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Weighting the influencing factors on offshore wind farms availability

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ABSTRACT: The present paper shows the importance of wind turbine availability on an offshore wind farm and how this availability relies on three factors: wind turbine systems reliability, systems maintainability and efficiency of logistics activity. The paper deals with all identified factors that contribute to the availability of the offshore wind farm and determines their relative importance based on the Analytical Hierarchy Process (AHP). The proposed methodology can be used and adapted for each specific situation taking into operational and maintenance data, wind farm location (shore distance), water depth, site accessibility (vessels and crew), weather dependence (meteorological and oceanographic factors), opportunistic maintenance, spare parts and other related factors. The results show the most important factors and their weight, supporting the decision making process and allowing increasing offshore wind farm availability.

1 INTRODUCTION

Wind power generation became very popular in the last years. Wind turbines are installed and used to produce an environmental and clean energy through the conversion of kinetic energy into mechanical work and then into electricity. In offshore wind farms the power generated by each individual wind turbine is connected in an array to one or more offshore substations and then delivered to shore through a subsea transportation system.

Wind farm availability and its efficiency have a huge impact on operational costs, representing about 90% of capital expenditure (OPEX). This importance requires a special attention to reduce turbines downtime as low as possible. When Wind Turbines (WTs) are installed offshore in a functional array, designated as Offshore Wind Farms (OWFs), there are some characteristics that must be taken into account when assessing the accomplishment of their mission.

One important characteristic to observe is the availability of the WTs that is determined by several factors such as air temperature, precipitation, humidity, pressure, and other atmospheric variables that influence both the amount of power available in the wind as well as the efficiency by which wind turbines capture and covert this power. However, there are other factors as ocean waves, currents, surface temperature and other water related parameters that must also be considered because not only impose major loads on foundations and challenges to vessels, but also directly influence the nature of the overlying atmosphere. Studies must integrate all these meteorological and oceanographic factors as well as other situations that can affect OWFs availability. In a general way all these elements will not affect OWF availability directly. In fact, availability is determined by systems reliability, systems maintainability and logistics efficiency.

Tavner et al. (2008) developed a work about more than 6000 modern onshore wind turbines and their subassemblies, ranging in size from 300–1800 kW, in Denmark and Germany over 11 years and show that the analysis yields some surprising results about which subassemblies are the most unreliable but stresses that Mean Time to Repair (MTTR) is also important.

The present paper is structured into five sections. Section 1 refers to an introduction to the issue and presents some questions about it. Section 2 introduces Offshore Wind Farms (OWFs) and some characteristics related to availability of such installations. Section 3 presents the Analytic Hierarchy Process (AHP) and how it is applied in practice. In Section 4 it is proposed a methodology to determine the weight of selected attributes on the availability of OWFs and Section 5 describes some conclusions and future works.

2 OFFSHORE WIND FARMS

A wind farm (WF) is made up of a number of wind turbines (WT). The concept of an onshore and an offshore wind farms is quite similar relying the great difference on the WT foundation. When a turbine is offshore the foundation must be strong enough to create sufficient moment and holding force to withstand the movements and bending moments of the wind acting on the turbines, but there are some factors that must be considered when designing the foundation, as:

- Water depth;
- Wave load;
- Ground conditions;
- Turbine-induced frequencies.

Uzunoglu et al (2016) developed a work about floating offshore wind platforms describing the platform behavior in waves and classifying the platforms according their stabilization and pointing out the advantages and disadvantages of each design approach.

Regarding WTs, the technology of modern WTs became mature and their construction has become relatively consistent around the three-bladed, upwind and variable speed concept.

However, WTs can be presented on different configurations, mainly based on the following three architectures (Tavner, 2012):

- Geared WTs, with a gearbox, a high-speed asynchronous generator, and a partially rated converter;
- Geared WTs, with a gearbox, a medium-speed synchronous generator, and a fully rated converter;
- Direct-drive WTs, with no gearbox but a low-speed synchronous generator and a fully rated converter.

