LCTU
Low Carbon Transition Unit

Energy Policy Toolkit on

System Integration of Wind Power

Experiences from Denmark

DANISH ENERGY AGENCY

Abbreviations

AC	Alternating Current
ATC	Available Transmission Capacity
BRP	Balance Responsible Parties
CHP	Combined Heat and Power production
DC	Direct Current
DEA	Danish Energy Agency
DSO	Distribution System Operator
EU	European Union
GHG	Green House Gas
GW	Giga Watt
HVDC	High Voltage Direct Current
kV	Kilo Volt
kW	Kilo Watt
LCTU	Low Carbon Transition Unit
LEDS	Low Emission Development Strategies
MVAr	Technical specification on reactive power
MW	Mega Watt
PSO	Public Service Obligation
R&D	Research and development
RE	Renewable Energy
TSO	Transmission System Operator
TWh	Tera Watt Hours

Contents

Introduction

Countries around the world face critical energy choices. The goal of economic growth and future prosperity is challenged by energy needs and international efforts to find solutions to mitigate global warming. Thus the energy choices revolve around choosing appropriate policies and measures, on decisions with regard to the energy mix and on the timing and scope of grid investments etc. However, a key question for energy planners in growth economies and developing countries remains whether today's investments in energy infrastructure should be based on traditional fossil fuels or on the present and emerging renewable energy technologies?

The traditional fossil fuel oriented approach may still be cost-efficient in the shorter run compared to some of the more costly renewable energy sources but is clearly unsustainable in the longer run.

The alternative and more sustainable approach is that of energy efficiency and renewables. While fossil fuel prices are expected to rise further, the cost of renewable energy technologies may very well fall due to maturing of the technologies and an increase in demand with associated economics of scale. Thus the necessity of transferring the energy systems from reliance on fossil fuels towards renewable energy sources does not necessarily run counter to future economic prosperity.

This policy toolkit is a first of three on Danish lessons learned in the area wind energy. The three wind policy toolkits all focus on key aspects and challenges and barriers with regard to increasing the share of wind energy. This first wind toolkit addresses the challenge of integrating increasing shares of fluctuating wind power into the power grid. The Danish case proves that this challenge is manageable by applying the right set of policy tools and measures, notably with regard to system operation and market instruments. The two following wind toolkits will present and discuss Danish lessons learned on the physical planning of wind turbines and wind farms and on support schemes and financing for wind power.

Wind power today amounts to approximately 30% of total Danish power supply, and with already decided policy measures, this share is projected to grow to 50% in 2020 and is thus in line with the long-term goal of full conversion to renewable energy in 2050. This development which goes back to the energy crisis of the 1970s has fostered a unique cluster of experiences and

expertise that may prove valuable to other countries that wish to green their energy profiles and continue further on the green growth path.

The toolkits are drafted by the Low Carbon Transition Unit (LCTU) under the Danish Ministry of Climate, Energy and Building. The LCTU will publish a series of toolkits providing specific, technical and concrete information on Danish experiences and lessons learned on tools and measures in promoting renewable energy and energy efficiency, targeting practitioners, governmental energy experts and policy makers in growth economies and developing countries. The aim is to give qualified guidance to countries in their implementation of Green House Gas (GHG) reduction measures and Low Emission Development Strategies (LEDS).

Comments to this policy toolkit as well as queries on the Low Carbon Transition Unit are most welcome. The idea is to further refine recommendations according to identified needs in growth economies and developing countries. For comments and queries please contact: Mr. Peter Larsen, Head of Section, pla@ens.dk, phone +45 3392 6826. For more information on the Low Carbon Transition Unit and its policy toolkits please visit www.ens.dk/LCTU.

Wind Power System Integration framework

Expansion of clean energy sources is a key part of the global green energy transition. In this connection wind power has already proved to be a mature and important technology. Introducing larger shares of wind power into the grid is a great opportunity as it can improve energy security through diversification of the energy mix and through decentralisation and geographic scattering of power generators but naturally it also poses challenges.

The main challenge is to ensure that power demand is met at all times as the wind power production fluctuates as the wind blows. The traditional power generators, like hydro, thermal and nuclear are more predictable and stable in their production patterns than wind power. Furthermore wind power is often also more decentralised with many and relative smaller production units posing a challenge of having a larger number of installations to work with. The Danish experience shows that the variable and decentralised production can be handled, while still maintaining an efficient and resilient power sector with very high security of supply.

Long term planning and a stable and supportive policy framework in Denmark have been key to the successful large scale integration of wind power in distribution and transmission networks. The aim has been to transmit power most efficiently and with least associated costs from the production sites to the demand centres. The political framework embraces a range of issues such as common goals or targets, design of taxes and incentives for developers as well as regulation and legislation to ensure well-functioning market conditions that stimulate investments.

System operation and the power market represent the two central pillars on which the successful Danish integration of wind power has been build:

- System operation with accurate wind forecasts and adequate reserve capacity for periods with little wind and a demand side that automatically adapts in situations where there is too little or excess production from wind power.

- A well-functioning power market – in which players trade themselves into balance, i.e. supply equals projected demand (intra day market) and a market for balancing power (the regulating power market) operated by the TSO.

Structure of the Power Sector and its stakeholders

Over the decades Denmark has built up a well-functioning power system that gives consumers high technical supply reliability. The power system has traditionally been based on a limited number of large thermal power stations. However, particularly over the past two decades this set-up has changed significantly, with the predominant proportion of new capacity being established as decentralised CHP plants, and wind turbines. The decentralised power production set-up has required the development of new methods for controlling and regulating the power system at the same time as it has provided a more diverse energy mix and hence more security of supply as renewable are less exposed to import constraints and price fluctuations.

FACT

Factsheet

The electric power infrastructure

The supply of electricity has changed significantly since the 1980s. Before 1990 most of the electricity was delivered from few large scale power plants. As a result of a consecutive policy pursuing higher efficiency through increased cogeneration of power and heat (CPH) and deployment of wind power an increasing share of demand is met by small scale CHP and wind. In particular during the 1990s huge investments took place in these new technologies leading to a much more decentralised production and an increase in the number of producing units. This development changed the requirements for planning and operation of the power system.

The maps in figure 1 compare the centralised coal-based Danish energy system of 1985 to the decentralised one of 2009 with greater reliance on renewable energy sources.

During the 1980s and 1990s, many district heating plants have been converted to combined heat and

