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Savonius Turbine Pitch Control with IoT Philosophy

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Abstract. Renewable energies have experienced a great growth in recent years, thanks to their versatility and low environmental impact, and supported by progress in electronic, mechanical, control and systems engineering. This work reports the theoretical study, development and implementation of an adjustable Savonius rotor. The design of the turbine will allow the regulation of the position of the blades on the axial axis. This will allow the turbine to always extract the maximum power, regardless of wind speed. The work is divided into the following parts: A first stage where the mechanical system that will allow the regulation of the position of the blades will be developed. In the second part, a permanent magnet generator will be selected according to the speed and torque characteristics of the rotor. The third part will study the power topology and the control to be used for energy extraction always working at the maximum power point (MPPT). The last part of the work will consist in adding sensors to the whole system so that we can control all the rotor variables: wind speed, voltage, current, etc. In this last part, we will also capture, store and process the variable of the system to be designed using IoT sensors using the MQTT protocol. The article will be complemented with a section in which the results of the work will be collected as well as future proposals for improvement.

Key words. Savonius Turbine, Hydrokinetic, Kinetic, Pitch Contorl, MPPT Control

1. Introduction

Power generation based on wind turbines has reported a significant increase in recent decades, making it one of the most widely used and promising renewable energy sources worldwide. Wind turbines harness the kinetic energy of the wind to generate electricity in a clean and sustainable way, making them an environmentally friendly alternative and a solution to reduce greenhouse gas emissions.

A wind turbine consists primarily of three elements: the blades, the tower and the generator. The turbine blades are aerodynamically designed to capture the maximum amount of kinetic energy from the wind. As the wind blows, the blades rotate, which in turn rotates the turbine shaft. This shaft movement is connected to the generator, which converts mechanical energy into electrical energy [1].

The location of wind turbines is a key factor in ensuring maximum performance. They are installed in areas with consistent and substantial wind speeds, such as on coasts, mountains or open areas without obstacles. In addition, other factors, such as landscape impact, interference with migratory birds and noise effects, must be considered when choosing suitable locations for installation.

The main benefit of wind energy is its renewable and clean nature. Unlike fossil fuels, wind energy produces no greenhouse gas emissions and does not pollute the air, water or soil.

Another positive aspect of wind turbine-based generation is its ability to be used on both large and small scales. Wind farms with multiple turbines can generate large amounts of electricity that can power a community or even an entire city. On the other hand, smaller wind turbines, known as home wind turbines, can be installed in individual homes and provide power for household use [2].

Wind power offers a promising, sustainable energy solution, but faces challenges like wind intermittency and efficient energy storage. Despite these hurdles, wind energy's environmental benefits, potential for energy independence, and promotion of technological advancement position to play a key role in a cleaner energy future.

2. Savonius Turbine

Savonius type turbines are a type of vertical axis turbines used to generate power from wind [3]. These turbines were invented by the Finnish engineer Johann Ernst Elias Bessler Savonius in the 1920s [4].

One of the main characteristics of Savonius-type turbines is their simple and robust design. Its shape consists of two or more semi-cylinders joined vertically, giving it an appearance like a barrel cut from a vertical axis, capturing and harnessing the power of the wind to generate energy [5].

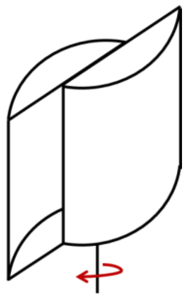

Figure 1 : Savonius Turbine

Another important feature of these turbines is their ability to capture and utilize wind from any direction. Unlike horizontal axis turbines, Savonius type turbines are omnidirectional, which means they do not need to be constantly facing the wind direction to operate efficiently. This makes them ideal for areas with changing or unpredictable winds.

In addition, Savonius type turbines can take advantage of low-speed winds. Unlike other turbine designs that require high speeds to generate power, these turbines are capable of operating in low-speed winds, making them accessible in areas with less favorable wind conditions.

