PARAMETERS INDEPENDENT ON THE TYPE OF FLOATING OFFSHORE WIND PLATFORM

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ABSTRACT:

The main developments in offshore wind power are focused on wind turbines with foundations on seabed. However, there exist important limitations for installing these structures exist in places with high depth within short distance from the coast.

This means that the progress of offshore wind energy around the world is tied to the development of safety and low cost floating platforms for renewable energy offshore devices .

Therefore, the first aim of this paper is to know which alternatives exist for a floating offshore wind farm establishment and design parameters are independent or dependent of platform configuration. In order to evaluate each alternative, the request inversion for each configuration has been analysed.

From this point of view, the conclusion is that a string configuration for the electrical network is better than a star configuration. With regard to maintenance, it would be better to have a proper vessel only if the number of trips is more than three.

Keywords:
Offshore, energy, floating, wind turbine.

RESUMEN:

Los principales avances en la energía eólica marina se centran aerogeneradores cimentados en los fondos marinos. Sin embargo, existen importantes limitaciones para la instalación de estas estructuras, en lugares en los que se alcanza una elevada profundidad a poca distancia de la costa.

Esto significa que el progreso de la energía eólica marina en todo el mundo está ligado al desarrollo de plataformas flotantes para dispositivos de energía renovable en alta mar seguras y de bajo coste flotantes

Por lo tanto, el primer objetivo de este trabajo es conocer qué alternativas existen para un establecimiento flotante de energía eólica marina y los parámetros de diseño son independientes o dependientes de la configuración de la plataforma. Con el fin de evaluar cada alternativa, para cada configuración se ha analizado la solicitud de inversión.

Desde este punto de vista, la conclusión es que una configuración en cadena para la red eléctrica es mejor que una configuración de estrella. Con respecto al mantenimiento, sería mejor tener un buque propio, sólo si el número de viajes es más de tres.

Palabras clave:
Offshore, energía, flotante, aerogenerador.

1.- INTRODUCTION

Nowadays the European energy framework is constrained by the mandatory regulations on Climatic Change, like the *Kyoto Protocol*, and by the dependence from foreign fossil fuels producers. In order to reduce the emissions of greenhouse gases and increase its independence from fossil fuels producers, European Union (EU) established in 2009 that 20% of final energy consumption should be from renewable sources in 2020 [1].

Due to the reduced available locations and the environmental constrains for inland renewable energies, marine renewable energies will increase its presence in the European energy framework. In this sense, offshore wind will make a substantial contribution to meeting the EU’s energy policy objectives through a very significant increase – in the order of 30 – 40 times by 2020 and 100 times by 2030 – in installed capacity compared to today [2].

Therefore, offshore wind farms are becoming one of the most significant source of renewable energy. The technological constrains for the current designs are the distance to shore and depth. These designs are restricted to operate at 100 metres depth, however much of the regions with the highest available energy request to operate deeper. Thus, the next step is developing floating structures that can operate in deep waters.

One of the most important difficulties of these systems is the absence of references to evaluate the costs of these structures in a preliminary design phase. Due to tariff constraints [3] [4], economic profitability is drastically conditioned by each technical solution. In this sense, considering knowledge of floating wind farms is short, some approximations for cost evaluation of fixed offshore wind energy [5] [6] or onshore wind energy [7]have been proposed.

The design of these facilities is based on oil&gas industry; however the safety and economical design principia are totally different. Therefore, specific design criteria should be defined in order to choose any technical alternative.
Therefore, the main objective of this article is to know which are the main parameters involved in a floating offshore wind farm and which are involved in each phase of their life cycle. Results allow us to be conscious about what the most important costs are and minimize them in the future for the improvement of the competitiveness of floating wind farms.

2.- MATERIALS & METHODS

2.1.- DESIGN PARAMETERS

The costs for offshore wind generation have indeed been significantly higher throughout than for onshore wind farms, although recent technological improvements in the size and design of turbine technology and, in general, more efficient production patterns, may have the potential to narrow this gap.

Just as discussed earlier in this work, the main objective of this article is to know which are the main parameters involved in a floating offshore wind farm and which are involved in each phase of their life cycle

In order to analyse the economic effects of the design parameter, that affects the wind farms design, they have been separated into two groups:

- **Parameters dependent on the general features of the farm**. Such as power generated, turbine typology, etc..
- **Parameters dependent on configuration alternatives of the farm**.