More recently, innovative concepts of WTs have also been developed, such as the semi-direct drive WT or the WT adopting digital displacement transmission. These innovative designs theoretically promote systems with superior reliability and efficiency despite still being currently in research. Thus, further verification of their actual performance under various operation conditions is still required.

Since 2008, the market share of the gearless or direct-drive turbines has increased from 12% to 20% meaning that there are an increasing number of WTs of different concepts appearing in onshore wind farms. Regarding the offshore wind market it is notorious that it still be dominated by gear-driven turbines (IEA, 2013).

Nowadays the mainstream products in the commercial wind power market are geared and conventional direct-drive WTs. The UpWind project (Faulstich & Hahn, 2009) studied different concepts of WTs revealing that the direct-driven ones are superior to the conventional gear-driven in the following aspects:

- Free of gearbox failure;
- Improved reliability for the hydraulic system;
- Less problems in mechanical brakes.

On the contrary, direct-driven WTs suffer from more problems in electric subassemblies (e.g. pitch control and power electronic converter), rotor blades, and generators (Tavner et al, 2008) (Faulstich et al, 2008). In spite of turbine types, electrical, electronic control, hydraulic and yaw systems have shown much higher failure rates than rotor blades, gearboxes and generators do. However, they lead to shorter downtimes as they are easier to replace and repair. In contrast, rotor blades, gearboxes and generators show relatively low failure rates, but result in much longer downtimes due to the difficulties in logistics, lifting, replacing and repairing. A recent study also discloses that in onshore cases, 75% of the faults cause 5% of the downtime, whereas 25% of the faults cause 95% of the downtime (Faulstich et al, 2011).

Offshore Wind Farms have not only the same problems but also other situations that can promote and accelerate them due to specific operational conditions. The greatest challenge to offshore resource characterization is the marine environment itself. Physical measurements are logistically difficult and expensive, which explains why they are relatively sparse. To compensate, strong emphasis is placed on weather satellites and numerical weather prediction models to characterize the ocean environment for many marine activities.

Practice has shown that offshore operation and maintenance (O&M) is much more costly and sophisticated than onshore O&M.

OWFs may be inaccessible for long periods and as a consequence, any breakdown that needs manual repair or reset could lead to a long downtime and significant revenue loss. Even when weather and sea conditions are favorable, visiting an offshore site is still expensive due to the high cost of hiring suitable vessels. Frequent site visits could lead to many unnecessary costs that increase the cost of energy of offshore wind. However, costs resulting from unnecessary site visits can be reduced if the OWFs have a remote Condition Monitoring (CM) system.

Practice also had shown that the higher the wind speed, the lower the availability because it increases outages and limit the access to defective WTs. Thus, OWFs availability can be improved if the maintenance and repair activities are well scheduled (Faulstich et al, 2011). In addition to the impact of offshore weather, the availability of OWTs is also influenced by the availability of suitable vessels, spare parts and maintenance crew, where logistics efficiency is measured.

Santos et al (2016) presented a work referring some statistics of accidents and component failures of WT structures based on the failure data of main subassemblies and stating the existing condition monitoring techniques and methods relating them to WT operation and maintenance.

The same publicly available dataset allowed to draw statistics and discuss for the type of accidents, their frequency, failure causes and consequences, which permits, for example, the design/redesign of a WT, in reviewing and improving safety regulations and certification guidelines, in developing safer procedures for the operation and maintenance phase and when setting priorities in terms of mitigation efforts (Santos et al, 2015a).

The same authors also determined which factors influence most the turbines' performance, namely, the availability, overall cost and revenues, presenting a parametric study on how the variation of failure and repair models, vessels logistic times, weather windows and waiting times affect a WT performance (Santos et al, 2015b).

A strategy for combining corrective maintenance replacements with age-based imperfect preventive maintenance repairs on an offshore WT consisting of several degraded components was proposed (Santos et al, 2015c). The authors used failure models based on onshore WT and simulate operation and maintenance activities using Generalized Stochastic Petri Nets with predicates and Monte Carlo simulation, considering logistic resources, times and costs, and weather constraints.