Electric power infratructure 1985

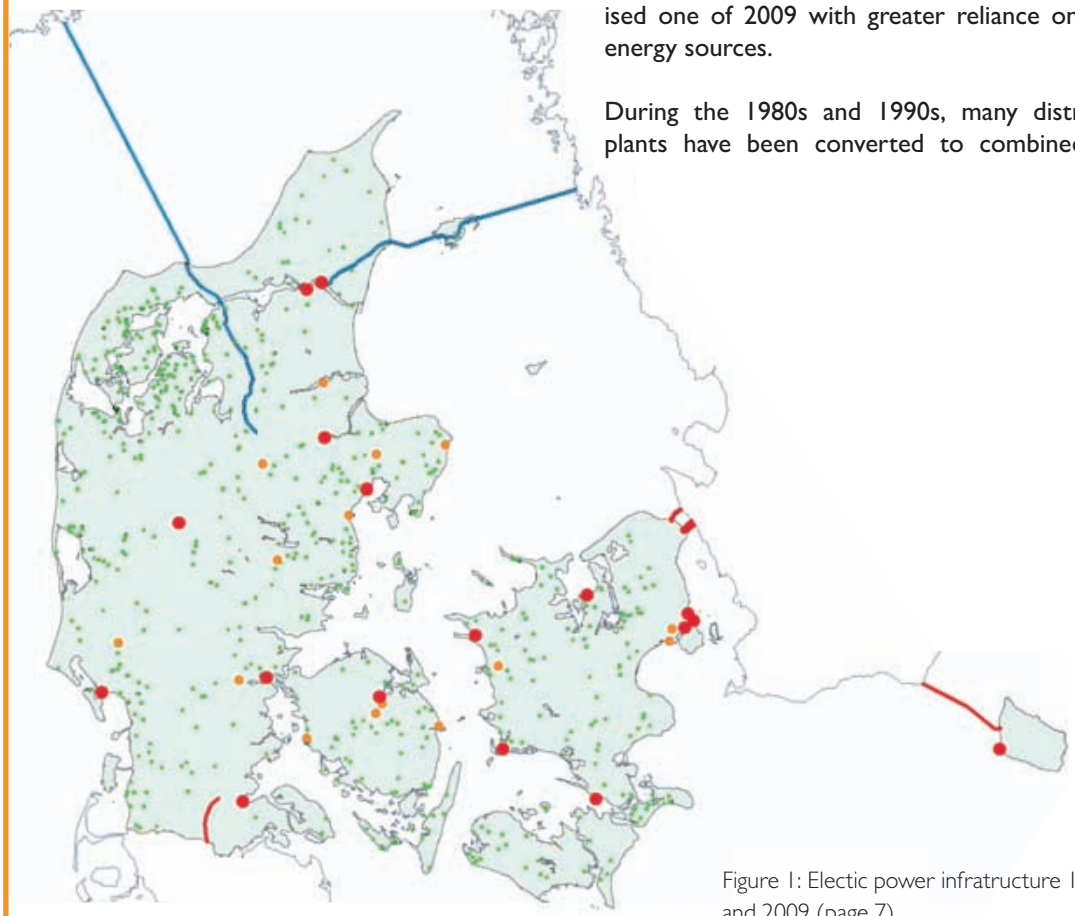


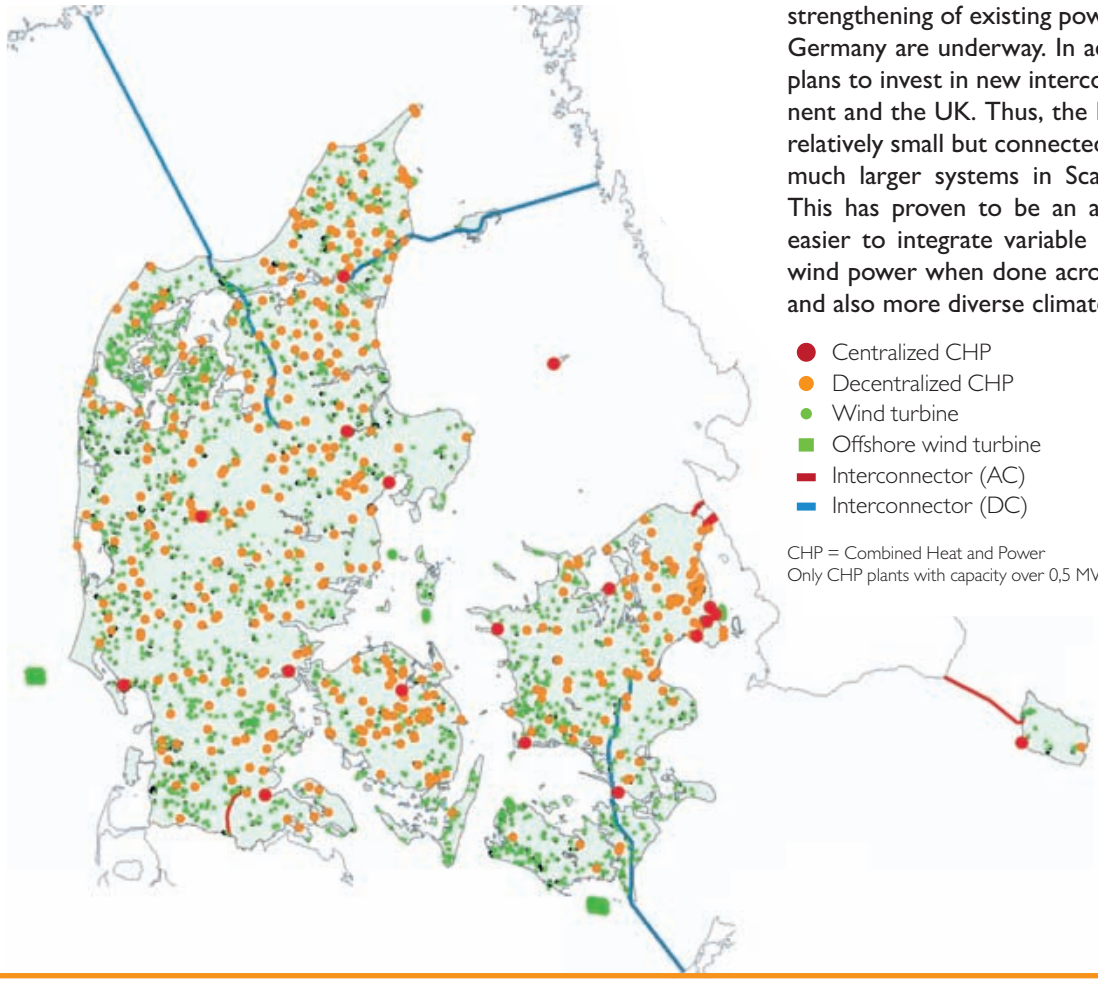
Figure 1: Electic power infratructure 1985 (page 6) and 2009 (page 7)

power production, mainly gas fuelled. This development has been enabled by government-led heat planning establishing a framework for local authorities. The financial incentive to invest in the CHP conversion was facilitated by an electricity generation subsidy for small-scale CHP plants.

Total installed capacity of power generating equipment has for the last decade been around 13 GW – including wind turbines. Thermal capacity has been slightly declining and was by end 2010 approximately 9.5 GW. Peak load demand has been rather stable for several years around 6.5–6.6 GW. Annual demand is app. 35 TWh. The internal transmission grid is strong and interconnector capacity to the neighbouring countries equals almost peak load (Germany 2.5 GW, Sweden 2 GW and Norway 1 GW + 700 MW under construction).

Since 2009 an east-west cable linking the two parts of the country has been in operation and further strengthening of existing power links to Norway and Germany are underway. In addition, there are other plans to invest in new interconnections to the continent and the UK. Thus, the Danish power system is relatively small but connected to and integrated with much larger systems in Scandinavia and Germany. This has proven to be an advantage as it is much easier to integrate variable power sources such as wind power when done across a wider geographical and also more diverse climate area.

Electric power infratructure 2009



- Centralized CHP
- Decentralized CHP
- Wind turbine
- Offshore wind turbine
- Interconnector (AC)
- Interconnector (DC)

CHP = Combined Heat and Power
Only CHP plants with capacity over 0,5 MW are shown.

The table below shows the wind deployment as percentages of national power supply. The figures are based on statistics up until 2011. For future years the figures are projections based on a baseline scenario – a so-called "frozen policy" projection. Hereby an assessment is given of how wind deployment will evolve in the future if no new policies are introduced.

Wind power's share of domestic power supply, %							
Statistics						Frozen policy scenario	
1990	1995	2000	2005	2010	2011	2015	2020
1.9%	3.5%	12.1%	18.5%	21.9%	28.1%	35.7%	50.1%

Table 1: Source: Danish Energy Agency's statistics (1990-2011) and frozen policy scenarios to 2015 and 2020[1].

1. The 2020 frozen policy scenario is based on the 28 March 2012 Danish parliamentary energy agreement including policies and measures arriving at 50 % of electricity supply from wind power in 2020 and a decrease in gross energy consumption by more than 12 % in 2020 compared to 2006. The parties behind the agreement represent 171 seats out of 179 in the parliament. The agreement establishes a framework for the policy on climate and energy up to 2020 and outlines the direction Denmark will take until 2050, where the goal is full conversion to renewable energy.

The more than 4,500 onshore wind turbines installed in Denmark to date is a result of local decision-making that has driven their distribution, scattered quite evenly across the Danish territory, although concentrations of turbines are higher in the western part of the country and in coastal regions where wind is ample. Major wind farms (offshore) are purposely more evenly distributed between east and west.

In Denmark in 2011 a total of 3,080 MW onshore wind power capacity produced around 6,442 GWh, while a total of 871 MW offshore wind power capacity produced around 3,405 GWh, reflecting the higher wind speeds at sea.

Looking at the geographical distribution wind power production in western Denmark in 2011 was around 7,140 GWh while eastern Denmark had a production of around 2,706 GWh.