This paper will be focused on the parameters that are dependent on configuration alternatives of the farm. In addition to this, two types of those parameters will be defined:

- **Parameters independent on the type of floating platform**.
- **Parameters dependent on the type of platform**.

This paper will explain only **design parameters that are independent of the type of floating platform** chosen.

Through the study of the whole lifecycle of the process of a floating offshore wind farm three types of these design parameters have been defined:

- Farm Configuration: depending on the type of electrical network.
- Installation: in relation with the type of vessel used for transport and installation of the floating platform.
- Maintenance: taking into account the required level of exigency.

Each one them will now be analysed separately.
A general explanation of each of these alternatives is shown in:

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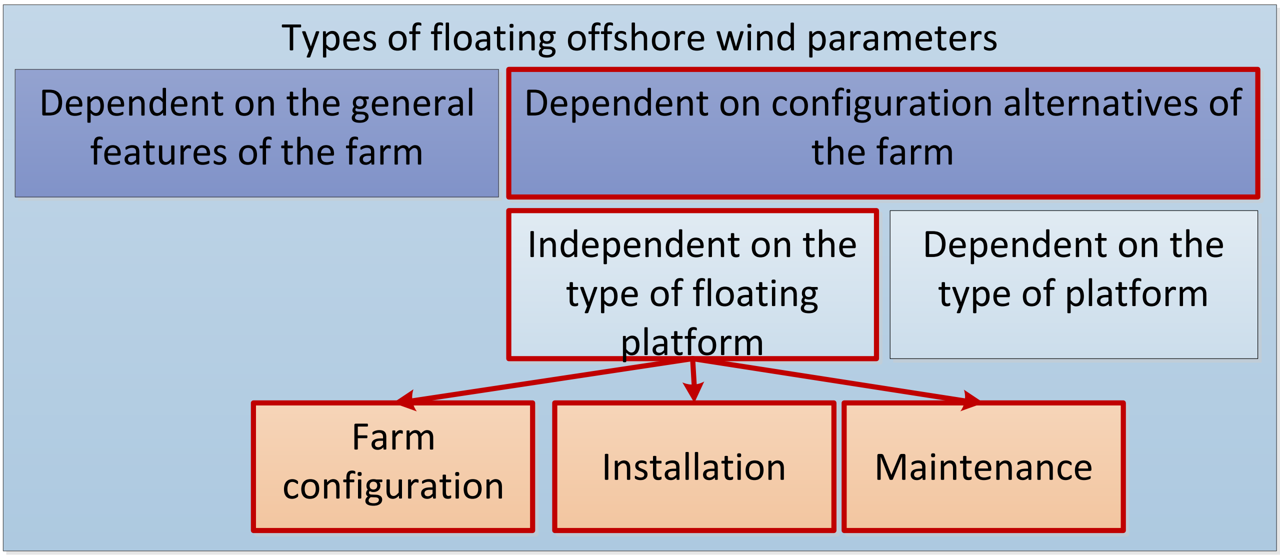

Figure 1.. – General schema

2.1.1.- Farm configuration. Electrical network

An important technological complexity is added by the electrical evacuation of the offshore farm, due to the deep water placement.

The electrical connection system for an offshore wind farm can be divided into the offshore collection system and the transmission link to the shore.

The offshore collection system collects power from the offshore wind farm. Each wind turbine in an offshore wind farm is connected the internal grid via star or string configuration (two basic types of electrical connection settings).
From the offshore collection point, the transmission link to the shore can be HVAC, HVDC with thyristor-based line commutated converters (LCC), or VSC-HVDC. HVAC connection is the solution adopted by all existing wind farms.

In general, there are two basic types of electrical connection settings [8]:

- **String connection.** In this configuration, number of wind turbine generators connects radially with each other and supply power to the feeder. In string cluster configuration, each wind turbine has its own step up transformer which adapts the feeder or collector platform voltage.
- **Star connection.** In this configuration, each turbine is connected directly to the platform where step up transformer exists. In star cluster configuration, no individual transformer exists for wind turbine so multiple collector platforms with transformers and switchgears are required.

