T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

IMPROVEMENT OF VAWT SAVONİUS TURBİNE MECHANİCAL POWER FOR THE POWER GENERATİON PURPOSES OF SHORE POLES

MASTER'S THESIS

Wissal Rajeb

Department of Mechanical Engineering

Mechanical Engineering Program

September, 2023

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(Y2113.081010)

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Thesis Advisor: Assist. Prof. Dr. Mohammed ALKRUNZ

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DECLARATION

At this moment declare concerning the study "Improvement of VAWT Savonius Turbine Mechanical Power for the Power Generation Purposes of Shore Poles”, which I submitted as a Master. The thesis is written without any assistance in violation of scientific ethics and traditions in all the processes from the Project phase to the conclusion of the thesis, and the works I have benefited from are from those shown in the References. (11/09/2023)

Wissal Rajeb

FOREWORD

I want to start by thanking God in the greatest way possible for allowing me to be who I am today and giving me the determination and confidence to finish this thesis.

I also want to thank my family for teaching me to follow my goals, never give up, and for supporting me in my decision to get a master's degree abroad.

I consider myself very lucky to work with Dr. Mohammed Alkrunz. I want to thank him for being so kind and helpful as he helped me through the research process. He is a leader in his domain and an intelligent individual who never stops motivating me.

Finally, I am grateful to Istanbul Aydin University for all that it has done for me, academically and by introducing me to extraordinary individuals who have motivated, challenged, supported, and motivated me.

September 2023 Wissal Rajeb

IMPROVEMENT OF VAWT SAVONİUS TURBİNE MECHANİCAL POWER FOR THE POWER GENERATİON PURPOSES OF SHORE POLES

ABSTRACT

This study presents an improvement in the design of the VAWT Savonius turbine based on changing the swept area to provide better power generation. It is aimed at this design to provide charging poles to be located along the shore. The swept area is designed with a reasonable height and rotor diameter whereas the Savonius rotor is suggested to be made with two semi-circular shapes blades of aluminum that have an acceptable estimated load since this load plays a big role in the rotation of the turbine. In this research, the shaft frequency in rpm is estimated using the artificial neural network (ANN) where the annual wind speed data for different areas in Turkey are used. The Savonius turbine mechanical power calculation results show that different accepted power ranges can be obtained. Considering this design’s simplicity, multiple poles can be planted along the shore areas to provide a charging power supply for small electronic devices. This design is considered to be suitable for this kind of area since it is built with a low cost, does not need a specific wind direction, and can rotate with a low wind speed.

Keywords: Savonius Turbine, Swept area, shaft-frequency, Savonius rotor, wind speed.

VAWT SAVONİUS TÜRBİNİ MEKANİK GÜCÜNÜN KIYI DİREKLERİNİN GÜÇ ÜRETİMİ AMAÇLARIYLA İYİLEŞTİRİLMESİ

ÖZET

Bu çalışma, daha iyi güç üretimi sağlamak için süpürülen alanı değiştirmeye dayalı olarak VAWT Savonius türbininin tasarımında bir gelişme sunmaktadır. Bu tasarımda şarj direklerinin kıyı boyunca konumlandırılması amaçlanmaktadır. Süpürme alanı makul bir yükseklik ve rotor çapı ile tasarlanırken, Savonius rotorunun, bu yük türbinin dönüşünde büyük bir rol oynadığından, kabul edilebilir bir tahmini yüke sahip alüminyumdan yapılmış iki yarı dairesel şekilli kanatlardan yapılması önerilir. Bu araştırmada, Türkiye'nin farklı bölgeleri için yıllık rüzgar hızı verilerinin kullanıldığı yapay sinir ağı (YSA) kullanılarak rpm cinsinden şaft frekansı tahmin edilmektedir. Savonius türbin mekanik gücünün hesaplama sonuçları, kabul edilen farklı güç aralıklarının elde edilebileceğini göstermektedir. Bu tasarımın basitliği göz önüne alındığında, küçük elektronik cihazlar için şarj güç kaynağı sağlamak üzere kıyı bölgeleri boyunca birden fazla direk dikilebilir. Bu tasarımın düşük maliyetle inşa edilmesi, belirli bir rüzgar yönüne ihtiyaç duymaması ve düşük rüzgar hızıyla dönebilmesi nedeniyle bu tür alanlar için uygun olduğu düşünülmektedir.

Anahtar Kelimeler: Savonius Türbini, Süpürme alanı, şaft frekansı, Savonius rotoru, rüzgar hızı.

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ABBREVIATIONS

GHG : Green House Gases

WT : Wind Turbine

HAWT : Horizontal Axis Wind Turbine

VAWT : Vertical Axis Wind Turbine

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I. INTRODUCTION

One of the prime commodities in modern civilization is energy. The amount of energy consumed has become an indicator of the standard of living and the degree of industrialization. At present, nearly ninety percent of the world's energy comes from the combustion of fossil fuels, i.e., coal, petroleum oils, natural gas, etc. People use fossil fuels to meet nearly all of their energy needs, such as powering vehicles, producing electricity for light and heat, and running factories. (Nimvari et al., 2020).

Based on the collected data for the Global Energy Statistical Yearbook 2020, emissions are increasing almost every year globally, which endangers the future of the Earth and human life. One way to reduce the impact of emissions caused by GHG is to use renewable energy sources. In particular, significant attention is paid to renewable and pollution-free energies like wind and solar. Although clean energy is inevitable, it is interesting for researchers, scientists, and engineers to create other types. Furthermore, wind energy has become one of the most viable alternative energy resources, with recent technological advances leading to more efficient turbine designs. Also, wind energy is renewable as long as the wind keeps blowing. Unlike finite fossil fuels, which contribute to environmental pollution and climate change, wind energy is clean and does not produce greenhouse gas emissions or air pollutants during operation. As such, it refers to harnessing the wind's power to generate electricity or perform mechanical work. Also, wind energy involves converting the kinetic energy present in the wind into usable energy. This is typically achieved through wind turbines with large blades mounted on a rotor that spins when the wind blows.

In 2015, different aspects of WT enhancement helped increase the effective output power of a WT by increasing the aerodynamic efficiency of wind turbines. However, in 2018, the HAWT is commonly known and utilized, while the VAWT is relatively new, and research is being conducted on it due to its advantages over the HAWT. In 2019, all types of VAWTs were studied, including the hybrid Savonius-

Darrius, but we did not cover many variations of each type to decide if any variation had better performance. All types of wind turbines are developing, and wind turbine machines, in general, are becoming more complex and flexible. (Eftekhari et al., 2022).

Thus, there are two types of wind turbines to extract wind energy: horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs). VAWT designs can be split into two main categories: lift types (Darrius) and drag types (Savonius). Savonius wind turbines have suitable starting characteristics, relatively low operating speeds, are simple in structure, and can capture wind from any direction. Many researchers have experimentally and numerically investigated the effects of design parameters such as the number of blades, the amount of overlap and separation gap between rotor buckets, section field profile change, the upper and lower plates of the blades in the static and dynamic states of the rotor, the aspect ratio of the rotor, and power augmentation devices for improving the aerodynamic performances of Savonius wind rotors. (Altan, B. D., & Atılgan, M. 2012).

Horizontal Axis Wind Turbine (HAWT): It is a type of wind turbine where the main rotor shaft and electrical generator are positioned horizontally, and the blades rotate around a horizontal axis perpendicular to the direction of the wind. HAWTs are the most common type of wind turbine used for generating electricity on a large scale.

The principal working mechanism of a HAWT involves the following steps:

- Wind Capture: The rotor turbine's rotor blades are designed to capture the kinetic energy present in the wind. The shape and angle of the blades are optimized to maximize the extraction of wind energy.
- Rotation: As the wind blows, it causes the rotor blades to rotate around the horizontal axis. The rotational motion is transmitted through the rotor shaft to the generator, which converts the mechanical energy into electrical energy.
- Power Generation: The generator uses electromagnetic induction to convert the rotational motion into electrical energy. The generated electricity is then transmitted to the power grid or stored in batteries for later use.

Advantages of HAWTs:

- Efficiency: HAWTs have higher energy conversion efficiency compared to other wind turbine designs. Their orientation allows them to capture wind from any direction, maximizing energy production.
- Scalability: HAWTs can be built in various sizes, ranging from small turbines for residential use to large-scale installations for commercial electricity generation.
- Mature Technology: HAWTs have been in use for many years and are well-established technology. This means that there is a wealth of knowledge and expertise available for their design, installation, and maintenance.

Disadvantages of HAWTs:

- Space Requirement: HAWTs require a significant amount of space to operate effectively. Large wind farms need expansive areas of land, which can be challenging to acquire in densely populated regions.
- Visual Impact and Noise: The large size and rotating blades of HAWTs can cause visual impact and generate noise. This can be a concern for nearby residents and impact the landscape’s aesthetics.
- Wind Dependence: HAWTs require a minimum wind speed to start rotating and a certain range of wind speeds to generate electricity efficiently. In areas with inconsistent or low wind resources, HAWTs may not be suitable. (Wenehenubun.F.et al .2015) (Hansen, H.O. 2015) (Global Wind Energy Council.2021)

Vertical Axis Wind Turbine (VAWT): It is a type of wind turbine where the main rotor shaft and generator are positioned vertically, and the blades rotate around a vertical axis. Unlike HAWTs, VAWTs can capture wind from any direction without the need for wind-tracking mechanisms. The principal working mechanism of a VAWT involves the following steps:

- **Wind Capture**: The turbine's rotor blades are designed to capture the kinetic energy present in the wind. The shape and angle of the blades are optimized to maximize the extraction of wind energy.
- **Rotation**: As the wind blows, it causes the rotor blades to rotate around the vertical axis. The rotational motion is transmitted through the rotor shaft to the generator, which converts the mechanical energy into electrical energy.
- **Power Generation**: The generator uses electromagnetic induction to convert the rotational motion into electrical energy. The generated electricity is then transmitted to the power grid or stored in batteries for later use.

