Resonance Control System of a Vortex Wind Turbine for Energy Generation through Structural Redesign

RICARDO YAURI[1], GARDY LOPEZ[1], JUAN DAMAZO[1], VANESSA GAMERO[2]
[1]Facultad de Ingeniería, Universidad Tecnológica del Perú, Lima, PERÚ
[1]Universidad Nacional Mayor de San Marcos, Lima, PERÚ
[2]Departamento de Engenharia de Sistemas Eletrônicos, Universidade de São Paulo, São Paulo, BRAZIL

Abstract: - The consumption of electrical energy is increasing due to problems related to the deficient energy supply in certain localities, which affects the basic needs in rural communities where, currently, the efforts to distribute electricity by the authorities, through common technologies, are not enough. On the other hand, there is also the problem of the overexploitation of non-renewable energies, which produce large amounts of C02. To reduce these problems, renewable energies that do not generate polluting waste are used, but the ability of engineers is needed to achieve prototypes that give good results. The purpose of this research is to carry out the design and simulation of a control system and redesign of a Vortex wind turbine mast to keep it in resonance and generate electrical energy. The study objectives are met by verifying the specific results through requirements analysis, simulation design, and system validation. As a result, the parameters to generate vortices and keep the system in resonance were identified. In addition, the redesign of the mast of the Vortex wind turbine was obtained.

Key-Words: - Wind power, wind turbine, vortex, renewable energy, Ansys, electric power, resonance

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1 Introduction

Since 2019 the consumption of electrical energy has been increasing, [1], generating two problems. The first is due to the deficient supply of energy in certain locations, affecting basic needs in rural communities, as described in studies by INEI, [2], and Osinergmin (Supervisory Body for Investment in Energy and Mining), [3] demonstrating that Efforts made by electricity producers and authorities are not enough

As a result of the great demand for energy, the problem related to the pollution produced by the use and overexploitation of non-renewable energies arises, [4]. In recent years, the most used non-renewable energies were coal, which produces large amounts of C02 and oil and is in danger of causing marine discharges. In addition, there is a relationship between a greater demand for energy and generation sources, causing great pollution in the environment. To mitigate these problems, renewable energies that do not generate polluting waste can be used, [5], [6].

The reality in Peru, since 2020, is that most of the energy produced is taken from non-renewable energies, while 73.6% of internal production comes from oil and mineral deposits, [7]. It is for this reason that the Peruvian government seeks to promote the production of renewable energy, planning to increase its use by 80% by the year 2050.

In addition, currently, 5 wind power plants are operating in districts such as Máncora, Talara, and Cupisnique and 2 new wind farms located in Chota have been projected, [8], [9]. The use of renewable energies helps to solve the two problems previously presented, but the ability of engineers is needed to achieve useful prototypes that can be used for the benefit of society, [10].

Based on the above, the research problem has been identified as follows: How can the Vortex wind turbine be kept in resonance for the generation of electrical energy? Therefore, this research shows the design of a control system and redesign of the mast to keep the Vortex wind turbine in resonance, to generate energy, being necessary to meet the following specific objectives: Study the behavior of the Vortex wind turbine mast; Identify the parameters that allow the correct generation of vortices to keep the system in resonance; Carry out control to reduce the error between the oscillation frequency and the natural frequency of the structure during wind capture; Redesign the mast of the Vortex wind turbine to keep the system in resonance.

The contribution of the paper is to provide value to solve the energy crisis that is experienced in the world, due to the overexploitation of non-renewable energy sources that pollute the environment whose aspects are observed in the literature review. The research method used will be non-experimental since a real vortex wind turbine is not used and simulation software will be used to meet the objectives.

This paper is organized into the following sections: Section 2 describes the most relevant works for the investigation. Section 3 defines the concepts related to the technologies used in this paper. Section 4 describes the development process carried out. The results are shown in section 5 and the conclusions are shown in section 6.

2 Literature Review

This section describes studies that show research on the use of clean renewable energy as a contribution to solving the energy crisis through engineering technologies.

