Chapter 1

Introduction

Wind energy is one of the most important energy resources on earth. It is generated by the unequal heat of the planet surface by the sun. In fact, 2 per cent of the energy coming from the sun is converted into wind energy. That is about 50 to 100 times more than the energy converted into biomass by plants.

Several scientific analyses have proven wind energy as a huge and well distributed resource throughout the five continents. In this way, the European Environment Agency in one of its technical reports evaluating the European wind potential [1], estimates that this potential will reach 70.000TWh by 2020 and 75.000TWh by 2030, out of which 12.200TWh will be economically competitive potential by 2020. This amount of energy is enough to supply three times the electricity consumption predicted for this year (2020). The same study also evaluates the scenario in 2030 when the economically competitive potential increases to 200TWh, seven times the electricity consumption predicted for this year (2030).

Today electricity from wind provides a substantial share of total electricity production in only a handful of Member States (see Figure 1.1), but its importance is increasing. One of the reasons for this increment is the reliability of this energy resource, which has been proven from the experience in Denmark. In this country 24% of the total energy production in 2010 was wind-based and the Danish government has planned to increase this percentage to 50% by 2030.

Following Denmark, the countries with the highest penetration of wind power in electricity consumption are: Portugal (14.8%), Spain (14.4%) and Ireland (10.1%)

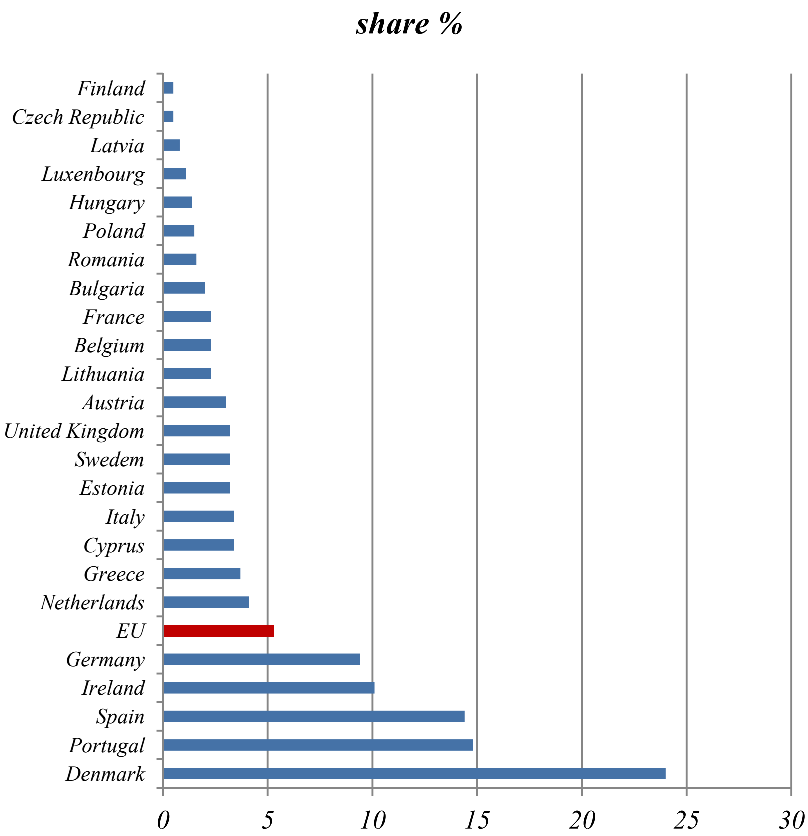


Figure 1.1 Wind share of total electricity consumption in 2010 by country [2].

This spectacular growth of the wind power share in the electricity consumption is supported in the new installed wind power capacity. In this way, more than 40% of all new electricity generation capacity added to the European grid in 2007 was wind-based [4]. However, this year was not an exception, wind power is been the fastest growing generation technology except for natural gas in the decade (2000-2010), see Figure 1.2.