Below the principles of grid connection of wind turbines and the associated financial regime is briefly outlined, as well as the principles of wind turbines having priority access to the grid – which provides security for independent power producers to feed in their wind power to the grid.

Wind Power in Denmark

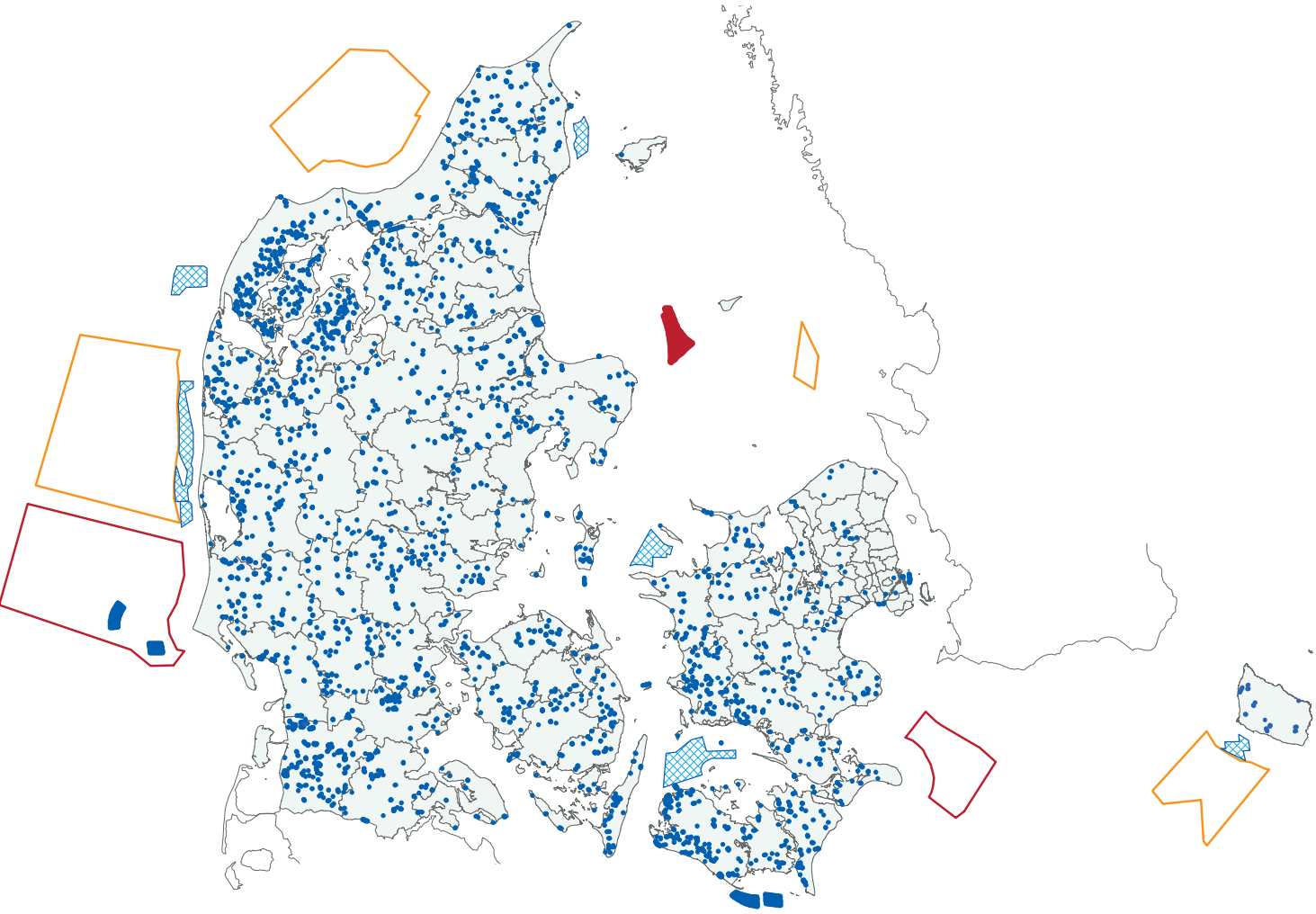


Figure 2: The map pictures in blue – the existing on- and offshore wind turbines, showing the quite even geographical distribution between east and west. Further the 400 MW Anholt offshore wind farm currently under construction is pictured in orange as well as designated areas for future offshore and near coast wind power.

Grid connection and its finance

Traditionally, onshore wind turbines have been connected to the power system through distribution grids less than 100 kV. This applies to both individual wind turbines and wind farms. Grid reinforcements were necessary in the local 10 kV grid due to the growing wind turbine capacity. As turbine size increased reinforcements were in some cases also necessary in the 50/60 kV grid. The transmission grid was in general able to cope with generation from wind turbines connected to the distribution grid.

In 2002 and 2003 the first large offshore wind farms of around 160 MW each were commissioned. Integration of that size required connection to the transmission grid because it was not possible to convey these large power volumes in the existing, low-voltage grid. Future large scale capacity from wind power will also be connected to the transmission grid.

The increased amount of wind power has displaced some of the large central power stations and thus the system services these systems have traditionally delivered. It therefore became necessary to make increased requirements regarding the connection of wind turbines and their system characteristics (such as low voltage fault ride-through capability, power and frequency control), which had previously been delivered from thermal power plants.

Priority access to the grid provides an assurance to connected generators of renewable power that they will be able to sell and transmit their power in accordance with connection rules at all times.

In order to ensure that new wind turbines are safe and can be incorporated into the power system, a Secretariat for the Danish Wind Turbine Certification Scheme has been set up and located at the Danish National Laboratory for Sustainable Energy at the Technical University of Denmark (Risø DTU). The specific regulations are described in Danish Energy Agency's Order no. 651 of 26 June 2008 on the technical certification scheme for the design, manufacture, installation, maintenance and servicing of wind turbines. The secretariat has a website at www.vindmoellegodkendelse.dk. The technical prescriptions for the connection of wind turbines to the electricity grid can be found at www.energinet.dk.

Tree different finance regimes for grid connections exist. For onshore wind power the grid company is obliged to establish the connection on a cost sharing basis. In the 1980s extensive negotiations regarding the distribution of costs for grid connection took place between utilities and independent wind power producers. As no agreement could be reached the government intervened in 1986 and issued a detailed regulation obligating the utilities to connect according to a detailed specification of cost sharing. Today the regulation remains in force and only minor adjustments have been added since the first version. Wind power, specifically, gets further financial support under the Promotion of Renewable Energy Act, which specifies that the developer and the distribution system operator (DSO) share the cost of connection. The principle is that the developer pays the connection from the wind turbine above 1.5 MW to a defined connection point inside the designated wind areas defined in the municipality planning. The distribution system operator further is obliged to reinforce the grid if necessary, in consultation with the TSO, and the distribution system operator pays. The cost is passed on to the consumer through the Public Service Obligation. Wind turbines are also exempt from charges on the use of the transmission system.

Large offshore wind farms under the tendering regime are set up with an internal grid system that leads to a connection point on a transformer platform. The grid connection consists of this transformer platform, a cable transmitting the power to shore and the land cable from the arrival point to the place where the grid connection is linked to the overall transmission grid onshore. The TSO is obliged to finance the transformer platform and the transmission cable ashore as well as the necessary grid reinforcement.

For offshore wind power outside the tendering regime (open door) the developer finance the grid connecting to the nearest shore.

In all cases the TSO or DSO is also responsible for carrying out any necessary reinforcement of the underlying grid. The responsibilities are divided in this way to promote wind power by making the necessary grid available without costs to the producer.

KEY

Key points and recommendations from the Danish case:

- Wind power like all other power generators need grid connection. It is important to ensure the needed grid investments is in place in due time and to give the grid operators incentives to finance the needed grid connection and enforcements, and the needed ancillary services.
- Large wind farms need to be connected to the transmission grid.
- Priority access is a guaranty to wind power producers that they will have access to sell their power in the market place at all times.
- Consider the appropriate financing model for grid connection of wind power (e.g. cost sharing between grid companies and developers).

Stakeholders

Below is an overall presentation of the relevant stakeholders in the Danish case on integration of wind power into the grid.

