-day and balancing mechanisms. The session relies on Lectures 1-5 available at "Lecture notes for 31761 - Renewables in Electricity Markets".

Problem 1: General description of intra-day and balancing markets

This Problem is based on the Nord Pool website, website, as well as the Energinet webpages for the "wholesale electricity market" and the ancillary service market.

1.1 What is the common name of the intra-day market in Nord Pool? How does it work?

Elbas is an intraday market for trading power operated by Nord Pool Spot. Elbas supplements Elspot and helps secure the necessary balance between supply and demand in the power market for Northern Europe. At Elbas, buyers and sellers can trade volumes close to real time to bring the market back in balance. Prices are set based on a first-come, first-served principle where the lowest sell price and highest buy price take priority and are available to trade up to 60 minutes before delivery (75 minutes in the UK).

1.2 When is it possible to trade in the intra-day market? Can one trade just 5 minutes before delivery?

At 14:00 CET, capacities available for Elbas trading are published. The gate closure times for intraday trading on ELBAS are shown in Table 1.
Trading between different countries is allowed until 60 minutes before the start of each power-hour. Later gate closure times are only valid for trades within the countries marked with an asterisk. For example, trades between market participants in the Belgian and German price zones are only possible until 60 minutes before the power-hour starts while intraday trades within each of those two price zones can be agreed upon until significantly later gate closure times, for example until 5 minutes before the start of the power-hour in Belgium.

Table 1: Elbas gate closure

Country	Minutes before hour of delivery
NO	60
SE, FI, DK, EE	60
DE*	30
NL*, BE*	5

1.3 What is the area covered by this intra-day market? Is that the same than for the day-ahead market?

Elbas 4 was launched in 10 European countries (the Nordics, Baltics, Germany, Belgium and the Netherlands).
The area considered for the day-ahead market (Elspot) is different: only Nordic and Baltic region.

1.4 What is the intra-day market for, and who could have interest in participating?

The majority of the volume handled by Nord Pool Spot is traded on the day-ahead market. For the most part, the balance between supply and demand is secured here. However, incidents may take place between the closing of Elspot at noon CET and delivery the next day. A nuclear power plant may stop operating in Sweden, or strong winds may cause higher power generation than planned at wind turbine plants in Germany.
Elbas allows market participants with wind and solar power generation to adjust their commitments based on latest production forecasts. But also other market participants can reduce their expected imbalances this way and increase their profits by selling own available but unused flexibility. This can facilitate the transmission system operator's task to balance the system in real-time.
Moreover, functioning as a balancing market to the day-ahead market, the intraday market offers great opportunities for risk reduction as well as increased profit by giving access to a wide selection of counterparts with different production mix, marginal costs and general market conditions.

1.5 What is the purpose of the balancing market? Who is responsible for activation of regulating power in Denmark?

The purpose is to have production and consumption balanced in real time (security of supply). The TSO has the ultimate responsibility to keep its transmission system in balance.

1.6 What is the name of the (dynamic) list for all available regulating power on a given day in Scandinavia?

The dynamic list is named NOIS (Nordic Operational Information System). NOIS is a common Nordic list including bids from Danish, Norwegian, Swedish, and Finnish players. Should it be necessary to regulate the power in the Nordic countries, the cheapest bid placed on the common list will be activated, however, giving due consideration to possible restrictions in the interconnections between the countries.

1.7 Is that possible that a generator in Norway helps balancing the system in Denmark?

It is possible that a generator in Norway helps balancing the system in Denmark. If there is no congestion between countries the cheapest unit is enabled to balance the system.

Problem 2: Setting up our own balancing market

This Problem builds on Exercise Session 1 which focused on day-ahead markets. Especially, we assume that the day-ahead market was cleared following Problem 4, i.e., based on the list of supply and demand offers described in Problems 2 and 3, respectively.

Before actual operation, a list of market players who can provide balancing services for that time unit is gathered. To simplify things, all of these players already participated in the day-ahead electricity market. Only generators (not demand) are ready to provide balancing. These include:

Supplier name	Supplier id.	Up quant. [MWh]	Up. Price [€]	Down quant. [MWh]	Down Price [€]
FlexiGas	G_1	15	80	-	-
RoskildeCHP	G_4	5	50	15	15
BlueWater	G_5	20	35	20	5

2.1 What is the generation schedule for these generators after the market clearing of Problem 4 (in Exercise Session 1)? Please re-calculate their revenues after day-ahead market clearing.

The market equilibrium is at a quantity of 202 MWh and a price of 32 €/MWh. The revenues and payments of market participants are illustrated at Table 2 and Table 3.

