Analysis of The Stress in The Anchors of Floating Wind Turbines in The Open Sea

Joseline Astudillo
Universidad Católica de Cuenca
Carrera de Ingeniería Industrial
Fab Lab
Avenida Las Américas y General Torres
+593 979166871. Ecuador
jlastudillot67@est.ucacue.edu.ec

Juan Carlos Gárate
Universidad Católica de Cuenca
Carrera de Ingeniería Industrial
Fab Lab
Avenida Las Américas y General Torres
+593 992955003. Ecuador
jgaratea@ucacue.edu.ec

Rolando Andrade Calle
Universidad Católica de Cuenca
Fab Lab
Avenida Las Américas y General Torres
+593 995852603. Ecuador
rolando.andrade@ucacue.edu.ec

Daniel Icaza
Universidad Católica de Cuenca
Carrera de Electricidad
Avenida Las Américas y General Torres
+593 985154839. Ecuador
dicazaa@ucacue.edu.ec

Abstract– In this research, the bending stresses produced in the anchors of offshore wind turbines and their maximum rupture limits are analyzed. The aim is to avoid reaching these maximum limits and to guarantee the correct operation of electricity production systems through wind turbines in the open sea as an interesting option in energy transition processes.
The transient behavior of the wind turbine structure is improved, as long as the fixings of the anchor points are guaranteed and the position of the wind turbine is vertical as far as possible. In reality, waves produce tension fluctuations in the mooring lines, which means that the wind input is not as constant at the level of the blades. However, this fluctuation is significantly reduced thanks to the hydrodynamic damping, it is there where the anchor points play a transcendental role and guarantee the stability of the turbine.

Keywords– Renewable energy, marine energy, wind power, floating wind turbine, stress.

I. INTRODUCTION

Currently, renewable energies are being widely used in countries to transform their systems based on fossil fuels for systems with high contributions of clean energy. The technologies that are playing a transcendental role and that tend to revolutionize the electrical energy market are wind and solar photovoltaic, in addition to the old hydroelectric. Nor should the contributions of renewable energy be neglected in a lesser proportion such as geothermal, biomass, tidal, among others. They are important when coupled together with those of greater proportion and reduce power fluctuations, by their very nature they are intermittent and in the energy mix they will be of support to maintain the stability of the joint system.

Several countries have achieved enormous development in renewable energy systems, including Denmark [1]. To maintain the continuity of the electricity service, battery storage systems have been included. Several authors such as A. Cano et al.[2] and Lui et al. [3] have mentioned that an adequate option is to design hybrid systems as long as the potentialities of the place allow it.

In other recent publications, the imperative need to allocate sufficient resources to increase the penetration levels of renewable energy is addressed, governments and public institutions related to the energy area are named as calls to manage sufficient economic resources for the benefit of countries and regions [4]. There are interesting experiences in which the private sector has also been present in helping to maintain an environment as less aggressive as possible for living beings in the world, ratifying that renewable energy is called to be the protagonist in the five continents [5].

Renewable energy resources on the high seas are becoming very important and the physical space available is extensive and these energy systems are being of great contribution in countries that have access to the sea with the purpose of satisfying the growing demand for clean energy [6]. Indeed, floating power technology consisting primarily of solar and wind power has become an attractive area of interest for academic research and commercial development.
Wind energy is being studied a lot and it is sought to guarantee that its systems provide abundant energy and the useful life of this technology is as long as possible [7], [8]. In the last ten years, offshore wind power has been extensively developed and commercialized, and we have witnessed major applications and commercialization of a

number of floating platforms for wind power exploration [9], [10].

For example, Europe's mainland coastal areas are becoming more populated and space to install renewable energy technologies is becoming limited [11]. That is why we turn to marine energy and other classes that have large spaces and significant energy potential [12]. The solution is accompanied by a series of floating marine platforms with a variety of brands that can support an impressive range of sustainable and environmentally friendly activities [13].

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II. MATHEMATICAL MODELING.

A. Wind Turbine System

The power of the wind is found by the equation:

$$P = \frac{1}{2} A \rho v^3 \qquad (6)$$

A = rotor area (m^2).
ρ = density (kg / m^3)
v = speed

The power of the wind turbine depends on the power coefficient of this and the equation is as follows:

$$P_w = C_p P_v \qquad (7)$$

C_p = Power Coefficient.