Transmission system operator

The transmission system operator (TSO), Energinet.dk, is responsible for the Danish power system. It is therefore also the responsibility of the TSO to ensure that the physical balance in the power system is maintained. The TSO is also responsible for the development of rules which provide the settings for a well-functioning power market, with regard to the wholesale as well as retail.

Balance responsible parties

Production, consumption and trade activities must be assigned to the balance responsible parties (BRP) who must enter an agreement with the TSO to assume responsibility for the specific activities, i.e. production, consumption or trade. Upon entering the agreement on balance responsibility the BRP assumes the financial responsibility for the imbalances they may incur. More than 40 players are registered at the TSO as balancing responsible. The majority is only engaged with trade while some are also engaged as producers and/or consumers. Examples on players are; Deutsche Bank, Dong Energy, EDF, Enel, Energi Danmark, Gazprom, J.P. Morgan, Merrill Lynch, Morgan Stanley, Shell and Vattenfall.

Power suppliers (local power trading companies)

The power supplier concludes contracts for the supply of power with the end users. The power supplier buys power either at a power exchange (e.g. Nord Pool) or directly from a power producer, or from another supplier. The end user has the right to change from one power supplier to another supplier; by changing supplier the end user helps promote market competition.

Supplier of last resort

Suppliers of last resort are authorised companies supplying end users that have not exercised their right to choose a power supplier. The tariff of the supplier of last resort is regulated by the Danish Energy Regulatory Authority.

Grid companies

The grid companies are responsible for operating the distribution network just like the TSO is responsible for operating the larger transmission grid. The grid companies are also responsible for metering data on production as well as consumption. The grid companies also have the obligation to keep track of which BRP each end user has chosen, and to supply the TSO with information on metered data for consumption and production per BRP; these data are used by the TSO for settlement of imbalances. All grid companies operate as monopolies.

The producer

The producer produces power and sells the power either directly to a power supplier or to Nord Pool power exchange. The producer also sells power to or buys power from the TSO in the regulating power market. This enables the TSO to maintain and create balance in the power system and ensure the security of supply.

Consumers

The end user consumes the power bought from the power supplier. As a result of the liberalisation, all end users have access to the grid and are therefore free to choose their own power supplier. Just like production, consumption can also be used in the regulating power market in order to create balance in the power system.

Nord Pool – the Nordic power exchange

Nord Pool Spot is the Nordic power exchange owned by the Danish TSO and the other Nordic TSOs. The power exchange has two market places for electricity trading: Elspot and Elbas. Trade on Elspot is based on the auction principle. One day ahead of operation Nord Pool matches sales- and purchase bids in order to calculate the spot market price in consideration of limitation of the capacity on the interconnectors between the so called bidding areas. On Elbas, players trade imbalances occurred after gate closure at Elspot, to obtain balance. Financial trading and hedging takes place at the Nasdaq OMX Commodities platform. For further details please see the Market chapter below.

System operation

The nature of wind power is that it is produced when the wind blows and not in correlation to ongoing power consumption. The unpredictability of wind power makes it necessary to have the capability to regulate both up and down so as to accommodate deviations in wind power forecasts. In addition, there must be both appropriate access to reserves for voltage and frequency regulation and automatic and manual reserves. The reserve categories listed are all integrated elements in the operation of the Danish power system, regardless of the share of wind power in the system. However, it is essential to use the reserves most appropriately by using the newest prognosis information available and acting proactively in order to avoid surprisingly large imbalances within the hour of operation.

An effective operation of the power system can make the system more adapt to larger shares of variable renewable power. Denmark is now rapidly moving beyond 30% wind in power supply. There are several reasons to the success of integrating this large share of wind into the power system such as interconnections to neighbouring countries and an efficient system operation working hand in hand with the liberalised Nordic power market.

System operation is done day-to-day, hour-to-hour and minute-to-minute by the Danish Transmission System Operator and includes various aspects and features with relevance for a successful integration of wind power into the grid. These include transmission capacity, forecasting and grid codes.

The Danish electricity transmission system ultimo 2012

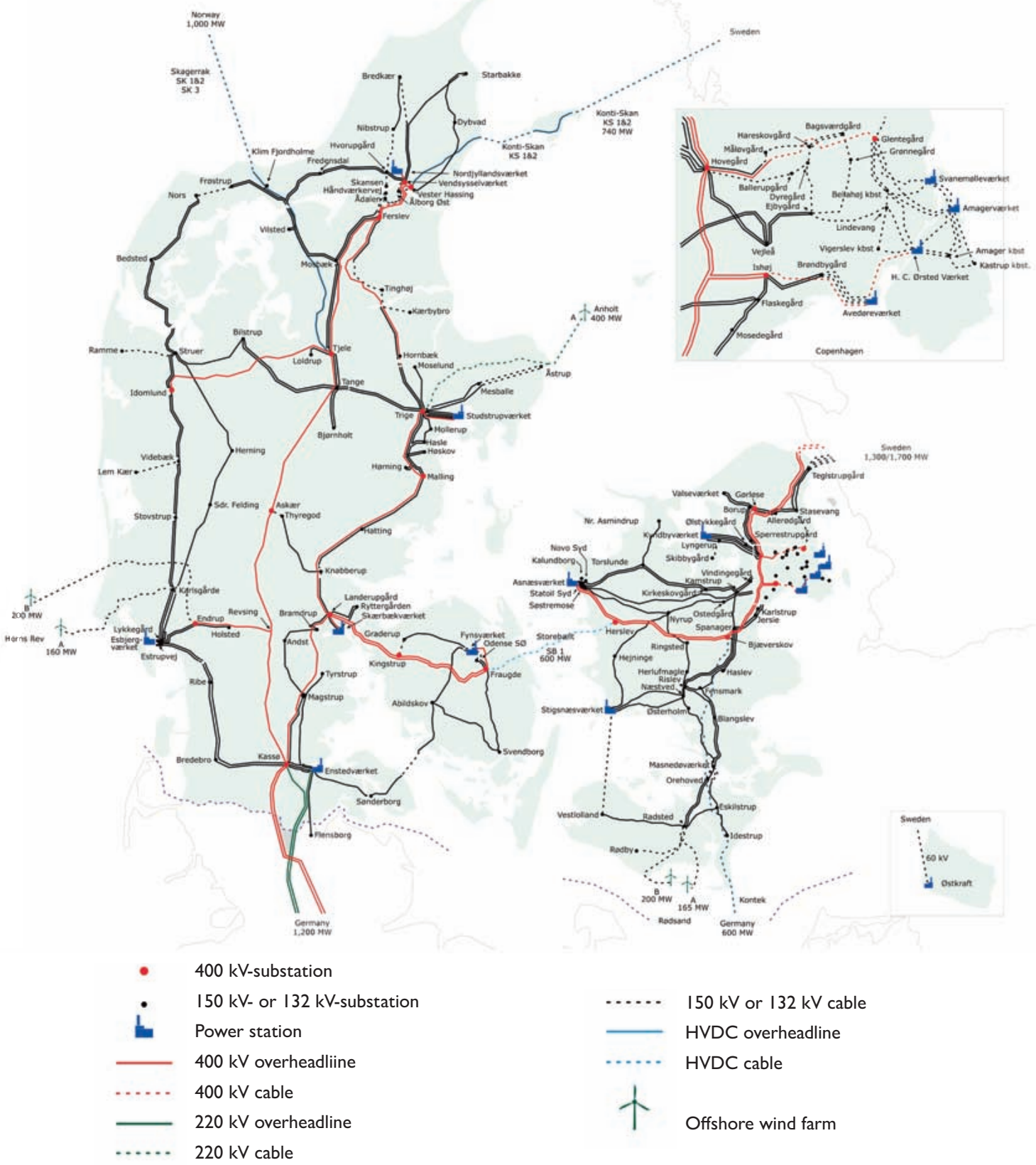


Figure 3: Map by the Danish TSO[2]

2. Map by the Danish TSO, Energinet, www.energinet.dk/SiteCollectionDocuments/Engelske%20 dokumenter/El/Jylland-fyn-sjælland%20-%20stadie%202012%20-%20UK.jpg.

