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On wind power integration into electrical power system: Spain vs. Denmark

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Introduction

There is an increasing demand for the integration of non-conventional generation units in the electrical power systems in order to reduce the economical dependence of fossil fuels and to contribute to a more sustainable and more efficient power system. These new non-conventional technologies are based on renewable sources and they are usually dispersed over the territory. Thus, they are mostly considered distributed generation (DG). Moreover, renewable resources have natural variations. Then, their integration in power systems has not only a number of technical challenges, but also economic and regulatory to meet with the targets of security of supply, in terms of reliability, availability and power quality.

Wind Power integration

The current integration level of DG in EU is important. In Denmark, DG supplies 40% of the electricity demand and installed DG capacity in Spain is also high, close to 25%. Therefore, there is a shift from the traditional centralized operation and control of power systems to a decentralization, which arises a number of challenges. Nowadays, wind power is the most non-conventional generation technology spread over Europe, with almost 70% of world wind power capacity installed in 2005, and its penetration is increasing over the world. However, wind power provides less than 3% of the European power needs.

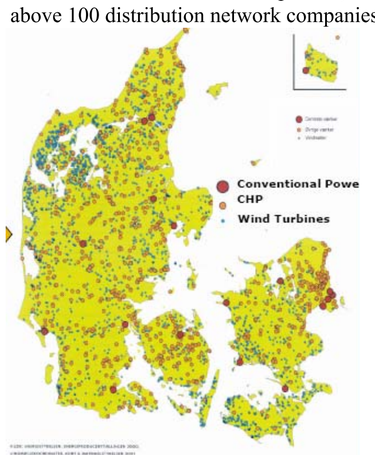
There are a number of issues about wind power integration which is also reflected in the technical grid codes requirements and regulations which vary considerably from country to country. Here, it is pointed out some of the different considerations on wind power integration according to network and operation and control, focusing in the existing differences between the two countries with large scale power penetration in the final power production, Denmark and Spain.

Denmark holds the world record of electricity consumption generated by wind power, 20% in 2005, although it is the third European country and the fifth in the world with 3,1 GW wind power installed. It is the core of global wind power development because the creation of a cluster around wind power where manufacturers, suppliers, research and educational institutions combine knowledge and expertise to innovate and advance in wind technology. By way of illustration, approximately half of the installed 40.000 MW globally in 2005 are turbines produced by Danish manufacturers.

Wind power in Spain represents the second position in installed wind power in 2005, both in Europe and the world, with 10 GW. And it is also the second in electricity consumption generated by wind power with 8%, but far from Denmark.

Danish Power System

It is electrically divided into two areas, with different size and non-synchronous, which means there are managed differently. A HVDC link will connect these two grids by the year 2009. Since 2005 Energinet.dk is the only Danish transmission network operator, as well as for natural gas, and it belongs to the state. However, there are above 100 distribution network companies.



Danish power plants. Source: Energinet.dk

- WESTERN DENMARK (Jutland and Funen)

It forms part of the continental European synchronous area UCTE. Transmission grid is operated at 400 kV with a combination of ring connections and radial structure, and 150 kV with as a parallel grid. It is connected to the UCTE synchronous area through German border via 400 kV, 220 kV and 150 kV AC lines (1200 import/800 export MW).
It is also connected to the Nordel synchronous area, which includes Sweden, Norway and Finland, via HVDC links to Norway (1000 MW) and Sweden (720 MW), which makes possible the exchange of energy without being synchronized.
The most common distribution voltage levels are 60, 20 and 15 kV, although it is possible to find 10 kV.
Western Denmark total interconnection capacity is 2920 (import)/2530 (export) MW, which represents about 40% of the power capacity at this area and 75% of the maximum demand.
The winter peak demand is 3.800 MW and in summer, the minimum demand is 1.200 MW.
The installed power capacity is 7400 MW.

- EASTERN DENMARK (Zealand)

It represents a part of another synchronous area, the Nordel. The Eastern transmission network is composed by a 400 kV radial grid and a 132 kV ring connected grid. It is connected to Sweden via AC lines (1700 import/1300 export MW) and through HVDC connection to Germany (600 MW).
The current distribution voltage levels are 132 kV, 50 kV and 30 kV.
Total interconnection capacity is 2300/1900 MW, which is also around 40% of its generation and 85% of the maximum demand.
The winter peak demand is 2.700 MW and, the minimum demand is 1.000 MW in summer.
The installed power capacity is 5350 MW.