Table 2: Producer's production and revenues

Supplier name	Supplier id.	Quantity produced [MWh]	Market price [€/MWh]	Revenues [€]
Nuke22	G_2	100	32	3200
ShinyPower	G_3	32	32	1024
BlueWater	G_5	70	32	2240

Table 3: Consumer's consumption and payments

Demand name	Demand id.	Quantity purchased [MWh]	Market price [€/MWh]	Payment [€]
WeLovePower	D_1	35	32	1120
CleanCharge	D_2	23	32	736
ElRetail	D_4	38	32	1216
QualiWatt	D_5	43	32	1376
IntelliWatt	D_6	6	32	192
El-Forbundet	D_7	57	32	1824

2.2 Draw the supply curve corresponding to these balancing offers

→ See Figure 1

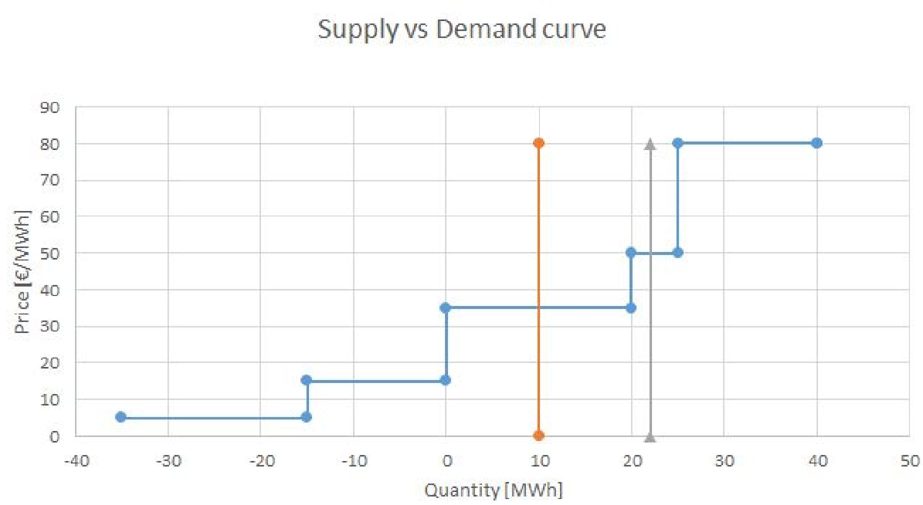

Figure 1: Supply curve of balancing offers

2.3 Nuke 22 has a problem with its cooling system, yielding a shortage of 22MWh in comparison with the amount contracted through the day-ahead market. What is the resulting demand for our balancing market? Add this demand curve to your previous drawing.

The cooling problem of Nuke 22 results to a final production of 78 MW. The demand in the balancing market is $\Delta P = 22\,\text{MW}$ (Demand > Production).

2.4 What is the resulting balancing price, and who will provide the balancing service? How many MWh and in which direction?

The resulting balancing price is $\lambda^B = 50$€/MWh, because if the supply will be increased by 1 unit (1 more MWh to be produced), unit G4 with an offer price of 50 €/MWh will produce. The balancing service will be provided by G5 (20 MWh) and G4 (2 MWh).

2.5 Calculate the revenues and payments for all participants in this balancing market. Deduce the combined revenues, considering both day-ahead and balancing markets

In the balancing market, the settlement leads to:

- G2 paying 22 MWh · 50 €/MWh = 1100€
- G5 receiving 20 MWh · 50 €/MWh = 1000€
- G4 receiving 2 MWh · 50 €/MWh = 100€

Considering both day-ahead and balancing stages

- G2 receives 100 MWh · 32 €/MWh = 3200€ at the day-ahead market and has to pay 1100€ at the balancing market. So, in total G2 receives 2100 €.
- G5 receives 70 MWh · 32 €/MWh = 2240€ at the day-ahead market and an additional amount of 1000€ at the balancing market. So, in total G5 receives 3240 €.
- G4 receives 100€ at the balancing market.

2.6 Go again through points 2.3-2.5 now considering that it is CleanCharge that needs 10 MWh more than in the original day-ahead contract.

CleanCharge needs 10 MWh more than the original day-ahead contract. The demand in the balancing market is $\Delta P = 10\,\text{MW}$ (Demand > Production).
The resulting balancing price is $\lambda^B = 35$€/MWh, because if the supply will be increased by 1 unit (1 more MWh to be produced), unit G5 with an offer price of 35 €/MWh will produce. The balancing service will be provided by G5. In the balancing market, D2 and G5 participate.

In the balancing market, the settlement leads to:

- D2 paying 10 MWh · 35 €/MWh = 350€
- G5 receiving 10 MWh · 35 €/MWh = 350€

Considering both day-ahead and balancing stages

- D2 pays 23 MWh · 32 €/MWh = 736€ at the day-ahead market and an additional amount of 350€ at the balancing market. So, in total D2 pays 1086 €.
- G5 receives 70 MWh · 32 €/MWh = 2240€ at the day-ahead market and an additional amount of 350€ at the balancing market. So, in total G5 receives 2590 €.