Transmission and interconnector capacity

The power transmission and distribution systems connect power generation units in Denmark and abroad to Danish consumption sites. The transmission grid ('power freeways') connects generation nodes with power consumer nodes. The transmission system consists of 400, 220, 150 and 132 kV installations and is interconnected to the transmission systems of Germany, Sweden and Norway.

The distribution grids are owned and operated by the local grid companies, which transmit the power to the individual consumers.

The TSO provides an online snapshot of the power flowing through the Danish transmission lines, updated every minute[3].

A strong transmission and distribution grid with strong interconnections to neighbouring power markets is an important element in large scale wind deployment.

In the Danish case the interconnectors to Norway and Sweden are especially important as the interconnectors to these two countries make it possible to balance wind power and hydro power. When Danish wind turbines generate more power than required, surplus power is often transmitted to Norway or Sweden, which reduces the draw on the water reservoirs. When the wind calms down, the hydro power stations increase production, transmitting power to Denmark. Interconnectors help spread inexpensive wind power production to a larger market, increasing its value, while decreasing power prices in the areas to which it flows. Robust interconnections and an efficient market and cooperation between the Scandinavian TSOs have proved to be important in importing and exporting environmentally friendly power and in increasing the share of wind power in Denmark.

KEY

Key points and recommendations from the Danish case:

- Interconnectors to neighbouring countries with balancing power (e.g. hydro power) should be considered and pursued.
- Interconnectors help the spreading of fluctuating wind power to a larger area/market, thus making it easier to integrate.

FACT

Factsheet

The Danish interconnectors to neighbouring countries

interconnectors to neighbouring countries are important to the functioning of the power market. The interconnectors have been established and upgraded over a long period of time. Today there are DC-links to Norway, and both AC-links and DC-links to Sweden and Germany. The main driver for the investments was originally bilateral trade between the integrated utilities. Interconnections have expanded the trading area and this has in return added flexibility in an economically efficient way. With the introduction of the liberalised Nordic power market and the increased share of wind power in Denmark the interconnectors have become integrated parts of the Danish system operation. When new interconnectors are assessed today the value for the market including ability to handle the variable wind generation is the determining factor.

3. http://energinet.dk/Flash/Forside/UK/index.html.

Forecasting

Wind forecasts are used to calculate how much wind power the wind turbines will generate minute by minute. With currently approximately 30% wind power of annual power supply today and projected to climb to approximately 50% in 2020 accurate forecasting has become more and more important. One meter per second more or less of wind, and hence an unexpected sudden increase or decrease in wind power generation may be quite noticeable in the system as well as costly. However, today's wind forecasts are so advanced that it is possible to estimate production with high certainty up to 36 hours prior to the actual production hour – although sometimes there are quite large prognosis errors that must be balanced up to and within the hour of operation. Another important thing is how the prognoses are used in the system operation. Every six hours the prognoses are updated due to new weather forecasts, and as the hour of operation approaches, the prognoses are also updated with real-time information. This way, system operation has as good knowledge of possible regulating power needs (originating from the wind power uncertainty). The power trading on the day-ahead market platform, Elspot, where power is traded from 12 hours and up to 36 hours ahead of delivery is further explained in the market chapter below.

KEY

Key points and recommendations from the Danish case:

- Reliable wind power forecasts help the TSO in the overall system operation and the integration of wind power.
- Forecasts should be regularly updated (e.g. every six hours)
- Forecasts should be linked to the market place and be an integrated part of the functioning of the market.
- The Danish case shown high certainty in forecasts and underline that they are an important tool for day-to-day and hour-to-hour planning and system operation.

FACT

Factsheet

Forecasting

The Danish TSO has developed a management and forecast system with an enhanced real-time monitoring of the grid including real-time estimates of wind power fed into it. To receive input into the system, the Danish TSO requires all plants greater than 10 MW of capacity to provide production data every five minutes.

The Danish system has focussed on strengthening forecasting to better plan system operation and day-ahead congestion management including the commitment and economic dispatch of controllable power plants, contingency analysis, the assessment of grid transfer capacity, and the need for regulating power. Over the past 20 years the Danish TSO has in cooperation with the power industry and universities developed its "Operational Planning System" tool for integrating forecasts of wind and CHP output including heat demand forecast into planning down to two hours ahead of the time of operation. The goal is to push this horizon up to a few minutes. This two-pronged management system combining its own estimates of wind power, small CHP output and demand with real-time monitoring of the grid enables the TSO to track the output of the entire range of power plants in the Danish system. In addition, the developed management system also provides the TSO with a picture of the power flows between the Danish and neighbouring grids including in Germany, Norway, and Sweden and thus facilitating balancing across a much larger area.

Before 2003, wind turbine owners had no responsibility to produce according to their forecasts. In 2003 this was changed and wind turbines were required to pay the costs of being out of balance (i.e., for producing more or less than what is forecast and sold in the day-ahead market). To compensate, wind farm operators can claim a refund on top of the feed-in premium, under the Promotion of Renewable Energy Act. Thus the operator of a wind farm has incentive to minimise the divergence from forecast output.

Technical Regulation

The technical regulations help ensure the physical operation of interconnected high-voltage grids and system security. Technical regulations consist of regulation concerning:

- Overall system description – dimensioning, load shedding requirements, system MVAr balance – (technical specification on reactive power), etc.
- Grid connection – system properties that plants must possess in order to be connected to the Danish public electricity supply network as well as the grid impacts plants must be able to withstand in order to continue to provide stable operation.
- Grid equipment – rules for the installation and operation of overhead lines, cables, substations, transformers, High Voltage Direct Current (HVDC) substations and the like, as well as protection, remote control and recording equipment.
- System operation – requirements to system operators, balance-responsible parties and TSO must act to ensure stable, reliable system operation. They include provisions on and procedures for system operation as well as requirements for the collaborating control centres.

Connection of large wind farms – in the Danish case primarily situated offshore – must fulfil the connection rules set by the TSO Energinet.dk (Technical Guidelines TG 3.2.5). The rules cover, among other things, the technical requirements that a wind farm must meet at the connection point (the transformer platform). These requirements deal with control capabilities, the output of reactive power, the ability to remain operational and to continue production when there is a grid outage, gradient limitation and the contents of operation agreements.

For further information please see: www.energinet.dk/EN/El/Forskrifter/Technical-regulations/Sider/default.aspx.

KEY

Key points and recommendations from the Danish case:

- Technical regulation must be in place in appropriate detail to ensure the physical grid functioning and system security.

Grid codes

A grid code is part of the technical regulations and defines the requirements to generation according to technology, size and point of connection.

The Nordel Grid Code, most recently updated in 2007, applies across the whole Nordic synchronous area. In addition, Denmark has its own requirements. The first version of a grid code for wind turbines in Denmark was put into force in 1999. Before this several technical specifications existed for the connection to the distribution network. Generally, these old specifications required wind turbines to disconnect from the grid during abnormal voltage and frequency events.

The new code from 1999 required wind turbines to remain connected and continue to deliver power to support the grid in case of fault. New wind turbines connected at high voltage level should also be controllable remotely so that they can be curtailed if necessary.

As 90% of wind turbines are connected at the medium voltage (60 kV) level and below, similar grid codes now also apply at that level. With the expected further development of more advanced wind power technology, wind turbines are likely to become better equipped in providing other ancillary services that would support and enhance the security of supply. The grid code has to be continuously revised to keep pace with the changing requirements of the power system

The Danish TSO has over the years managed to operate the system almost without curtailing the wind generators. In rare cases a national TSO demands a stop of turbines due to outage of elements in the grid (emergency situation). Curtailment of wind turbines by the TSO has until now only been ordered twice for 200-300 MW for 6-8 hours. It happened in 2010 and in 2008. In both cases due to outage of one of the strong interconnectors to the neighbouring countries. Since 2009 negative prices has been allowed at Nord Pool power exchange – Elspot, providing incentives to increase demand/decrease supply in hours of high supply of variable generation. The implementation of negative prices has significantly reduced the need for curtailment.

In order to harmonise the requirements within the European Union the association of European Transmission system operators ENTSO-E has now drafted a pan-european code for connection of generating facilities. During the next years the national requirements will gradually be harmonised against this common set of rules.