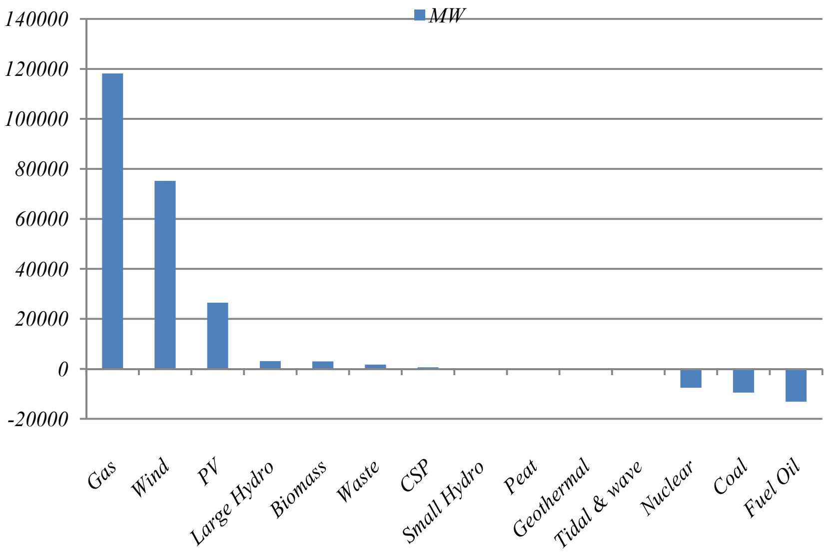


Figure 1.2 Net changes in the EU installed capacity 2000-2010 [2].

The considered scenario used by the European Union for the Second Strategic Energy Review [5] suggests that wind will represent more than one third of all electricity production from renewable energy sources by 2020 and almost 40% by 2030, representing an accumulated investment of at least 200-300 billion Euros (or about a quarter of all power plant investments) by 2030.

Due to the fast growth of the onshore wind energy exposed before, in many countries the best places to build a wind farm onshore are already in use, so in the future of this technology, offshore wind power is destined to have an important role. Because, offshore wind energy can be the way to meet the objectives of the new Energy Policy for Europe since it's an indigenous resource for electricity production, as well as clean and renewable.

Offshore wind can and must make a substantial contribution to meeting all three key objectives of EU's energy policy: Reducing greenhouse gas emissions, ensuring safety of supply and improving EU competitiveness in a sector in which European businesses are global leaders.

Nowadays, offshore wind energy is emerging and installation offshore wind farms at sea will become increasingly important. 430 MW of offshore wind power capacity were installed in 2009, the 4% of all the installed wind energy capacity. But, with 1107 MW of new installed capacity, 2010 was a record-breaking year for offshore wind power.

This trend is not only an issue of the last two years, offshore capacity has been gradually increasing since 2005 and in 2010 it represents around the 10% of all new wind power installations, see Figure 1.3.

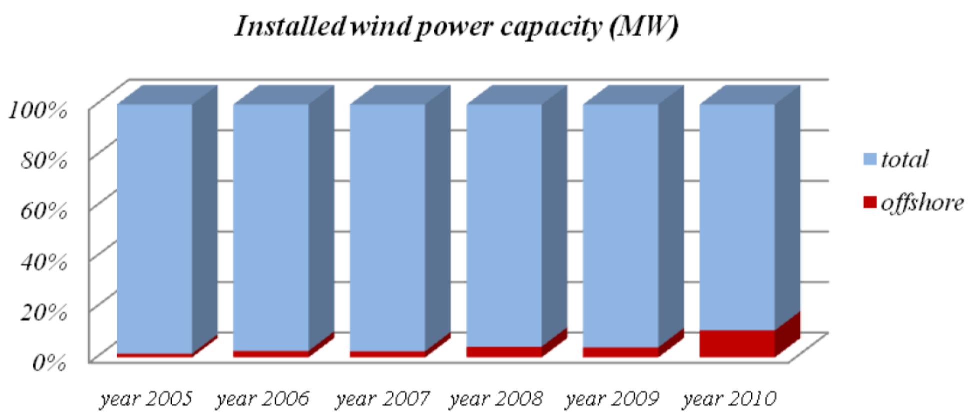


Figure 1.3 Offshore wind power share of total installed wind power capacity [2].

Furthermore, this energy resource will cover a huge share of the electricity demand, since the exploitable potential by 2020 is likely to be some 30-40 times the installed capacity in 2010 (2.94 GW) , and in the 2030 time horizon it could be up to 150 GW (see Figure 1.4), or some 575 TWh [5].

