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PATTERN RECOGNITION AND DAMAGE DETECTION IN THE “ENERGÉTICA 2030” WIND TURBINE FIBER GLASS TOWER THROUGH MACHINE LEARNING

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Abstract. In a world leading toward the systematization of task, current tools, like machine learning, aim to spare time, energy and most importantly, increase safety. In SHM these kinds of technologies provide faster, cheaper and better monitoring to recognize flaws or damage in general structures. Following the project of ENERGETICA 2030, a project founded by the Ministry of science in the in the frame of the program Colombia científica, leaded by the Univercidad Nacional de Colombia and financed by the world bank in view to promote the research capacity of the local universities focused to modern problems like green energies, a study of the structural behavior of a rural wind turbine has been done through machine learning to recognize behavior patterns and detect possible damage in a fiber glass tower. The methodology is based in a local characterization with strain gauges, and a general characterization with accelerometers, installed at various heights of the tower. With partial sensing of environmental variables and total control of the structural components, like the guy cables tension and bolt base's tightening, it's possible to induce controlled damage, like a loose bolt or an increase of the tower rigidity by increasing the guy cable tension. Once the undamaged data is acquired, it can be proceeded to generate the induced damage and acquire the new data which will feed an algorithm (Neural Network). Once trained, the system will recognize the occurrence and the type of damage. The accelerometers giving the general behavior, like a pause in the process of lifting or a guy cable break (strong acceleration about 2 m/s suddenly) or a tendency of the tower to bow (significant change of the local strain slope, stair-like). As the world seeks sustainable alternatives to fossil energy, the number of off-shore wind turbine has increased, as well as smaller prototypes for houses and rural zones. With this in mind, it's important to provide an unsupervised automatized system who monitors the structural health, to ensure the safety and increase the lifetime of the structure, even more with structures based on composite material.

1 INTRODUCTION

Find new alternatives to produce or improve the already existing renewable energy, is one of the challenges of tomorrow. With the recent awareness of the global warming, it can be seen a global preoccupation about the implementation and optimization of this technology, with the increase of green energy resources, passing from less than 1% of the global energy production in the 90's to 20% in 2020 and with an objective of 40% in 2030 [12, 2]. Colombia is not to be leave besides, and with a strong grown of interest, one of the main topics of research of the government is about renewable energy [9]. With 2 wind farms and a total of 25 wind turbine (WT), Colombia is seeking to increase his wind-based energy and reach a total of 16% of the total electricity created from these devices in the next years [10]. This project is the continuation of ENERGETICA 2030, its main purpose was the design and built of an operational wind turbine and its implementation in the outside of the city of Medellín. Ended in the early 2023 see Figure 1, the wind turbine count with a tower made in composite material, specifically polyester reinforced with fiber glass, in [13], it is say that this material is only used about 16 % of the commercial wind turbine, a low percentage explained due to the high complexity of this material to be monitored and to maintain with conventional techniques or even with continuous monitoring like a structural health methodology. The main purpose of this paper is to study the behavior of this tower made in composite material, with local and general censoring, coupled with a computational model for validation, and generate a methodology of Structural Health Monitoring (SHM) based on the prototype already installed.

Figure 1: Wind turbine installed in EAFIT Llanogrande

Various research have tried to associate damage detection with pattern recognition in wind turbines components and the responses of composite material, unfortunately, due to the high complexity of this material, highly depended of the fiber stack disposition and very expensive, studies in laboratory are most suitable than a scaled prototype and offers less information than a real in situ study. The use of machine learning techniques for damage detection through patter recognition in composite material is part of the newest and most research theme in field of structural health monitoring. According to [6], the current techniques to monitor the structure of a wind turbine can be divided in 2 groups: Load measurements(NDT methods, strain measurements, acoustic emission, ultrasonic method, thermography, machine vision) and global measurements (vibration method). According to this classification, some recent studies have been found, working on the monitoring of wind turbine structure, focusing in the tower and it's basement. Additional to the method of monitoring, [1] make a recount of the data and signal processing used by others research in monitoring of wind turbine structures, like a statistical method, trend analysis, filtering methods, time domain analysis, spectrum analysis, time synchronous averaging, Fast Fourier Transform, amplitude demodulation, order analysis and wavelet transforms. Some research propose others methodologies or ways to improve/validate the research, and this due, once again, to the high price of having a true scale prototype; [14, 3, 4] propose real data from a true scale (97 meters offshore wind turbine) monitoring system, whiteout critical damage in it, [7, 8] propose a preliminary study based on finite element analysis to anticipate potential damage, with a vibration model analysis, similar to it [7] have done a study in laboratory with a small scale study, focusing in vibration based excitation, with damage induced of bolt looseness, before scaled it up to a true scale model in finite model to propose virtual results and anticipated behavior.

