Wind energy has played a major role in the green transition up to now, but

Bottlenecks in Power Grids stop Wind Turbines

Most European countries are heading for a green future. Governments have seen wind power as a popular green technology. Subsidies have boosted wind power in several countries and the production cost per kWh has fallen to a competitive level.

However, the green politicians do not mention the need for additional transmission capacity.

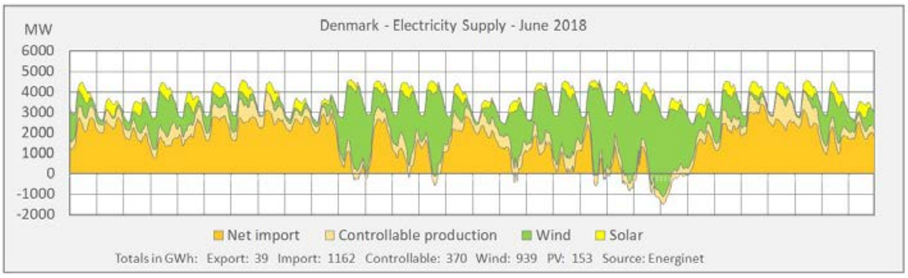

Fig. 1 - Import was the major Danish source of electricity in June 2018

Wind power is fluctuating and non-dispatchable. This was known from the beginning. The solution was supposed to be flexible electricity demand, smart grids and "power-to-x". The smart solutions did not materialize in perceptible magnitude up to now.

The first wind power plants were small units, which could be connected to local grids. Now, wind power plants are installed in large parks and connected at the transmission level.

The result has been a dramatic increase in the long-distance electricity transport. Overhead power lines are for some reason less popular than wind turbines.

A wind park can be planned and built in a couple of years. In contrast, it takes ten years or more to prepare and install a large power line. The alternatives to HVAC[1] overhead lines are HVAC cables and HVDC[2] links. Both alternatives have severe technical and/or economic challenges.

The lesson is that the development of wind power requires a considerable extension of the transmission grids. This was realized too late or not yet in several countries. Most political decision makers do not want to include new power lines in their green agendas.

This note will comment on transmission problems and grid planning in some European countries.

Swedish TSO[3] speaks out about wind power and infrastructure

The Swedish Energy Authority has published a 12 pages mission plan for the preparation of a strategy for a sustainable wind power development[4] (in Swedish). The new strategy is supposed to be ready by the beginning of 2020.

[1] HVAC: High voltage alternating current
[2] HVDC: High voltage direct current
[3] TSO: Transmission System Operator
[4] Energimyndigheten: Uppdragsplan - Strategi för hållbar vindkraftsutbyggnad Miljömålsrådsåtgärd, 2018-10-19

Several parties have an interest in the matter and a right to be heard. This includes the Swedish TSO, Svenska Kraftnät (SKN, Swedish Power Grid).

The seven pages answer from SKN can be characterized by the following quotations from the summary (my translation):

- *Initially, SKN misses a description of the underlying analyses, which have been made on the proposed effort, i.e. which analyses underlie the assessment that just a very strong expansion of wind power is necessary in order to reach the target of 100% renewable electricity production by 2040.*
- *Besides, it is the judgment of SKN that the proposal lacks a detailed description of how the mission plan will consider the technical conditions of the power system, the influence on the electricity market and the assumed role of SKN as responsible for the power system.*

In a subsequent section, SKN refers to a previous request to identify idle grid capacity. The free capacity in the Swedish transmission grid is microscopic in relation to the Swedish wind power vision. SKN explains that 100 TWh wind energy corresponds to more than 30-35 GW installed capacity. This amount would require comprehensive grid expansions.

It is also necessary to take into consideration that it can take 10-15 years to build new facilities for transmission and distribution.

- *It is important to take into account, that SKN and other parties of society have different roles and responsibilities and that the interests are not always compatible. SKN is doubtful if it is expedient to execute this work as a strategy report by the Agency for Nature Conservation and the Energy Authority, unless the proposed clarifications have been done and a clear mandate has been defined.*

Bottlenecks in the present Swedish electricity transmission system are frequently limiting electricity import. Average availabilities for import in 2018 are shown in fig. 2.