KEY

Key points and recommendations from the Danish case:

- Grid codes could be designed to require wind turbines to e.g.:
  - disconnect during abnormal voltage and frequenzy events
  - remain connected to the grid in case of fault
  - be controllable remotely
  - curtail if necessary.

FACT

Factsheet

Grid Codes

The grid code for wind defines e.g. the requirements to generation at variation in voltage level and frequency. In the point of connection a wind power plant (above 25 kW) must be able to withstand voltage drops down to 20% of the voltage in the point of connection over a period of minimum 0.5 seconds without disconnecting, as shown in the figure below.

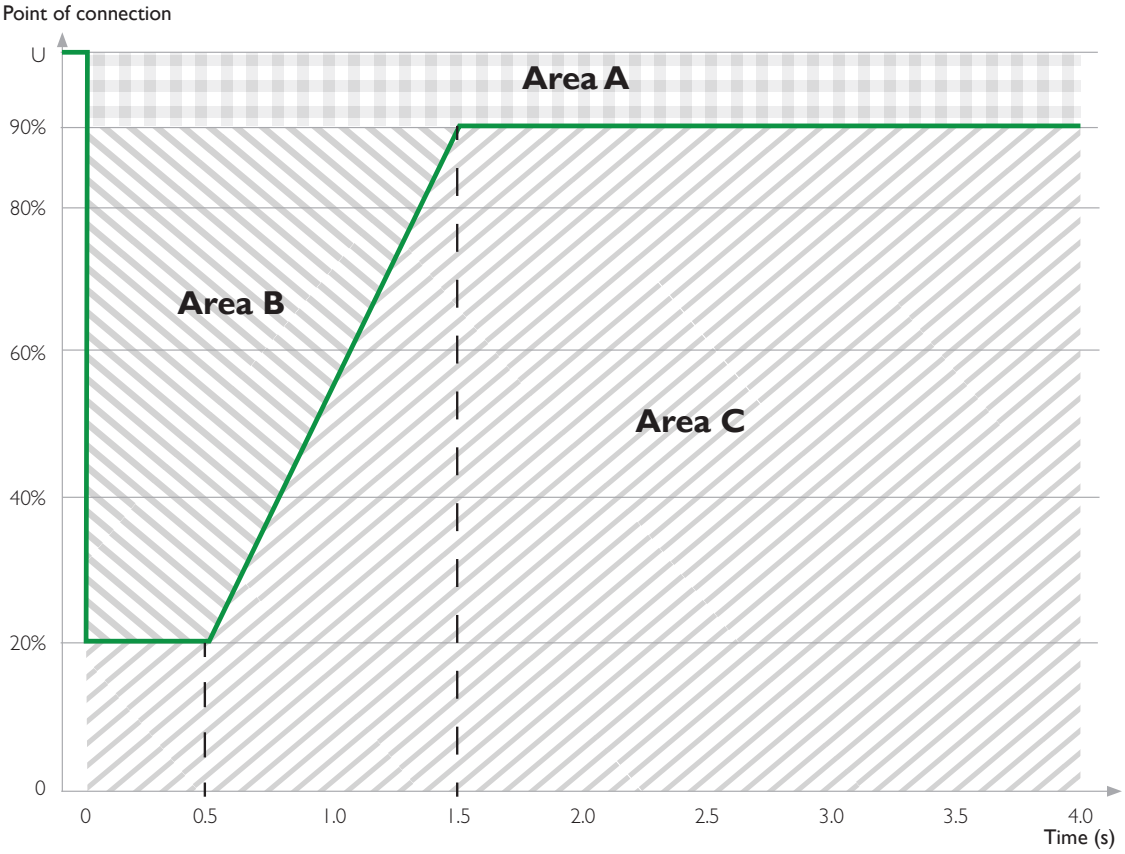


Figure 4: Operational requirements in Danish grid code issued by the Danish TSO for wind turbines above 25 kW – frequency and voltage span. Source: Energynet.dk Technical regulation 3.2.5 for wind power plants with a power output greater than 11 kW, 55986/10 (www.energinet.dk/EN/El/Forskrifter/Technical-regulations/Sider/Regulations-for-grid-connection.aspx)

Market

The Danish power market is an integral part of the Nordic whole sale power market. Trade on the wholesale market is put into effect via the power exchange Nord Pool, which facilitates trade between producers and traders. This section takes the point of departure in the Danish power market liberalisation and ownership unbundling.

The Nordic power market, Nord Pool was the world's first international power exchange. It has served as example for several other power exchanges now operating around the world. Every day large amounts of power are traded and transferred between the different market regions and countries in the Nord Pool market. The Nordic market ensures that generators produce according to price signals and merit order dispatch and thus brings down the cost of power to consumers. The market also improves security of supply.

In the Danish case the Nordic market makes is possible to export wind power at times with strong wind and subsequent low power prices. The variable wind power is spread across a wider area and thus counters the risk of having a sudden peak in production in a confined grid area and with little demand. The geographically larger market area should in itself make it possible to have larger amounts of wind power in all the Nordic countries – not primarily in Denmark as is the case today – as the strength of the wind is linked to low pressure areas usually moving from west to east. In other words when wind production is peaking in one area it is likely to be low in other areas and vice versa.

A market based operation of the power system has been a central element in Danish energy policy for more than a decade. The market consists of many important building blocks and aspects – all of which relevant for an effective and successful grid integration of wind power.

The Danish market design objective is to provide the use of the most efficient generating unit – the idea of merit order dispatch – to cover demand, minimise the need for balancing and utilise potential for flexibility in demand and production.

While wind turbines have relative high up-front investment costs, the marginal production cost for wind power is close to zero as there is no fuel cost. As the amount of wind energy in the grid literally fluctuates with the weather, there is more or less demand for production from other sources. This affects the supply curve and thus also equilibrium price, meaning that a situation with low wind projections gives a high price that incentivises other producers to produce more – and vice versa, if the there is a high projection of wind production. The Danish market model sends a strong incentive to power suppliers only to produce when it is profitable.

Liberalisation

Following the liberalisation many new players have entered the power market. Perhaps the most significant step towards the fully liberalised power market was taken in 1999 implementing an EU directive on full liberalisation of power markets. Entailed in the directive was an unbundling of the transmission grid from power generation.

The great advantage of a market based approach is that market forces in itself balances supply and demand through the price signal (a detailed description of the functioning of the Nordic power market is given in the fact sheet on exchange and trade). Furthermore, unbundling of generation and transmission companies ensures that transmission companies do not have commercial interest in the production capacity, and therefore provide fair and equal access to the market place (the grid) and cannot exploit the ownership of the transmission grid to exercise market power, or even have a disincentive to connect and transmit power from new generators.

Ownership unbundling between generation/supply companies and ownership and operation of the overall energy grid (the transmission grid) has in the Danish case made the power market a level playing field for all power producers.

KEY

Key points and recommendations from the Danish case:

- A liberalised market is recommendable as it balances supply and demand according to the merit order through the price signal.
- Unbundling of generation and transmission will ensure that transmission companies do not have commercial interests in the production side and thus eliminates associated market risks and creates a level playing field for all power producers.

FACT

Factsheet

Liberalisation and ownership

Danish policy makers decided to fully open up the Danish energy market to competition in the late 1990s and early 2000s as market forces through price signals were seen as an effective way of ensuring an economically efficient transition of the energy system. Before that the Danish energy market had been dominated by two vertically integrated power utilities (i.e. companies that own both the production and transmission side) that controlled the western and eastern part of the country's power market respectively.

The Danish decision to change policy was in line with the establishment of a single European market. Following up on the Single European Act of 1986 the European Commission given its mandate to promote European market integration, took the first steps in the mid-1990s to open up the national European energy markets to competition.

Focussing on vertically integrated energy monopolies as the main barrier towards an integrated single energy market the first energy market liberalisation package in the European Union was launched in 1996-1998 and followed by subsequent legislation in 2003 and 2008. The general idea of the initiative was to break up the energy monopolies and through this move to split the competitive (production, wholesale) from non-competitive activities (transmission). The aim was to stimulate competition and an efficient resource allocation and investment in cross-border interconnections across the EU.

In the Danish case a new wholly state owned TSO acting as a completely independent entity by law was established in 2004. The TSO is not allowed to have any commercial interest in generation. The entire power and gas transmission system is now owned by the TSO.