However, despite these advantages, Savonius-type turbines have some limitations. Compared to other types of turbines, their efficiency in converting wind energy into electrical energy is relatively low, resulting in a lower amount of power generated. In addition, their cylindrical design produces significant aerodynamic drag, which limits their ability to produce power during high winds [6, pp. 152–154].

In summary, Savonius turbines are an interesting and versatile option for wind power generation. Their simple design, omnidirectional capability and ability to take advantage of low wind speeds make them an attractive option in areas with changing or less favorable wind conditions. However, their efficiency and power generation capacity may be limited compared to other types of turbines.

3. Design Objective

The traditional Savonius turbine does not allow blade position regulation, so the efficiency of the rotor cannot be adjusted according to the blade tip speed.

Efficiency is defined by the power coefficient, Cp, which is the power generated by the rotor divided by the theoretical power available from the wind [4].

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

The equation shows the wind power as a function of wind incidence area (A), air density (ρ), and the wind speed itself (v) [7, pp. 767–772].

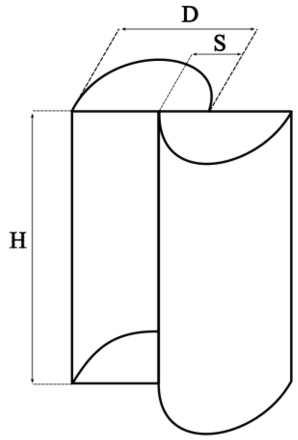

Figure 2 : 3D view of a Savonius Turbine

The velocity coefficient or specific velocity (λ) must also be defined, which determines the ratio between the tangential velocity at the blade tip (v_t) and the wind speed (v). On the other hand, the mechanical variables of the turbine must be defined, for the modeling of the turbines, the blade diameter (D), and the overlapping of the turbine, one over the other (S) must be considered [8].

Once these two concepts have been defined, the maximum power coefficient can be calculated, which in the case of a Savonius rotor is of the order of 0.18 [9].
With this premise, the aim is to analyze how the maximum operating point of a turbine varies. The first equation presents the formula for calculating the theoretical power generated by a turbine. In this equation, the incident area is considered constant; however, if this area is allowed to vary as a function of the overlap, it is possible to adjust the power in relation to this parameter. In this way, the point of maximum power is reached when the Overlap is equal to zero.

Figure 3 shows a qualitative graph of how, theoretically, the power generated by the turbine varies as a function of the wind incident area.

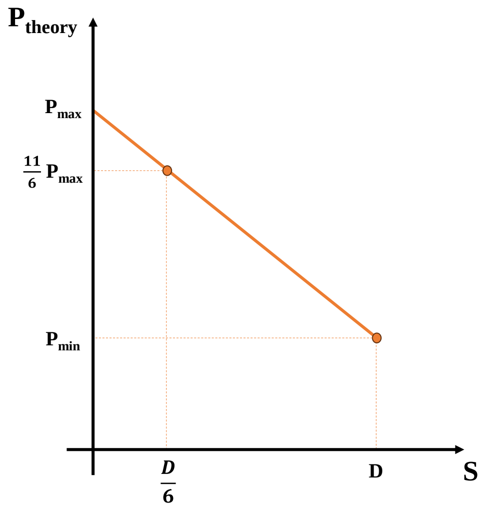

Figure 3 : Qualitative plot describing theoretical power as a function of overlap

On the other hand, the characteristic curves of Savonius turbines should be analyzed. These curves describe the relationship of the power coefficient versus the *Tip speed ratio* (λ).