Advantages of VAWTs:

- Omnidirectional Wind Capture: VAWTs can capture wind from any direction, making them suitable for areas with turbulent or unpredictable wind patterns. They do not require wind tracking mechanisms like HAWTs.
- Scalability and Compact Design: VAWTs can be built in various sizes and can be installed in compact spaces. They are well-suited for urban and residential environments where space is limited.
- Lower Noise and Visual Impact: VAWTs generally produce less noise and have a lower visual impact compared to large HAWTs. This makes them more suitable for locations with stricter noise regulations or aesthetic considerations.

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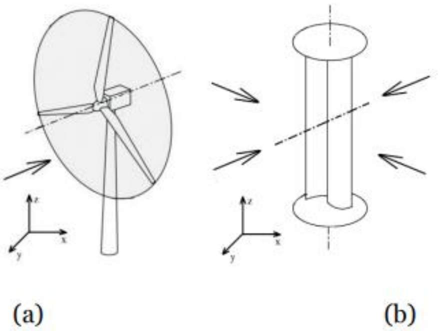
Disadvantages of VAWTs:

- Lower Efficiency: VAWTs typically have lower energy conversion efficiency compared to HAWTs. Their design and orientation can result in lower aerodynamic performance and reduced power output.
- Increased Mechanical Complexity: VAWTs often require additional mechanical components to transfer the rotational motion from the vertical axis to the generator. This complexity can increase maintenance and operational costs.
- Limited Availability of Commercial Designs: There is a relatively smaller market for commercial VAWTs compared to HAWTs. This can limit the availability of standardized designs, spare parts, and maintenance services. (Wenehenubun.F.et al .2015) (Hansen, H.O. 2015) (Global Wind Energy Council.2021)

Wind turbines can be classified by the way they extract energy from the wind flow: using purely drag, lift forces, or both. The horizontal axis wind turbine (HAWT) is purely lift type. Due to the special shape of the blade, the pressure distribution around the blade generates the lift force along the blade length. This type of rotor is called the propeller type. Lift-type devices offer the most efficient way to convert wind energy into electrical or mechanical energy. (Burton et al. 2002: 41–51).

The wind profile in urban areas is characterized by lower mean wind speed and larger fluctuations in both direction and magnitude in comparison to rural areas. (McIntosh 2009) The HAWT design is not preferable for operation in urban areas, since they demand a control system installation to follow these wind speed and direction changes.

Meanwhile, the VAWTs are less dependent on the changes in wind direction. Therefore, they are assumed to fit better in the built environment. VAWTs may operate using both drag and lift forces, and their blades can be straight or curved. They do not require the yaw drive mechanism needed by the HAWTs since they can catch wind from any direction. Examples of both turbine types are shown in Figure 1. As shown schematically in Figure 1, the Savonius wind turbine and VAWTs in particular are not impacted by variations in wind direction. (Marmutova, S. 2016)



(a) (b)

Figure 1: HAWT and VAWT with the direction of Wind

II. LITERATURE REVIEW

As a renewable and sustainable type of energy, wind energy has attracted a lot of interest. Wind turbines, which turn wind energy into electricity, are essential for using this rich resource. With a focus on design, performance, and environmental factors, this survey of the literature offers an overview of significant research findings and advances in technology relating to wind turbines. Important contributions to the field are highlighted in the sources referenced below.

The authors present a design that combines the characteristics of two designs of small-scale vertical axis wind turbines (VAWT); Savonius and Darrieus turbines. In this research, the authors analyzed different VAWT rotors commonly used for low speeds. The authors considered the need for a small amount of energy for household applications such as lighting. The study stated that the combination of the two mentioned designs can show high advantages and features. Namely, the Savonius turbine is considered a self-starting model that provides high torque while the Darrieus turbine is not a self-starting model where it can show higher efficiency when compared to the other design. Therefore, the authors conclude that the combined design increases the capacity of power generation at low wind speeds (P. K. Chandrasekhar. Et al. 2019).

(Mohammed H. A. 2012) compared two models of two and three blades with an aspect ratio (H/D = 1) to study the performance of the corresponding designs. The presented models are created from an aluminum sheet, and the blades were built of semi-cylindrical half-diameter shapes. Due to several factors, particularly the Savonius wind turbine's maximum performance at (TSR = 1) and a high starting torque at low wind speed, these two models were tested and studied using a low-frequency turbine designed for this purpose. Thus, the measured and estimated findings show that the two-blade Savonius wind turbine is more effective than the three-blade Savonius wind turbine under similar test conditions. The Savonius wind turbine's net torque will decrease as the number of blades increases because more surfaces will drag against the wind's airflow, which will also cause more reverse torque to build.

(Langlang G. et al.2019) present a review of the power and torque on Savonius type L vertical wind turbines. Based on the authors, the Savonius-L vertical axis wind turbine was chosen because the edge of the blade is curved like the letter L, which allows for the keeping of dropped wind at the turbine's blade while also increasing power. Since this angle will be used as a variable of input in the simulation, it is important to take it into effect. The scenario is the amount of power that the turbine can produce under various conditions, including wind speed, rotor rotation speed, and torque. The following scenario involves electricity dependent on the turbine's number of blades. At a wind speed of 20 m/s, a turbine with two blades may collect the maximum power of another turbine. Thus, more power can be obtained by the turbine and more torque can be generated the faster the wind moves. Additionally, the rotor torque will be less the faster the rotor rotates. The power will be smaller when there are more turbine blades. If employing two blades, the blade on the Savonius type L turbine is ideal.

(Chandrakant R S. et al 2021) present to use the most amount of wind energy possible, they have chosen wind tree applications for this paper's numerical analysis of three different vertical axis rotor design types. Three distinct geometrical configurations—the Savonius helical Bach rotor, the simple Savonius rotor, and the primary Bach rotor—are simulated using computational fluid dynamics to determine how well they would operate. Also, these three rotors' coefficients of power and power output are assessed. A MATLAB-based simulator is created to assess the power generated by these three rotors, and the results are compared with CFD findings for validation. Thus, according to their research, the simple Savonius and simple Bach rotors were compared, and the helical-type Bach rotors outperformed them.

In the study of (Lajnef. M. et al. 2020), the author presents that The performance of a Helical Savonius wind turbine is affected by the overlap distance and the blade shape. In this research, the authors, the flow field characterizations, torque variation, and power coefficient are used for performing assessment procedures using modeling. Thus, the authors are motivated in their research by the current results to look into how to make the winding Savonius rotor work better. Therefore, Future research may focus on using an appropriate defector system above the delta-bladed rotor.

Some studies experimentally investigate various Savonius wind turbine shapes to identify the optimal operation parameters by researchers (N.H. Mahmoud et al 2012). Although, it was discovered that rotors with two blades are more effective than those with three and four. Also, a rotor with end plates performs more efficiently than one. Therefore, Performance-wise, double-stage rotors are superior to single-stage rotors. As such, the functioning of the rotors without overlap, ratio is better than that of the rotors with overlap. The outcomes also demonstrate that as the aspect ratio rises, the power coefficient does as well. Thus, the findings from the measurements of the static torque for each rotor at various wind speeds confirm the work's findings as summarized in their research. Also, by measuring the amount of mechanical torque on the rotating shaft and the rotational speed at various wind velocity values, the mechanical power for the tested Savonius rotor is calculated.

(Altan. B. D& Atılgan. M. 2012) present intended to increase the rotor performance of the Savonius wind rotor with the theoretical method by focusing on a curtain arrangement as a wind deflector with a simple construction, which has been designed to increase the performance of the Savonius wind rotor. Also, this curtain arrangement has been placed in front of the rotor to prevent the negative torque that occurs on the convex surface of the Savonius wind rotor and causes the performance of the rotor to be low. Thus, it has become possible to make more efficient use of wind energy increasing the low-performance level of the Savonius wind rotors.

In the study (Comparison of Blade Dimension Design of a Vertical Wind Turbine Applied in Low Wind Speed) the authors present The type of vertical turbine utilized` for this study as a Savonius, which comprised blades with a half-cylinder-shaped profile. The swept area had a significant impact on how well the turbine rotated. The swept area has an impact on both the drag and lift forces. There were positive and negative aspects to both forces. Because of this, dimensional engineering was used to create the turbine's ideal performance. The overlap ratio, or distance between the blades, was connected to the dimensions. Because variations in the overlap ratio have an impact on the swept area, the overlap ratio plays a part in both upwind and downwind wind flow. Thus, the overlap ratio was varied experimentally at distances of 0 cm and 10 cm. (Yuliandi, R. B et. Al 2018)

This study presents how modifying the variable swept areas can generate the most power from vertical axis wind turbines (VAWTs) researchers (Jazuli Fadil et al. 2017). As such, the authors utilized VAWTs of the H-Darrius type, which have expandable blades and a radius when the wind speed is low, these turbines automatically increase their swept area; when the wind speed is high, they automatically retract. As such this move, the efficiency is raised and more power is obtained at low wind speeds. Through different swept areas, these creative designs discovered that power generation rose 260% over the turbines. Also, this turbine's rotor diameter and blade height are 50% more than their minimum values. It shows a maximum attachment of 50% for the swept area. Thus, the performance of the VAWT is seriously affected by this design. With a cut-in wind speed of 2 m/s, the turbine would start rotating and increase power output by 260%.

