Renewable Energy 66 (2014) 41–48

Contents lists available at ScienceDirect

Renewable Energy

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

Life-cycle cost analysis of floating offshore wind farms

Castro-Santos Laura*, Diaz-Casas Vicente [1]

Department of Naval and Oceanic Engineering, Integrated Group for Engineering Research, University of A Coruña, C/Mendizábal, 15403 Ferrol, A Coruña, Spain

ARTICLE INFO

Article history:
Received 8 April 2013
Accepted 2 December 2013
Available online 17 December 2013

Keywords:
Cost breakdown structure (CBS)
Floating offshore wind farm
Marine renewable energy
Life-cycle cost

ABSTRACT

The purpose of this article is to put forward a methodology in order to evaluate the Cost Breakdown Structure (CBS) of a Floating Offshore Wind Farm (FOWF). In this paper CBS is evaluated linked to Life-Cycle Cost System (LCS) and taking into account each of the phases of the FOWF life cycle. In this sense, six phases will be defined: definition, design, manufacturing, installation, exploitation and dismantling. Each and every one of these costs can be subdivided into different sub-costs in order to obtain the key variables that run the life-cycle cost. In addition, three different floating platforms will be considered: semisubmersible, Tensioned Leg Platform (TLP) and spar. Several types of results will be analysed according to each type of floating platform considered: the percentage of the costs, the value of the cost of each phase of the life-cycle and the value of the total cost in each point of the coast. The results obtained allow us to become conscious of what the most important costs are and minimize them, which is one of the most important contributions nowadays. It will be useful to improve the competitiveness of floating wind farms in the future.

1. Introduction

The development of new energy sources is necessary to sustain our current lifestyle. This occurs due to the fact that fossil fuels have a limited life span [1]. Hence, the use of renewable energies, the use of which is unlimited, will be of utter importance. Moreover, in 2009 the European Union (EU) has established that 20% of final energy consumption should come from renewable sources in 2020 [2].

In relation to renewable energies, the future will be directed toward its use in the marine environment. In this sense, offshore wind will make a substantial contribution to meeting the EU's energy policy requirements through a sharp increase – in the order of 30–40 times by 2020 and 100 times by 2030 – in installed capacity compared to present day. Otherwise, the distance to the shore and the depth are the main constraints in this technology. Thus, the next step is to develop floating structures, which can operate in deep waters. In this context, two different floating platforms prototypes have already been installed: spar substructure called Hywind in Norway and the WindFloat semisubmersible platform in Portugal [3].

However, one of the most important difficulties in the development of a new technology is the absence of procedures which allow us to evaluate the costs of the floating structures [4]. In this sense, there is an approximation to the cost of a spar system which describes the general costs, but which has not taken into account the relationships between variables [5]. Furthermore, other studies are focused on technical or theoretical aspects [6]. Considering that the availability of knowledge in relation to floating wind farms is scarce, cost experiences of fixed offshore wind energy or onshore wind energy [7] can be used as a starting point, being useful to determine tariffs in the future [8].

Therefore, the main objective of this article is to become aware of what the main costs are involved in a floating offshore wind farm and which are the fundamental variables involved in each phase of their life cycle. In addition, three different floating platforms will be considered: semisubmersible, Tensioned Leg Platform (TLP) and spar. Results allow us to be conscious of what the most important costs are and minimize them in the future improving the competitiveness of floating wind farms.

2. Methodology

The study of the life-cycle can be considered in several ways: the economic [9], the environmental [10], among others. Nevertheless, the methodology used for the present analysis is based on the Cost Breakdown Structure (CBS), which is part of the life-cycle cost system of the floating offshore wind farm [11]. CBS defines the main costs and sub-costs taking into account the disaggregation of the process.

* Corresponding author. Tel.: +34 981337400x3890.
E-mail addresses: laura.castro.santos@udc.es (C.-S. Laura), vicente.diaz.casas@udc.es (D.-C. Vicente).
[1] Tel.: +34 981337400x3857.

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.12.002

Firstly, the main phases in the process of the floating offshore wind farm are defined. Thus, the total Life-Cycle Cost System (LCS) of a Floating Offshore Wind Farm (FOWF) is decomposed in the costs of each of the main phases of the process: definition cost ($C1$), design cost ($C2$), manufacturing cost ($C3$), installation cost ($C4$), exploitation cost ($C5$) and dismantling cost ($C6$). Therefore the LCS can be formulated as [12]:

$$LCS_{FOWF} = C1 + C2 + C3 + C4 + C5 + C6 \quad (1)$$

However, in order to obtain their main dependences, each of these costs can be subdivided in the correspondent sub-costs which will be analysed separately in the following steps.