When you have relevant information on the real-time behavior of wind turbines, it is possible to optimize their operation. In [11], the authors recognize the importance of communication and data sharing in real-time wind generators, to establish control through a wireless communication system. It is mentioned that torque, voltage, and current data are used to control power in wind.

In [12], there is a similar opinion, about errors in data transmission that impair proper functioning, for this reason, they also use the same power supply cables as information transmission channels. In addition, the need to maintain communication between a wind turbine and a control base is described, where the wind turbines report anomalies in emergency cases to take immediate actions using the Power Line Communication technique for remote access and administration within buildings, but not in rural or remote sectors.

When talking about wind power, it is related to the efficiency of the generator, so it is important to know the factors that influence the generation of high power. In 2021, according to [13], a probabilistic evaluation of the wind energy potential in different cities will be carried out, identifying the best areas to implement wind turbines. Weibull, Rayleigh, Nakagami, Lognormal, and inverse Gaussian probability functions were applied.

On the other hand, in [14], it is stated that a wind turbine can be implemented in any geographical area, considering the design of a flow concentrator that allows increasing energy generation and improving its power. According to the simulations carried out in this paper, it is shown that the output speed of the flow concentrator is a higher value than the speed required by the wind turbine to start, making its operation longer and increasing wind power regardless of the conditions. from where it is located.

The research described in [15], mentions that it is important to know the operating frequency of wind turbine devices in wind farms (WF). These meet communications requirements to be able to meet demand using wind turbines. To make these estimates a Gaussian mixture model is used to model the actual output of the WFs. In addition, this contributes to avoiding structural fatigue and design control strategies of two degrees of freedom that controls the force of the generator and the angle of inclination.

The need to use renewable energy is important for sustainable development as described in the paper, [16]. It is mentioned that they have new methods to simulate and represent the electrical and mechanical characteristics of variable wind speeds in turbines. Therefore, this paper proposes an extended simplified model for a variable-speed motor of a wind turbine. This approach broadens the scope of studies for network frequency control by considerably reducing the computational load. The results show a good fit of the model with minimum delays of about 3% of the wind turbine. In addition, with the proposal, computational time is reduced by up to 80% compared to a detailed model.

In the research developed by [17], it is explained how the Unified Power Quality Conditioner (UPQC) is one of the personalized power devices (CP) that mitigates the problems of charging current and supply voltage contributing to the penetration of renewable energy in the electricity grid. The use of electronic devices and non-linear loads produce harmonics that affect the waveform of voltage, so a grid power system (grid-wind turbine) is used. The simulation results allow comparing two electric power generation techniques, obtaining a distortion factor (THD) of less than 5% for voltage.

On the other hand, [18], comments that the variability of renewable energy distribution (RESs) presents serious challenges for energy management (EM). This study proposes a paradigm based on artificial neural networks (ANN) to predict wind power generation and demand, using meteorological parameters, including wind speed, temperature, and atmospheric pressure. The results show that ANN provides high effectiveness and precision for wind power forecasting.

The contributions are related to the papers described above, where most of the research seeks to capture wind energy in the most efficiently. The authors propose and analyze ways to improve power generation, implementing controllers or installing wireless communication systems between a power plant and the wind turbine, using probabilistic ways to find the most suitable territory for its operation, and adding flow concentrators. For this reason, one of the strengths of this research is to carry out the study of power control for wind turbines, so that the system remains continuously in resonance due to the instability of the wind and that there is no constant flow of energy, thus complying with the expected standards.

However, there is an important gap that could improve this system, considering whether the natural frequency of the structure is equal to the oscillation frequency to generate ordered vortex patterns and obtain maximum resonance, which does not happen due to wind variation. Therefore, this research presents an innovative proposal by showing a control system that allows the oscillation frequency to be controlled and remains close to the natural frequency of the structure.