In the study of (Blade shape optimization of Savonius wind turbine at low wind energy by artificial neural network), the authors present using commercial code software ANSYS-CFX and artificial neural networks to numerically forecast the best blade shape for a Savonius wind turbine at low wind speeds to increase the power coefficient value. To estimate the Savonius wind turbine's ideal blade form at a wind speed of 3 m/s and a tip speed ratio TSR of 0.8, simulations present the study of several models used to build artificial neural networks. The effectiveness of the optimum and conventional models has been evaluated over a broad TSR range (0.2-1.2). The power coefficient enhancement ratio that was attained is 55%. Thus, according to the data, the Savonius wind turbine's ideal blade shape is superior to a semicircular one at TSRs between 0.6 and 1.1, making it a better idea for use in urban areas with its difficult conditions and low wind speeds. (Al-Shammari, S, A. et al 2020)

III. PRELİMİNARİES

In contrast, VAWTs have low-pressure coefficients, therefore the scope for major research on VAWT rotors is to improve their performance. VAWT rotors have different types, such as Savonius rotors. Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically as the plane of rotation is vertical. Blades are also vertical in this arrangement. The biggest advantage of VAWTs is they don’t require a yaw control mechanism to be pointed into the wind. Thus these are used turbine's rotor blade section is random or there is the presence of large obstacles like trees, houses, etc. Also, VAWTs don’t require a tower structure and can be placed near the ground, enabling access to electrical components. Some drawbacks are the low efficiency of wind production and the fact that large drag is created for rotating the blades on a vertical axis.

A. Force Basic Concepts in Types of Turbine

The terms turbines (rotors), also known as aerodynamic lift and aerodynamic drag devices, relate to two different categories of wind energy conversion systems. In real practice, fluid airflow across solid objects happens frequently. Many physical phenomena are caused by it, such as the lift force generated by airplane wings, the dust in high-wind turbines, etc., and the drag force acting on vehicles, trees, etc.

The two processes—body movement through a quiet fluid and fluid motion over a single body—are compared. The fluid and the body must move about one another. These movements are referred to as outside flow or flow over bodies.

1. **Lift Force (L):** A body covered in motionless fluid experiences just normal forces on its surface. However, perpendicular shear pressures are also applied to a body's surface. The flow direction is a component of both of these forces. As a result, pressure and wall tension acting in the flow direction combine to produce drag. The parts of pressure and wall-shear forces that tend to move the body toward the fluid flow are called lift. As a result, the lift/drag ratio

significantly affects a wind turbine's efficiency, and it is ideal for a turbine blade to run at the highest percentage for the best wind energy extraction. The movement of the wind turbine blades of a high-speed turbine is based on lift forces. The blades' linear speed is often many times greater than the wind's. When compared to the drag type, the torque of the lift force is lower.

2. **Drag Force (D):** The wind moves more slowly than low-speed turbines. They are primarily propelled by drag. The rotor shaft receives an average amount of torque. There are two types of wind turbines: (a) horizontal axis wind turbines and (b) vertical axis wind turbines. The axis of rotation in horizontal-axis turbines is horizontal concerning the ground. In this particular case, the blades are parallel to the ground and the rotating shaft is parallel to the surface.

The axis of rotation in vertical-axis turbines is vertical about the ground. It has been found that when a body is pushed to move through a fluid, particularly through a liquid, it encounters some resistance. It is good knowledge that running on water is extremely challenging because of the water's significantly higher motion resistance compared to air. The powerful pressures the moving winds put on the human body are also felt. Drag force is the force a fluid in motion applies to a body as it moves in the direction of the fluid. By connecting the body being subjected to fluid flow to a calibrated come and finding the displacement in the direction of the flow. Like friction, drag is often a negative force that is minimized if possible.

In comparison to vertical-axis designs, horizontal-axis or propeller-type turbines are more typical and well-developed. Machines with vertical axes run independently of the wind. Direct coupling to the axis at ground level is possible for the gearbox and the generating equipment. The following limitations of vertical-axis machines are present: they are not self-starting; controlling speed in strong winds is complex; and the torque increases with each rotation as the blades travel forward or backward from the wind. Most of the operating machines are of the horizontal-axis kind as a result of these limitations. (Lumley, J. L. and Panofsky, H. A. 1964.)

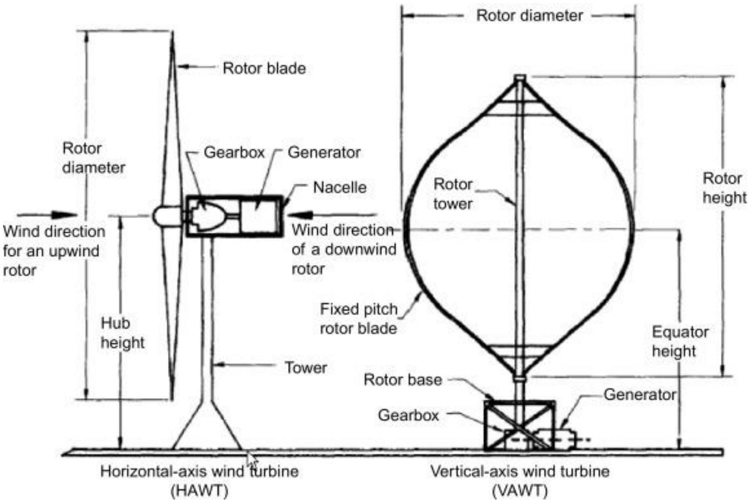


Figure 2: View of a wind turbine with a vertical and horizontal axis

B. Types of VAWT

Several types of Vertical Axis Wind Turbines (VAWTs) vary in their design and configuration. When comparing VAWT types, factors such as efficiency, starting performance, structural integrity, and scalability are often considered. Each design has its advantages and disadvantages, which can vary depending on the specific application and site conditions.

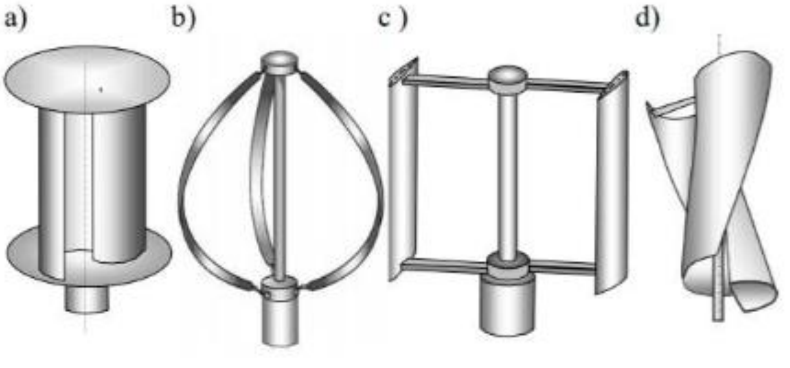


Figure 3: Design of VAWT : a) Savonius. b) Darrius. c) H type. d)Spiral

There are a few common types:

Savonius Type: The Savonius wind turbine is a kind of VAWT with blades with curves that are shaped like a "S" and in a semicircle. As the wind passes over the curved blades, drag will be created, causing rotational motion. The Savonius turbine is known for its ease of use, dependability, and capacity to begin rotating at low wind speeds. However, compared to other VAWT designs, it often has lower efficiency. (Moura. A.P. et al. 2019)

Darrius Type: The Darrius wind turbine, commonly referred to as the "eggbeater" turbine is a VAWT with vertical blades that resemble airfoils and are bent like them. As the wind passes over the curved blades, lift forces are produced, which cause the turbine to spin. Darrius turbines are appropriate for both urban and suburban settings and can gather wind from any direction. However, compared to certain other wind turbine designs, they may have compared efficiency and frequently need extra mechanisms for self-starting. (Grupta. A et al 2016)

H-Type: The Darrius turbine design has been modified for use in the H-type wind turbine. The top and bottom of the vertical axis are each equipped with an extra straight blade. The Darrius turbine's stability, self-starting abilities, and general performance are all intended to be improved by this configuration. (Khaled. M. et al. 2015)

Spiral Type: A VAWT having blades that are formed like a spiral or helix is known as a spiral windmill or spiral VAWT. The blades' helical design makes it possible for them to efficiently collect wind coming from various directions and produce rotational motion. Several configurations of spiral turbines are possible, including single- and multiple-helix designs. They are known for their small size, simplicity, and capacity to begin rotating in the presence of low winds. (Chauhan, V, S. et al. 2016)

The Savonius & Darrius VAWT is a basic model to develop a research and testing methodology. It is well observed that the Cyclogira-type wind turbine is at the upper hand and best performing while the Savonius is at the lower end.

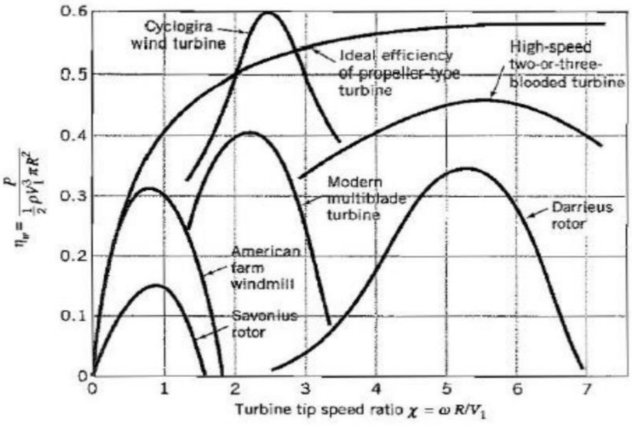


Figure 4: Efficiency trends for wind turbine types versus tip speed ratio

C. Design of Rotor Wind Turbine

A wind turbine's design must take into account several factors to be effective and affordable. An effective blade design is generally understood to maximize lift and reduce drag on the blade. The airfoil should face the relative wind in a way that exposes the least amount of surface to the wind's drag force to minimize drag.