By law the mandate of the TSO is to ensure the stability of the transmission system and to facilitate and monitor the functioning of the energy market as well as to promote interconnections and the expansion of renewable energy. In other words the TSO must operate the system in a way that facilitates fair and equal competition among different production units.

Exchange and Trade – The Nordic power exchange – Nord Pool

In Denmark power can be traded both bilaterally between producers/traders and distribution companies/end-consumers/traders and via the Nordic power exchange. Denmark is part of the Nordic Power Exchange (Nord Pool), which is owned by the TSOs in the Nordic countries. It is a wholesale market where most of the power trading takes place. This system has eased integration of wind and reduced costs of buying power from abroad. The exchange serves as a cost efficient backup and balancing of the wind generation. The market is not regulated by Danish energy regulation.

Nord Pool has divided the Nordic market area into bidding areas linked with interconnectors operated by the TSOs. Denmark is divided into two bidding areas (east and west). One of the consequences of this is that all physical trading between areas must take place via Nord Pool. This is due to the fact that the power exchange is tasked with optimising the flow between several bidding areas in the Nordic market, taking capacity restrictions on the interconnectors into consideration. The day ahead spot market, Nord Pool uses implicit auction, which means that allocation of interconnector capacity trade of power is done simultaneously. When there is a lack of transfer capacity (congestion), the Nordic area is divided into various price areas (market splitting), which may consist of one or several bidding areas.

The power exchange has two market places for power, the day ahead Elspot and the intraday market Elbas.

Elspot is the core of the market – based on the auction principle – a so called day-ahead platform, where the bulk of power is traded, from 12 hours up to 36 hours ahead of delivery. Once a day Nord Pool will find a market price for the various price areas by matching purchase and sales bids. The price cross is fixed at noon the day before delivery. This timescale also fit to thermal plants, providing sufficient time to ramp production up or down. It also fits to the less predictable wind power production. When trading has closed on Elspot, it can continue through the intraday market, Elbas, with continuous trading up to 60 minutes ahead of delivery. In the Elbas market, players can trade themselves into balance when Elspot is closed. For activated bids from wind turbines the Elbas market can be used to balance deviations from forecasted generation.

The ability to trade close to real time for independent power producers such as wind power producers is an advantage as shorter forecasts naturally are much easier to predict.

The volume of power traded on Elbas only amounted to approximately 1% of exchange traded power in 2011. This low figure gives credit to mainly the well-functioning market but also the advanced forecasting in the market and especially the Danish wind forecasting. It is not as easy as it may seem to forecast wind power generation 36 hours ahead with high certainty.

In order to ensure a sustainable physical balance in the power system the Danish TSO needs regulating power and various types of reserve capacity. The regulating power market operates up to 15 minutes before delivery. This is not part of the Nord Pool exchange.

Regulating power is production capacity or consumption offered by the market players to the TSO during the actual day of operation. In principle, the balance responsible player forwards bids for upward and downward regulation stating the volume offered (MW) and the price of activating the power (price/MWh). No matter whether the necessity to regulate power occurs in Denmark or in any other Nordic country, the Danish TSO will always be responsible for activating the Danish regulating bids. When it is necessary to up regulate, the TSO buys the volume needed from the balance responsible party who has forwarded the up regulating bids placed at the lowest price. Regulating power and balancing power are usually priced at marginal prices.

Offers to provide additional power or reduction in consumption are made directly to the Danish TSO, which passes them on to the Nordic Operational Information System, along with offers from the other TSOs. Providers of short-term flexibility – which includes consumers who can offer to reduce their consumption – can be shared over the whole Nordic area because of the Nordic Operational Information System.

These three markets provide considerable ability for producers, retailers, and consumers to calibrate and recalibrate their trades in the face of the increasing variability and uncertainty resulting from a larger wind power share.

The Danish retail market – or end users' market – has been fully liberalised since 2003. This means that Danish power consumers have the right to choose from whom they want to buy.

The Danish TSO is responsible for ensuring a well-functioning power retail market. This means that the TSO initiates or participates in work which has the purpose of ensuring that power consumers are offered better products, prices or conditions on the power market. Furthermore, the TSO is responsible for establishing the rules applying to the retail market.

KEY

Key points and recommendations from the Danish case:

- An effective market place reduces power production and system operation costs.
- A large market area allows for greater integration of wind power.

FACT

Factsheet

Exchange and trade

It is important to be aware that the market principle is a way to arrange the power trade and system balancing – it does not change the way electricity is flowing in the grid. The nature of electricity and electromagnetic physics is the same, no matter economic and institutional regulation of the sector.

The exchange of power across the Nordic power market has been facilitated by the deregulation of the Nordic market around 2000. With deregulation cross border tariffs were removed and the integrated spot market exchange, Nord Pool was created.

The power price is determined by the balance between supply and demand. Factors such as the weather or power plants not producing to their full capacity can impact how much power can be transported through the grid and will therefore influence the price of power. This is called 'transmission capacity'. While the price of power is determined according to supply and demand, it also becomes clear where there are issues in the grid when the price of power goes up. This makes it easier to identify where production or capacity is lacking, as there is too high demand compared to production supply.

Variations in price can develop in the different bidding areas of the Nordic Market, which result from transmission bottlenecks. When this occurs, the system operator – through the day-ahead market – will buy electricity in the cheaper area and sell it in the more expensive area, causing power to flow from the low price area toward the high price area, at the same time reducing the price difference between them. Approximately 75% of all Scandinavian electricity is traded in Nord Pool.

The figure below show in the top – that the farther away from the production hour the larger the sales volume is – as the operating hour approaches the volume in power sales decreases. Conversely the value of the market price per MWh increases the closer the trade approaches the operating hour as indicated in the bottom of the figure.

Hourly power contracts for physical delivery during the next 24-hour period are traded in the day-ahead spot market (Nord Pool Spot) owned jointly by the Nordic TSOs. It is on the spot market that the market price is settled for every hour and for every regional area. At the spot market the TSOs defines the physical trading possibilities by announcing the possible transfer between the different areas. Members of the spot market are commercial traders and producers.

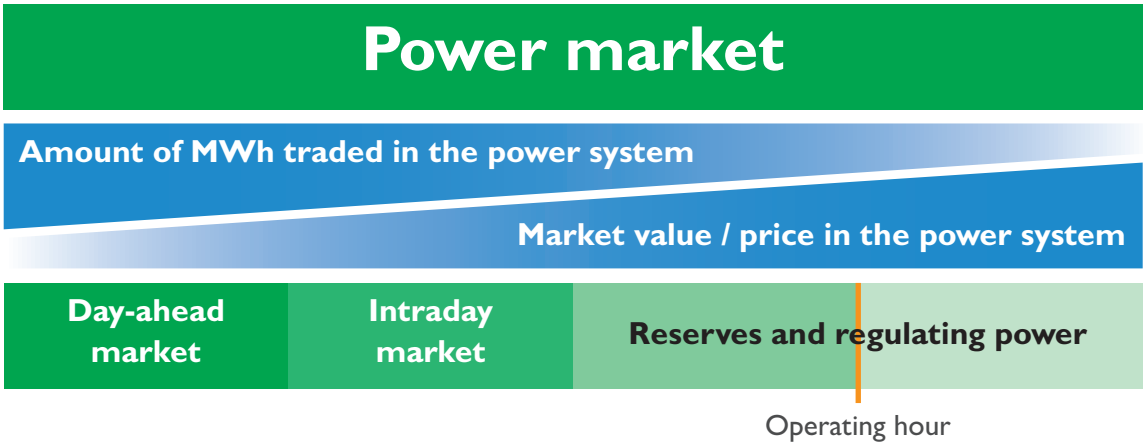


Figure 5: Source: Energynet.dk (www.energinet.dk/EN/El/Engrosmarked/Viden-om-engrosmarkedet/Sider/Viden-om-engrosmarkedet.aspx)

The spot market trade is followed by a second market the ELBAS (Electricity Balance Adjustment System) which is a cross border intraday market where electricity is traded up to one hour before delivery. ELBAS is a system where adjustments to the committed day-ahead market are made continuously. The main objective is to enable the participants to fulfil their obligations as committed in the spot market settlement before the TSOs force them to do so in the national balancing markets. Available Transmission Capacity (ATC) is allocated by the various TSOs after the day-ahead auction at the spot market, and it is automatically updated after each ELBAS trade. ELBAS provides direct access to counterparts from the entire Nord pool area and Germany and recently also from Belgium and the Netherlands.