3 Control and Wind Turbines

3.1 Control System

Every controlled system is made up of different components, where a block diagram allows showing the functions of each element. In addition, these systems can be integrated into solutions to carry out explorations in space, applications in robotic equipment, and updated production lines, [14]. Its representation is shown in Fig. 1, where the variable C(s) and input R(s) are observed as output. At the beginning, the comparison of the output with the input is made and the error that must be corrected is obtained.

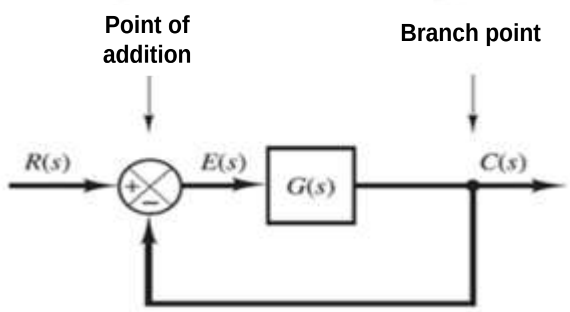

Fig. 1: Closed Loop Block Diagram

Among the concepts related to control systems, we have:

- System modeling. It allows analysis in a control system by modeling the system following physical principles.
- System error. It is attributed to factors such as the variation in the input of the reference signal that causes errors in time steps and stationary state.
- Control device. It becomes necessary when using some kind of controller physical element.

3.2 Bladeless Wind Turbines

Energy sources such as water, sun, or wind are classified as clean energies that do not produce greenhouse gases, [19], [20]. These are not exhausted and are continually renewed such as biomass, wind, solar, and geothermal among others, wind energy is one of the most important resources.

Wind energy uses kinetic energy from the wind, and transforms it into electrical or mechanical energy, [21]. Traditional wind turbines are composed of blades on an axis called wind turbines and are connected to supply networks called wind farms. In the case of this article, they are used in wind farms installed on land (onshore).

3.3 Vortex Wind Turbine

The new technology of vortex wind turbines does not use blades for their operation but obtains energy thanks to the oscillation of its mast. This is one of the most ecological technologies, with advantages such as low maintenance cost and safe for wildlife because it does not use gears, [22]. Resonant-type wind turbines work through the effect of vorticity, using a perpendicular device embedded in the ground, whose rigidity is sufficient to support the resonance of its structure. One of the main advantages is that it does not have moving components, therefore, lubrication or maintenance costs are reduced.

The design of a wind turbine is carried out using mathematical equations that govern the operation of the structure. This has a core, where the upper part supports the mast, through a rigid cylinder designed to oscillate. It is here where the maximum oscillation amplitude is found while in the lower part, it is anchored to the ground (Fig. 2).

4 Description of System

For the development of this paper, the VDI-2206 methodology, also called Mechatronics methodology, developed by "The Association of

German Engineers" (Verein Deutscher Ingenieure, VDI) was used. The VDI-2206 methodology is applied to this project by identifying the project objective, requirements analysis, design of the simulation system, and validation of the system. Using this methodology, the design process can be managed, improving the quality of the final product.

The VDI-2206 methodology for the simulation of mechatronic systems presents innovative features, such as the systemic approach instead of individual components, risk management, and the integration of multiple disciplines, resulting in a more efficient design. In addition, it is oriented towards the needs of the end user and covers the entire product life cycle, reducing development costs.

Fig. 2: Vortex wind turbine structure, [11]

4.1 General Scheme

To carry out the investigation, the following steps are carried out: The model of the Vortex wind turbine is simulated in Ansys to know the behavior of the wind around a cylinder. In parallel, the analysis of the model is carried out and the control system is implemented using the Matlab software. In this case, first, the mathematical modeling of the system is carried out and the differential equation of the plant is obtained. Subsequently, a control system is designed to control the oscillation frequency. After knowing the behavior of the wind on the structure, the diameter of the mast to be controlled is identified, through a mechanism to expand and contract it. Finally, the list of components needed for the implementation of the control system is presented. These described procedures are shown in the scheme of Fig. 3.