Additionally, the respective magnitudes of the wind speed and the blade velocity define the angle of this relative wind to the blades. In this case, the critical thing to notice is that while the blade velocity rises from the inner edge to the tip, the wind velocity remains constant across the swept area. This suggests the wind's relative angle to the blade is always changing. Now, many variables that affect how a wind turbine is designed are listed below:

Diameter of the Rotor: The power produced is a useful amount since it is directly related to the square of the rotor's diameter. Fundamentally, it depends on the relationship between the amount of electricity that must be generated at the best possible efficiency and the local average wind speed. Power generated,

$$P = \eta_e \, \eta_m \, C_P \, P_0 \tag{2.1}$$

$$P = \left(\frac{1}{2}\right) \eta_e \ \eta_m \, C_p \, A \, \rho \, V_\infty^3 \tag{2.2}$$

$Efficiency$ of electrical generation

$$P = \left(\frac{1}{8}\right) \eta_e \, \eta_m \, C_P \ \pi \, \rho \, D^2 \, V_\infty^3 \tag{2.3}$$

η_m = efficiency of mechanical transmission

The mathematical equations listed below can be applied in the absence of hard data:

- For slow rotors

$$P = 0.15 \times V_\infty^3 \times D^2 \tag{2.4}$$

- For faster rotors

$$P = O.20 \times V_\infty^3 \times D^2 \tag{2.5}$$

D. Choice of the number of blades

Both the design and operation of a wind rotor depend on the number of blades used. A larger number of blades is known to cause turbulence in the system, while a smaller number wouldn't be able to efficiently capture the maximum quantity of wind energy. Therefore, each of these limitations should be used to calculate the number of blades, along with an in-depth analysis of its relationship to the TSR.

So, for an n-bladed rotor rotating at an angular velocity, we get the following relation: Let ta be the time it takes one blade to move into the position that the preceding blade previously controlled.

$$t_a = \frac{2\,\pi}{n \times \omega} \tag{2.6}$$

Again, let t_b represent the amount of time needed for the turbulent air caused by the blades' interference to disappear and for normal air to return. Now, the main factor determining this will be the wind speed and the rate of wind flow. As a result, it is dependent on the wind speed V and the length of the significantly perturbed wind flow, say d. Here it is:

$$t_b = \frac{d}{V} \tag{2.7}$$

t_a and t_b should be equivalent to extract the most power possible.

$$t_a = t_b \tag{2.8}$$

$$\frac{2\pi}{n \times \omega} = \frac{d}{V} \tag{2.9}$$

$$d = \frac{2\pi V}{n \times \omega} \tag{2.10}$$

Empirically, determining *d* is required.

E. Power Speed Characteristics

The amount of mechanical power that can be obtained from the wind is greatly dependent on the wind speed, and for every wind speed, there is a turbine rotation speed that is optimal for maximizing the amount of wind power collected at the turbine shaft. At any speed other than this best speed, the system performs below par. Therefore, determining the ideal turbine speed during the range of normal wind stream velocities would be our main objective. Because wind speeds differ from location to location, this phenomenon is essentially region-specific. Now, the shaft's mechanical power supply is as follows:

$$P = \left(\frac{1}{2}\right) \times C_P \times A \times \rho \times V_\infty^3 \tag{2.11}$$

As common information, C_p depends on both the TSR and the pitch angle. The formula mentioned above may be mentioned as follows for a wind turbine with a radius R:

$$P = \left(\frac{1}{2}\right) \times C_P \times \pi \times R^2 \times \rho \times V_\infty^3 \tag{2.12}$$

Now, the TSR is:

$$\lambda = \frac{\omega \times R}{V_\infty} \tag{2.13}$$

It is possible to express the maximum shaft power production for every wind speed as:

$$P_m = \left(\frac{1}{2}\right) \times \left(\frac{R^5}{\lambda^3}\right) \times\ C_P \times \pi \times \omega^3 \times \rho \tag{2.14}$$

$$P_m =\ \alpha\ \times\ \omega^3 \tag{2.15}$$

F. Features of Torque Speed

For each wind speed, the maximum shaft power output may be represented as:

$$T_m = \frac{P_m}{\omega} \tag{2.16}$$

$$T_m = \left(\frac{R^5}{\lambda^3}\right) \times 0.5 \times C_P \times \pi \times \omega^2 \times \rho \tag{2.17}$$

It can be observed that the torque and rotational speed are rapidly connected to the C_p curve's best operating region.

Solidity: The ratio of the extended blade area to the wind-intercepted area determines the solidity of a wind rotor. In most cases, the projected blade area refers to the blade area that is projected into the wind flow or that is met by the wind instead of the real blade area.

Tip speed Ratio: The definition of a wind turbine's tip speed ratio (TSR) is

$$\lambda = \frac{2\,\pi\,R\,N}{V_\infty} \tag{2.18}$$

where,

- V_∞ = Speed of Wind without any rotor intervention.
- R = Radius of the Rotor, which signifies the swept area.
- N = Rotational speed of the rotor in rpm.
- λ = Tip Speed Ratio.

The difference between the rotating speed of a blade's tip and the actual wind velocity is known as the tip speed ratio (λ) for wind turbines. It is non-dimensional and highly effective. Tip speed ratios for 3-blade turbines range from 6 to 7.

G. Coefficient of Power

A wind turbine's coefficient of power essentially represents how well wind energy is converted into mechanical energy, which can be used to power the generators. It varies from the total system efficiency because it excludes the mechanical gearbox losses and the losses associated with producing electrical power.

The mathematical maximum value for horizontal axis machines, sometimes referred to as the Betz limit, is approximately 593 (16/27 or 59.3%). For excellent turbines, it is between 35 and 45 percent.

$$C_p = \frac{Wind\ Machine\ Output\ Power}{Wind\ Stream\ Power\ Content} \tag{2.19}$$

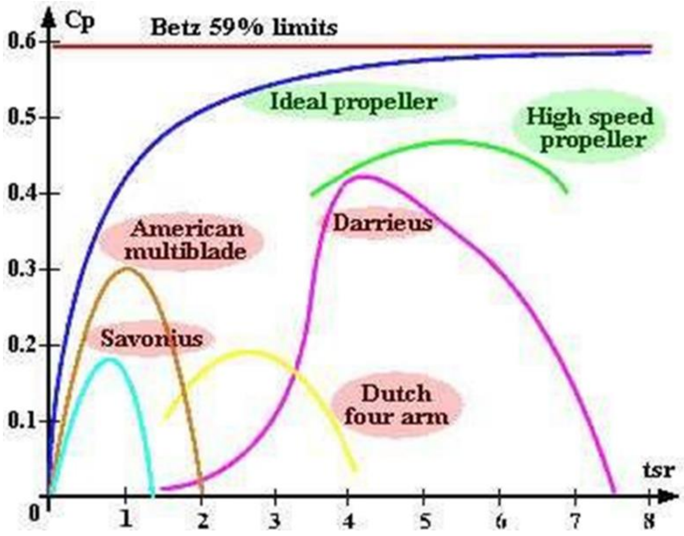


Figure 5: C_p Vs TSR curve for different rotor types

Wind Turbine Ratings & Specifications

For researchers to study the turbine ratings and, in turn, serve as a medium for comparison, a variety of parameters have been developed. One of the most frequently used assessments is the Specific Rated Capacity (SRC), which is essentially the ratio between the power rating of the generator used in the system to the rotor-swept area.

$$SRC = \frac{Power\ rating\ of\ the\ generator}{rotor\ swept\ area} \tag{2.20}$$

Between these ranges, the ratio often varies: $0.2 \geq SRC \geq 0.6$

The top limitations apply to more oversized rotors, while the lower limit is for smaller rotors.

H. Degree of Freedom

The wind generator's power output is optimized using two basic degrees of freedom:

Yaw orientation: The capacity to rotate every turbine unit such that the rotor faces directly into the constantly changing direction of wind flow is what it amounts to. This is done mostly with the help of motors and is covered in depth under pitch control. The information produced by the wind shafts, which serve as this system's sensors, is used to power the motors.

Pitch of blades: Researchers can keep an almost constant rotation rate with the constantly changing wind speeds by changing the blades' pitch. In general, the control is carried out to maximize the turbine's power generation efficiency. If the system is attacked by high wind gusts, the pitch of the blades and the pitch control mechanism may operate as brakes.

The number of blades in a Savonius turbine is one of several variables that affect its performance. Here are some things to think about when determining how many blades a Savonius turbine has, along with sources that back up the facts:

- Power coefficient and torque: The number of blades affects the turbine's power coefficient and torque characteristics. Research has shown that increasing the number of blades can increase the power coefficient, resulting in higher torque output. However, there is an optimal number of blades for maximum performance, beyond which further increases may lead to diminishing returns or increased drag. (Noguchi, H, et al.1982)
- Starting torque and self-starting capability: The number of blades also affects the turbine's starting torque and self-starting capability. Generally, turbines with more blades have higher starting torque and are more likely to self-start at lower wind speeds. However, this may come at the expense of reduced overall efficiency. (Jeyaraj, N, et al 2017)

Aerodynamic forces and drag: The number of blades influences the distribution of aerodynamic forces and drag on the turbine. A Savonius turbine with a smaller number of blades may experience higher drag but also lower rotational losses. Conversely, a turbine with more blades may experience reduced drag but potentially higher rotational losses. (Chen, D, et al 2009).