The same tools were used to model the planning of operations and maintenance activities of an offshore WT, where three maintenance categories were classified according to the size and weight of the components to be replaced and the logistics involved, such as vessels, maintenance crew and spares, the associated delays, and costs (Santos et al, 2018).

Assuming that availability can be defined as the "ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided" (CEN, 2017), there are some factors that contribute to the achievement of higher probabilities. From the above information, if one tries to resume which factors influence OWFs availability, it can be stated that are three generic issues:

- Reliability – can be defined as the "ability of an item to perform a required function under given conditions for a given time interval" (CEN, 2017);
- Maintainability – can be defined as the "ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources" (CEN, 2017);
- Logistics Efficiency – includes all supporting activities that contribute for O&M success.

RELIABILITY	MAINTAINABILITY	AVAILABILITY
CONSTANT	INCREASE	INCREASE
CONSTANT	DECREASE	DECREASE
INCREASE	INCREASE	INCREASE
DECREASE	DECREASE	DECREASE
INCREASE	CONSTANT	INCREASE
DECREASE	CONSTANT	DECREASE

Figure 1. Reliability and maintainability influence on availability.

Figure 1 shows the contribution of reliability and maintainability issues on availability.

However, introducing the third factor (logistics efficiency) it becomes more complex to analyze and understand the dynamics of availability. Thus, a methodology is needed that includes all factors and develop a method to achieve individual importance measures to overcome this difficulty, justifying the work presented in this paper. The relevant factors will be introduced as the criteria to be taken into account on the proposed methodology presented in Section 4.

3 THE ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) is a widely used tool for decision-making processes that involve alternatives and their numerical evaluation, being considered as a Multi Criteria Decision Making (MCDM). The methodology was firstly developed by Saaty (1980) corresponding to a simple way to analyze complex problems where subjective and objective factors are considered to make decisions.

The AHP process is used in complex decision problems and their evaluation is performed by weighting each attribute or alternative using a pair-wise comparison matrix (Zhong & Youchao 2007).

The AHP can be applied to a huge variety of situations. Vaidya & Kumar (2006) developed a study showing an increasing number of papers dealing with AHP over time, most of them from USA (47%) and Asia (33%). It is also referred that AHP applications cover social, manufacturing, political, engineering and many others areas.

Triantaphyllou et al. (1997) explained how Multi Criteria Decision Making methodologies are considered as critical decision tools for many scientific, financial, political and engineering challenges and used it to calculate the most important maintenance criteria among cost, capacity to repair, reliability and availability.

Hijes & Cartagena (2006) applied the methodology to classify equipment and support the decision for maintenance strategy. The authors started from the identification of critical equipment concluding with their quantification, called equipment criticality index, representing their criticality.

Bevilacqua & Braglia (2000) used the AHP process to select the maintenance strategy for an important Italian oil refinery involving five alternatives (preventive, predictive, condition-based, corrective and opportunistic maintenance).

Zio et al (2003) apply a decision support system to identify the most important parameters for reliability assessment.

Other works try to deal with uncertainty of the parameters or subjective judgements, using simulation approaches (Levary & Wan 1998) or fuzzy logic (Braglia & Bevilacqua 2000) (Al-Najjar & Alsyouf 2003) (Dagdeviren & Youksel 2008).

Regarding wind energy some works can be also referred. For example, AHP was also used to identify the barriers to developing renewable energy technologies in Nepal and rank them. The barriers were categorized into six types (social, policy and political, technical, economic, administrative and geographic) and it was observed the most important ones (Laxman & Yoenbae, 2018).

Akbari et al (2016) performed a study to investigate logistics capabilities of offshore wind ports for supporting the installation and operation and maintenance phases of offshore wind projects applying the AHP methodology and assessing the suitability of some ports located off the North Sea coast of the United Kingdom.