P_v =Power of the wind

$$P_w = C_p \frac{1}{2} A \rho v^3 \qquad (8)$$

The final power depends on the performance of the electric generator as well as the multiplication system.

$$P_{elect} = \eta_m \eta_e P_w$$

$$P_{elect} = \eta_m \eta_e C_p \frac{1}{2} A \rho v^3 \qquad (9)$$

Area needed to produce that power:

$$A = \frac{2P_{elect.}}{\eta_m \eta_e C_p A \rho v^3} \qquad (10).$$

B. Controller.

Generally, the controller power output is given by;

$$P_C = V_{bat}(I_{WT}) \qquad (11)$$

Where; V_{bat} is multiplication of the nominal voltage DC in the battery for I_{WT}

III. FLOATING ENERGY SYSTEM

In deep water places where solar and wind resources exist and are used, sufficient efforts are made to convert them into electricity. Particularly the wind resource is highly exploited in various countries of the world that have access to the sea. A hybrid power system that is very well coupled is the solar photovoltaic and wind turbine, it is a prospective and feasible solution to reduce the levelized cost of electricity. Several studies have been carried out by researchers worldwide, especially to identify patterns of dynamic responses of blocks of hybrid floating energy systems. Researchers like Seif Eddine Ben Elghali et al. [14], before making large investments, first carry out simulations using different optimization techniques and sensitivity analysis. The results achieved after the energy conversion process under operating conditions such as fluctuations in platform movements decreased by having equidistant and high resistance anchor points. The total power output increased between 8% and 16% depending on climatic factors [15].

Below, in Fig 1, the representative scheme of an offshore wind structure is presented [16].

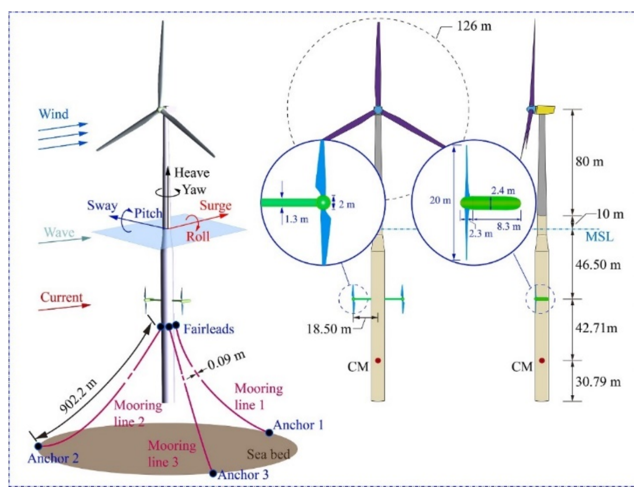


Fig 1． Structural model of an offshore wind system.

IV. ANCHOR

In the investigation, plastic blocks were selected instead of compact cement and to analyze the rigidity that is available, knowing that plastic as such can have years of years of use.

In this case, laboratory tests are carried out to determine its degree of resistance to bending.

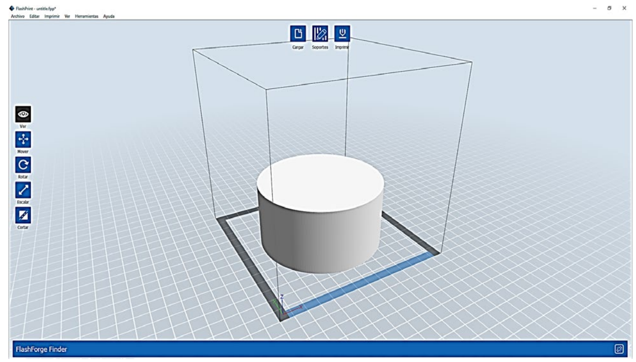
Regarding the guidelines for bending, it is established that this type of test will compare the different specimens, thus measuring the bending capacity of each one, according to regulation D790, which explains that the minimum dimensions of the specimens will be 20cm x 10 cm and a thickness of 3.2mm.

The machine used for the bending tests is the Versa Loader ASTM D1883; AASHTOT-193, maximum load of 45Kn, varied speeds, it is very easy to use and its main characteristic is that it is used in rapid tests. See Fig. 2.