Generation mix

Denmark has around 6000 power generation units that can be classified in three types:

- Centralized thermal power stations: 7400 MW; that use mainly coal and located on 15 special sites and are operated for primary control.
- Combined Heat and Power (CHP) units: 2200 MW; that typically use natural gas, waste and biomass. They are operated decentralized and are around 700 generators, including industrial and local plants.
- Wind turbines: 3150 MW; that are spread over all Denmark, decentralized operated and they are approximately 5000 units.

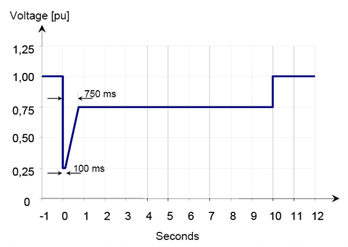
No centralized generation is mostly connected to the distribution network in Western area while in the Eastern the situation turns round because Copenhaguen. The power control centre only can organize the network over 100 kV and the non-dispatchable generation units are beyond this centralized control.

Future power supply

Denmark has a long-term energy strategy, called “Energy 21” plan, since 1996. The plan establish that the utilization of renewable energy in Denmark will have to rise from a level around 8% by that day to 12-14% by 2005 and 35% by the year 2030. Western Denmark has already exceeded its target for 2005 in 1500 MW.

Grid code

Wind turbines have to reference grid codes, depending on they are connected to transmission network, *TF 3.2.5 Wind turbines connected to grids with voltages above 100 kV* (Energinet, 2005) or to distribution network, *TF 3.2.6 Wind turbines connected to grids with voltages below 100 kV (*Energinet, 2004).



Ride-through capabilitiy front 3-phase short-circuit. Source: Danish grid code for wind turbines connected to grids with voltages below 100 kV.

Regulation

Danish electricity market is a free market since 2003.

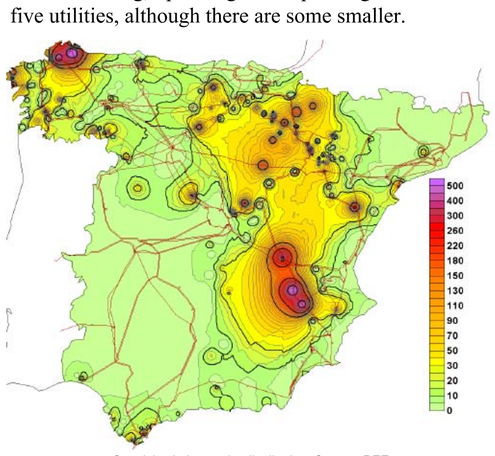
Denmark has given a wide range of incentives for renewables, and particularly, for wind energy. The subsidies depend on when the turbine has been connected and its age.

Off-shore

Denmark has two off-shore facilities: Horns Rev 160 MW and Nysted 158 MW. They that are operated like traditional power plant and then, connected to the transmission grid.

Spanish Power System

Spanish network has two different kinds of power systems mainly because geographical reasons. Red Eléctrica de España (REE) is responsible for secure and reliable operation of the power system, as well functioning energy market and for owning, operating and expanding the transmission infrastructure for electricity. Distribution is concentrated in five utilities, although there are some smaller.



Spanish wind capacity distribution. Source: REE

- BULK POWER SYSTEM (the Peninsula)

It forms part of the UCTE. The transmission system is composed by a meshed network of 400 and 220 kV facilities. It is connected to the UCTE through France border via 400 and 220 kV AC lines (1400 MW maximum).
Spanish system allows that Portugal also forms part of UCTE with connections at 400 and 220 kV (2100 MW maximum). Moreover, Spain is also connected to Morocco through a submarine 400 kV AC line (400 MW), which permits the synchronous operation between the north of Africa and Europe.
Some areas have a high voltage distribution network at 132 and 110 kV that are partially meshed and are used as a kind of sub-transmission network. The range of distribution voltage levels is wide: 66, 45, 30, 25, 20, and 11 kV.
The winter peak demand in Spain is 43.400 MW. Nowadays, the peak demand in summer is also important, around 38.500 MW. The minimum demand is 19.000 MW.
On windy days, wind power has reached up to 20% of power production but special regime can not provide all the energy needed..