4.2 Simulation of the Vortex Wind Turbine using Ansys

The evaluation of the wind turbine is carried out inside the wind tunnel considering the boundary conditions, where the blue arrows represent the entrance of the wind at a certain speed and the red arrows are the exit of the wind in Fig. 4.

4.3 Control System to Reduce the Error between the Frequency of Vortices

In this section, the forces surrounding the wind turbine (boundary conditions) are identified for correct mathematical modeling. Once all the forces are identified, the dynamic equations that govern their behavior are found. In Fig. 5 the elements for the modeling of the wind turbine are observed: Where "V" is the wind speed, "m" is the mass of the mast, "c" is the damping constant of the material, "k" is the elasticity constant and "D" the diameter of the mast.

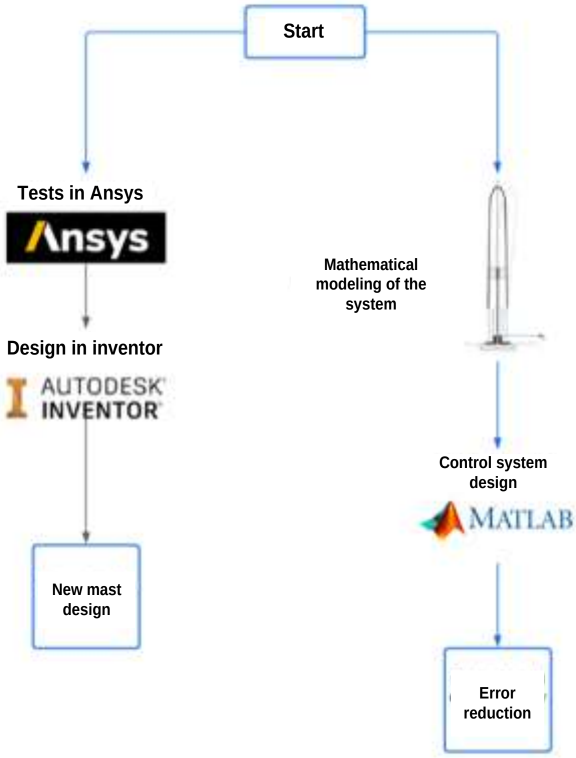

Fig. 3: Development scheme

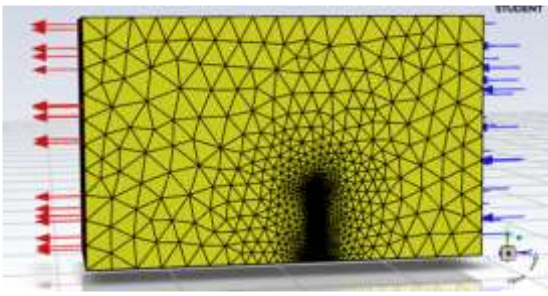

Fig. 4: Boundary Condition Simulation

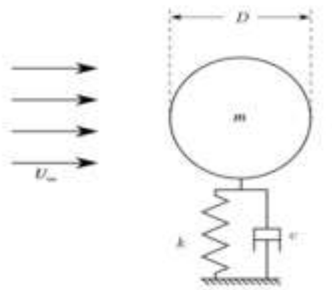

Fig. 5: Modeling of the Vortex wind turbine, [25]

A reference signal "r" is used, which is the reference diameter, which is not constant because it depends on the wind speed. This signal will take any erroneous value that will be subtracted with the variable "Dr" and generate an error signal that enters the PID. Once the position of the plant is obtained, we can use this signal and find the oscillation frequency from it (Fig. 6).

4.4 Redesign of the Mast for the Vortex Wind Turbine

It is necessary to make changes to the structure, shape, or design of the mast. Therefore, the development of the prototype implies having a structure of variable dimension, where for a certain wind speed, the Vortex wind turbine has a specific size, depending on the increase and/or reduction of the wind speed. In this case, the dimension of the solid must vary proportionally to the speed. In Fig. 7 the structure, designed in the Inventor software, is shown in three different positions.