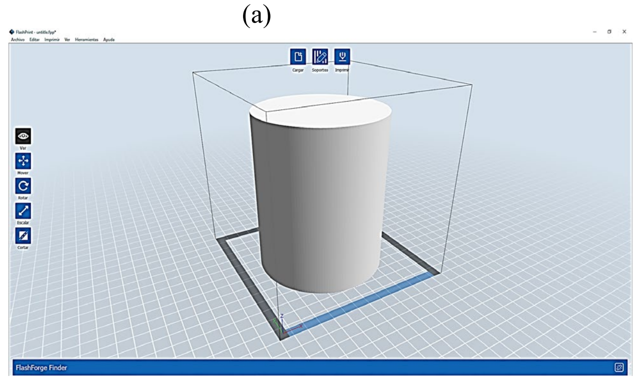
Fig 2. Versa Loader ASTM D1883.

The tests were carried out in the UCACUE soil laboratory located in Ricaurte. For the bending tests, the plates were used as specified in the D790 standard, as for the compression tests, the cylinders were used.

When performing these tests, the material with the highest resistance to breakage will be known and which of all has been the most flexible, thus providing the ability to discern and be able to generate a baseline which will help to generate further investigations. See Fig. 3.



(a)



(b)

(c)

Fig 3. Experimental analysis. (a) Design of specimen 1. (b) Design of specimen 2. (c) Specimen subjected to bending

In order to verify if there are differences between the six types of material in 12 cm filled test tubes that will serve as part of the anchors of the wind turbines, the means of the maximum resistance in bending tests were compared. The results shown in Table 1 allow us to observe that there are significant differences between the materials studied, according to the ANOVA test F (5/12 gl) = 11.804, p=0.000. Likewise, there are three subsets of data that must be taken into account considering that sometimes more than one material is located in two subsets. At a general level, it is noted that the common Resin is the most resistant material to bending and the TPU the least resistant material.

Table 1. Descriptive data and ANOVA test to compare the six materials in filled 12 cm prints.

Material	Number of cylinders for analysis	Average	95% confidence interval for the mean		Minimum load (kN)	Maximum load (kN)	Deformation (plg)
			Lower limit	Upper limit			
ABS	3	20,21	15,89	24,55	18,97	22,20	0,20
Fiber C.	3	49,80	45,47	54,14	47,89	51,31	0,20
PLA	3	60,37	-42,48	163,24	13,09	90,16	0,16
Resin BIO	3	43,54	42,83	44,24	43,23	43,78	0,20
Common Resin	3	100,56	87,88	113,23	95,12	105,25	0,20
TPU	3	2,85	1,02	4,69	2,05	3,51	0,20
Total	18	46,22	28,88	63,57	2,05	105,25	

In this case, the difference found for the variances has to do with an unusual and atypical behavior of the PLA material. When including this material (PLA) in the analysis, the results must be carefully analyzed considering this limitation.

Fig 4 shows the behavior of the six materials in which a very unusual behavior of PLA is observed. It turns out that, in this material, there was a specimen that did not resist more than 0.013 kN. Except for this exception, homoscedastic values are observed in the other materials, which means that internally they obtained similar values in the tests. The most resistant material was the common resin that supported a load of 105.25 kN.

Next, in Fig 4, the curves of the resistance tests carried out at the laboratory level are presented.

