Renewable Energy 63 (2014) 125–132

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Technical note

Uncertainties in the design of support structures and foundations for offshore wind turbines

Vicente Negro*, José-Santos López-Gutiérrez, M. Dolores Esteban, Clara Matutano

Universidad Politécnica de Madrid, C/Profesor Aranguren S/N, 28040 Madrid, Spain

ARTICLE INFO

Article history:
Received 25 May 2013
Accepted 23 August 2013
Available online 28 September 2013

Keywords:
Offshore wind farms
Monopiles
Gravity based structures
Technical standards
Technical recommendations

ABSTRACT

Offshore wind industry has exponentially grown in the last years. Despite this growth, there are still many uncertainties in this field. This paper analyzes some current uncertainties in the offshore wind market, with the aim of going one step further in the development of this sector. To do this, some already identified uncertainties compromising offshore wind farm structural design have been identified and described in the paper. Examples of these identified uncertainties are the design of the transition piece and the difficulties for the soil properties characterization.

Furthermore, this paper deals with other uncertainties not identified yet due to the limited experience in the sector. To do that, current and most used offshore wind standards and recommendations related to the design of foundation and support structures (IEC 61400-1, 2005; IEC 61400-3, 2009; DNV-OS-J101, Design of Offshore Wind Turbine, 2013 and Rules and Guidelines Germanischer Lloyd, WindEnergie, 2005) have been analyzed. These new identified uncertainties are related to the lifetime and return period, loads combination, scour phenomenon and its protection, Morison – Froude Krilov and diffraction regimes, wave theory, different scale and liquefaction.

In fact, there are a lot of improvements to make in this field. Some of them are mentioned in this paper, but the future experience in the matter will make it possible to detect more issues to be solved and improved.

1. Introduction

Offshore wind market has exponentially grown in the last years (see Fig. 1). According to statistical studies from the European Wind Energy Association (EWEA), 1166 megawatts (MWs) were installed in 2012, 33% more installed MWs than in 2011. Thus, there are currently 4995 MWs installed in 55 offshore wind farms in 10 European countries [1].

This growth, supported through different European Union Framework Programs, has its origin in the approach of ambitious challenges reached year after year in the last decade. Thus, the number of MWs installed has increased over time due to several factors such as the construction of more powerful wind turbine generators or the installation of a high number of wind turbines in each farm. These have been accomplished by greater depths, the improvement in foundation design and their scour protection systems, or the increased investment to connect wind farms to the grid.

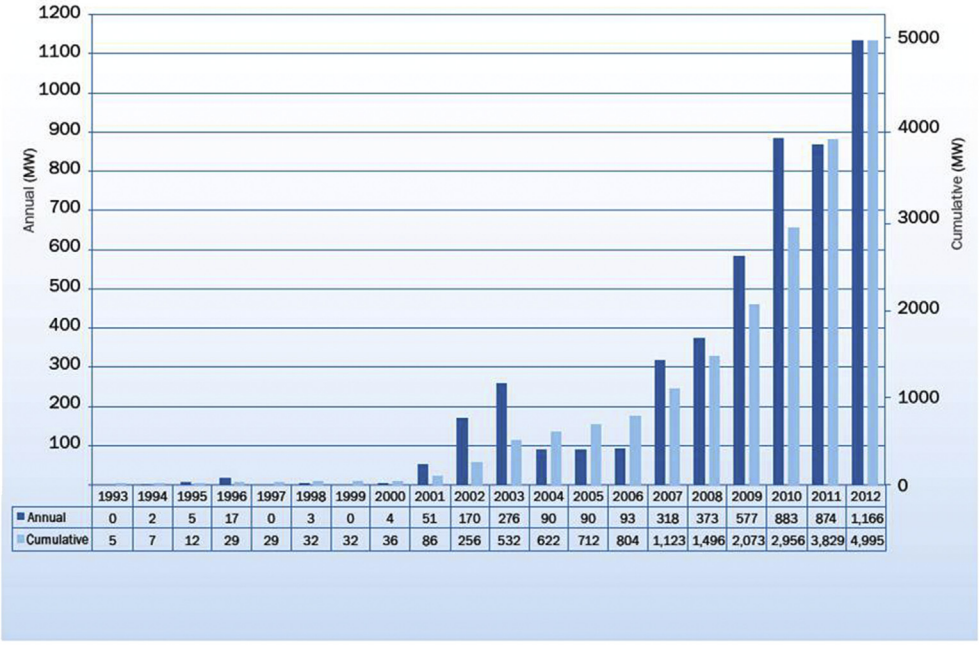
However, despite this growth, there are still many uncertainties in the offshore wind energy industry [2]. These uncertainties can be due to a lack of experience. Some of these uncertainties are related to foundation design: loads combination and return period, scour phenomenon characterization under combined waves and currents actions, scour protection design, soil-structure interaction, wave loads determination, soil properties, transition piece design, different scales, etc.