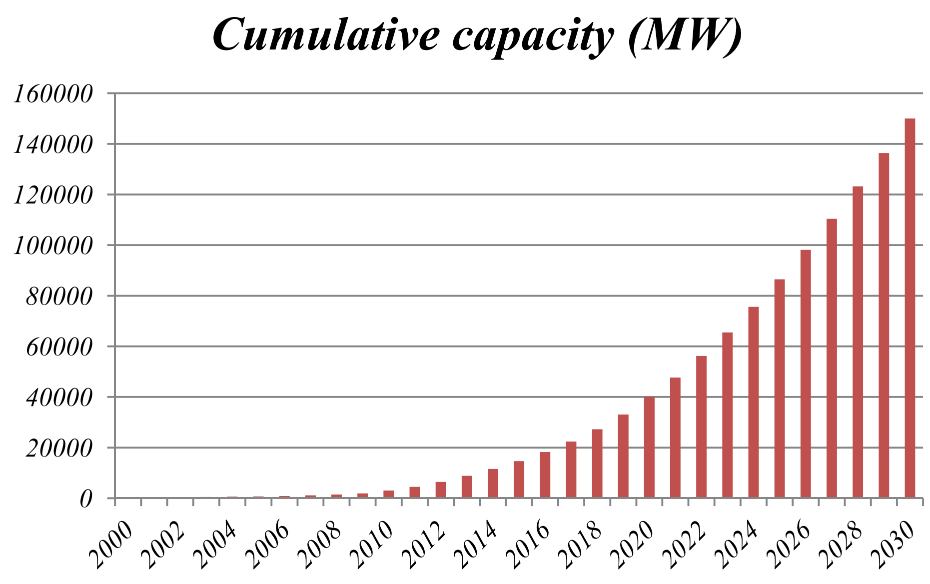


Figure 1.4 Estimation for offshore wind power capacity evolution 2000-2030 [3].

Wind energy is now firmly established as a mature technology for electricity generation and an indigenous resource for electricity production with a vast potential that remains largely untapped, especially offshore.

Thus, the EU is pushing a stable and favorable framework to promote offshore wind farms and renewable energy in general. To this end, it is implementing plans such as the third internal energy market package of October 2007 [6] or the energy and climate package presented in January 2008 [7].

Supported in this favorable framework, Europe has become the world leader in offshore wind power, especially United Kingdom and Denmark. The first offshore wind farm was being installed in Denmark in 1991 and in 2010 the United Kingdom has by far the largest capacity of offshore wind farms with 1.3 GW, around 40% of the world total capacity.

As regards of the rest of the countries of the union, only nine countries have offshore wind farms and most of them located in the North Sea, Irish sea and Baltic sea, Table 1.1.

Country	*Cumulative capacity (MW)*	*Installed capacity 2010 (MW)*
Belgium	*195*	*165*
Denmark	*853.7*	*207*
Finland	*26.3*	*2.3*
Germany	*92*	*80*
Ireland	*25.2*	*-*
Netherlands	*246.8*	*-*
Norway	*2.3*	*-*
Sweden	*163.7*	*-*
United kingdom	*1341.2*	*652.8*
TOTAL	*2946.2*	*1107.1*

Table 1.1 Offshore wind cumulative and installed capacity in 2010 by country

Nevertheless, offshore wind is not only an issue of the mentioned three seas in the European Union. In the south for example, Italy has planned around 4199.6 MW distributed in 11 wind farm projects for the upcoming years. French republic has also planned 3443,5 MW and three additional projects in the Mediterranean sea.

In the same way, the Iberian Peninsula is no exception to the growth and development of offshore energy. Offshore wind farms with 4466 MW total rated power are planned for the upcoming years, This means that the Iberian Peninsula has planned four times the offshore power in Europe in 2008. Even Croatia (392 MW) and Albania (539 MW) have planned offshore wind farms [8].

Furthermore, in the south/center of the European Union, there are two wind farms under construction one in Italy (90 MW, Tricase) and another one in France (105 MW, cote d'Albatre) located in the English channel.

As a result of these efforts, EU companies are leading the development of this technology in the world: Siemens and Vestas are the leading turbine suppliers for offshore wind power and DONG Energy, Vattenfall and E.ON are the leading offshore operators.

This evolution of the wind farms from onshore to offshore have led to some technological challenges, such as the energy transmission system or energy integration in the main grid.

Onshore wind farms have adjusted their characteristics well to the size and features of each wind farm as a result of the huge experience in this field. But for offshore, there are only a few built wind farm examples and the energy transmission is through submarine cables, so the definition of the most suitable layout is still an open discussion.

Offshore wind farms must be provided with reliable and efficient electrical connection and transmission system, in order to fulfill the grid code requirements. Nowadays, there are many and very different alternatives for the offshore wind farms transmission system configurations.