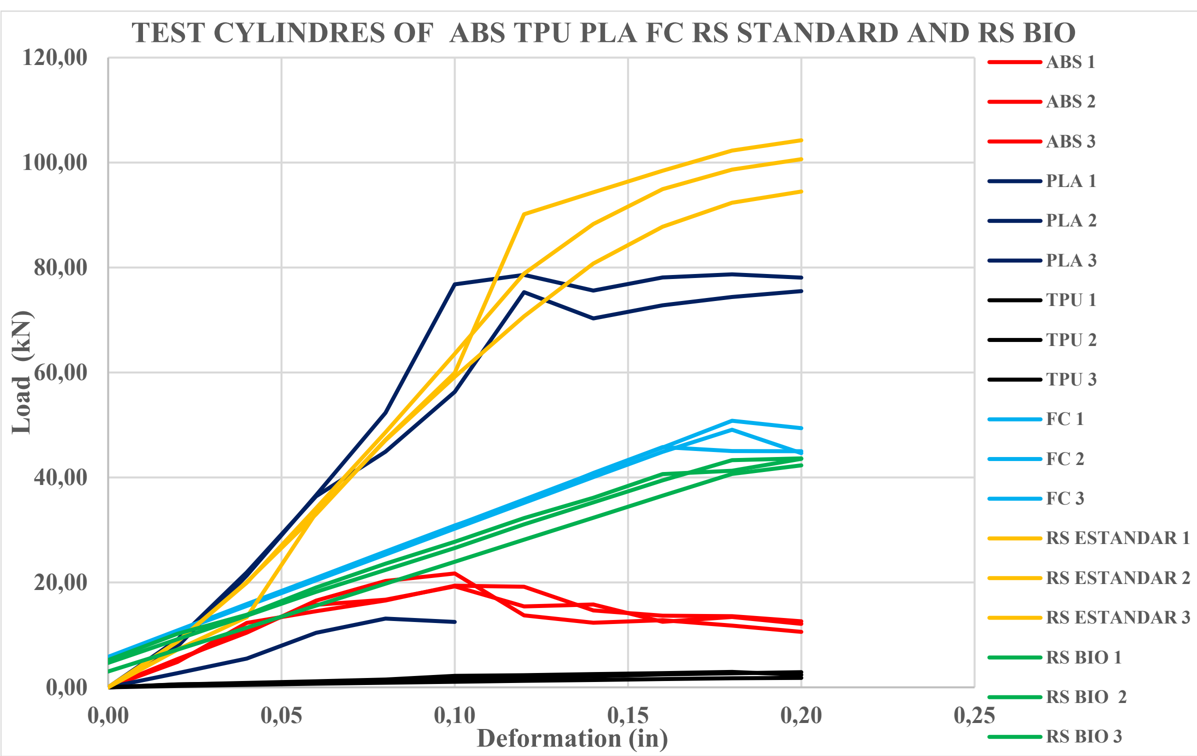


Fig 4. Results of the resistance levels in the cylinders

The next material was the PLA that has similarities with the common Resin. However, PLA is also located in the second group, together with Carbon Fiber, Bio Resin and ABS, all of them with a similar average resistance. The lowest level is reported for TPU, which has a resistance level of 3.51 kN, however, this is not different from ABS and BIO Resin, which apart from being located in the second subset, is also located in the third subset.

According to table 14, RS STANDARD is considered the most resistant material to compression, supporting a maximum load of 105.25 kN and with a deformation of 0.15 in., however, it can be seen that it has a deformation equal to that of TPU, this indicates that the standard resin supports high loads and deforms almost the same as the other materials in this analysis, even when they support much lower loads.
According to this analysis, PLA supports a maximum load of 90.16 kN and a deformation of 0.13 inches, which indicates that this material deforms at a lower load than that exerted on the standard resin. Regarding the bending tests, this material showed superior behavior to the other materials, supporting a maximum load of 19.99 kN and a deformation equal to the other materials of 0.20 inches, with the difference that it did not reach break.

V. CONCLUSIONS

Figure 5 shows the simulated Voltage-Power curves referring to the wind system at different values of Cp when the wind turbine operates normally without affecting the anchor points, maintaining complete stability.

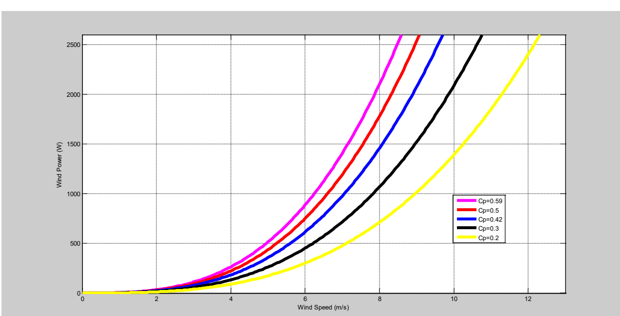


Fig. 5. Wind speed- DC power curve for different values of Cp.

These analyzes are first subjected to experimentation at the laboratory level, for which the new Fab Lab laboratory of the Catholic University of Cuenca in Ecuador is used given the growing development of renewable energies, specifically wind energy in Ecuador. Although various wind farms are currently being implemented in continental Ecuador, it is not unusual that in the future it can be implemented in the open sea, which Ecuador enjoys, including the Galapagos Islands, which requires avoiding the use of fuels fossils. The anchor points become an interesting point of analysis given the improvements in materials in recent times and it is of interest to the UCACUE to develop new products and services in favor of society.

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