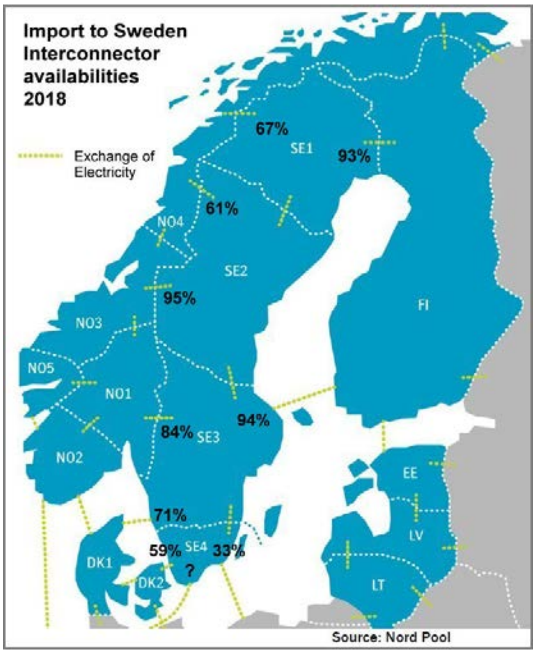

Fig. 2 - Swedish import availabilities in 2018, mainly due to internal bottlenecks

Grid operators must report the reasons for temporary limitations to Nordpool, hour by hour. A four digits code has been developed for the purpose. The first two digits indicate the reason and the last two digits indicate the area or the location.

For import from Denmark, most Swedish limitations have the code 1624, where 16 means "Stability" and 24 means "The West coast corridor in Sweden (SE3)", which is an internal Swedish bottleneck. The export capacity from the two Danish price zones to Sweden was reduced during 64% of the hours in 2018 for DK1 and 84% for DK2 respectively.

The nominal internal transfer capacities between the four Swedish price zones are from north to south: 3.3 GW, 7.2 GW and 5.4 GW.

Connecting 30-35 GW wind power to this system will be a challenge of a magnitude, which seems not yet to be understood by the energy planners.

The clear statements from SKN are unusual and welcome.

Increasing German Costs of Security Measures

It has been difficult to get an overview of the total German costs of corrective measures due to congestions in the power grid. Since 2015, the Bundesnetzagentur (BNA)[5] has published a quarterly report on network and system security[6] with details about the German security measures.

The German grid problems have a well-known combination of causes:

- Surplus of wind power in the north
- Large consumption of electricity in the south
- Insufficient grid capacity for power transmission from north to south
- A single price electricity market preventing the market from solving the problem

The result is a need for interventions with compensation to the market participants concerned. This is a clumsy imitation of what an efficient market design could have done.

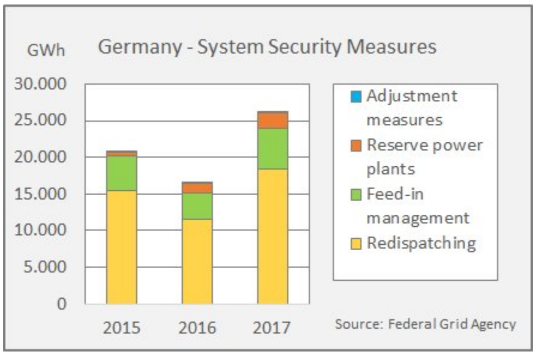

Fig. 3 - Volume of system security measures. For comparison: Denmark's electricity consumption was 34,000 GWh in 2018.

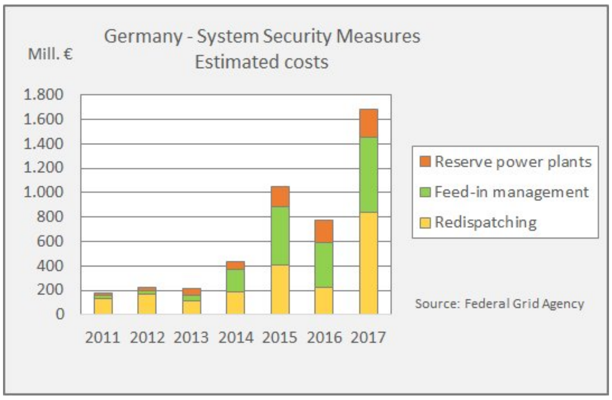

Fig. 4 - The total cost of corrective measures exceeded € 1,600 million in 2017.

Possible interventions according to BNA:

- **Redispatching:** Reducing and increasing electricity feed-in from power plants according to a contractual arrangement with a network operator or with a statutory obligation towards the network operator with reimbursement of costs.
- **Feed-in management:** Curtailment of energy fed into the grid from renewable sources and combined heat and power plants at the network operator's request with reimbursement of costs.

