The electricity grid

Analysis of Danish power system function

SUMMARY

The Energy Agreement of 22 March 2012 launched a series of analyses of the energy system, including an analysis of the electricity network's functionality when the proportion from wind increases, with a primary emphasis on the period after 2020. Another analysis defined in the energy agreement covers international connections - options and effects. These analyses should be viewed as a whole as international connections are an important element in the electricity network's functionality. This report and its annexes constitute a single reporting on both electricity analyses.

The electricity network's functionality should be interpreted broadly. The network ties production and consumption together in order to ensure that new and existing generating capacity be available regardless of the technology involved. The network will ensure supply of supply for consumers with a high degree of security and provide for the possibility of a flexible consumption that can contribute to the balancing of the power system. Finally, international connections will enable that Denmark benefit from an efficient international electricity market, both in terms of the benefits of trade across borders and mutual support in the operation of the countries' power systems.

In the analysis of the electricity network's functionality, the focus is on the ability to provide electricity when there is demand or in other words to ensure supply. Operating costs of power stations and general economic framework conditions are not within the scope of this analysis.
Security of supply in Denmark is very high, and Denmark is ranked together with the Netherlands and Germany in the European top-third of countries in this field. In Sweden and Norway - two countries to which Denmark is often compared - the extent of outages is 3-5 times higher. This is because the network in Norway and Sweden is much weaker, as less of the network is cabled underground and the climate is harsher.

Security of supply is achieved through networks and plants jointly

Functionality of the power system is measured by calculating when there are disruptions. Supply disruptions have been historically recorded and measured by the network companies and collected systematically by the trade association Danish Energy. It is apparent from investigations into the cause of such outages that they are due either to planned outages, as a result of maintenance of the network, or to unplanned outages due to storms or the like. About 3/4 of the disruptions are caused by the distribution network, while the remaining 1/4 are due to the transmission grid.

Cabling the distribution networks underground means fewer interruptions, and since the distribution network have been largely cabled, the scale of the disruption is decreasing. This trend is expected to continue, with further undergrounding of distribution networks primarily benefitting the 50-60 kV networks.

In the last 10 years, the average consumer was interrupted for 45 minutes a year, and over the past 5 years the interruptions only lasted for an average of 25 minutes. The improvement over time can be best exemplified by comparing the effects of the storm of the 8th January 2005 with the storm 28th October 2013. In 2005 there were extensive and long interruptions, while in 2013 only a few momentary pauses occurred, although the DMI (Danish Meteorological Institute) classified the storm in 2013 as being worse than in 2005. The transmission network will be developed to cope with future wind

integration developments and be adaptable to ongoing developments. Components delivering ancillary services supplement power plants as protection against disruptions. Any disruption is therefore due to the transmission network and is expected at this level.

In the operation of the electricity system there are a number of technical parameters which are engaged to ensure the immediate balance between consumption and production. They are collectively called ancillary services and address issues of voltage regulation, voltage support during faults and inertia. Such services are mainly provided by large-scale power stations, but with fewer plants available emphasis is to provide ancillary services in a different way.

Energinet.dk believes that in 2020 the East Danish power system, in normal situations, could function without centralised power plants in operation. This does not mean that thermal plants are dispensable, however the dependence on whether they are in operation or not is significantly reduced. Initiatives have been launched to internalize the markets for ancillary services, particularly purchases of reserves, to allow the most socio-economically inexpensive suppliers to be activated across national borders. This will be in natural continuation of the existing operation with foreign countries which has been practised in the Nordic region and on the Continent for decades. In this cooperation each country contributes a proportionate share of the required demand for the fast primary reserves. Via the international interconnections, countries are therefore mutually dependent on each other for stable supply.