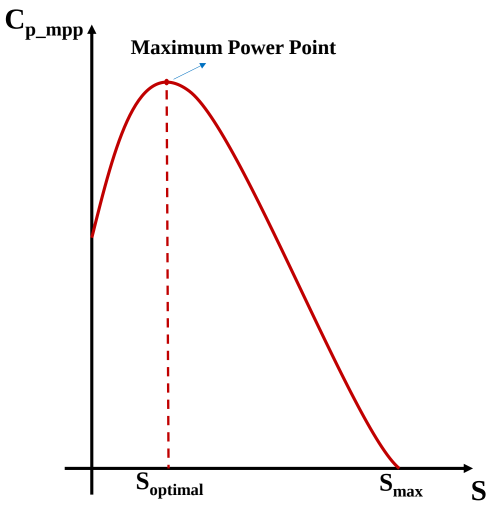

Figure 4 : Characteristic curve for a Savonius turbine

Figure 4 shows that the maximum power coefficient is reached when the Overlap value is equal to D/6. This shows that the point of maximum efficiency (maximum power coefficient) does not necessarily coincide with the point of maximum power generation.

Figure 3 shows the characteristic curves of the Savonius turbine. These curves describe the relationship between the power coefficient versus the speed rate (λ).
The height of the curves depends directly on the overlap of the blades. As the overlap increases, the size of the curve is reduced, both in the x and y axis, this is because the maximum power coefficient that the turbine can have will be much lower than in the case where the overlap is of a width of d/6, overlap where the maximum power coefficient will be obtained.

In case the turbine overlap is kept fixed, the power coefficient will become maximum at a fixed λ value.

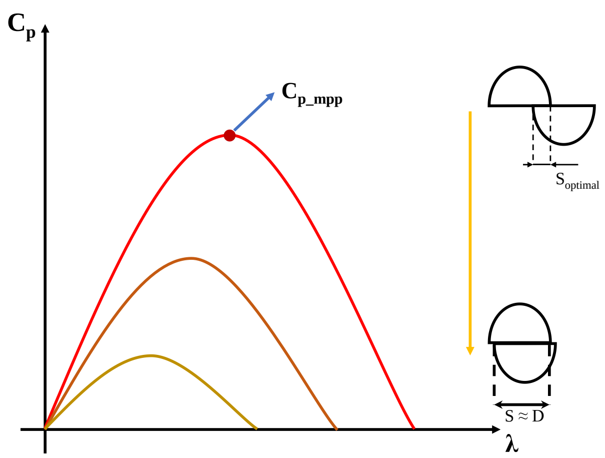

Figure 5 : Characteristic curves of a Savonius turbine

With this problem in mind, we will try to always keep the maximum of each curve by controlling the opening of the blades

4. Design Proposal

The work proposal involves the design of a system that allows the axial displacement of the blades of a Savonius rotor. This will allow, using a suitable control system to ensure that the turbine always works with maximum efficiency regardless of the wind speed, to work following the maximum power point (MPPT).

Therefore, the system to be designed will consist of the following blocks, as shown in the following figure.

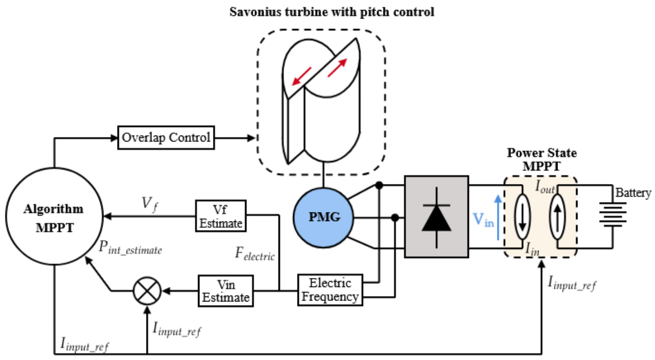

Figure 6 : General work outline

- **Savonius Rotor.** Mechanical system that allows the blades to move in the transverse axis.
- **Electrical frequency measurement system.** Design of an electronic instrumentation system for phase-to-phase PMG electrical frequency measurement.
- **PMG Generator.** A permanent magnet machine will be selected based on the available characteristics.
- **Power Stage.** The most suitable topology will be selected for the extraction of energy on a DC bus, formed by a battery system.
- **Control System,** for the Savonius rotor to operate at maximum power point (MPPT).
- **Communication IoT.** MQTT protocol for turbine parameter monitoring and control.