This is because the main difference in the transmission system between onshore wind farms and offshore wind farms is the cable used. Offshore wind farms need submarine cables. That present a high shunt capacitance in comparison to overhead lines [9]. The capacitive charging currents increase the overall current of the cable and thus reduce the power transfer capability of the cable (which is thermally limited).

Due to the spectacular growth of wind energy, many countries have modified their grid codes for wind farms or wind turbines requiring more capabilities. Some countries have specific grid codes referring to wind turbine/farm connections, such as Denmark, Germany or Ireland. The great majority of these countries have their grid code requirements oriented towards three key aspects: Power quality, reactive power control and Low Voltage Ride Through (LVRT).

The new grid code requirements are pushing new propositions in fields like power control, power filters or reactive power compensation, with new control strategies and components for the transmission system in order to integrate energy into the main grid.

These propositions have strong variations depending on the grid codes and the different kind of transmission systems such as: Medium Voltage Alter Current (MVAC) configurations or High Voltage Direct Current (HVDC) configurations.

For onshore wind farms, depending on the size and location features, their characteristics are well adjusted. However, for offshore wind farms the definition of the most suitable layout is still an open discussion.

The objective of this book is to contribute to this open discussion analyzing the key issues of the offshore wind farm's energy transmission and grid integration infrastructure. But, for this purpose, the objective is not the evaluation of all the electric configurations. The aim of the present book is to evaluate a representative case.

The definition of the electric connection infrastructure, starting from three generic characteristics of an offshore wind farm: the rated power of the wind farm, the distance to shore and the average wind speed of the location. In this way, it is possible to identify the problematic aspects of the energy transmission and grid integration based on this representative specific case.

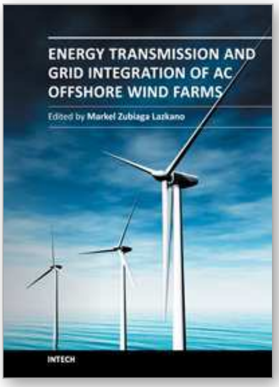
In short, the development of an evaluation and simulation methodology to define the most suitable layout depending on the size and location of each wind farm, as for the onshore wind farms. This pre-design has to be suitable to connect to a distribution grid. Therefore, it has to fulfill the grid code requirements.

To accomplish this goal, this book contributes to the better knowledge of the nature, the causes and the problematic aspects of the electric connection infrastructure. The following key issues are evaluated.

- Submarine cable modeling options and the accuracy of those models.
- The influence of the main components of the offshore wind farm in its frequency response is analyzed, to help avoiding harmonic problems in the offshore wind farm at the pre-design stage.
- Transient over-voltage problems in the electric infrastructure of the offshore wind farms are characterized, more specifically, transient over-voltages caused by switching actions and voltage dips at the PCC.

Then, based on those evaluations of the key issues of the electric connection infrastructure, several solutions to fulfill the grid codes are proposed and tested via simulation:

- The management of the reactive power through the submarine power cable is evaluated and dimensioned for a specific case.
- The passive filters are dimensioned for the considered specific case. Furthermore, the most suitable location for these filters is analyzed (onshore / offshore).
- The auxiliary equipment to protect the offshore wind farm upon switching actions and fault clearances are discussed.
- The auxiliary equipment to fulfill the grid codes during voltage dips at the PCC are dimensioned.



Energy Transmission and Grid Integration of AC Offshore Wind Farms

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ISBN 978-953-51-0368-4
Hard cover, 248 pages
Publisher InTech
Published online 21, March, 2012
Published in print edition March, 2012

This book analyses the key issues of the offshore wind farm's energy transmission and grid integration infrastructure. But, for this purpose, there are not evaluated all the electric configurations. In the present book is deeply evaluated a representative case. This representative case is built starting from three generic characteristics of an offshore wind farm: the rated power, the distance to shore and the average wind speed of the location. Thus, after a brief description of concepts related to wind power and several subsea cable modeling options, an offshore wind farm is modeled and its parameters defined to use as a base case. Upon this base case, several analyses of the key aspects of the connection infrastructure are performed. The first aspect to analyze is the management of the reactive power flowing through the submarine cable. Then, the undesired harmonic amplifications in the offshore wind farms due to the resonances and after this, transient over-voltage problems in the electric infrastructure are characterized. Finally, an offshore wind farm connection infrastructure is proposed in order to achieve the grid code requirements for a specific system operator, but not as a close solution, as a result of a methodology based on analyses and simulations to define the most suitable layout depending on the size and location of each offshore wind farm.

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