Peaks of solar power challenging system control

In the spring of 2024, Energinet[1] let it be understood that it expected to have problems in securing the balance between production and consumption of electricity on Saturday and Sunday throughout the summer of 2024 due to the increase in solar power and low demand for electricity at weekends.

Therefore, it has been natural to keep an eye on market prices, productions and exchanges of electricity in the summer of 2024.

It seems that Energinet got it right. The spot prices in Denmark (day-ahead) have been zero or negative every weekend since April and until mid-August.[2]

The same trend is seen in the neighbouring countries.

The wake-up call

On Sunday 7 April 2024 in the afternoon, Energinet's resources for downregulation became exhausted in the middle of the afternoon. The price for downregulation reached €1000 per MWh.

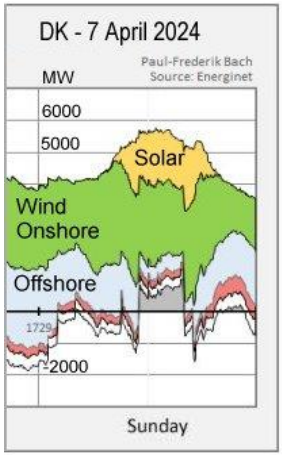

Fig. 1 - Need for further reduction. Large contribution from offshore wind, but poor contributions from solar and onshore wind.

This prompted Energinet's Vice President System Operations, Klaus Winther, to write the following on LinkedIn (my translation):

> ***So, it finally became spring in Denmark - but not without worries*** ☀
> *Spring typically brings greater RE production and lower consumption, which we got to feel this past weekend. On Sunday 7 April, there was low/negative prices as a result of high production from solar and wind and low consumption both north and south of Denmark.*
> *This meant that we in Energinet's control centre activated all available downregulation bids in Denmark at hour 16, but at the same time up to 4100 MW of solar and wind continued to operate. The next step, which was not that far away at all, would be to shut down either production facility connected directly to the transmission network or distribution-connected facilities.*
> *It is obviously not a desirable situation to be in for either the control centre or the manufacturers. One of the best things you can do for the green transition and the integration of wind and solar, is to act flexibly and enter bids for the balance market. It is also a very good business.*
> *If, on the contrary, we from the control centre have to pull the "emergency handle", you will be compensated with the spot price, which was negative on this day, and at the same time you will have to trade the balancing yourself. I don't understand that you want to take that risk when you could make money by supporting the green transition and system security.*
> *Spring has only just begun and the upcoming weekend looks breezy and sunny again. I hope that all the manufacturers with this appeal will find occasion to give their procedures a spring check. Then I will be able to enjoy the many weekends with wind and spring sun with peace of mind.*

Fortunately, it did not go as badly as Klaus Winther feared. We will try to understand why.

[1] Energinet: Danish transmission system operator (TSO)
[2] See http://pfbach.dk/firma_pfb/weekly_operations_2024.htm

The flexible electricity demand – an unattainable dream

When the ideas about a future with wind power as a dominant supplier of electricity in Denmark were developed, it was also discussed how the balance between consumption and production could still be ensured. The logic was simple. If production could not be controlled, consumption had to be made flexible.

At that time, the electricity market was new in Denmark. The electricity market had to ensure both optimal operation and the balance between production and consumption. There had to be full symmetry between supply and demand.

Flexible consumption had no significant importance in the following decades, and even with the current investment in Power-to-X, there are very long prospects for the demand side to play a significant role in balancing the electricity system's operation.

Denmark has had the good fortune that the electricity markets in Europe were linked together so that the neighbouring countries could provide the necessary regulating work. However, there are signs that this opportunity is drying up.

Negative spot prices		Nordpool						
Number of hours		System	DK1	DK2	DE	NO2	SE3	SE4
1 January	24 August	price						
	2010	0	9	5	10	0	0	0
	2015	0	43	25	84	0	0	0
	2020	0	139	76	239	1	5	5
	2021	0	80	17	127	0	5	5
	2022	0	28	2	40	0	2	2
	2023	111	158	114	165	92	173	116
	2024	174	309	228	358	172	380	361

Table 1 - From 2023, the negative spot prices have also affected neighbouring countries. For the sake of a fair comparison, the results for all years apply to the period 1 January to 24 August. Price zones: DK1 Western Denmark. DK2 Eastern Denmark, DE Germany, NO2 Southern Norway, SE3 and SE4 Southern Sweden.