5. Mechanical Design

One of the key points of this project is the mechanical design of the Savonius rotor. The design consists of creating a mechanism that allows the regulation of the blade position, seeking a robust and simple system.

For this purpose, a rack and pinion system has been implemented to move the blades. This system is composed of a driving gear (pinion), that will transmit the movement to the rack. The rack will be a linear gear that accompanies the movement of the turbine blade. In this way we achieve direct control over the size of the overlap, being able to take it from the optimum point to the point where the overlap becomes maximum, when the blades are closed.

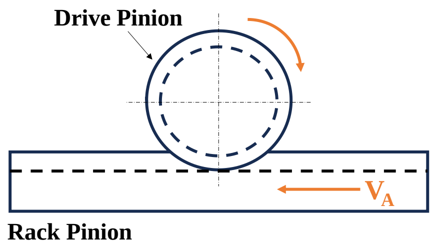

Figure 7 : Operation of the rack pinion and drive pinion mechanism

The size of the overlap is then defined as a function of the output power, which means that this distance must always be taken to a constant output power, varying angular velocity as a function of the overlap opening.

The rack feed rate for one complete revolution of the pinion is given by the following expression:

$$A = \pi \cdot dp = p \cdot Z \qquad (2)$$

Where:

- **A** is the advance realized by the rack pinion**.**
- **Dp** is the primitive drive pinion diameter.
- **P** is the pitch of the teeth**.**
- **Z** are the teeth of the pinion.

Reformulating this expression, we obtain that the displacement to be searched is:

$$A_{\text{objetive}} = \frac{\varphi}{2} \cdot dp = \frac{\varphi}{2 \cdot \pi} \cdot p \cdot Z \qquad (3)$$

Where φ is the spin to be made by the pinion to achieve this feed rate.

Equation 3 describes the relative advance of the rack as a function of the pinion rotation angle. Knowing the relative advance, we can know the movement of our turbine from the point of protection, where both blades are overlapped, to the optimum operating point, this will be when the overlap between the two, the overlap, is a value of d/6. Therefore, the maximum travel will be $\frac{11}{12}d$. With this value, it is possible to obtain the angle of rotation necessary to reach that position.

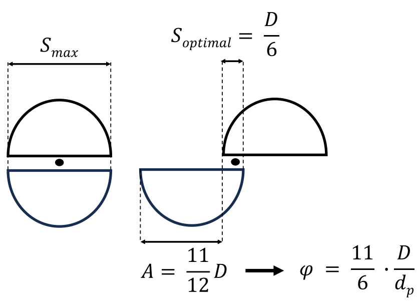

Figure 8 : Calculation of the maximum relative feed rate of the rack from the protection point to the optimum working point.

Once the necessary calculation has been made to obtain the frontal area of the turbine (A), the theoretical calculation of the theoretical power of the turbine as a function of the area, or in our case of the overlap, since it maintains a linear relationship with the area.

Based on this premise, it is possible to predict how the power coefficient varies as a function of the overlap, and of the indicator speed at the turbine blades, in our case, the wind speed.

$$A = h \cdot (2 \cdot D - S) \qquad (4)$$

The new theoretical power, as a function of overlap and fluid velocity may be obtained by replacing equation 4 into equation 1.

$$Pt(S, v) = \frac{1}{2} \cdot \rho \cdot v^3 \cdot (2 \cdot D \cdot h - S \cdot h) \qquad (5)$$

Where:

- **Pt** is the theorical power
- **ρ** is the fluid density, in this case, the air.
- **v** is the fluid velocity
- **D** is the blade diameter
- **H** is the blade height
- **S** is the overlap

Figure 9 shows the prototype of the system developed for the theoretical demonstration. In this case, the design was based on a commercial PMG generator.