AHP was also used to analyze wind power generation risk based on wind power characteristics and the several stages of the project risk factors identified by phasing of construction of wind power feasibility study and design phase, investment and financing stage, building construction phase and operations and maintenance phases of the four stages of risk into account, and then build a relatively complete risk assessment system (Xinyao et al, 2017).

Liu et al (2012) used fuzzy AHP to make decision on the wind power integration schemes considering the characteristics of the wind power integration.

Bai et al (2017) determined the weights of the decision objectives and the health management decision of wind turbine blade based on the fatigue test data by applying the Analytic Hierarchy Process and Fuzzy (AHP-Fuzzy) decision method.

Sagbansua & Balo (2017) used AHP methodology to decide about the selection of the best turbine among brands for 1.5 MW, evaluating from technical, economic, environmental and customer attributes.

This selection plays an important role in the desired life cycle. The same authors used AHP to increase wind farm energy efficiency by evaluating four main criteria technical, economic, environmental and customer attributes based on time and space and choosing the most appropriate turbine (Sagbansua & Balo, 2017).

Mahdy & Bahaj (2018) also used AHP methodology to produce offshore wind suitability map for appropriate offshore wind locations. The developed work was applied to Egypt and links the methodology to site spatial assessment in a geographical information system, with the objective to scale renewable energy capacity from 1 GW to 7.5 GW by 2020 through offshore wind. The same objective was assumed by Ayodele et al (2018) for Nigeria by presenting data obtained with proper evaluation of the wind resource while taking into consideration environmental, social, and economic factors, being possible to use it to select the optimal site selection.

AHP methodology starts with the definition of the decision criteria in the form of a hierarchy structured on different levels where the top level corresponds to the goal or overall objective. Next levels are related to criteria and sub-criteria (if applicable) and the lowest level to the alternatives. Figure 2 shows the structure of AHP methodology for three defined criteria and five alternatives.

It follows with the weighting process beginning with the criteria and sub-criteria (if existing) and then the alternatives relatively to the immediate higher level by simple pair-wise comparisons.

These judgement matrices can be defined from reciprocal comparisons of criteria at the same level or all possible alternatives (Wang et al. 2007).

The judgement scores refer to Saaty scale using a discrete scale from 1 to 9, as shown in Table 1.

The intermediate values between two adjacent numbers at the above Table (2, 4, 6 and 8) are applied when this compromise is needed.

Despite the wide use of the referred scale, other type can be used as referred in a study that presented

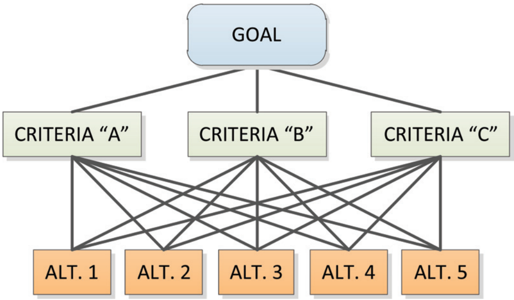

Figure 2. AHP structure.

Table 1. Pair-wise comparison scale.

Comparison	Explanation	Value
Equally	The two attributes contribute equally to the upper-level criteria	1
Moderately	Experience and judgement slightly favour one attribute over another	3
Strongly	Experience and judgement strongly favour one attribute over another	5
Very strongly	One attribute is strongly favoured and its dominance demonstrated in practice	7
Extremely	The evidence favouring one attribute over another is of highest possible order of affirmation	9

Table 2. Random index scale.

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.59

78 different scales to perform pair-wise comparisons (Triantaphylou et al. 1994).

As the pair-wise comparisons are the key of the decision making process, a correct quantification is one of the most important steps of AHP.

During the process, when comparing two criteria or alternatives there is a reciprocal relation that can be represented by a square matrix.

$$A = \begin{bmatrix} 1 & a_{12} & \ldots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \ldots & a_{2n} \\ \ldots & \ldots & 1 & \ldots \\ \frac{1}{a_n} & \frac{1}{a_{2n}} & \ldots & 1 \end{bmatrix}$$

As can be seen, based on the reciprocal rule it is not necessary to perform a full comparison since:

- If $aij = \alpha$ then $aji = 1/\alpha$ (where $\alpha \neq 0$)
- If $aij = 1$ then $aji = 1$

Thus, the total number of judgements necessary in a matrix (with n matrix elements) is determined by:

$$\frac{n(n-1)}{2}$$

After the judgement matrix has been developed, the eigenvector of the matrix is calculated in a way to weight the elements of the referred matrix.