Besides network failures, interruptions can in principle also be due to issues at the production plant, but historically there have been no power shortages due to lack of generation inadequacy on the production side. The Danish power system has, for the past two decades, been characterised by ample production capacity. In future, more wind power will be added leaving less room for thermal generation. At the same time, many thermal plants are approaching the end of their technical lifespan, and the economics of these plants are under pressure. Therefore, thermal capacity will decline. In recent years, more than 2,000 MW of capacity in the older central plants has been taken out of service, and such developments are expected to continue. This also applies to decentralized CHP (Combined Heat and Power) plants, meaning the period of the large overcapacity of thermal generation is about to come to an end. It is therefore highly relevant to analyse the importance of the power plants in relation to security of supply in the future.

Simulation runs for 2020 and 2025 and scenarios for 2035 and 2050

Although the reason for supply disruptions has historically been rooted in electricity grids or in operational events, this analysis focuses on thermal capacity and cross-border interconnectors. The reason is that with an increased generation capacity in the electricity system from wind and solar power, existing fossil-fuel generation is being displaced. Furthermore, the electricity market ensures the flow of electricity back and forth across national borders via the cross-border interconnectors. Undergrounding large parts of the domestic grid system in Denmark has already been decided and will reduce faults in the grid. Operating an electricity system with more than 50 percent wind power - or for that matter 30 percent wind power, as is the case today - is substantially different from operating an electricity system with a smaller contribution from wind power.

In order to examine the significance of generation capacity for security of supply in the future, the analysis applies a method which takes account of a large proportion of wind power. However, wind power may not be the only thing missing on a cold winter's day, as thermal power plants are not 100% available. They are subject to regular revisions or faults as well. Thus, the likely availability is what determines security of supply. Security of supply is analysed using a probability model covering all generation plants and cross-border interconnectors. Based on consumption profiles, an hour-for-hour Monte-Carlo

simulation is run, which using 'roll of the dice' probability models examines whether domestic production and imports from abroad are available. The model also includes the probability that import is not possible from interconnectors. It is measured for each hour whether there is sufficient capacity to meet consumption demand.

Simulations were carried out for the years 2020, 2025, 2035 and 2050. For the first two years, domestic production is projected based in part on statements from the owners and in part on assumptions regarding the continued phase-out of centralized and decentralized capacity. Runs for the years 2035 and 2050 are on the basis of scenarios common for all of the energy analyses. These scenarios have been designed so that the level of security of electricity supply is the same as today, i.e. disruptions due to generation inadequacy are expected to occur every ten years, cross-border electricity interconnectors are included on a par with domestic generation capacity, and current interconnectors are included along with planned expansions to Norway, Sweden, Germany and the Netherlands.

The results of the simulations for the risk of generation inadequacy are as follows:

Up to 2025 are the simulations based on projections

- The security of supply is expected to improve in Western Denmark and can be maintained at similar levels in Eastern Denmark up to 2025, in spite of plant closures, as international interconnections, wind and solar power offset the decrease in thermal capacity. In addition to the risk of power shortages, interruptions to electricity networks will still occur, but less frequent than the historical norm.
- Developments in Eastern Denmark are sensitive to changes in assumptions of thermal capacity and new interconnections, including delay up to 2020 in commissioning the planned cross-border interconnector linked to Kriegers Flak. It is not expected that this will have an effect on security of supply, because if this happens Energinet.dk will introduce alternative initiatives to secure capacity as a transitional measure until Kriegers Flak comes on line. In this context strategic reserves are being considered.

In 2035 and 2050 the simulations are based on scenarios

- In 2035 and 2050 more thermal capacity is required, but the demand for more thermal capacity depends on the scenario. In the case of a wind and hydrogen scenario there is a need to add considerable extra capacity to ensure
- the status quo for the security of supply, while in the two biomass scenarios only a little extra thermal capacity seems to be necessary. Also in 2035 and 2050 there will occur interruptions in electricity networks equal for all scenarios.

Measures to ensure security of supply

There are a variety of options to ensure the security of supply in the future. These include the network, where improvements already today are implemented, and measures on the demand side. When the network is reinforced or distribution networks cabled underground, this alone improves security of supply. Regional differences in generation adequacy in Denmark could be offset with, for example, a new interconnector between East and West. International connections other than those already decided upon can also contribute to security of supply both in Denmark and in neighbouring countries. However, also in future the trading gains will be the primary reason for investments in interconnectors.