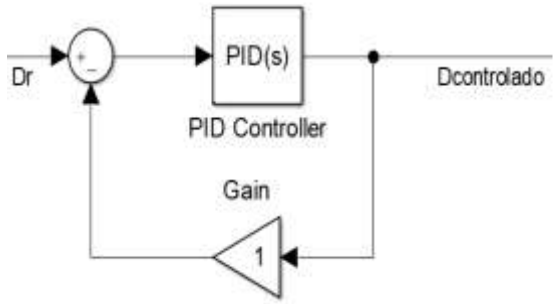

Fig. 6: Diameter controller

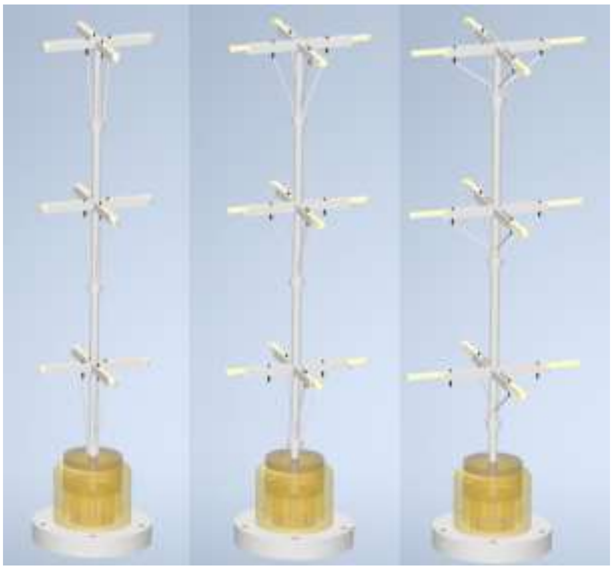

Fig. 7: Mechanism to increase and decrease the diameter

The designed mechanism (seen from the outside) is a structure that increases in size on the lateral sides. For this to happen, there is the transformation of a vertical movement into a horizontal movement using the connecting rod. Initially, there is a diameter of 39 centimeters when there is a wind speed of 4 meters/second (ms). As the wind speed increases, the fins will expand to the maximum diameter of 96 centimeters when the wind speed increases to 9.9 meters/second (Fig. 8).

5 Results

5.1 Identification of Speeds and Diameters

In the case of the analysis of the behavior of the wind with the designed structure, it moves from the left side to the right side, where the vector traces show it, obtaining a wind speed of 3.9 ms^-1. In Fig. 9 the color legend positioned on the left side is observed, which describes the intensities of the speeds. When the wind is 50 centimeters close to the Vortex device, its speed gradually decreases to 3.73 ms^-1, close to 25 centimeters.

As can be seen in Fig. 9, the wind speed in the Vortex device is null or zero and the solid represents a restriction to the passage of the wind. In the upper part of the mast, there is a shade of red, which describes a maximum speed of 5.33 ms^-1, due to the aerodynamic effect.

Fig. 8: Maximum diameter

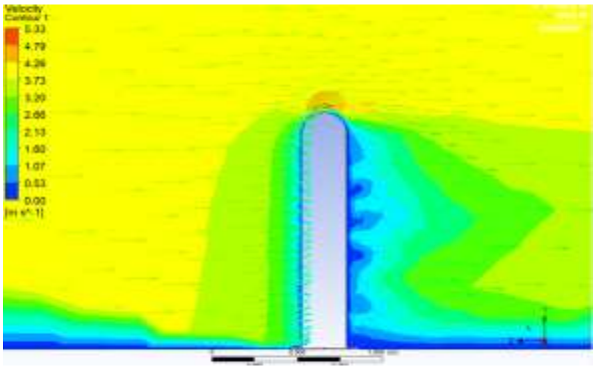

Fig. 9: Opposition to wind

Fig. 10 shows the pressure or force that is generated around the Vortex device. In the path of the wind, the pressure is 0 pascal (PA), when it is 25 centimeters from the mast. On the other hand, the pressure or force exerted on the wind turbine increases up to 10 PA, which is equivalent to 10 Nm^-2.