[5] The Federal Grid Agency
[6] Website in English: https://www.bundesnetzagentur.de/EN/Areas/Energy/Companies/SecurityOfSupply/NetworkSecurity/Network_security_node.html

- **Reserve power plants:** Deployment of reserve power plant capacity to compensate for a deficit of redispatch capacity according to a contractual arrangement with costs being reimbursed
- **Adjustment measures:** Adjustments of feed-in and/or offtake of electricity at the network operator's request without compensation for costs if the other measures are insufficient.

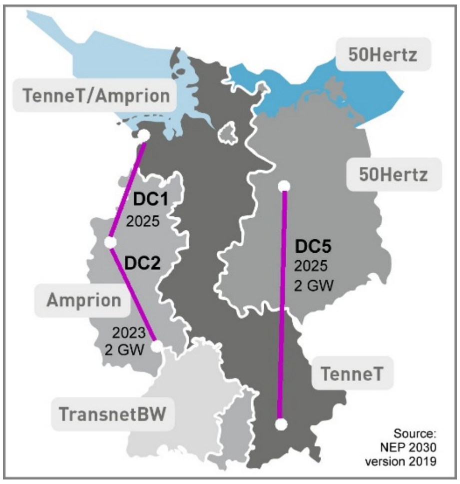

Fig. 5 - The first new HVDC links

Germany has some years been preparing corridors for new transmission systems from north to south in Germany.

Fig. 3 and 4 show that the extent of interventions can be different from year to year, but also that the general trend has been increasing. The interventions in the coming years will depend on the balance between new wind power and additional transmission capacity.

The installation of new wind parks should be postponed until the corresponding grid reinforcements are in place.

More than 15 years lead-time for new power lines in Germany

The German bottlenecks were predicted many years ago. See for instance the E.ON Netz Wind Report 2004[7]. E.ON Netz was concerned about the booming production of wind energy in Germany.

A headline in the Wind Report 2004: *Wind power needs a corresponding grid infrastructure – grid expansion necessary*. Fig. 6 shows an illustration from the report.

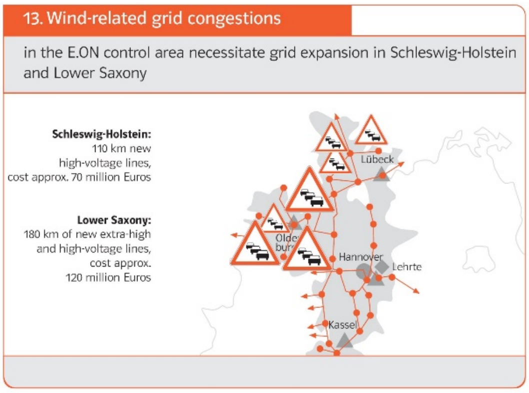

Fig. 6 - E.ON Netz prediction from 2004

During meetings with Eltra at that time, E.ON Netz told that the planned installation of wind power offshore and onshore in Northern Germany would occasionally close the border for export from Denmark. It has happened as predicted, and the planned grid reinforcements in Schleswig-Holstein are not yet ready.

We know from later reports that the German decision makers did not ignore the problems. Germany has a detailed national grid planning[8]. A comprehensive grid development plan is published regularly.

The real problem is that the development of new wind and solar power has not been harmonized with realistic plans for installation of corresponding infrastructure. Political decision makers claim progress of the green transition when a wind farm has been commissioned, but the wind farm cannot be fully utilized until the infrastructure is ready.

[7] https://docs.wind-watch.org/EonWindReport2004.pdf
[8] https://www.netzentwicklungsplan.de/en/front (English version)

From the Wind Report 2004:

> *In Schleswig-Holstein, due to the many wind power plants installed there, the grid capacities are now exhausted when there is strong wind. Although the approvals procedures for the required grid expansion measures have already been initiated, it can be assumed that it will be several years before the planned power lines are realized.*

The grid expansion in Schleswig-Holstein includes replacing an existing 220 kV line by a 380 kV line from Kassø in Denmark to Hamburg Nord (TTG-005 in fig. 7) and building of a new 380 kV line at the west coast (TTG-P25). According to the German grid development plan 2019, these projects will be ready for operation in stages between 2019 and 2022.

Thus, the lead-time has been at least 15 years. The German wind energy production has grown from 18.6 TWh (2003) to 108.6 TWh (2018), while waiting for new infrastructure.

Fig. 7 - Grid projects in Schleswig-Holstein

The unlucky British Western Link

Scotland has a surplus of wind power, which is supposed to be used in England. However, the power grid has its bottleneck at the border between Scotland and England.