I. Electricity Generation Methods

Even though they are normally employed to transfer electrical power to mechanical power, motors may also be used to generate electricity when they receive mechanical power. Wind turbines use the mechanical energy of the wind to generate electricity by rotating the generator's shaft. Whether a motor generates alternating current (AC) or direct current (DC) depends on the motor's cost, maintenance requirements, and the purpose for which it was designed.

Large wind turbines hardly employ DC motors because they are expensive to produce and maintain and since residential electricity is already AC. Both AC and DC generators can be utilized for small wind turbines, however, DC generators are more frequently employed to charge batteries. Electricity is produced by electromagnetic induction mostly using synchronous and asynchronous AC generators. Stators, rotors, and armature coils are used to produce energy in synchronous motors. The stator generates a spinning EMF because AC flows through it. DC electricity is used to power the rotor, which generates its magnetic field. The revolving magnetic field causes the rotor to revolve at the same speed as or in coordination with it because the rotor's EMF attracts to the opposite pole of the rotating magnetic field. The force needed to move the rotor, however, stops it from rotating if there is no rotation on it.

Asynchronous generators, sometimes referred to as induction or squirrel cage generators, induct power into the rotor as opposed to using a direct electrical connection. The stator wire generates a rotating electromagnetic field when AC electricity passes through it. The squirrel cage's bars are subjected to current, which creates a force that causes the cage to rotate. The primary means by which this kind of motor generates energy is through a difference in rotational velocities between the magnetic field and the cage. The rotor will rotate between the north and south poles when the cage's rotational speed decreases due to the revolving magnetic field.

The force created by this differential will increase current production, which will speed up cage rotation. Because the rotor is asynchronous and rotates more slowly than the rotating magnetic field, this will keep happening. Although it would seem like this kind of generator can generate power, to keep its magnetic field in place, it has to be constantly supplied with current. An internal alternating current generated by DC generators is changed into a direct current before the output connections.

The wires are commonly wrapped on the rotor of small DC generators, which rotates between two stationary permanent magnets. Similar to AC generators, a rotating magnetic field that submits the winds to alternate north and south magnetic poles produces an internal alternating voltage in the winds. Two brushes complete the circuit by completing the application of this voltage to the output terminals using a segmented conductor known as a commutator. Only a positive pulsing voltage is generated as a result of the commutator's inversion of the negative half of the AC signal. By adding more coils or poles to the rotor, this moving voltage may be balanced out to provide an essentially constant voltage, which when the terminals are connected to a load, produces an approximately constant current. It is possible to make use of DC motors as replacements for DC generators, which are no longer thoroughly developed due to the excessive complexity and low dependability of the contacts and commutators. The motors may be used as generators without needing to be modified, but choosing a motor with the right voltage, current, and torque characteristics is necessary to provide the necessary power for a given input torque and RPM.

DC motors have a beginning torque that must be overcome for the motor shaft to rotate when used as generators. The engine will operate at its highest RPM and generate the least amount of current during a free run, which is characterized by the absence of torque. The motor will generate its maximum power while it is operating at half of its maximum RPM without any load. Motors are designed to operate within a specified range, and going above that range might cause mechanical and thermal damage to the motor. Figure 5 represents the general curve of a DC motor and shows that its rated operating is less than its maximum efficiency and equal to around 25% of the stall torque. (Jeremy Lane et al. 2018)

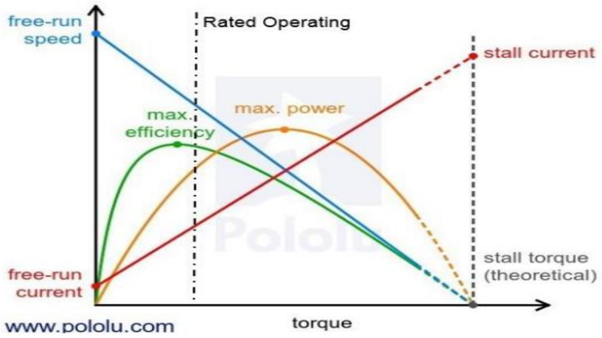


Figure 6: The graph below illustrates the connection between torque and power efficiency, RPM, and power.

IV. PROBLEM FORMULATİON

The mechanical force applied to the rotating shaft and the rotational speed at various wind speed readings are used to calculate the mechanical power for the tested Savonius rotor. A digital anemometer with a propeller design measures wind speed.

A digital tachometer is used to measure the speed of the shaft's rotation (Baskaran, A. et al 2016). The mechanical power may be approximated at each wind speed using the observed torque and rotational speed values.

$$P_m = T \times \omega \tag{3.1}$$

$$\omega = \frac{2\,\pi\,n}{60} \tag{3.2}$$

$$T = F \times r \tag{3.3}$$

$$F = (m - s) \times g \tag{3.4}$$

where:

- T is the mechanical torque (Nm)
- ω is the angular speed (rad/s)
- P_m is the mechanical power (W)
- n is the shaft rotational speed (RPM)
- r is the pulley radius (m)
- F is the force acting on the rotor shaft (N)
- m is the mass loaded on the pan (kg)
- s is the spring balance reading (kg)
- g is the gravitational acceleration (m/s^2)

The power coefficient C_p and static torque coefficient C_{ts} can be determined from the following equations:

$$C_p = \frac{P_m}{P_w} \tag{3.5}$$

$$P_w = \frac{1}{2}\ \rho\ A\ V^3 \tag{3.6}$$

where

- p is the air density (kg/m^3)
- A is the swept area for the rotor (m^2)
- V is the wind speed (m/s).

The static torque coefficient is calculated from

$$C_{ts} = \frac{4T}{\rho\, D^2\, V^2\ H} \tag{3.7}$$

The ratio between rotor height (H), and rotor diameter (D) is called the aspect ratio:

$$\alpha = \frac{H}{D} \tag{3.8}$$

The Area is the swept area of the rotor, while the Depth and Length are measurements of the rotor's height and diameter. Torque is used to calculate the moment coefficient.

$$C_m = \frac{T}{(\,0.5) \times \rho \times \mu^2 \times A \times R} \tag{3.9}$$

where:

- ρ is the fluid density,
- μ is incoming wind speed,
- A is the rotor-swept area
- R is the rotor radius.

The moment coefficient is used to calculate the power coefficient. where λ is the TSR.

$$C_p = \frac{T \times \omega}{(0.5)\, \rho\, \mu^3\, A} = C_m \times \lambda \tag{3.10}$$

A. The Rotor Concept on the Savonius Turbine

The rotor concept of the Savonius turbine is characterized by its simplicity and ability to capture wind from any direction. However, Savonius turbines generally have lower efficiency and produce less power. They are more suitable for low wind speed environments and small-scale applications. (Gorlov, A. M. 2002).

The blade is arranged on a vertical axis, either in an "S" or "C" shape configuration. The concave side of each blade faces the center of the rotor, while the convex side faces outward. The blades are positioned so that the wind pushes against the concave side as it flows past the turbine. This creates a higher pressure on the open side compared to the convex side, resulting in a net force that generates torque and causes the rotor to rotate. (Baskaran, A et al 2016).

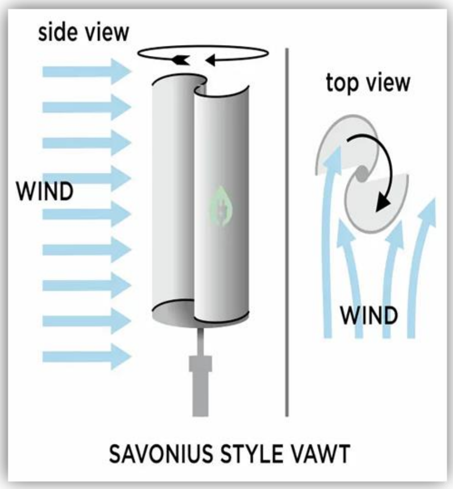


Figure 7: Schematic description of flow characteristics around Savonius rotor

In general, the internal distance between the blades of a Savonius turbine is typically determined based on factors such as the size of the turbine, the desired torque and power output, and the wind conditions in the location where the turbine will be deployed. To optimize the performance of the turbine, the internal distance between the blades is often set to achieve an appropriate balance between the wind capture efficiency and the reduction of drag forces during rotation. The distance should allow for efficient wind flow into and through the turbine while minimizing interference between the rotating blades.

The internal distances between the blades can vary from a fraction of the radius of the turbine to several times the radius. For smaller Savonius turbines, the internal distance can be around 10-20% of the rotor radius. In larger turbines, the internal distance may be larger, typically around 20-30% or more of the rotor radius. It's important to note that the specific design parameters, including the internal distances between the blades, are often determined through experimental testing, numerical simulations, and optimization techniques to achieve the desired performance goals. (Gorlov, A. M. 2002).

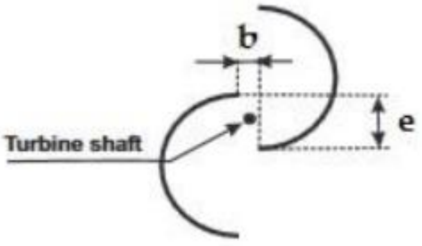


Figure 8: Turbine Shaft

B. Methodology

Learn several scenarios from the on-the-ground observation that directly apply to the test site conditions. Based on observing a few of the regions considered suitable for testing, the Marmara Islands beach on the shore of Bosporus was chosen as one of the locations with wind speeds capable of moving the Savonius turbine.

The next step is to conduct a study of the literature to collect information from subsequent similar references from other studies, which will then be compared with formula analysis relevant to this research. The data-gathering method for wind turbines is further supported by information retrieval over the Internet. The shaft frequency is estimated using an artificial neural network in this study.