Simulations were carried out using a random diameter and speed, but without being able to generate vortices around the cylinder. Subsequently, simulations were carried out with other values such as 3.33 ms and a diameter of 0.3281 meters, generating an ordered pattern of vortices (Fig. 11).

5.2 Control System Simulation

The simulation results show that the wind changes every second with values between 5.33ms and 9.33ms. The wind speed simulation is presented in Fig. 12.

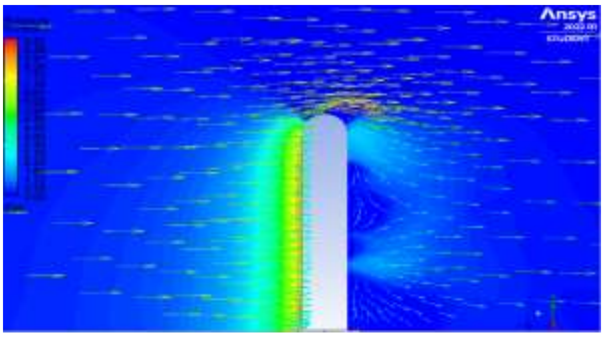

Fig. 10: Pressure behavior

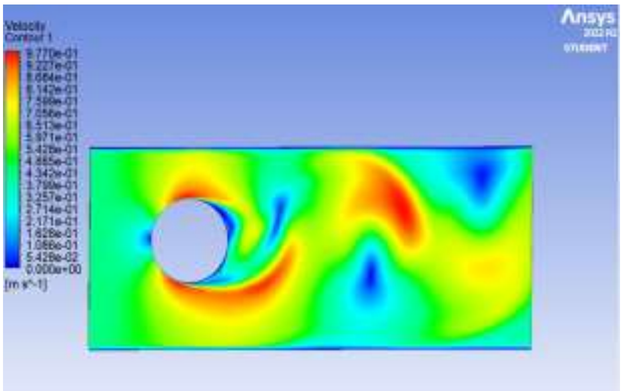

Fig. 11: Simulation with a calculated diameter

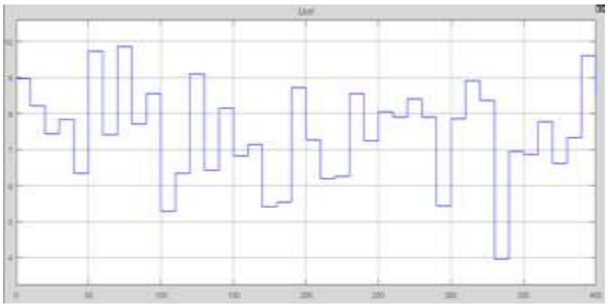

Fig. 12: Wind speed simulation

In addition, the diameter of the wind turbine varies between 0.96 meters and 0.39 meters as a minimum. The controlled diameter always tries to put itself in the same position as the reference diameter, checking that the diameter of the mast is being controlled correctly for each variation in wind speed (Fig. 13).

The oscillation frequency seeks to stay as close to the natural frequency, so it is impossible to get a straight line for the vortex frequency because it depends on the wind speed. The control of the diameter can be maintained in a constant range with an error between 0.1 and 0.2, approximately 13% (Fig. 14).

As a result of the simulation processes and evaluations carried out, the new design of the mast is obtained. In Fig. 15 a section of the vortex planes is shown.