In order to avoid new overhead lines, a subsea HVDC cable was laid between Hunterston in Scotland and Deeside in Wales (fig. 8).

The £ 1 billion project has impressive data. The marine cable is approximately 385 km long. It was the world's first 600 kV HVDC cable.

Fig. 8 – 2200 MW subsea HVDC-link bypassing the bottleneck

The link was expected to be ready for operation in late 2015, but did not go live until December 2017. The performance of the link has since then been modest.

Renewable Energy Foundation (REF) in London has published the outage data[9] (fig. 9). For the operational period from 7 December 2017, the average availability was 40%.

REF has calculated the total constraint cost for the border. REF mentions that not all of these costs would have been avoided if the interconnector had been working as promised, but some considerable part would have been prevented.

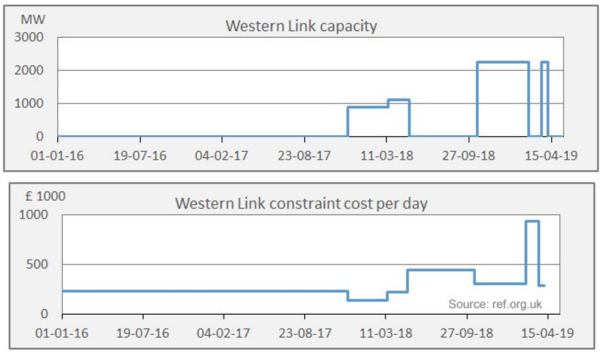

Fig. 9 - Capacity and constraint cost per day

[9] https://www.ref.org.uk/ref-blog/351-western-link-outages-increase-consumer-costs-for-scottish-wind-farms-

A recent update from Western Link says:

Tuesday, May 07, 2019: Following a trip on the Western Link protection systems on 6 April 2019, specialist vessels and engineers are now at the site of the fault repairing a section of the cable. The fault occurred in the Irish Sea, around 150 km from Hunterston.

The interconnector is expected to be ready for operation again at the end of May.

Denmark must implement large scale "power to x" within 10 years

A political agreement from 2018 sets a 55% target for renewable energy in Denmark by 2030. The target includes all types of energy consumption. The share of renewable energy was 27% in 2017.

A screening of Danish waters[10] has identified areas for at least 12.4 GW offshore wind power. The corresponding annual energy production could be about 45 TWh or 162 TJ. The total Danish energy consumption was 633 TJ in 2017, of which 171 TJ was renewable energy[11]. Additional 162 TJ renewable energy before 2030 would fulfil the aim.

The Danish production of wind energy was 53 TJ in 2017. A total production of 53 + 162 = 215 TJ would exceed the traditional electricity consumption in Denmark by 93 TJ or 76%. The overflow would be even larger due to existing CHP (combined heat and power) and other renewable electricity production than wind power.

The answer to this dilemma is called *power to x*, which means that the electricity must be converted to something else, perhaps already on an offshore platform.

It seems to be an unrealistic dream that this can be done in full scale and under realistic commercial conditions within 10 years.

Infrastructure lead-time ignored or underestimated

The installation of wind power is only the beginning of a green transition. Decision makers did not yet specify where to send the fluctuating power and how to utilize it. It takes new facilities for transmission and conversion (power-to-x).

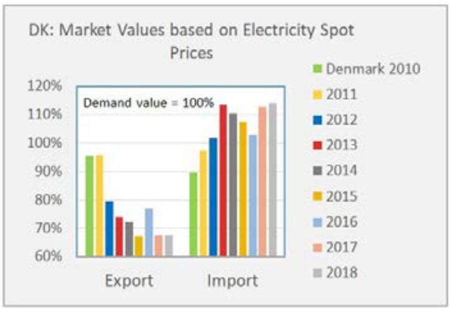

Fig. 10 - Danish export and import prices moving apart

Denmark has been able to export the fluctuations, but at the cost of decreasing export prices and increasing import prices (fig. 10). This strategy will fail with increasing penetration of wind power in the neighbouring countries. The barriers to Danish export to Germany and Sweden are clear indicators. Due to the high penetration of wind power in Denmark, the development of power-to-x facilities is more urgent in Denmark than in other countries.

A green transition requires European countries to boost the infrastructure development and moderate wind and solar power development in order to avoid unacceptable curtailment of wind energy.

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[10] Havvindspotentialet i Danmark, Energistyrelsen, 26. april 2019 (in Danish)
[11] Energistatistik 2017, Energistyrelsen (in Danish)