The artificial neural network performs estimations to obtain data as experimental. According to Figure 8, the Savonius turbine is presented. The Savonius turbine's wrapping half circle is formed of an aluminum sheet and it is encased in a ferrous metal plate. This Savonius turbine is built with a rotor diameter of D = 90 cm and a height of 70 cm. The purpose of Savonius turbines is to analyze how the swept (projected) area affects the vertical axis turbine Savonius and hence the performance.

V. RESULTS AND ANALYSİS

The power coefficient of the rotor as a function of a TSR in the presence of variable wind conditions at 4.68 KG. A mean entering wind speed of 3 m/s is represented by the power coefficients with TSRs ranging from 0.241 to 0.312. The function of the power coefficient under stable conditions indicates the rotor prefers to operate with TSRs closer to the optimum when the wind speed hits the minimal value. This fall in the power coefficient demonstrates the losses given by the absence of a control mechanism.

The TSR impacts when the wind speed increases while the rotor keeps the same rotational frequency. The moment from the generator works as a slowdown for the rotor, decreasing the power coefficient. It should be noted that because the rotor torque is a function of time, the power coefficient under reliable wind situations is calculated by averaging the torque across a stabilized revolution. It is also possible to determine the power coefficient as a function of time during a single rotation with a constant wind speed. Thus, under conditions of steady wind, it is possible to determine both the averaged power coefficient and the power coefficient's instantaneous values.

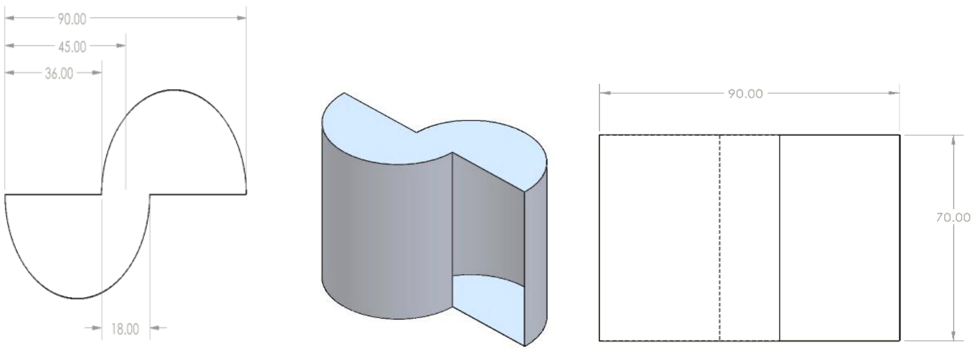


Figure 9: Savonius Turbine

The result of the proposed design as it is shown in Figure 9 is analyzed in this section.

In this study, the density of air is considered as ρ = 1.225 kg/m^3 where the swept area of the Savonius turbine is calculated as follows:

$$A = D \times H \tag{4.1}$$

The volume and mass of air in the turbine are calculated as:

$$V_t = \left(\frac{D}{2}\right)^2 \pi\, H \tag{4.2}$$

$$M_t = \rho \times V_t \tag{4.3}$$

The volume of air entering the turbine gap is C/D of the total volume of the turbine

$$V_i = \frac{C}{D} \times V_t = \frac{1}{4}\pi\, C\, D\, H \tag{4.4}$$

The mass of air entering the turbine:

$$M_i = \rho \times V_i \tag{4.5}$$

The force of the wind on the Savonius turbine is calculated as:

$$P = F_t \times v = \frac{1}{2}\rho\, A\, v^3 \tag{4.6}$$

$$F_t = \frac{1}{2}\rho\, A\, v^2 \tag{4.7}$$

The utilization of "drag force" and "lift force" on force limitations are the two options for turning wind power into kinetic energy. Drag force rotors use the F_w force produced by the wind on a certain angle in area A:

$$F_w = C_w \times F_t \tag{4.8}$$

The drag coefficient Cw gives information about its aerodynamic properties and is considered here a $C_w = 1.33$ since the body of the turbine is built as an open-semi sphere.

Table 1: Turbine Parameters

Parameter	*Value*	*Unit*
Turbine Diameter, D	0.9	m
Turbine Height, H	0.7	m
Blade Thickness	0.0012	m
Swept Area, A	0.63	m^2
Turbine Weight, W_t	4.68	kg
Turbine Radius, r	0.45	m
Blades Distance, e	0.18	m
Turbine Gap, C	0.36	m

The study shows that the Savonius turbine can rotate at a wind speed of 3m/s. Frictional force against its axis turbine (F_g) can be calculated where the friction coefficient is considered u = 0.1.

- Frictional Force:

$$F_g = m \times g \times u = 4.68 \times 9.81 \times 0.1 = 4.596N \tag{4.9}$$

- Drag Force:

$$F_w = C_w \times 0.5 \times \rho \times A \times v^2 = 4.619N \tag{4.10}$$

Then, the rotation check is performed as follows where the positive result means that the turbine is expected to rotate at this average wind speed.

$$F_w - F_g = 4.619 - 4.596 = 0.023N > 0 \tag{4.11}$$

As a result, the Savonius turbine has a range of rotational speeds that satisfy:

$$F_w > m \times g \times u \tag{4.12}$$

With a Savonius wind turbine, it does not matter which way the wind blows because the body with the open face towards the wind will always exert greater force, moving the rotor. This makes this particular type of wind turbine perfect for places where the wind is particularly turbulent. The calculation of speed and power of the Savonius turbine is performed respectively.

This table presents wind speed and Shaft Frequency in the Biosphere area in Turkey. It is rotating and averages at 3.43 and TSR is 0.31.

Table 2: Speed of Savonius Turbine Bosphures

MONTHS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
JANUARY	3.06	24.72	2.59	1.16
FEBRUARY	3.61	20.58	2.15	0.97
MARCH	3.61	20.58	2.15	0.97
APRIL	3.33	22.09	2.31	1.04
MAY	3.06	24.72	2.59	1.16
JUNE	3.33	23.09	2.42	1.09
JULY	3.61	20.58	2.15	0.97
AUGUST	4.17	20.75	2.17	0.98
SEPTEMBER	3.89	20.75	2.17	0.98
OCTOBER	3.06	24.72	2.59	1.16
NOVEMBER	3.33	23.09	2.42	1.09
DECEMBER	3.06	24.72	2.59	1.16

Table 3: Power of Savonius Turbine Bosphure

MONTHS	WIND POWER	WIND ACCELERATION	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
JANUARY	11.06	3.01	14.11	6.35	16.43
FEBRUARY	18.15	2.09	9.78	4.40	9.48
MARCH	18.15	2.09	9.78	4.40	9.48

APRIL	14.25	2.41	11.27	5.07	11.72
MAY	11.06	3.01	14.11	6.35	16.43
JUNE	14.25	2.63	12.31	5.54	13.39
JULY	18.15	2.09	9.78	4.40	9.48
AUGUST	27.98	2.12	9.94	4.47	9.72
SEPTEMBER	22.71	2.12	9.94	4.47	9.72
OCTOBER	11.06	3.01	14.11	6.35	16.43
NOVEMBER	14.25	2.63	12.31	5.54	13.39
DECEMBER	11.06	3.01	14.11	6.35	16.43

This table presents wind speed and Shaft Frequency in many regions area in Turkey. It is rotating and averages at 2.58 and TSR is 0.31.

Table 4: Speed of Savonius Turbine in Many Regions of Turkey

REGIONS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
MARMARA	3.3	23.13	2.42	1.09
SOUTH EAST ANATOLIA	2.7	13.31	1.39	0.63
AEGEAN	2.6	18.92	1.98	0.89
MEDITERRANEAN	2.5	18.61	1.95	0.88
BLACK SEA	2.4	14.61	1.53	0.69
CENTRAL ANATOLIA	2.5	18.61	1.95	0.88
EAST ANATOLIA	2.1	10.71	1.12	0.50
TURKEY AVERAGE	2.5	18.61	1.95	0.88

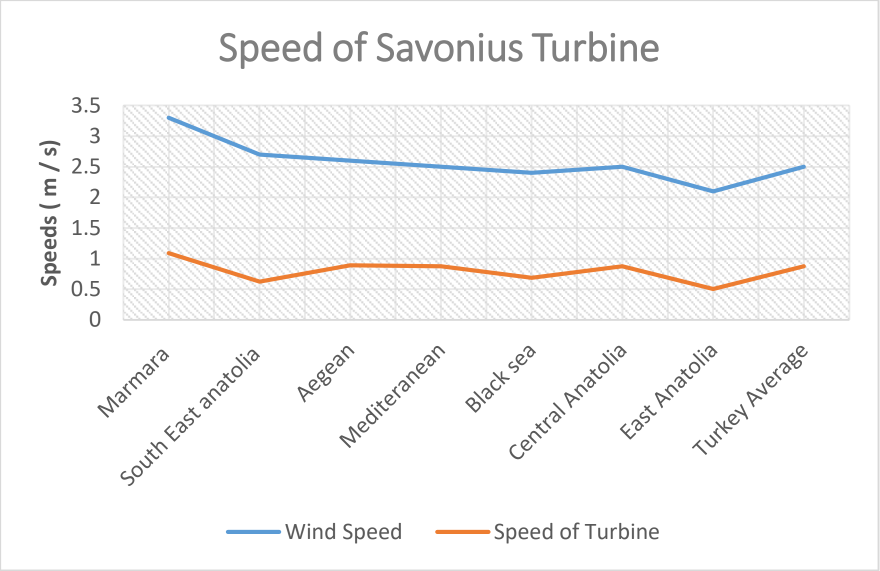


Figure 10: Chart Speed of Savonius Turbine

Table 5: Power of Savonius Turbine in Many Regions of Turkey

REGIONS	WIND POWER	WIND ACCELERATIONS	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
MARMARA	13.87	2.64	12.36	5.56	13.46
SOUTH EAST ANATOLIA	7.60	0.87	4.09	1.84	2.56
AEGEAN	6.78	1.76	8.27	3.72	7.37
MEDITERRANEAN	6.03	1.71	8.00	3.60	7.01
BLACK SEA	5.33	1.05	4.93	2.22	3.39
CENTRAL ANATOLIA	6.03	1.71	8.00	3.60	7.01
EAST ANATOLIA	3.57	0.57	2.65	1.19	1.34
TURKEY AVERAGE	6.03	1.71	8.00	3.60	7.01