Like said early, only 16% of the towers are made of composite material, all this studies have been done in wind turbine towers mostly made in metal or simulate the response in structures made of conventional materials, additionally, most of the study propose a methodology based on vibration and natural frequency analysis, and less propose a study using strain analysis, only [5, 14], furthermore, machine learning and patter recognition aren't used yet in this area, and are being only used in others elements like the blades[11].

2 DATA ACQUISITION SYSTEM

For the monitoring system, the challenge was to take in count all the possibility of behavior of the tower in function of the damage induced. With this in mind, it was decided to acquire data from a general behavior with 6 sets of accelerometers, and 11 strain gauge, for a local response, installed in strategic points of the surface according to a first computational model. The structure count of a base bolted and 8 guy cables, the disposition of the structural monitoring layout of the tower can be seen in the Figure 2 and detailed in Table 1

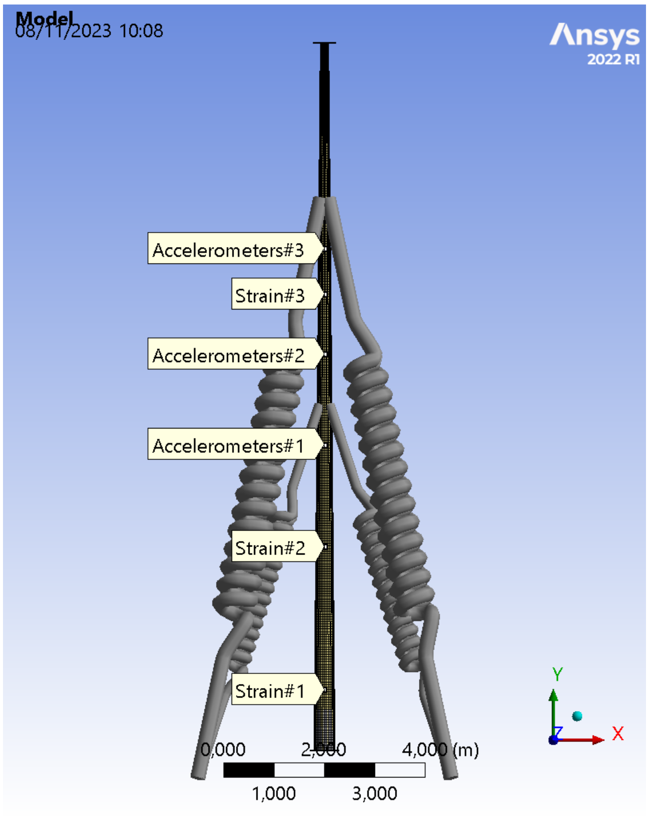

Figure 2: Sensors disposition in the FEA model

Sensor type	Set	Height (m)	Direction
Accelerometer	1	6.15	North East
Accelerometer	2	7.91	North East
Accelerometer	3	10.1	North East
Strain gauge	1	1.21	North South East Diag +45° Diag -45°
Strain gauge	2	4	North South East
Strain gauge	3	9.06	North South East

Table 1: Sensor layout disposition

3 COMPUTATIONAL MODEL

3.1 Mesh independency

The FEA model have the purpose to be the prediction of the actual wind turbine tower in function of potential damage and is showed on Figure 2. It was made preliminary of shell elements to reduce the complexity of the case. A convergence study indicate the minimum number of elements and the minimum computational time needed to reach an acceptable results, and can be seen in Figure 3. it was decided to work with a mesh element of 0.1m. Additionally, the model count of 8 springs elements to simulate the behavior of the guy cables.