The balance responsible is able to adjust purchase and sale up to one hour before the hour of operation. One hour before operation all settlements are fixed.

Reserve capacity is production capacity or consumption offered in advance by the balance responsible parties to the TSO's disposal in return for an availability payment. The Danish TSO buys various types of reserve capacity; these types of capacity differ with respect to response rate etc. The term "ancillary service" is a general term for the reserve capacity bought by the TSO in order to ensure a reliable and efficient operation of the electricity system.

All power stations with available capacity participate in the Nordic electricity market on a continuous basis. They state how much extra power they can produce at a given time and at what price. Furthermore they state how much of their planned production they can stop at short notice, if a power surplus should arise. By combining online readings from all wind generators with statistical calculations, forecasts can be adjusted to make deviations manageable.

For the purpose of physical balancing of the national electricity systems in the hour of operation the TSOs buy regulation reserves on the regulating power market which is a third market following the spot market and the intra-day market – ELBAS. The market establishes a price for both upward and downward regulation. The price is based on the spot price with a premium for increased production and a deduction for reduced production. This means that a generator selected in the regulating power market receives more than the spot price if it is demanded to increase production and if demanded to reduce generation it receives a payment for the part they do not produce. Consumption can also be used for upward and downward balancing. With the regulating power market each TSO is able to cope with deviations from forecasted balance between supply and demand. After activation of regulation up or down, the balance is usually met within a band of few MWs. Remaining minor imbalances are managed by automatic frequency reserves paid for in a separate regime between the TSO and the generators having the ability. This would normally in Denmark be large conventional power units – typically fired by coal, natural gas or biomass.

Example

A balancing responsible sells electricity on the market from wind turbines. The generation forecast the morning on the day before the hour of operation is 110 MWh and this amount is sold on the spot market. But due to changes in the weather forecasting the balance responsible adjust the generation down to 100 MWh after the spot market is closed. Since 10 MWh now is missing to comply with the committed sales 10 MWh is purchased from a generator in the ELBAS market. The balance responsible is now responsible to supply 100 MWh. One hour before the hour of operation all contracts are fixed. But just before the hour of operation the wind is declining further and real generation is only 95 MWh. The TSO is settling the final balancing by activating bids on the regulating power market, follows the development in generation and activates up regulation by 5 MWh. Up regulation is more expensive than the spot price. Since the financial contracts are closed one hour before the hour of operation the balancing responsible receives payment for the 100 MWh sold on the market. But the balancing responsible sold only 95 MWh and has to pay the TSO for the 5 MWh not delivered. The price for these 5 MWh is higher than the spot price and incurs a (minor) loss for the balancing responsible stakeholder not being able to fulfil original commitments.

Legal framework of the power market

When large quantities of wind power are produced and hence prices are low, flexible consumption, such as large heat pumps and heating elements at decentralised heat and power plants, can play a constructive, price equalising role. With more than 55% of the net energy demand for heating being supplied from district heating systems, Denmark has one of the highest shares of district heating in the world. This fact has given Denmark a unique opportunity to increase the efficiency of power and heat production by using combined heat and power (CHP) plants for the production.

The increasing share of renewables in the Danish power market have made it necessary with ever more detailed and comprehensive technical demands and standards for the power accessing the transmission and distribution grids, including – of course – power generated by wind turbines.

FACT

Factsheet with references to the legal framework applied to the Danish power market

Key legislation related to renewable energy is: Act on promotion of renewable energy consolidated act 1074/2011), Act on Electricity Supply (consolidated act 279/2012), Act on the Danish TSO (consolidated act 224/2009).

English translations of previous versions of the legislation are available at www.ens.dk/EN-US/INFO/LEGISLATION/ENERGY_SUPPLY/Sider/Forside.aspx.

There are for each of the acts issued a number of ordinances. The two most important in this context are: Ordinance on grid connection of wind turbines 1063/2010, Ordinance on system operation and use of transmission grid 891/2011.

The Danish TSO who is responsible for operation of the electricity system has issued a number of regulations to be complied with for electricity generation equipment. They are all online and can be accessed via www.energinet.dk/EN/El/Forskrifter/Sider/default.aspx.

The Danish TSO has issued a set of market regulation which functions as guidelines that are necessary in order to ensure that the electricity market functions properly and that settlement is performed correctly. The market regulations deal with issues such as terms and conditions for change of supplier, daily handling of notifications, balance settlement and standards governing the transfer of data between players. The market regulations consist of 12 independent regulations with associated appendices. For details see: www.energinet.dk/EN/El/Forskrifter/Markedsforskrifter/Sider/default.aspx.

Key messages

This energy policy toolkit has presented the Danish case and experiences and lessons learned on integrating increasing shares of wind power into the power grid with the aim of making them available to growth economies and developing countries.

The policy tools and measures in the Danish case and the related opportunities and barriers are not unique to Denmark. The tools and measures may, when adjusted to specific national circumstances, be applied by all countries that are about to integrate variable power sources, such as wind power, into the overall power grid and system.

Integration of variable renewables into the grid is sometimes and misleadingly presented as an insurmountable task. The Danish case proves this wrong. Not only is an effective and cost-efficient integration of wind power feasible, it can also improve energy security through diversification of the energy mix and through decentralisation and geographic scattering of power generators.

Central and long-term planning has been one of the trademarks of the Danish case and has ensured timely and relevant investments in the power grid and system. Thus the grid and system have been developed incrementally in order to make them more adapt to handle the steadily increase in wind power production.

Today the strategic planning of future grid investments follow the current political energy agreement with adopted measures and policies toward 2020 as well as the Danish long-term goal of full conversion to renewable energy in 2050. Naturally such future benchmarks give guidance on the appropriate and cost-efficient transition of the power grid and system from being based on traditional fossil fuels and toward a steadily greater renewable energy base.

The main and overall messages from the Danish case on integrating wind power into the grid are the following:

- Ambitious targets, long-term planning and strong and stable political framework conditions can pave the way for significant private investments by creating a positive and secure long-term investment climate.
- Strong and independent TSOs are vital to a successful system integration of wind power.
- A well-functioning market such as the Nordic power exchange Nord Pool ensures a transparent and cost-efficient transfer of power from areas with high production and low demand to areas with low production and high demand. This, naturally, provides power producers with a clear incentive to adapt production to the market signals.
- Unbundling of generation and transmission creates a level playing field for all power producers.
- Interconnectors to neighbouring countries or to a wider grid area that allow surplus energy to be easily transferred from one area to another help increase the security of supply.
- Technical demands and specifications such as grid codes for wind power can ease the integration of wind power into the wider grid and power system.
- Advanced forecasting can help the TSOs in the operation of the wider power system including possible activation of regulating power generators.

These messages should be seen in continuation of the key points and recommendations presented throughout the policy toolkit. It is the aim to further expand and qualify these key points and recommendations in order to provide the best guidance possible to countries that wish to learn more about how to tackle the integration of wind power into the grid most appropriately.

LCTU
Low Carbon Transition Unit

Energy Policy Toolkit on

System Integration of Wind Power

Experiences from Denmark

This is one of a series of energy policy toolkits by the Danish Low Carbon Transition Unit providing specific, technical and concrete information on Danish experiences and measures and results in promoting renewable energy and energy efficiency, targeting practitioners, governmental energy experts and policy makers.

The Low Carbon Transition Unit can also offer to engage in assessing the measures and policies from the Danish case under specific country circumstances through cooperation with countries and in the form of workshops and seminars.

Comments to this policy toolkit as well as queries on the Low Carbon Transition Unit are most welcome. The idea is to further refine recommendations according to identified needs in growth economies and developing countries.

Comments to this paper as well as queries on the Low Carbon Transition Unit are most welcome and may be directed to:

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For more information on the Low Carbon Transition Unit please visit www.ens.dk/LCTU

DANISH ENERGY AGENCY