There are also two types of string connection. The principal differences between them are the power of the cable used and the quantity of it. Type 1 uses only 100 MW cable. However, Type 2 uses 100 MW and 5 MW.
Internal cabling (or internal line) is the cable which joins the turbines to the substation and the connection point of the park (Those are lines of 5MW).
The evacuation line, (generally, high voltage lines) connects the offshore connection point with the ground connection point (Those are 100 MW lines).
The connection point from where the evacuation line to ground usually is a substation in which the transformers are located. To this grid connection point is where the line evacuation of 100 MW comes.
On the other hand, star connection can be of two basic types, depending on how the wiring has been joined.
A general schema of these types of electrical connections is shown in the following figure:

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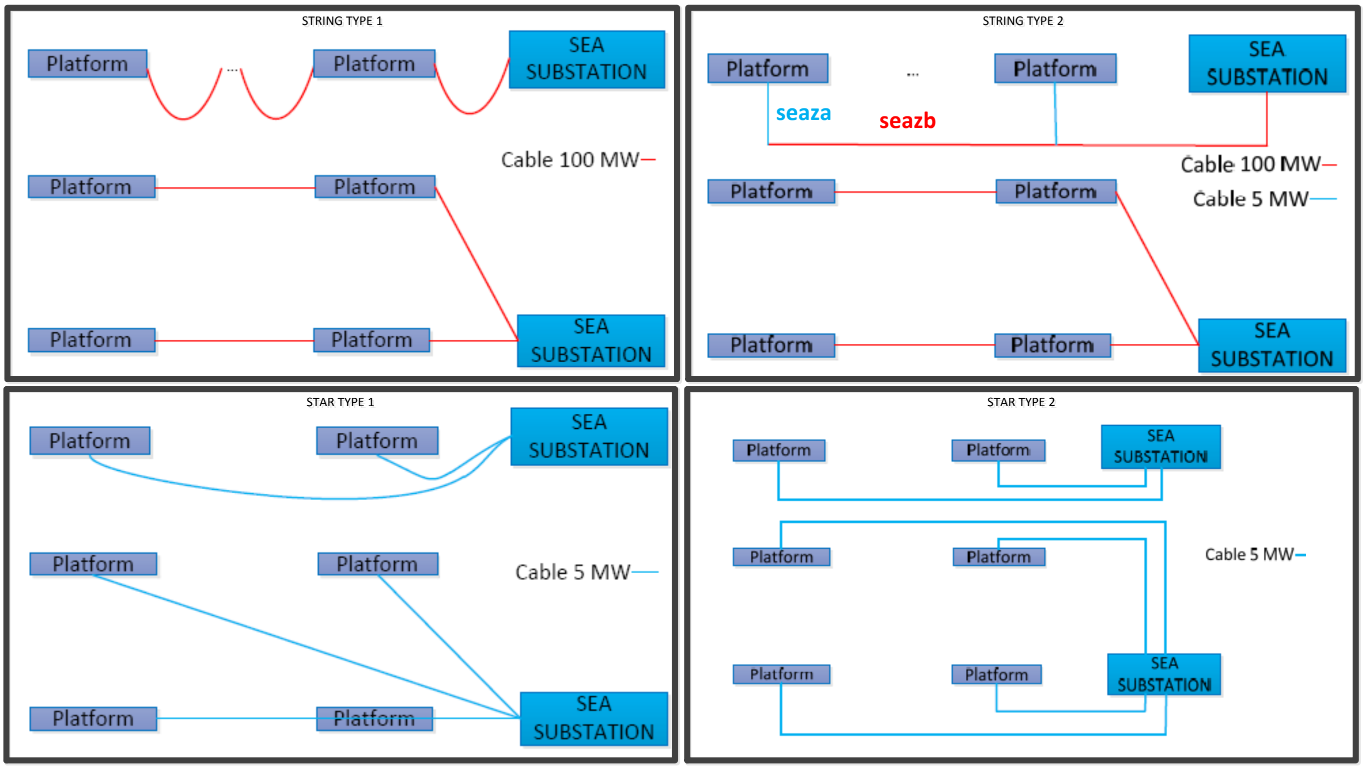

Figure 2.. – Electrical subscripts

Firstly, it would be evident that connection with more power was more expensive. However, it will be also dependent on the quantity of cable used.
Otherwise, the cost of the electrical farm configuration could be calculated taking into account the following expression:

$$C_{configuration} = \sum_{z=1}^{z=3} (N_{seaza} \times d_{seaza} \times C_{seaza} + N_{seazb} \times d_{seazb} \times C_{seazb}) + N_{sea4} \times d_{sea4} \times C_{sea4} + N_{onshore} \times d_{onshore} \times C_{onshore}$$

Being:

- N: number of electrical cables
- d: length of the electrical cable (m).
- C: cost of the electrical cable (€/m).