Finally, the LCS_{FOWF} will be applied to the particular case of the Galician coast (North-West of Spain). For this purpose, a tool has been developed in order to obtain the maps of the costs in this region. The application of this resource to the three most typical floating platforms will give an approximation of which of the three are more cost-effective [13]. There is multi-criteria decision-making in order to select the most important floating offshore wind platforms. They are based on cost and technical challenges as to minimize the induced motion, design the wind turbine, improve the coupling between the floating platform and the wind turbine or the installation and O&M process [14]. In this sense, the three floating platforms most cost-effective: the semisubmersible, the Tensioned Leg Platform (TLP) and the spar.

3. Calculation of the total cost

3.1. Definition phase

The definition phase is composed by all the preliminary studies needed to carry out the floating offshore wind farm as, for instance, the economic viability of the project, the environmental and wind resource studies which indicate the best exploitation area, etc. In this sense, the definition cost ($C1$) will be composed of three main sub-costs [15]: market study cost ($C11$), legislative factors cost ($C12$) and farm design cost ($C13$), as is shown in Fig. 1. In this sense, the legislative factors considered will be the social and environmental impact surveys and the authorization for the farm installation. Furthermore, the farm design cost is composed by the study of the offshore wind resource, the sea conditions and the geotechnical characteristics of the seabed.

Considering all the sub-costs explained, the main dependences in definition cost are the number of wind turbines (NWT) and the power of each wind turbine (PWT) [13]. Although other parameters, such as depth, wind resource or geotechnical conditions, can be taken into consideration, they will be excluded from the $C1$ formulae because of the lack of data.

$$C1 = f(\mathrm{NWT}, \mathrm{PWT}) \quad (2)$$

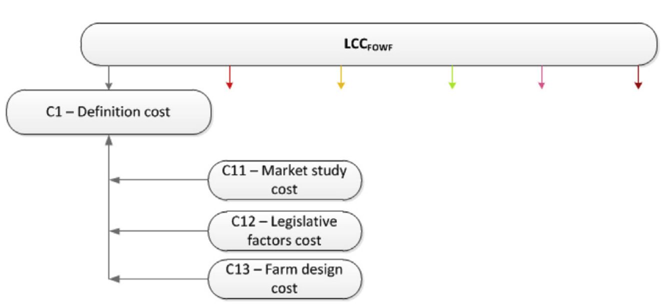

Fig. 1. Definition cost.

3.2. Design phase

The economic viability calculated in the definition phase will determine if the rest of the stages will be carried out. Therefore, if this study has positive results, the design will be the next phase. In this sense, the design phase will focus on the costs of the management and the engineering of the real floating wind farm designed, as Fig. 2 shows. It includes, for instance, the calculation of the distance between wind turbines and lines of wind turbines, the number of wind turbines of the farm depending on the population or the industry consumption, the dimensioning of the electric cables and substation, the calculation of the mass of the mooring and anchoring, etc. Furthermore, although in the present study the floating platform and the wind turbine dimensions have been considered as fixed, the design phase can also include these calculations in other studies.

The main dependences in relation to design cost also are the number of wind turbines and the power of each wind turbine involved:

$$C2 = f(\mathrm{NWT}, \mathrm{PWT}) \quad (3)$$

3.3. Manufacturing phase

The manufacturing phase involves the fabrication of each of the components in a floating wind farm: wind turbines manufacturing ($C31$), floating platforms manufacturing ($C32$), mooring manufacturing ($C33$), anchoring manufacturing ($C34$) and electrical component manufacturing ($C35$), Fig. 3.

Wind turbine manufacturing cost is made up of the cost of the rotor, tower and nacelle of each wind turbine installed in the offshore wind farm.

Moreover, costs related to platforms, mooring or anchoring have two sub-costs which depend on the type of platform involved. In this sense, two different sub-structures will be considered: wind turbine platforms and basic platforms (substation platforms, whose number will be dependent on the power of the offshore wind farm, and accommodation platform). Their cost will be calculated taking into account their construction in a shipyard and their certification cost. In terms of the electrical components manufacturing, there also are two different sub-costs: electrical cable manufacturing cost ($C351$) and substation manufacturing cost ($C352$).

Wind turbines manufacturing cost depends on the number of wind turbines (NWT) [16], the power of each wind turbine (PWT) and the cost per MW of turbine (C_{MW}) [17]:

$$C31 = f(\mathrm{NWT}, \mathrm{PWT}, C_{MW}) \quad (4)$$

However, platforms construction is the most outstanding cost in terms of manufacturing [5]. To evaluate its value an Activity-Based Cost (ABC) method has been used. It distributes direct labour [18], material [19] and activity costs [20] of the platforms taking into

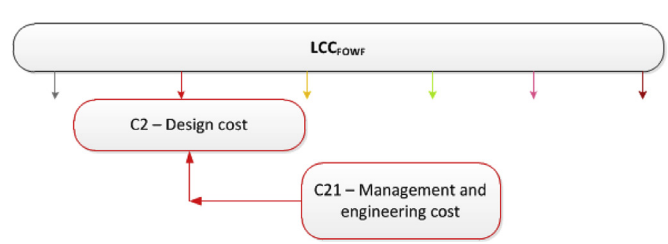

Fig. 2. Design cost.