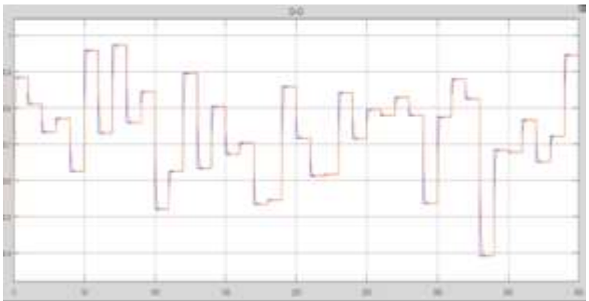

Fig. 13: Diameter control

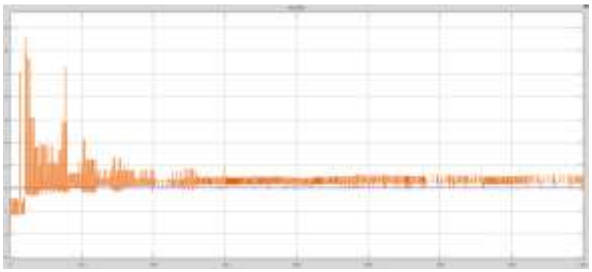

Fig. 14: Comparison of natural frequency and oscillation frequency

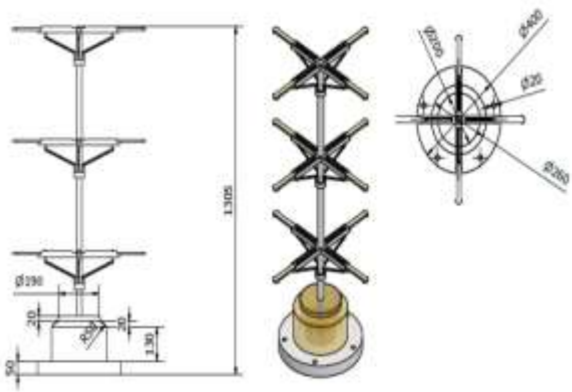

Fig. 15: Vortex Diagrams

The system generates an alternating voltage signal from the position and speed of the mast performing diameter control (Fig. 16). In addition, Fig. 17 shows the power generated by a point charge per turn.

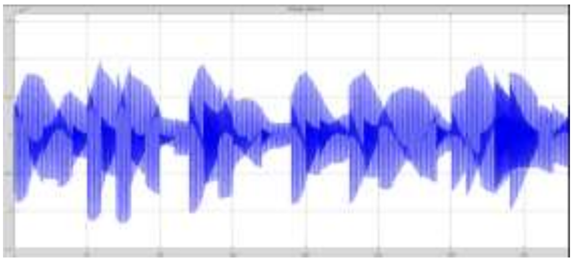

Fig. 16: Alternate voltage

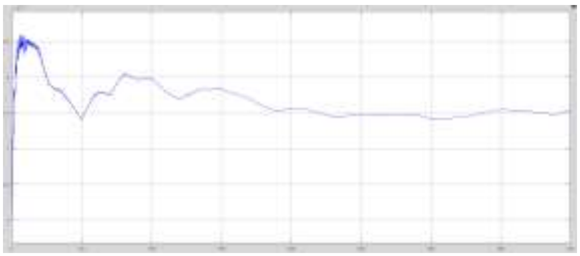

Fig. 17: Average power

6 Conclusions

Through the simulation in Ansys, the relationship between the generation of vortices with the diameter and the speed of the wind is identified. This is because for each wind speed a different diameter is generated to keep the generation of vortices constant, so it is necessary to control the oscillation frequency. With this, it is possible to reduce the error between the oscillation frequency and the natural frequency, obtaining a percentage error of 13%. In this investigation, a simulation error could not be obtained because the physical system was not implemented to carry out a comparative analysis.

In addition, a mechanism was created that allows the mast to expand and contract its diameter according to the wind speed at a specific moment, performing a redesign generated by the control system. Finally, the average power of a point charge that oscillates in a loop is calculated. This verifies that the resonance of the system has an impact on the generation of energy.

It is for this reason that our project, compared to other investigations, shows simulation mechanisms to evaluate the capture of wind energy the most efficiently before physically building the system, saving costs and implementation time. Furthermore, technically, the results differ from other projects reviewed in the literature, because we consider the natural frequency of the structure and its relationship with the oscillation frequency to generate ordered vortex patterns and obtain maximum resonance.

As further work, it is recommended that, for correct visualization of the generated power, the design of the generator must be carried out considering the magnetic field of the magnet, number of charges, number of turns of the coil, and the diameter.

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