The subscript "seaz" is based on the offshore electrical cable located in the farm. Thus, the term "a" is the part of the cable which goes from the floating offshore platform to the seabed and the term "b" is the part which goes from one wind turbine to another. On the other hand, the concept "sea4" is based on the offshore electrical cable which transports the electricity from the floating offshore wind farm to onshore. Finally, "onshore" refers the electrical cable which is located onshore. The cost of the electrical cable will be based on specialized manufacturers [9] [10].

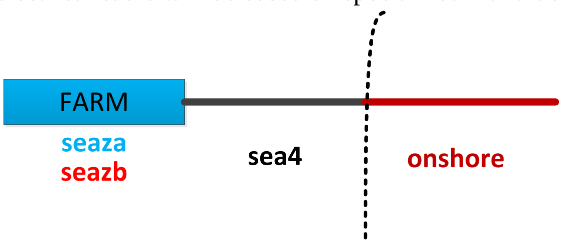

Figure 3.. – Electrical subscripts

2.1.2.- Installation

Installation costs of the wind farm are a very important item. The deep water site and the requirements that require floating platforms are the main reason.

There are two basic types of installation:

- Offshore installation.
- Onshore installation.

Offshore installation can be carried out by jack – up vessels or by a combination of barge, tug and floating crane.

Regarding onshore installation, it can be done in two ways. The first one, only wind turbine is mounted onshore, so a port crane will be needed, a barge and a tug. However, in second one, turbine and platform are assembled in a harbour or in a shipyard. For this second option, the barge will not be necessary.
The cost of the installation is based on the following formulae [11]:

$$C_{installation} = C_{port} + C_{transport} + C_{installationprocess}$$

Being:

- C_{port}: cost of the cranes, movements and area at port.
- $C_{transport}$: cost of the transport
- $C_{installationprocess}$: cost of the offshore installation process using cranes.

All these costs will depend on the type of installation [12]. Thus, for instance, the second way of onshore installation does not have so much offshore cost, because the most of the process is developed onshore [13].

2.1.3.- Maintenance

In general maintenance activities can be divided into:

- **Corrective maintenance** can be defined as a maintenance task performed to identify, isolate, and rectify a fault so that the failed equipment, machine, or system can be restored to an operational condition within the tolerances or limits established for in-service operations [14].
- **Preventive maintenance** can be described as maintenance of equipment or systems before fault occurs, it is the scheduled maintenance [15].
- **Predictive maintenance is a condition-based system.**

The main difference of subgroups is determination of maintenance time, or determination of moment when maintenance should be performed.

Corrective maintenance is performed if a component has failed, and preventive maintenance is performed to avoid failure. Scheduled maintenance is performed on scheduled times, and could e.g. be lubrication, tightening bolts, and changing filters. Condition-based maintenance is performed on the basis of the actual health of the component, and thus it requires a condition-monitoring system with on line monitoring and/or inspections [16]. For offshore wind turbines service visits are performed on a scheduled basis, where scheduled maintenance are performed, and at the same time inspections can be performed at a relatively low additional cost [17] [18].

The use of corrective maintenance is the most simple strategy, but it has several flaws. The failure of one minor component can cause escalated damage to a major component, which gives large repair/replacement costs. Further failures will often happen during a period with large wind loads, and the site will be unaccessible during that period, which will cause lost production. Thus the costs for corrective maintenance are associated with much large run certainty than preventive maintenance.Operation and maintenance are significant contributors to the cost of energy for offshore wind turbines.

As far as maintenance is concerned, this can be done in two ways [19]: onshore based or offshore based. Furthermore, several maintenance levels will be taken into account [20]: minimal, basic, intermediate, high and exhaustive.