Problem 3: One-price vs. two-price imbalance settlements

This Problem is a follow-up of Problem 2 (hence similarly building on Exercise Session 1). We therefore still assume that the day-ahead market was cleared following Problem 4, i.e., based on the list of supply and demand offers described in Problems 2 and 3, respectively. The list of players who can provide balancing services for that time unit was given in Problem 2.

Quite a few market participants are not able to meet their contracts, and will then induce imbalances. The full list includes:

Participant name	Participant id.	Deviation [MWh]
ShinyPower	G_3	+5
WeLovePower	D_1	+8
Nuke22	G_2	+10

In the above table, a deviation of +10 MWh means that the market participant (i) generates 10 MWh than his contract if being a supplier, or (ii) consumes 10 MWh more than his contract if on the demand side. We now aim at performing the imbalance settlement following both one-price and two-price systems.

3.1 Assess the overall system imbalance resulting from this individual imbalances. Will the system need upward or downward regulation?

In total, there is +15 MWh of production and +8 MWh of demand, which results to +7 MWh of production (excess production). The system will need down regulation.

3.2 Which are the units whose imbalance are putting the system off-balance, and which are (involuntarily) helping the system getting back to balance?

G2 and G3 are putting the system off-balance as their production is increased and D1 involuntarily helps the system due to the increase in demand.

3.3 Clear the balancing market as in Problem 2. Determine the balancing price and the schedule of the generator(s) involved in balancing.

A unit can provide down regulation at the balancing stage only if it has been already scheduled to produce power at the day-ahead stage. For this reason, down regulation is provided by G5 and the balancing price is $\lambda^B = 5$€/MWh.

3.4 What is the difference between the one-price and two-price imbalance settlements?

The rationale behind one-price balancing markets implies that deviations from the day-ahead schedule are settled at a price that is more favorable than the day-ahead price if the sign of the participant's imbalance is opposite to the sign of the overall system deviation.
Other balancing markets are designed according to the two-price (or dual-price) imbalance settlement principle. 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.

3.5 Calculate revenues and payments for the 3 market participants in imbalance, and for the generator(s) providing balancing under a one-price settlement.

In the balancing market, G3, G2, G5 and D1 participate.

- G3 receives $5\,\text{MWh} \cdot 5\,€/\text{MWh} = 25€$
- G2 receives $10\,\text{MWh} \cdot 5\,€/\text{MWh} = 50€$
- G5 pays $7\,\text{MWh} \cdot 5\,€/\text{MWh} = 35€$
- D1 pays $8\,\text{MWh} \cdot 5\,€/\text{MWh} = 40€$

Considering both day-ahead and balancing stages

- G3 receives $32\,\text{MWh} \cdot 32\,€/\text{MWh} = 1024€$ at the day-ahead market and an additional amount of 25€ at the balancing market. So, in total G3 receives 1049 €.
- G2 receives $100\,\text{MWh} \cdot 32\,€/\text{MWh} = 3200€$ at the day-ahead market and an additional amount of 50€ at the balancing market. So, in total G3 receives 3250 €.
- G5 receives $70\,\text{MWh} \cdot 32\,€/\text{MWh} = 2240€$ at the day-ahead market and has to pay 35€ at the balancing market. So, in total G5 receives 2205 €.
- D1 pays $35\,\text{MWh} \cdot 32\,€/\text{MWh} = 1120€$ at the day-ahead market and an additional amount of 40€ at the balancing market. So, in total D1 pays 1160 €.

G3 and G2 are penalized in the balancing stage as they sell their production surplus at a lower price than it could have received at the day-ahead market. G5 has to pay the market operator for repurchasing energy at the balancing market. Since this power was initially sold at the day-ahead market at the price $\lambda^S = 32€/\text{MWh}$. G5 realizes a net profit on the energy that is asked not to produce, as the repurchasing price $\lambda^B = 5€/\text{MWh}$ is lower than the initial selling price. In this case, D1 is rewarded as the additional consumption is paid a lower rate. This is done because it helps the system to be balanced, even though it is done involuntarily.

3.6 Calculate revenues and payments for the 3 market participants in imbalance, and for the generator(s) providing balancing under a two-price settlement. Compare with the outcome of 3.5.

In the balancing market, G3, G2, G5 and D1 participate.