On the bottom of the system and as seen of Figure 9, a stepper motor will provide rotational power directly to the pinion. The stepper motor was chosen because of its high precision for position control.

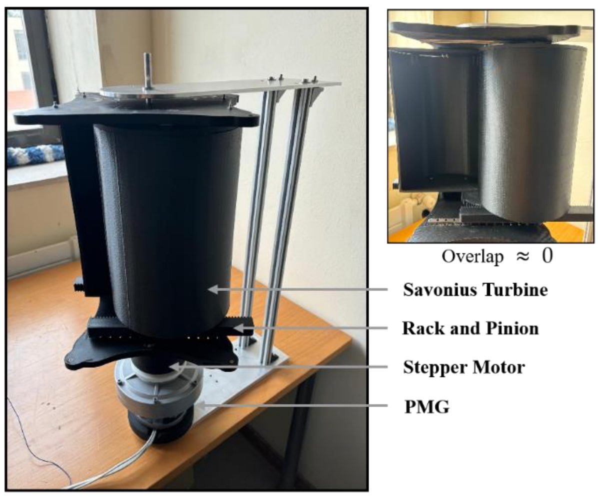

Figure 9 : Savonius turbine with pitch control

Continuing upwards, we find the transmission mechanism mentioned above.

Finally, we have the Savonius turbine blades, positioned both at the top and at the bottom of two rails that allow to isolate the displacement of the turbine on a single axis.

The structure has been designed for the holding torque of the stepper motor to maintain the overlap during operation, and to allow Dynamic changes on its value as the entire turbine rotates.

6. Operation of the Savonius turbine Pitch control system

In a conventional wind turbine, pitch control focuses on controlling the angle of attack of the blades according to the power of the system, thus modifying the efficiency of the system as a function of wind speed.

The main objective of this project is to linearly regulate the blade position, in this case, the variable to be controlled is the blade overlap. For this purpose, two alternative pitch control systems have been designed, whose detailed configurations are presented in Figure 10 and Figure 11.

Figure 11 shows the first operating system. It consists of:

- In zone 1 of operation, the turbine has not reached the minimum wind speed to start turning our generator, therefore, it will be closed.
- In zone 2, the turbine has reached the start-up speed (Cut - In), therefore, it starts working at the maximum power point, until it reaches the maximum speed point (Cut - Out).
- In zone 3, the turbine has exceeded the maximum operating speed and enters the protection zone, closing the turbine blades, where the overlap becomes maximum.

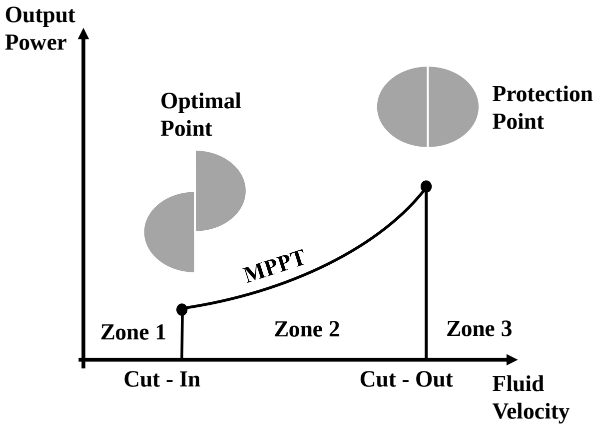

Figure 10 : First operating system

The second proposal, shown in Figure 11, consists of four operating zones, in which a maximum power zone has been included [11].