Thus, the possible types of maintenance are:

- Onshore maintenance, without permanent accommodation (minimal, basic, intermediate, high)
- Offshore maintenance, with permanent accommodation (exhaustive).

These alternatives are dependent on the number of maintenance trips needed per year: minimal maintenance supposes 1 trip, basic maintenance 2 trips, intermediate maintenance 3 trips, high maintenance 4 trips and exhaustive maintenance 5 or more trips.
The cost of maintenance will be composed by:

$$C_{maintenance} = C_{corrective} + C_{preventive}$$

Being:

- $C_{corrective}$: Cost of the corrective maintenance.
- $C_{preventive}$: Cost of the preventive maintenance.

Each of these costs will be different depending on the type of maintenance strategy: onshore or offshore.

3.- RESULTS

3.1.- INPUT DATA

The costs introduced in this paper have been calculated taking into consideration the following main inputs:

- Number of wind turbines: 21.
- Power of each wind turbine: 5 MW.
- Distance to shore: 20 km.
- Depth: 386 m.

3.2. - FARM CONFIGURATION

Farm configuration depends on cable quantity, wind turbine diameter, number of wind turbines, shore distance, deepness and cable cost, In this case, the aim will be to reduce the amount of cable, which is the most important factor.

In Option 2 of the star configuration more cable will be needed than in Option 1, so it has been rejected. It can be seen from the results of Table I that string configuration is more economical than star configuration

The cheapest option of all is the string configuration Option 1, as is shown in Table I. In fact, Option 2 string configuration rising up to 3.6 M€ more than the chosen option because, although there is 5 MW cable and its cost is less than 100 MW cable, the quantity of cable used is higher. On the other hand, Option 1 star configuration is 4.4 M€ more expensive than the option chosen because the quantity of cable is so high that it does not compensate its costs.

Table I. – Farm configuration costs

Farm configuration	Cost (M€)
String configuration 1	**57.8**
String configuration 2	**61.5**
Star configuration 1	**62.3**
Star configuration 2	**Rejected**

3.3.- INSTALLATION

Secondly, it is necessary to know which is the most favourable type of installation, which will be dependent on the vessel cost

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The choice of jack – up is discarded because its costs are higher than have a vessel only for wind turbines, as said the study of the CDTI (Industrial Technological Development Centre) [21].

So, after having compared several costs, the cheapest installation, both of wind turbines and platforms, is the Option 2 onshore installation, which eliminates the use of a barge. Option 2 offshore installation supposes 39.8 M€ more in costs that the option chosen, mainly due to the enormous cost of specialized floating cranes. Option 1 onshore has a slightly higher cost that the option chosen, only exceeds 772,5 €, but they are in the same range, as Table II shows:

Table II. – Installation costs

Installation	Cost (M€)
Offshore 1	**Rejected**
Offshore 2	**43.1**
Onshore 1	**3.3**
Onshore 2	**2.5**

3.4.- MAINTENANCE

Maintenance will depend on the number of trips with this purpose: more trips implies more cost.

Having a proper ship for maintenance means a greater cost if maintenance is minimal (M), basic (B) or intermediate (I). However, if the maintenance is high (H) or exhaustive (E) the fact of having your own ship will be beneficial.

Therefore, the conclusion is that it is better to have your own ship if you are going to carry out 3 or more maintenance trips, as Table III shows:

Table III. – Maintenance costs

Maintenance	Cost (M€)				
	M	B	I	H	E
Proper ship	**63**	**63.4**	**63.9**	**64.4**	**65**
No proper ship	**46.6**	**54.7**	**62.8**	**70.9**	**78.2**

4.- DISCUSION

After having examined all the possible options regarding a floating wind farm configuration, the best ones are the following:

- Option 1 string configuration.
- Option 2 onshore installation.
- Maintenance with a proper ship for 3 trips onwards.
- There is no accommodation.

On the other hand, the elaboration of this study allows us to know what will be the main variables in the implementation of a floating offshore wind farm. Thus, its cost, which represents bottleneck threat in this sector, can be determined.

This study was carried out for a preliminary analysis of a set of options, future works will be focused on increasing the details of each variable.

5.- ACKNOWLEDGMENTS

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