However, for complex analysis, judgements could be inconsistent due to human condition.

The AHP enables to evaluate this consistency applying a methodology to calculate the inconsistency ratio IR.

First a Consistency Index (CI) must be determined. The Consistency Index can be determined by the following expression:

$$C_I = \frac{(\lambda_{\max} - n)}{n-1}$$

where λmax represents the higher value of the calculated eigenvector and n the number of elements compared.

To calculate the Inconsistency Rate (IR) we must compare the Consistency Index (CI) with a called Random Consistency Index (RI).

$$I_R = \frac{C_I}{R_I}$$

The Random Index results from a sample of 500 reciprocal positive matrixes, as shown in Table 2 (Saaty, 1980).

If the value of the Inconsistency Ratio is smaller or equal to 0.10 the inconsistency is acceptable and if not it is needed to revise the judgement matrix until the Inconsistency Ratio reaches the desired value.

The AHP methodology will be applied in Section 4 to weight attributes or alternatives that have impact on the availability of OWFs, regarding their reliability, maintainability and logistics efficiency.

4 PROPOSED METHODOLOGY

Based on the above theory, a methodology is proposed to analyze how to increase OWFs availability regarding the most important factors or attributes concerning the probability of failure of WT systems and their maintenance and other related support activities. Some of these systems are illustrated in Figure 3.

From the point of view of systems reliability, it is necessary to understand the boundaries of the analysis and all functional failures that may occur.

Here a Failure Mode and Effects Analysis (FMEA) could be an interesting tool to look for potential failure modes, causes and their effects.

Regarding maintainability and support activities, it is necessary to observe the item itself and the type of maintenance (preventive or corrective) as well as many factors that can influence WTs downtime.

Thus, it all begins with the selection of the relevant factors that can influence the availability of OWFs, with two criteria, namely Reliability (R) and Maintainability (M) and following sub criteria referred as the main WT systems:

- Rotor Blades (RB)
- Pitch Mechanism (PM)
- Rotor Hub (RH)
- Main Shaft (MS)
- Main Bearing (MB)
- Gearbox (GB)
- Brake System (BS)
- Generator (GT)
- Coupling (CP)

The selected factors are:

- Wave Conditions (WC)
- Wind Speed (WS)
- Vessel Availability (VA)
- Shore Distance (SD)
- Crew Availability (CA)
- Remote Condition Monitoring (RC)
- Local Spare Parts (LS)
- Failure Complexity (FC)
- System Accessibility (SA)

Based on this information, the AHP structure is presented in Figure 4.

To apply the methodology it is necessary to assess a specific OWF and perform the analysis upon the inherent characteristics of that OWF.

To demonstrate the feasibility and applicability of the proposed methodology a simulation is

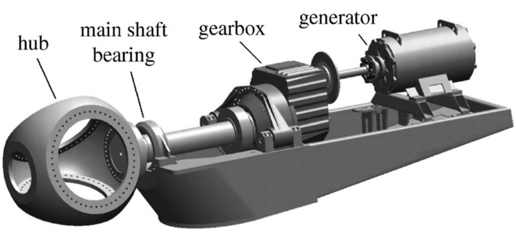

Figure 3. Main systems on a WT.