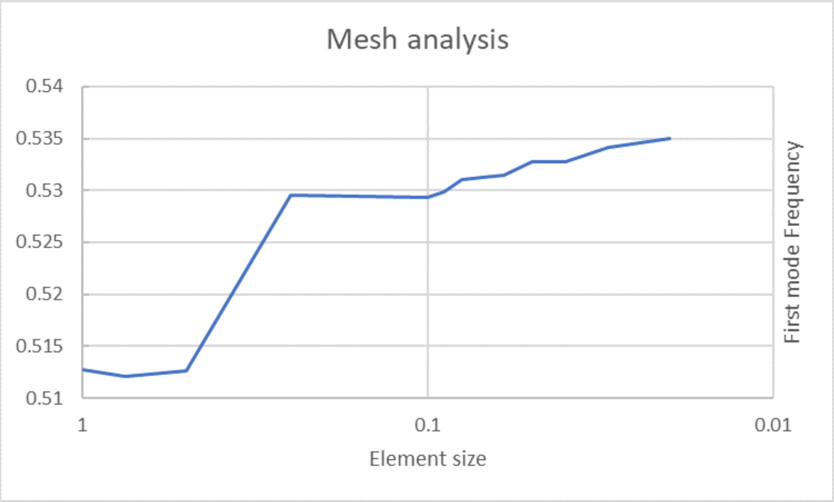

Figure 3: Mesh analysis

3.2 Model configuration

The FEA model was configured using the modal analysis of the tower without guy cable installed, this will be the base to select positive damage to apply. The accelerometer data has been analysed with Fast Fourier algorithm to determine the main modal frequency of the assembly. Figure 4 and Table 2 shows a good fit between the FEA model and the real data.

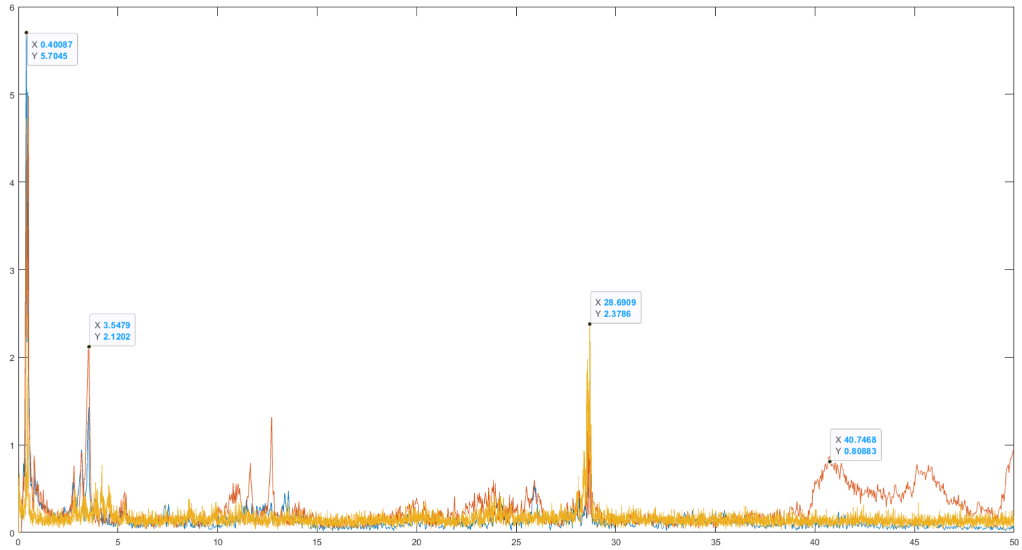

Figure 4: Real data frequency analysis without guy wires

Mode	Frequency
1	0.48079
2	0.48109
3	3.0606
4	3.0623
5	8.6392
6	8.6438
7	17.125
8	17.133
9	28.272
10	28.285
11	30.031
12	32.82
13	41.864
14	41.88

Table 2: Natural frequency excitation of the FEA model without guy wires

4 ESCOMPTED RESULTS

Using the computational model, it is possible to simulate the behavior of the structure when damage is applied, and integrate theses results to a model of patter recognition, this to analyse the tendency of the structure and conclude if a damage is present. Due to the configuration of the wind turbine, with 8 guy cables and a bolted base, the damage are focused on theses and it's impact on the health of the structure.

4.1 Undamaged configuration in normal operation

For an undamaged condition, the condition of operation correspond to all 8 guy cables correctly installed and with a pre-load of 1500N, the stiffness is assumed as equal of the core material with K=210 GPa. With this configuration, the natural frequency is shown in Table 3.

8 cables	
mod	freq
1	2.8564
2	2.8576
3	14.853
4	14.862
5	22.382
6	22.392
7	30.741
8	33.465
9	33.477
10	44.707

Table 3: Natural frequency of the structure with 8 guy wires

4.2 Damaged configuration

It's possible to perform some simulation with different damage implemented, these damage search to change the rigidity of the structure, and therefore, change the natural frequency of the structure. The results of the simulation ran are showed in Table 4. The damage selected are showed in the following Images and it represent a possible change in the guy wires with for Image 5 2 wires loose, in Image 7 2 pairs of same side are loose, in Image 6 2 opposite pairs remain, and in image 8 the critical case of only 2 guy cables sustaining all the structure.