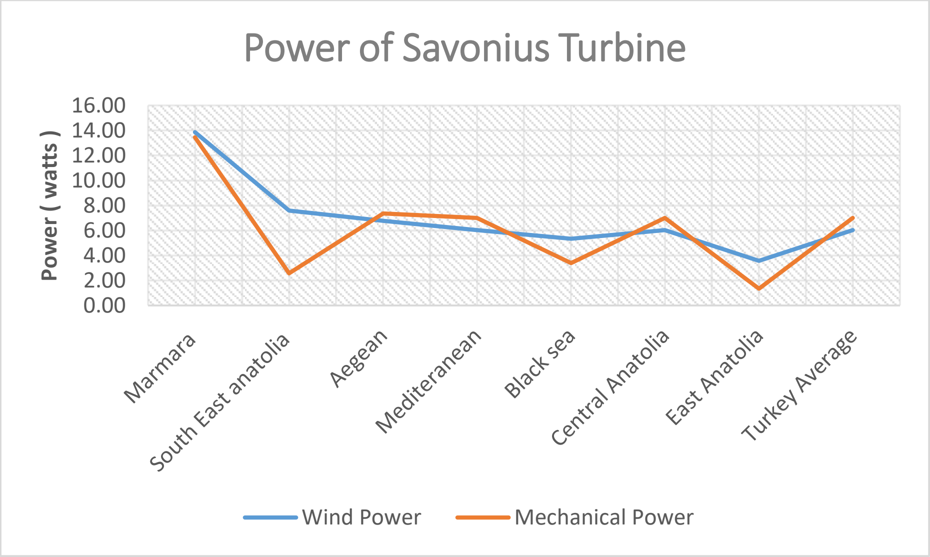


Figure 11: Chart Power of Savonius Turbine

This table presents wind speed and Shaft Frequency in the Aegean area in Turkey. It is rotating and averages at 3.29 and TSR is 0.28.

Table 6: Speed of Savonius Turbine Aegean Area

MONTHS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
JANUARY	3.967	20.7451	2.17	0.98
FEBRUARY	3.867	20.7451	2.17	0.98
MARCH	3.517	20.3577	2.13	0.96
APRIL	2.793	16.2623	1.70	0.77
MAY	2.663	14.6747	1.54	0.69
JUNE	2.796	16.3641	1.71	0.77
JULY	3.811	20.7451	2.17	0.98
AUGUST	3.329	23.095	2.42	1.09
SEPTEMBER	2.995	21.6124	2.26	1.02
OCTOBER	2.668	14.3232	1.50	0.67
NOVEMBER	3.698	20.7412	2.17	0.98
DECEMBER	3.32	23.1073	2.42	1.09

Table 7: Power of Savonius Turbine in the Aegean Area

MONTHS	WIND POWER	WIND ACCELERATION	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
JANUARY	24.09	2.12	9.94	4.47	9.71
FEBRUARY	22.31	2.12	9.94	4.47	9.71
MARCH	16.79	2.04	9.57	4.31	9.18
APRIL	8.41	1.30	6.11	2.75	4.68
MAY	7.29	1.06	4.97	2.24	3.44
JUNE	8.43	1.32	6.18	2.78	4.77
JULY	21.36	2.12	9.94	4.47	9.71
AUGUST	14.24	2.63	12.32	5.54	13.40
SEPTEMBER	10.37	2.30	10.79	4.85	10.98
OCTOBER	7.33	1.01	4.74	2.13	3.20
NOVEMBER	19.51	2.12	9.93	4.47	9.71
DECEMBER	14.12	2.63	12.33	5.55	13.42

This table presents wind speed and Shaft Frequency in the Central Anatolia area in Turkey. It is rotating and averages at 3.13 and TSR is 0.28

Table 8: Speed of Savonius Turbine in Central Anatolia Area

MONTHS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
JANUARY	3.449	21.3061	2.23	1.00

FEBRUARY	2.733	13.7143	1.44	0.65
MARCH	3.691	20.7398	2.17	0.98
APRIL	3.773	20.745	2.17	0.98
MAY	3.191	19.7644	2.07	0.93
JUNE	3.303	23.13	2.42	1.09
JULY	3.786	20.745	2.17	0.98
AUGUST	3.702	23.615	2.47	1.11
SEPTEMBER	2.876	17.8635	1.87	0.84
OCTOBER	2.408	14.7841	1.55	0.70
NOVEMBER	2.043	10.7355	1.12	0.51
DECEMBER	2.661	14.8326	1.55	0.70

Table 9: Power of Savonius Turbine in Central Anatolia Area

MONTHS	WIND POWER	WIND ACCELERATION	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
JANUARY	15.83	2.24	10.48	4.72	10.52
FEBRUARY	7.88	0.93	4.34	1.95	2.81
MARCH	19.40	2.12	9.93	4.47	9.70
APRIL	20.73	2.12	9.94	4.47	9.71
MAY	12.54	1.93	9.02	4.06	8.40
JUNE	13.91	2.64	12.36	5.56	13.46
JULY	20.94	2.12	9.94	4.47	9.71
AUGUST	19.58	2.75	12.88	5.80	14.32

SEPTEMBER	9.18	1.57	7.37	3.32	6.20
OCTOBER	5.39	1.08	5.05	2.27	3.51
NOVEMBER	3.29	0.57	2.66	1.20	1.35
DECEMBER	7.27	1.08	5.08	2.29	3.55

This table presents wind speed and Shaft Frequency in the East Anatolia area in Turkey. It is rotating and averages at 2.28 and TSR is 0.265

Table 10: Speed of Savonius Turbine in East Anatolia Area

MONTHS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
JANUARY	2.711	13.3121	1.39	0.63
FEBRUARY	1.934	10.7355	1.12	0.51
MARCH	2.257	10.857	1.14	0.51
APRIL	2.287	11.1622	1.17	0.53
MAY	2.577	19.0406	1.99	0.90
JUNE	2.577	19.0406	1.99	0.90
JULY	2.702	13.2999	1.39	0.63
AUGUST	2.676	13.8868	1.45	0.65
SEPTEMBER	2.078	10.7356	1.12	0.51
OCTOBER	1.795	10.7355	1.12	0.51
NOVEMBER	1.648	10.7355	1.12	0.51
DECEMBER	2.141	10.7362	1.12	0.51

Table 11: Power of Savonius Turbine in East Anatolia Area

MONTHS	WIND POWER	WIND ACCELERATION	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
JANUARY	7.69	0.87	4.09	1.84	2.57
FEBRUARY	2.79	0.57	2.66	1.20	1.35
MARCH	4.44	0.58	2.72	1.22	1.39
APRIL	4.62	0.61	2.88	1.29	1.51
MAY	6.60	1.79	8.37	3.77	7.51
JUNE	6.60	1.79	8.37	3.77	7.51
JULY	7.61	0.87	4.09	1.84	2.56
AUGUST	7.39	0.95	4.45	2.00	2.91
SEPTEMBER	3.46	0.57	2.66	1.20	1.35
OCTOBER	2.23	0.57	2.66	1.20	1.35
NOVEMBER	1.73	0.57	2.66	1.20	1.35
DECEMBER	3.79	0.57	2.66	1.20	1.35

This table presents wind speed and Shaft Frequency in South East Anatolia area in Turkey. It is rotating and averages at 3.02 and TSR is 0.288

MONTHS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
JANUARY	3.419	22.3599	2.34	1.05
FEBRUARY	3.419	22.3599	2.34	1.05
MARCH	3.419	22.3599	2.34	1.05

APRIL	2.836	17.3109	1.81	0.82
MAY	2.767	15.1497	1.59	0.71
JUNE	3.162	19.8604	2.08	0.94
JULY	3.982	20.7451	2.17	0.98
AUGUST	3.095	24.0709	2.52	1.13
SEPTEMBER	2.679	13.7599	1.44	0.65
OCTOBER	2.679	13.7599	1.44	0.65
NOVEMBER	2.295	11.3175	1.18	0.53
DECEMBER	2.513	18.8104	1.97	0.89

Table 12: Speed of Savonius Turbine in South East Anatolia Area

Table 13: Power of Savonius Turbine in South East Anatolia Area

MONTHS	WIND POWER	WIND ACCELERATION	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
JANUARY	15.42	2.46	11.55	5.20	12.16
FEBRUARY	15.42	2.46	11.55	5.20	12.16
MARCH	15.42	2.46	11.55	5.20	12.16
APRIL	8.80	1.48	6.92	3.11	5.64
MAY	8.17	1.13	5.30	2.39	3.78
JUNE	12.20	1.94	9.11	4.10	8.52
JULY	24.36	2.12	9.94	4.47	9.71
AUGUST	11.44	2.86	13.38	6.02	15.17
SEPTEMBER	7.42	0.93	4.37	1.97	2.83
OCTOBER	7.42	0.93	4.37	1.97	2.83
NOVEMBER	4.66	0.63	2.96	1.33	1.58
DECEMBER	6.12	1.74	8.17	3.68	7.24