- G3 receives $5\,\text{MWh} \cdot 5\,€/\text{MWh} = 25€$
- G2 receives $10\,\text{MWh} \cdot 5\,€/\text{MWh} = 50€$
- G5 pays $7\,\text{MWh} \cdot 5\,€/\text{MWh} = 35€$
- D1 pays $8\,\text{MWh} \cdot 32\,€/\text{MWh} = 256€$

Considering both day-ahead and balancing stages

- G3 receives $32\,\text{MWh} \cdot 32\,€/\text{MWh} = 1024€$ at the day-ahead market and an additional amount of 25€ at the balancing market. So, in total G3 receives 1049 €.
- G2 receives $100\,\text{MWh} \cdot 32\,€/\text{MWh} = 3200€$ at the day-ahead market and an additional amount of 50€ at the balancing market. So, in total G3 receives 3250 €.
- G5 receives $70\,\text{MWh} \cdot 32\,€/\text{MWh} = 2240€$ at the day-ahead market and has to pay 35€ at the balancing market. So, in total G5 receives 2205 €.
- D1 pays $35\,\text{MWh} \cdot 32\,€/\text{MWh} = 1120€$ at the day-ahead market and an additional amount of 256€ at the balancing market. So, in total D1 pays 1376 €.

The only difference with the outcome of 3.5 regards the balancing market results for the participants that are involuntarily decreasing the overall system imbalance. In this case, D1 is not rewarded and buys energy from the balancing market with the spot price $\lambda^S = 32€/\text{MWh}$.

3.7 Let us imagine that these 3 market participants in imbalance could have known about their real consumption/supply before the day-ahead market settlement. Adapt the list of offers of Exercise Session 1 and clear the day-ahead market. Deduce the revenues and payments of these 3 market participants. Would they have been better off in that case?

After adapting the list offers in the day-ahead market-clearing, the new supply and demand curves are illustrated in Figure 2. The equilibrium is at a quantity of 217 MWh and a price of 32 €/MWh. Producers G3, G5 and G2 will be supplying power at their maximum offers, 37, 70 and 110 MWh, respectively. Consumers D2, D1, D5, D7, D4 and D6 will be consuming 23, 43, 43, 57, 38, and 13 MWh, respectively.

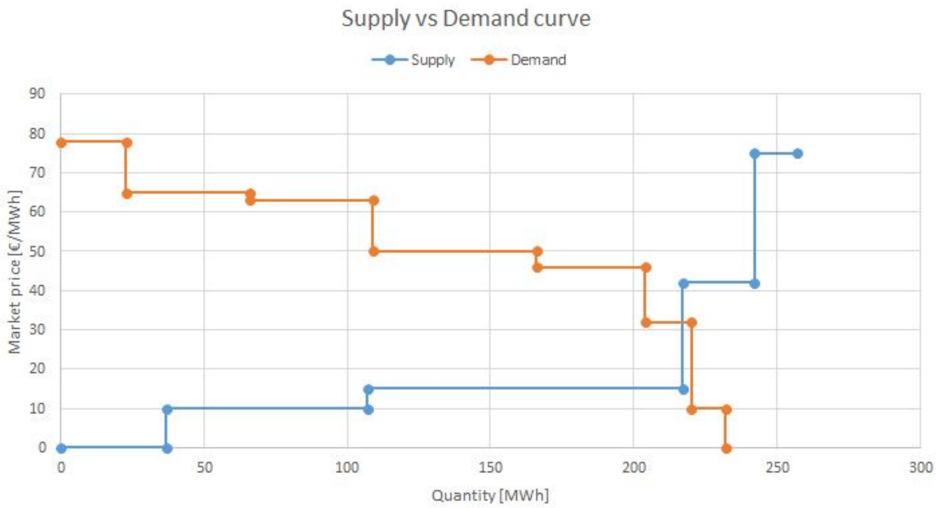

Figure 2: Supply and demand curve

The revenues and payments would be:

- G3 receives 37 MWh · 32 €/MWh = 1184€
- G2 receives 110 MWh · 32 €/MWh = 3520€
- G5 receives 70 MWh · 32 €/MWh = 2240€
- D1 pays 43 MWh · 32 €/MWh = 1376€

It can be noticed that the generators are in all cases better off. As far as the consumption D1 is concerned, the payment between cases 3.6 and 3.7 is the same. Comparing with 3.5, consumption D1 pays more in cases 3.6 and 3.7.

Problem 4: Analysis of the balancing situation for a given day based on data

For this Problem, we aim at understanding the balancing situation for a given day based on the data publicly available on the NordPool website. The webpages of interest are that for day-ahead prices and that for regulation and regulation prices. Let us focus on the market area DK1, for the case of 21 January 2015.

4.1 Extract day-ahead and regulation prices (Price up and Price down) to have them on a piece of paper, or a file to import in Matlab/R/Excel/etc. What do these prices mean?

4.2 Are these prices always equal or not?

4.3 Find example hours for each of the 3 potential balancing situations (up, down and no- regulation).

4.4 Do you expect the price for upregulation to be higher/lower than the day-ahead price? Explain why?

4.5 Same questions for the downregulation price.

4.6 Have a look at some other days in January to see how often the various balacing situations occur, and how different prices can be.

Optional extra Problems (available on demand)