There are also various methods to maintain domestic electricity capacity at a certain level. Such capacity mechanisms typically fall into three categories: strategic reserves, capacity markets and capacity payments. In many countries, different models are either under consideration or have already been

decided upon. None of the models is free. There are advantages and disadvantages to all three models. International experiences with capacity mechanisms shows that costs of capacity payments fall within the more expensive range and that capacity payments can be inefficient. With regard to securing electricity capacity in the electricity system, the same applies to the Danish basic amount, where in 2012-13 small-scale CHP plants received about DKK 1.2 bn. per year in capacity payments. Strategic reserves seems cheaper, but not necessarily a permanent solution, not least because they are difficult to utilise alongside combined electricity and heat production. It has to be emphasised that the experience various capacity mechanisms still is limited and that costs will differ from country to country. E.g. a strategic reserve in Sweden acts in another marked than the Italian capacity payment. The European Commission summarises in its review that strategic reserves have worked well with the energy markets where they have been used in Sweden and Finland in that they cause minimal distortion, and that they have successfully included the consumption side.

The European Commission further submits that the establishment of capacity mechanisms under some circumstances may be counter-productive and maintain inefficient generation capacity in the market. In liberalized markets, investments are not guaranteed by the state, notes the European Commission. Only where there is a real threat to the security of supply as a result of generation inadequacy, should existing plant economics become a social issue. The Commission also reaffirms the importance of the fact that public funds should not be used to compensate for reduced income.

Flexible consumption offset capacity requirements. It can be activated in various ways, but in Denmark, where there is an absence of an electricity-intensive sector, that volume is small. However, this could change if the smart grid concept is developed successfully.

As the need for the establishment of capacity mechanisms does not appear to be imminent, economic analyses contain no assessments of specific opportunities nor recommend any in particular. This assessment will be made at a later stage.

Summary of security of supply

- **Overall, security of supply is to be maintained at the current level without new initiatives for the next 10 years.** Capacity of wind and international interconnections will increase due to the initiatives adopted. The thermal capacity is expected to decrease, and the historic period of significant overcapacity for the thermal plants will end. The analysis shows that the years leading up to 2025 may necessitate special measures to ensure the current level of security of supply is maintained. If the requirements for security of supply were slackened in comparison to today, the need for new initiatives to ensure security of supply could be further postponed. This is especially important for Eastern Denmark, where the delay in a trading link via Kriegers Flak may lead to initiatives to secure capacity, e.g. via strategic reserves. Security of supply will remain at the same level, irrespective of this.

- **Reinforcement of the network will to some extent offset the decrease in thermal capacity.** Recent years' improvements in distribution networks, primarily through underground cabling has improved supply so though generation adequacy develop less favourably than expected in this analysis it is not assumed that supply disruptions should increase. Electricity consumers will not be aware of whether disruptions are due to generation inadequacy or faults in the distribution system because of trees falling on power lines for example. In addition, Denmark in an international context has a very high security of supply in general.

- **There are various possibilities to ensure sufficient generation capacity.** It may, for example, be achievable through international connections, paid reserves (strategic reserves), the introduction of a capacity market or increased stimulation of flexible consumption. The socio-economic lowest cost is presumed to be achievable through a combination of measures. International experiences with capacity mechanisms shows that the costs of capacity payments are generally on the high side and that existence of a dominant player makes it difficult to create such a market. Strategic reserves are cheaper, but not necessarily a permanent solution.

- **Any decline in thermal capacity is monitored as closely now as it will be in the future.** For example, Energinet.dk makes an assessment each time a central power plant is desired to be taken out of service on how this would affect security of supply. It is possible to pay to extend its operational life, so there is time to introduce compensatory measures. It may be that there is no need to do anything and the current level of security of supply can be maintained while in other situations minor changes in the network may be sufficient to deal with the problem. The legislation also allows for the provision of new capacity to ensure the security of supply, establishment of new peak-load capacity can be done in relatively few years.