A lot of wind and solar power is currently being installed in Northern Europe. The increasing number of hours with negative spot prices shows that electricity overflow has been growing everywhere in the past two years, especially in Germany (table 1 and 2).

The Danish and German values for 2020 and 2021 reflect the gas crisis, where electricity consumption also fell. It was a foretaste of what was to come.

The conclusion is that Denmark can no longer count on other countries to solve the overflow problems. As the flexible demand is long in coming, downregulations of Danish wind and solar power are becoming necessary to an increasing extent.

This means that owners of these plants must expect decreasing capacity factors.

2024	Neg.		2024	Neg.
1 Jan-24 Aug	hours		1 Jan-24 Aug	hours
Belgium	351		Portugal	193
France	322		Spain	224
Netherlands	390		IT North	0
Poland	130		IT Centre N	0
Czech Rep.	280		IT Sardinia	0
Slovakia	256		IT Centre S	0
Austria	266		IT South	0
Switzerland	258		IT Sicily	0
Hungary	240		Greece	11
Bulgaria	48		Serbia	0
Romania	71		Croatia	173
			Slovenia	198

Table 2 – Overflow in most European countries

The question is whether the current electricity market provides sufficient incentives for effective regulation of production for wind turbines and solar cells.

The electricity market from day-ahead to the moment of operation

Market participants must every day no later than 12:00 send buy and sell bids for the next day to an electricity exchange. Up to this point, weather forecasts are the basis for operators of wind and solar generation. The electricity exchange matches supply and demand taking

into account bottlenecks between price zones and publishes at the latest 13:00 operating plans and spot prices per hour for the next day.

The result constitutes **the spot market** or the day-ahead market. Producers can choose to maintain their bids for hours with negative spot prices. In that case, they have to pay to get rid of their production.

The intraday market allows market participants to make adjustments up to one hour before the moment of operation.

The regulating power market (or **the balancing market**) is the market participants' last opportunity to adjust their plans.

In addition to these three markets, market participants have the option of providing system services, including positive and negative reserves. These options will not be elaborated here.

It has been understood that as much wind and solar energy as possible should be produced. This thinking has created some reluctance to curtail production, even in overflow situations. Thus, a large part of the solar energy is traded as completely inflexible deliveries under PPA contracts (Power Purchase Agreements). Inflexible agreements will not be sustainable in the wholesale market in the long run.

Energinet publishes a large amount of data for the entire process up to operational moments and on to the settlement. In order to show prices and adaptation of production plans from the day before and until the moment of operation, the most important data have been selected for graphical presentation with newly developed software.

Week 23 has been selected as a typical case. With prices between €20 and €180 per MWh, the volatility of the spot market has been quite high on weekdays (fig. 2). Negative prices are seen on Saturday and Sunday, but not with such large fluctuations as on weekdays.

Fig. 2 – DK1 had negative spot prices Saturday and Sunday in week 23 of 2024

The imbalance prices from the regulating power market are more volatile than the spot prices. The highest imbalance price in week 23 is €469 per MWh Monday. The lowest price is not so extreme, namely -€29 per MWh Sunday.

Energinet publishes production plans for wind- and solar power day-ahead, 5 hours ahead, 1 hour ahead and "current".

Fig. 3 shows reductions of offshore wind before publication of the 1-hour forecast.

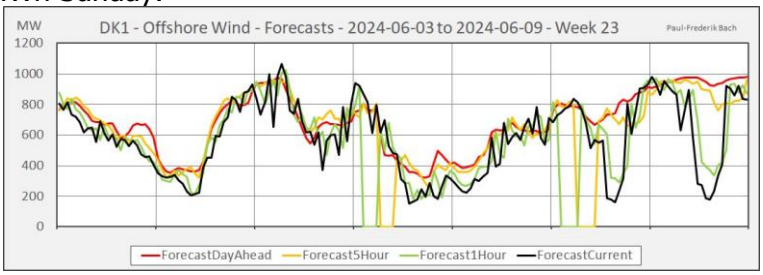

Fig. 3 – From red to black forecasts: offshore wind curtails production Saturday and Sunday. Coloured vertical lines are due to missing data.

In contrast, there are no significant reductions in production for onshore wind and solar power (fig. 4).

The same charts are available for DK2 (Eastern Denmark), and the results are the same.