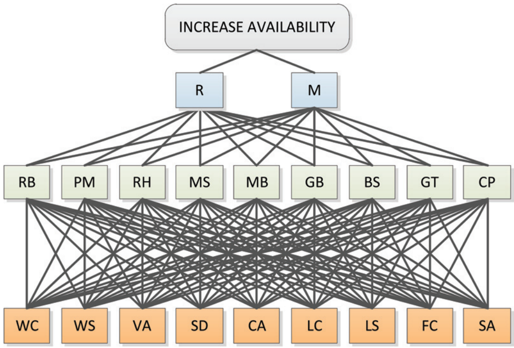

Figure 4. AHP structure applied to OWFs.

now presented. The first step is related to the comparison of the criteria specified (Reliability and Maintainability) where the results defined a value or weight of 0.8333 for Maintainability and 0.1666 for Reliability, regarding the importance of each factor (criteria).

A pairwise comparison of sub criteria regarding each of the criteria previously established is the next step. Figure 5 shows the referred analysis related to Reliability and Figure 6 shows the referred analysis related to Maintainability. The values shown in the referred Figures result from a sensitive pairwise comparison done by experts on the field about all sub criteria under assessment and taking into account the scale presented in Table 1. These experts must be selected from several areas (manufacturer, owner, maintenance, vessel service and others) and be analyzed for each specific situation (not a standard evaluation for every OWF). In the present simulation the values were determined based only on the knowledge of the authors on system's failures and only for demonstrative purposes. For example, the value of "5.00" placed on row 2 and column 4 of Figure 5 means that the Pitch Mechanism is 5 times more important than Main Shaft regarding Reliability.

Table 3 presents the results of each one of the referred analysis. These values, and the ones shown in Table 4 and 5, were obtained through the various steps of AHP methodology, namely the pairwise comparison (stated as a matrix), the corresponding normalized matrix and finally the determination of row averages.

It is noticed that in terms of Reliability the most important factor is the Gearbox, followed by the Main Bearing and Coupling.

Regarding Maintainability the most important factors are the Pitch Mechanism, the Rotor Hub and the Rotor Blades.

An intensive work about pairwise comparisons of all attributes for each of the sub criteria established follows now.

Each sub criteria involves 36 comparisons resulting in a global of 324 attribute judgements. Figure 7 shows the example for one factor (sub criteria) with the inherent results.

After all pairwise comparisons it is possible to achieve in two stages the desirable weights. At the first stage the weights of sub criteria in face of criteria were determined. Table 4 shows in descending order the weights for the sub criteria.

	RB	PM	RH	MS	MB	GB	BS	GT	CP
RB	1.00	0.20	0.33	0.50	0.14	0.11	0.20	0.33	0.14
PM	5.00	1.00	3.00	5.00	0.33	0.20	2.00	2.00	1.00
RH	3.00	0.33	1.00	1.00	0.14	0.14	0.50	1.00	0.20
MS	2.00	0.20	1.00	1.00	0.14	0.11	0.33	0.50	0.20
MB	7.00	3.00	7.00	7.00	1.00	1.00	3.00	5.00	2.00
GB	9.00	5.00	7.00	9.00	1.00	1.00	5.00	5.00	2.00
BS	5.00	0.50	2.00	3.00	0.33	0.20	1.00	1.00	0.50
GT	3.00	0.50	1.00	2.00	0.20	0.20	1.00	1.00	0.33
CP	7.00	1.00	5.00	5.00	0.50	0.50	2.00	3.00	1.00

Figure 5. Pairwise comparison relative to reliability.

	RB	PM	RH	MS	MB	GB	BS	GT	CP
RB	1.00	0.33	0.50	2.00	3.00	5.00	7.00	5.00	7.00
PM	3.00	1.00	2.00	5.00	5.00	7.00	9.00	7.00	9.00
RH	2.00	0.50	1.00	3.00	5.00	5.00	8.00	5.00	9.00
MS	0.50	0.20	0.33	1.00	1.00	3.00	5.00	3.00	6.00
MB	0.33	0.20	0.20	1.00	1.00	3.00	4.00	2.00	5.00
GB	0.20	0.14	0.20	0.33	0.33	1.00	2.00	0.50	3.00
BS	0.14	0.11	0.13	0.20	0.25	0.50	1.00	0.33	1.00
GT	0.20	0.14	0.20	0.33	0.50	2.00	3.00	1.00	3.00
CP	0.14	0.11	0.11	0.17	0.20	0.33	1.00	0.33	1.00

Figure 6. Pairwise comparison relative to maintainability.