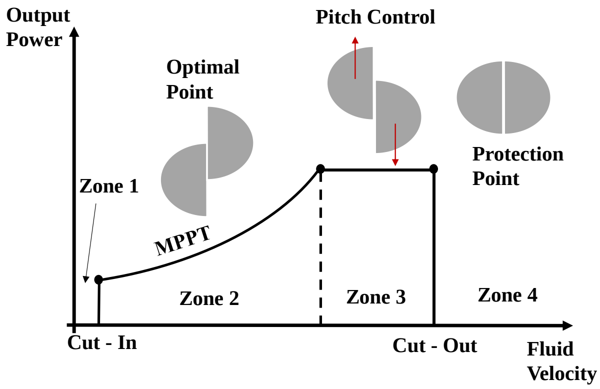

Figure 11 : Second operating system

- Zone 1. The rotor remains stationary until the minimum operating speed or Cut - In is exceeded, in the same way as in the previous proposal.
- Zone 2. In this zone the minimum operating speed has been exceeded. The overlap adapts until the maximum power point is reached.
- Zone 3. Once this working zone is exceeded, the pitch control system will start working. As the speed increases, the overlap will be regulated, in such a way that the power output remains constant. The working zone of our turbine would be delimited by the maximum speed (Cut - Out). Where it would enter in the zone 4 of operation.
- Zone 4, the maximum operating speed is exceeded, therefore, the blades will be closed completely and making the maximum overlapping.

7. Conclusion and future Works

In this work, a new mechanical design proposal is developed for the control of the blades of a Savonius turbine. In addition, two alternative operating systems are proposed for its implementation.

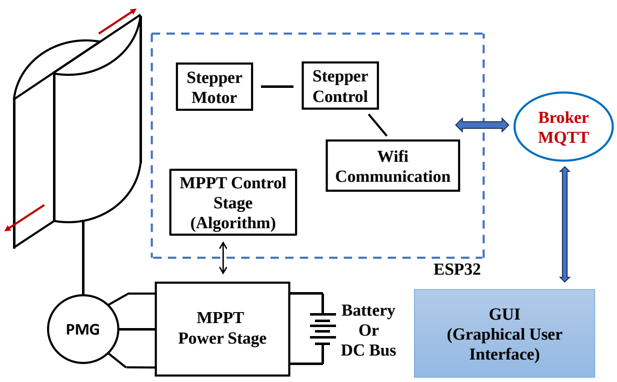

Figure 12 : Block diagram of the developed system

Figure 12 shows a schematic of the prototype where the following parts are highlighted:

- **Savonius Turbine with Pitch Control**. Savonious turbine blade control system.
- **Power Stage.** Rectifier stage, power converter

- **Parameters reading.** Starting from the electrical frequency of the PMG, the electrical and mechanical parameters will be obtained.
- **MPPT Algorithm**. Through an MCU unit, complete control of the overlap will be performed.
- **IoT technologies.** Implementation of IoT technologies for data monitoring and analysis.

By means of the MPPT algorithm, the turbine is made to operate in conditions that maximize its power generation. The system regulates the rotational speed, which is determined by measuring the electrical frequency of the generator.

Before starting up the system, tests were carried out to understand the behavior of the generator and to create a mathematical model. Thanks to this model, the speed at which the internal parts of the generator rotate can be calculated by simply measuring the frequency of the electric current.

The mechanical design of the system is the result of a thorough analysis of many factors and conditions. Despite its complexity, two problems have required special attention:

- **Aligning the center of mass with the rotational axis.** One of the complications was to develop a system that could keep the center of mass stationary, with respect to the axis perpendicular to the ground. The proposed system meets this specification, thus having the center of mass on the vertical axis of our turbine.

- **The system avoiding interference with the PMG**. It is essential to ensure continuity in power generation and power supply to the PMG. Therefore, the blade adjustment system must operate without interruptions in the generation process.

This solution offers a novel and unique approach, not only at the mechanical level but also in terms of its operating systems. In addition, an IoT-based data acquisition system is proposed to monitor in real time the electrical and mechanical variables of the system.

As a proposal for the future, numerical simulations are proposed. These simulations will make it possible to analyze the behavior of the system under different loading conditions and to evaluate the influence of various design parameters. A finite element analysis will be carried out to determine the stresses and deformations in the critical structures, as well as a computational fluid dynamic analysis (CFD) to optimize the aerodynamic profile of the blades.

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