This table presents wind speed and Shaft Frequency in South East Anatolia area in Turkey. It is rotating and averages at 3.22 and TSR is 0.296

Table 14: Speed of Savonius Turbine in the Mediterranean Area

MONTHS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
JANUARY	2.779	15.7076	1.64	0.74
FEBRUARY	3.528	20.3379	2.13	0.96
MARCH	3.375	22.9793	2.41	1.08
APRIL	3.38	22.9505	2.40	1.08
MAY	3.905	20.7451	2.17	0.98
JUNE	3.321	23.106	2.42	1.09
JULY	3.831	20.7451	2.17	0.98
AUGUST	3.35	23.0615	2.41	1.09
SEPTEMBER	3.404	22.6899	2.37	1.07
OCTOBER	2.62	18.4108	1.93	0.87
NOVEMBER	2.49	18.3663	1.92	0.87
DECEMBER	2.674	13.9821	1.46	0.66

Table 15:Power of Savonius Turbine in the Mediterranean Area

MONTHS	WIND POWER	WIND ACCELERATION	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
JANUARY	8.28	1.22	5.70	2.56	4.22
FEBRUARY	16.94	2.04	9.55	4.30	9.15
MARCH	14.83	2.60	12.19	5.49	13.20
APRIL	14.90	2.60	12.16	5.47	13.15
MAY	22.98	2.12	9.94	4.47	9.71
JUNE	14.13	2.63	12.33	5.55	13.42
JULY	21.70	2.12	9.94	4.47	9.71
AUGUST	14.51	2.62	12.28	5.53	13.34
SEPTEMBER	15.22	2.54	11.89	5.35	12.71
OCTOBER	6.94	1.67	7.83	3.52	6.79
NOVEMBER	5.96	1.66	7.79	3.51	6.74
DECEMBER	7.38	0.96	4.51	2.03	2.97

This table presents wind speed and Shaft Frequency in the Marmara area in Turkey. It is rotating and averages at 3.95 and TSR is 0.241

Table 16: Speed of Savonius Turbine in the Marmara Area

MONTHS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
JANUARY	4.619	20.7451	2.17	0.98
FEBRUARY	4.514	20.7451	2.17	0.98
MARCH	4.264	20.7451	2.17	0.98
APRIL	3.569	20.3541	2.13	0.96
MAY	2.769	15.2457	1.60	0.72
JUNE	3.479	20.5866	2.15	0.97
JULY	3.993	20.7451	2.17	0.98
AUGUST	3.679	20.7361	2.17	0.98
SEPTEMBER	4.263	20.7451	2.17	0.98
OCTOBER	3.88	20.7451	2.17	0.98
NOVEMBER	3.803	20.7451	2.17	0.98
DECEMBER	4.616	20.7451	2.17	0.98

Table 17: Power of Savonius Turbine in the Marmara Area

MONTHS	WIND POWER	WIND ACCELERATIONS	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
JANUARY	38.03	2.12	9.94	4.47	9.71
FEBRUARY	35.49	2.12	9.94	4.47	9.71
MARCH	29.92	2.12	9.94	4.47	9.71
APRIL	17.54	2.04	9.57	4.31	9.17
MAY	8.19	1.15	5.37	2.42	3.85
JUNE	16.25	2.09	9.79	4.40	9.49
JULY	24.57	2.12	9.94	4.47	9.71
AUGUST	19.21	2.12	9.93	4.47	9.70
SEPTEMBER	29.89	2.12	9.94	4.47	9.71
OCTOBER	22.54	2.12	9.94	4.47	9.71
NOVEMBER	21.22	2.12	9.94	4.47	9.71
DECEMBER	37.95	2.12	9.94	4.47	9.71

This table presents wind speed and Shaft Frequency in the Turkey area. It is rotating and averages at 3.38 and TSR is 0.286

Table 18: Speed of Savonius Turbine in Turkey Area

MONTHS	WIND SPEED	SHAFT FREQUENCY	ROTATIONAL SPEED	SPEED OF TURBINE
JANUARY	3.683	20.7376	2.17	0.98
FEBRUARY	3.689	20.6937	2.17	0.97
MARCH	3.541	20.3255	2.13	0.96
APRIL	3.168	19.7647	2.07	0.93
MAY	3.144	20.5085	2.15	0.97
JUNE	3.229	21.1422	2.21	1.00
JULY	3.994	20.7451	2.17	0.98
AUGUST	3.583	20.4162	2.14	0.96
SEPTEMBER	3.183	19.7043	2.06	0.93
OCTOBER	2.862	17.7104	1.85	0.83
NOVEMBER	3.035	24.4954	2.56	1.15
DECEMBER	3.496	20.4363	2.14	0.96

Table 19: Power Of Savonius Turbine in Turkey Area

MONTHS	WIND POWER	WIND ACCELERATION	ROTOR FORCE	MECHANICAL TORQUE	MECHANICAL POWER
JANUARY	19.28	2.12	9.93	4.47	9.70
FEBRUARY	19.37	2.11	9.89	4.45	9.64
MARCH	17.13	2.04	9.54	4.29	9.13
APRIL	12.27	1.93	9.02	4.06	8.40
MAY	11.99	2.07	9.71	4.37	9.38
JUNE	12.99	2.20	10.32	4.65	10.28
JULY	24.59	2.12	9.94	4.47	9.71
AUGUST	17.75	2.05	9.63	4.33	9.26
SEPTEMBER	12.44	1.91	8.97	4.03	8.32
OCTOBER	9.05	1.55	7.24	3.26	6.04
NOVEMBER	10.79	2.96	13.86	6.24	15.99
DECEMBER	16.49	2.06	9.64	4.34	4.18

VI. FUTURE CONCEPTS

Turkey's economy, which is the 17th biggest in the world and the sixth largest in Europe, will need more energy. Parallel to its economic growth over the past 10 years, Turkey has developed into one of the world's fastest-growing energy markets among OECD nations. Regarding electrical and natural gas requests, Turkey has been the second-largest economy after China.

The Turkish Ministry of Energy and Natural Resources' projections demonstrate that this situation will continue to be true long into the future. The foundation of Turkey's energy policies and plans is the security of its energy supply, as well as alternative energy sources, variety in energy sources, use of local energy resources to boost the economy, liberalization of the energy markets, and energy efficiency. This position has resulted in a focus on the most significant priority of using local and renewable energy sources as much as possible.

The primary drivers of the usage of energy are the fast pace of development, economic development, and increased individual income. Over the next ten years, energy utilization will be increasing by around 4-6% yearly. Through a variety of energy supply methods and energy source countries as well as the promotion of local energy production and energy efficiency to limit the development of total final consumption, Turkey's energy policies try to ensure secure, sustainable, and affordable energy. These energy-related goals can be found in Vision 2023, Turkey's economic growth plan for 2023, the year when the Republic of Turkey marks its 100th anniversary.

This vision includes several energy goals to establish Turkey among the top ten economic nations in the world with 500 billion USD in yearly exporters. Energy-related goals of Vision 2023 include promoting domestic energy sources, such as fossil fuels (lignite), increasing the proportion of wind and geothermal energy to 30% of the electricity mix, lowering energy consumption by 20% below 2010 levels through increased efficiency, and launching two or three nuclear power plants.

One of the main focus areas of Turkey's energy method has been renewable energy. The regulation on the Utilization of Renewable Energy Resources to Generate Electrical Energy (Renewable Energy Law, REL) was passed in 2005, marking the beginning of the considerable advancements achieved in the field of renewable energy. After 2005, the Turkish government continued creating, modifying, and applying several rules and regulations to help the investment and achieve its objective. (Turkey 2016 Review)

The overall amount of investments needed to fulfill Turkey's energy demand by 2023 is estimated to be approximately USD 110 billion, more than double the total amount invested over the previous ten years, according to the Ministry of Energy and Natural Resources. The great vision Turkey has for 2023 includes influencing goals for the renewable energy sector. These goals include having:

- 34,000 MW of hydroelectric capacity,
- 20,000 MW of wind capacity,
- At least 5000 MW of solar capacity,
- At least 1000 MW of geothermal capacity,
- At least 1000 MW of installed biomass capacity.

VII. CONCLUSİON

Data on wind speed measured in Turkey were statistically analyzed. Different locations determined the wind turbine characteristics for speed and power. The calculation results of the mechanical power of the presented Savonius turbine design showed that the power range of 9W to 16W can be obtained. Considering this design's simplicity, multiple poles can be planted along many areas to provide a charging power supply for small electronic devices. This design is suitable for many areas since it is built cheaply, does not need a specific wind direction, and can rotate with low wind speed.

The forces acting on the Savonius turbine design are the drag force rotor F_w and the Frictional force F_g where the following condition should be held to achieve the rotation of the turbine at a sample wind speed, $F_w - F_g > 0$. Besides, power generation may be increased throughout the generator's power range by modifying the Savonius turbine's swept area.

However, the accuracy of the averaged values as well as the difference between the wind speed parameters and the original ones must be estimated to evaluate the success of the used procedures. The wind power density was used to calculate the wind power potential.

As an objective function of statistical models, variables including choosing a location, height, wind generator selection, wind velocity, and wind power potential have been taken into discussion. These mathematical models are used to calculate the wind turbine system's generation of energy.

Control system analysis could be used to keep the wind turbine's performance parameters within the specified range. These advancements and increasing patterns for the use of wind power suggest an excellent future for the renewable energy sector. With this new technology, wind turbines may be created to provide the most electricity for the least amount of money.

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