Table 3. Sub criteria pairwise comparison results.

Reliability		Maintainability	
GB	0.2874	PM	0.3181
MB	0.2417	RH	0.2220
CP	0.1431	RB	0.1585
PM	0.1093	MS	0.0940
BS	0.0730	MB	0.0785
GT	0.0540	GT	0.0485
RH	0.0398	GB	0.0382
MS	0.0307	BS	0.0219
RB	0.0209	CP	0.0203

	WC	WS	VA	SD	CA	RC	LS	FC	SA
WC	1.00	1.00	1.00	0.33	0.20	0.14	0.20	0.17	0.25
WS	1.00	1.00	1.00	0.33	0.20	0.14	0.20	0.17	0.25
VA	1.00	1.00	1.00	0.33	0.20	0.14	0.20	0.17	0.25
SD	3.00	3.00	3.00	1.00	0.33	0.20	0.33	0.25	0.50
CA	5.00	5.00	5.00	3.00	1.00	0.33	1.00	0.50	2.00
RC	7.00	7.00	7.00	5.00	3.00	1.00	3.00	2.00	4.00
LS	5.00	5.00	5.00	3.00	1.00	0.33	1.00	0.50	2.00
FC	6.00	6.00	6.00	4.00	2.00	0.50	2.00	1.00	3.00
SA	4.00	4.00	4.00	2.00	0.50	0.25	0.50	0.33	1.00

Figure 7. Pairwise comparison relative to Gearbox.

Table 4. Sub criteria weights.

Sub criteria		Weight
PM	Pitch Mechanism	0.2833
RH	Rotor Hub	0.1916
RB	Rotor Blades	0.1356
MB	Main Bearing	0.1057
MS	Main Shaft	0.0835
GB	Gearbox	0.0797
GT	Generator	0.0494
CP	Coupling	0.0407
BS	Brake System	0.0304

Table 5. Attributes weights.

Attributes		Weight
CA	Crew Availability	0.2303
VA	Vessel Availability	0.1982
FC	Failure Complexity	0.1163
RC	Remote Condition Monitoring	0.0945
SD	Shore Distance	0.0856
LS	Local Spare Parts	0.0852
SA	System Accessibility	0.0771
WS	Wind Speed	0.0724
WC	Wave Conditions	0.0405

The second stage is referred to the determination of the weights of all attributes, reflecting the objective of the application of AHP methodology. Table 5 shows the referred attributes weight.

By the quantified results obtained it is observed that the factor or attribute most important is the crew availability (23.0%), followed by the vessel availability (19.8%) and failure complexity (11.6%). The less important factors are wave conditions (4.1%) and wind speed (7.2%). It very interesting to see that maintainability plays an important role on OWFs assessment and observe that questions related to the logistics, as vessel availability are crucial for OWFs availability.

A reference should be done to the present work referring that the selection of factors or attributes was done based on empirical knowledge about WTs and OWTs and thus, for real OWFs applications, it is needed to make an accurate study and specific evaluation.

5 CONCLUSIONS

The present work describes a methodology applied to an Offshore Wind Farm that allows to analyze the weight of several selected factors on its availability. It was shown that the AHP methodology is suitable to be used for that purpose, achieving quantified results.

Based on the demonstrative example it is shown that despite concerns about the reliability of all systems related to OWFs, maintainability is also very important. Maintainability of OWFs includes not only technical and technological aspects but other factors mainly related to logistics.

From the example it is notorious that there exists a huge difference from the Onshore Wind Farms and Offshore Wind Farms regarding the factors or attributes selection and inherent weights (influence) on availability. In fact, for OWFs some questions, as for example having a vessel available to travel and transport a blade or a hub, or people available to do the work become fundamental to reduce a WT downtime.

The work developed shows a methodology that can help who has responsibilities on the theme to make decisions and be aware for situations that affect WTs availability and decide about OFWs strategy.

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