All weekends from April to August have similar patterns. Offshore turbines deliver large downregulations based on price signals in day-ahead and intraday markets, but onshore turbines and solar power do not contribute significantly.

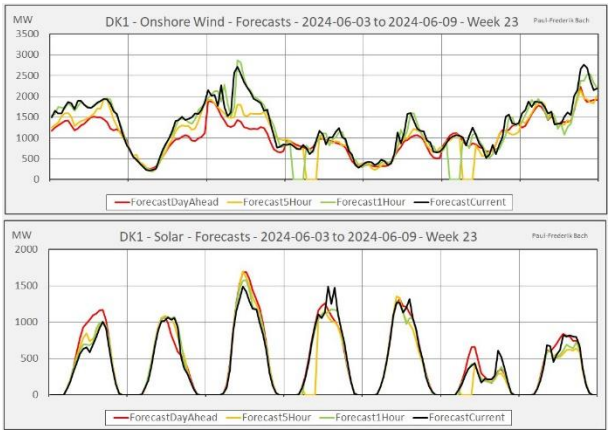

Fig. 4 - Practically no reduction for onshore wind and solar power from day-ahead to moment of operation

Uncertain optimum at zero prices

Before the market opening for electricity in Denmark in 1999, network losses were included in operational optimization. Due to the possibility of transit through Denmark, a lot could be gained by considering network losses. That possibility disappeared at the market opening.

In the spot market, the spot price is formed at the intersection of supply and demand curves. In the event of an overflow of electricity, bids for wind and solar power are decisive for the price level. This situation turns out to give a rather flat optimum, where the relocation of production has only a small economic effect for the market participants, but a significant effect on grid losses and system security. Therefore, it is natural to consider whether the transmission system operator (TSO) should have the opportunity to optimize grid operation in situations where it is of no importance to the market participants anyway.

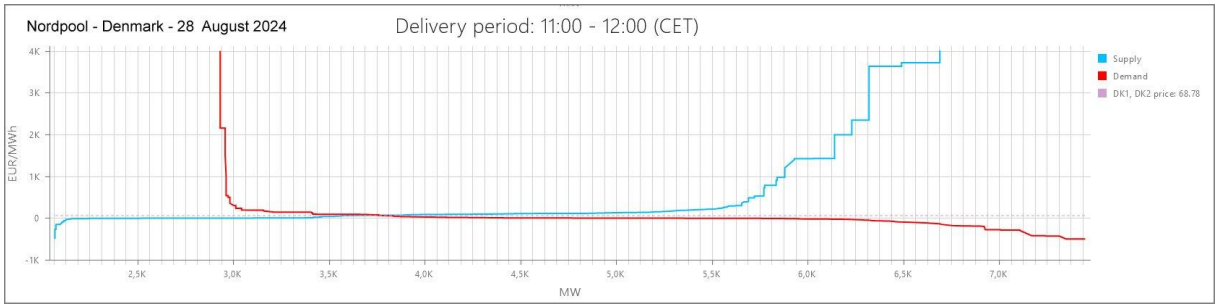

Fig. 5 - Example of a typical flat price cross around zero price in the spot market. Source: Nordpool.

Before the market opening for electricity in Denmark in 1999, network losses were included in operational optimization. Due to the possibility of transit through Denmark, a lot could be gained by considering network losses. That possibility disappeared at the market opening.

A continued installation of wind and solar power will increase the number of hours with prices in the spot market around zero. This will increase the need for a better optimization of operations than the current market design can offer.

This analysis raises two questions:

- Can operators of wind and solar power plants be given stronger incentives to contribute actively to the balance of the power system?

- Can the transmission system operator (TSO) be given better opportunities to optimize grid operation when the market price cross is very flat?

My suggestion

Electricity overflow is less of a problem if the system operator has access to sufficient down-regulation in the balance market.[3]

Operators of wind and solar parks should be obliged to bid a certain share (e.g. at least 75%) of the expected hourly production into the balance market as downregulation. The advantage of this solution is that the system operator can choose a desired amount and distribution of downregulation and thereby distribute the production taking into account both system security and network losses.

In this way, it is possible to avoid that the distribution of production is controlled by chance. It makes no appreciable difference to the market participants, as long as the adjustments take place in the flat part of the spot price intersection.

[3] Energinet: Balancemarked og balanceafregning, Vejledning til forskrift C2, 1. november 2021 (in Danish)