This paper analyzes some current uncertainties in the offshore wind market, with the aim of going one step further in the development of this sector. To do this, some already identified uncertainties compromising offshore wind farm structural design have been identified and described in the paper. Furthermore, this paper deals with other uncertainties not identified yet due to the limited experience in the sector.

In fact, according to the study methodology conducted during the research, the paper begins identifying different requirements influencing the design of the foundations. Later, identified uncertainties for offshore wind foundation design are listed, and doubts and solutions are exposed according the current situation of the market. On the other hand, due to the limited experience in the

* Corresponding author.
E-mail address: vicente.negro@upm.es (V. Negro).

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.08.041



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Annual	0	2	5	17	0	3	0	4	51	170	276	90	90	93	318	373	577	883	874	1,166
Cumulative	5	7	12	29	29	32	32	36	86	256	532	622	712	804	1,123	1,496	2,073	2,956	3,829	4,995

Country	UK	DK	BE	DE	NL	SE	FI	IE	NO	PT	Total
No. of farms	20	12	2	6	4	6	2	1	1	1	55
No. of turbines	870	416	91	68	124	75	9	7	1	1	1,662
Capacity installed (MW)	2,947.9	921	379.5	280.3	246.8	163.7	26.3	25.2	2.3	2	4,995

Fig. 1. Cumulative and annual offshore wind installations [1].

sector, some uncertainties have not been identified yet; these will be discussed in the paper with the aim of achieving an adequate and sustainable growth of the offshore wind technology.

2. Design requirements

The design of foundations and support structures of a wind turbine generator is very complex (Fig. 2 clarifies the meaning of "foundation" and "support structure" to be used along the paper). This implies taking into account numerous factors. Firstly, the different loads to consider for the structural design: wind turbine generator weight and loads due to the wind action, wave and current loads, operation and maintenance loads, etc. Also it is essential to consider terrain conditions and its main properties, construction and operation issues, and so on. The effect of all these issues, among others, makes the design of these structures very complex the design. However, there are some international recommendations and standards focused on this.

In force and current recommendations and standards for support structures and foundations design, with more relevance and use in the offshore wind industry, are the following ones:

- IEC 61400-1, 2005 [3].
- IEC 61400-3, 2009 [4].
- DNV-OS-J101, Design of Offshore Wind Turbine, 2013 [5]
- Guideline for the Certification of Offshore Wind Turbine, 2005 [6].

This paper is not intended as a critique of the before mentioned recommendations and standards, but some comments and contributions are given to help for improvements in the matter.

3. Existing uncertainties

Over the past 20 years, the rapid growth of offshore wind sector has been associated with the need to improve the design requirements present in offshore wind farms. To improve the design of these structures, it is necessary to know in depth the response of the foundations to the requests of external agents, their response to the fatigue during the operation phase, and the main characteristics of the seabed in which they are located. Therefore, nowadays there are still many uncertainties that question the design requirements used so far.

One of the most discussed uncertainties in the sector is the transition piece issue. The transition piece provides the connection between the support structure and the wind turbine generator. It represents the main weakness of the monopile foundation concept. The transition piece is jointed to the monopile using grouting to transfer all the loads and forces from the wind turbine tower through the transition piece down to the support structure.

Due to the wind and waves dynamic loads, grouting inside the transition piece crumbles (see Fig. 3). In many cases, there are not any clear solutions for this, but nowadays it is common to refill these pieces with new grout, to complete the connection with shear keys or to use conical instead of tubular sections (see Fig. 4).

On the other hand, soil condition is a key issue for the foundations design. A detailed knowledge of the nature and composition of the seabed remains a complicated and expensive task that requires a large investment in carrying out the design of foundations present in offshore wind farms.

In order to reduce costs, the characterization of the seabed in the area where a wind farm will be installed is usually done through a limited number of samples. Given the scarce number of samples taken, and assuming the non-homogeneity of the seabed in most