6 cables		4 cables opposite		4 cables side-side		2 cables	
mod	freq	mod	freq	mod	freq	mod	freq
1	2.8252	1	0.62549	1	2.6648	1	0.62549
2	2.8566	2	2.8566	2	2.8369	2	2.7476
3	14.689	3	3.3078	3	11.512	3	3.3078
4	14.855	4	9.0496	4	14.681	4	9.0496
5	20.396	5	14.855	5	14.74	5	13.884
6	22.383	6	17.78	6	21.212	6	15.024
7	30.198	7	22.383	7	24.828	7	17.78
8	30.741	8	29.25	8	30.741	8	25.417
9	33.466	9	30.741	9	31.645	9	29.25
10	40.916	10	33.466	10	38.33	10	30.741

Table 4: Different configuration with different response

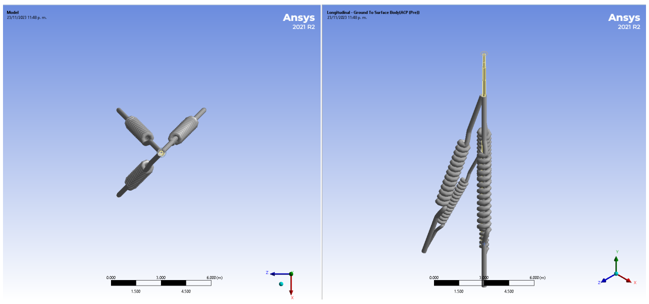

Figure 5: 6 guy cables configuration

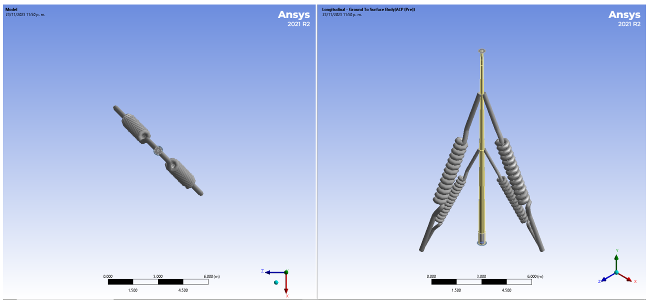

Figure 6: 4 guy cables configuration opposite

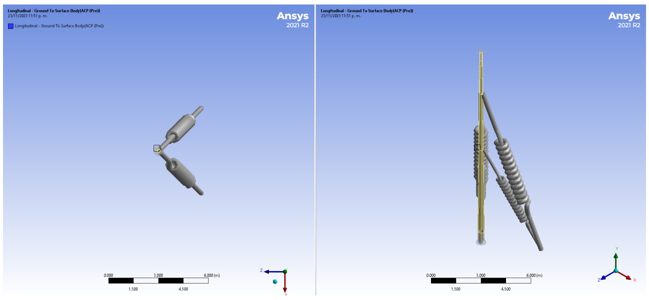

Figure 7: 4 guy cables configuration side to side

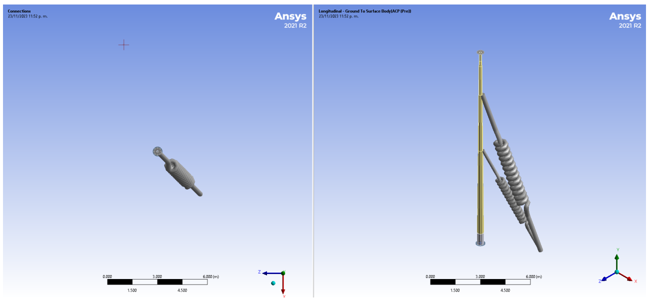

Figure 8: 2 guy cables configuration

5 Analysis

From the results of the simulation, we have an interval of data between undamaged state, different damage configuration and the natural frequency of the tower without any guy cable. The damaged data shows a tendency to be between the undamaged configuration and the wireless tower, showing a light difference on key modes (the first 8 mods being the most sensitive to changes), with the results being more alike of the normal configuration when less missing cable, and results more resembling to the wireless configuration with more missing cable presents. As is expected, the frequency tend to be lower according to the axis of the missing cable, this can be greatly seen in the configuration were only 2 pairs of opposite cable support the structure, with mods 1-3-5-7 being fairly close to the wireless configuration and the mods 2-4-6-8 being close to the operational configuration.

6 Conclusions

A wind turbine tower, with a configuration of supporting guy cables, will see his rigidity increase with the use of more guy cable, this to prevent any undesired excitation from the environment. However, this configuration can present some damage with the lose of tension in the cables. This damages, can be critics for the operation and need to be identified as early as possible. A study of the natural frequency of the structure can shown the change of the structure and can be associated to a tendency model with machine learning to prevent and alert that the structure is damaged and prevent further accidents.

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