- WEAK POWER SYSTEMS (Canary and Balearic Islands)

Canary Islands have six small power systems; almost each of the Canary Islands represents one. There is only an electrical connection between two of the islands through 66 kV AC line. The interconnection between the rests is currently impossible due to the big sea depths. As well, only the two biggest islands have a small transmission network at 220 kV and 66 kV is used as transmission grid.
On the other hand, some of the Balearic Islands are connected via submarine 110 or 30 kV AC lines and the whole main islands while be connected at 110 kV by the year 2007. Moreover, Balearic power system is planned to be connected by a High Voltage Direct Current (HVDC) link to the peninsula by the year 2009. The transmission network in the Balearic Islands is 220 kV, but 132 and 66 kV is also considered such a part of transmission grid in this case and they are largely meshed.

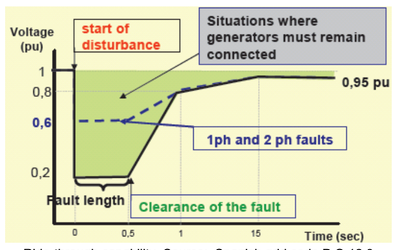
Generation mix

Generation, as distribution networks, are concentrated in five main utilities. By way of illustration, 60% of wind power belongs to them. Spanish generation power plants are divided in two big groups:

- Ordinary regime that includes the centralized power plants thermal units fuelled by natural gas (12.224 MW), coal (11.424 MW), uranium (7.876 MW) or oil (6.647 MW). Hydro power (16.657 MW) is included in this group.
- Special regime (19.142 MW) that includes non-conventional generation and can be considered as a distributed generation. It comprises both non renewable (6.645 MW) and renewable (12.497 MW), like wind power (9.800 MW). Wind power is placed all around Spain but like a wind farms. And special regime generation units are mostly connected to transmission or high-voltage distribution levels, that is, above 100 kV.

Future power supply

Spanish energy plan is “Plan de Fomento de las Energías Renovables 2000-2010”. The targets are set up in 12% of total energy demand and 30% of electricity production to be covered by renewable energy. Particularly, for wind power is expected a power capacity over 20.000 MW, which is expected it will represent 13,5 % of total generated electricity.



Ride-through capability. Source: Spanish grid code P.O.12.3 approved 20 October 2006

Grid code

Wind turbines connected to transmission level have to deal with the both operation procedures of grid code for transmission *P.O. 12.1 Soluciones de acceso para la conexión de nuevas instalaciones a la red de transporte* and *FP.O. 12.2 Instalaciones conectadas a la red de transporte: requisitos mínimos de diseño, equipamiento funcionamiento y seguridad y puesta en servicio* (MITYC, 2005).
Wind turbines connected to distribution level have to cope with the *RD 436/2004 Metodología para la actualización y sistematización del régimen jurídico y económico de la actividad de producción de energía eléctrica en régimen especial* (MITYC , 2004).

Grid code

The transition of Spanish electricity market to a free market began at 1998 and finished in 2000.
Spain has given a wide range of incentives for special regime generation units. These generators less than 50 MW have two choices to sell the energy: regulated price or pool price plus subsidies and premiums. Special regime units larger than 50 MW have only energy market as an option. For wind energy subsidies depend on the power and the age.

Differences

- Distributed generation (CHP and wind power) can reach 100% Danish Western demand on load demand days. However, wind power has only reach 20% of Spanish demand without important problems for the operation of the grid.
- There has been a pool price reduction with increased wind power production in Spain. This reduction is higher than the increase of balancing costs.
- International connections are used according to bilateral agreements and market. Then, some connections can export more import or viceversa.
- Refurbished or repowered for new turbines to meet ride-through requirement in front of faults.
- Danish subsidies for wind energy depend on when the turbine has been connected and its age while in Spain depends on the power and the age.
- Danish energy strategy is based on a long-term plan while Spanish is a short-term plan.
- Spanish transmission grid operator only worries about electrical power system.

Conclusion

The significant expansion of wind energy requires solving a series of technical and economic questions. This paper has point out the features of Danish and Spanish experience regarding wind power and power systems. Denmark shows that it is possible to operate properly a network with a high wind power penetration. A cluster where manufacturers, suppliers, research and educational can meet and work together and a long-term energy plan are key points.

It should be mentioned that further analysis in each fact for is required. Determining the best technical and economical alternatives require an assessment of each situation. Denmark can be a point of reference to achieve some of the Spanish targets, not only regarding wind power but also for the development of future power systems.