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# Design Calculation of Vertical Axis Wind Turbine (Savonius Type)

THIHA HTET NAING[1], KHIN NWE ZIN TUN[2], AYE AYE KHAING[3]
*[1,2,3] Department of Mechanical Engineering, West Yangon Technological University*

***Abstract- This paper presents the theoretical design of a two-bladed helical Savonius Vertical Axis Wind Turbine (VAWT) for small-scale power generation. Featuring 90° twisted semicircular blades, the design optimizes torque through drag differential and achieves a target output of 1500 Watts. rotor diameter, blade pitch, angle of attack, chord length, shaft strength, and segment spacing—were calculated to optimize the turbine's aerodynamic performance and ensure reliable power generation. The turbine can operate from wind speeds as low as 2 m/s, making it suitable for Myanmar's varied wind conditions. The study highlights its potential for decentralized energy use and suggests future improvements through gear and control integration.***

***Index Terms- Twist Angle, Savonius Wind Turbine, Wind Speed, Power.***

## I. INTRODUCTION

As global energy demands rise and environmental concerns intensify, the pursuit of sustainable and decentralized power generation has become increasingly critical. Wind energy, a clean and renewable resource, has emerged as a viable alternative to fossil fuels, offering significant reductions in greenhouse gas emissions and air pollution. Among the various wind turbine technologies, Vertical Axis Wind Turbines (VAWTs) have gained renewed interest due to their unique advantages in urban and offshore environments.

VAWTs operate independently of wind direction, eliminating the need for complex yaw mechanisms and allowing for simpler, more compact designs. Historically, research institutions such as NASA and Sandia National Laboratories have played a pivotal role in advancing VAWT technology. Their studies on aerodynamics, blade configurations, and prototype testing have laid the foundation for modern VAWT applications, including floating systems and hybrid designs.

The Savonius turbine, invented by Sigurd J. Savonius in 1922, is a drag-based VAWT known for its mechanical simplicity and self-starting capability at low wind speeds. Despite its relatively low efficiency, typically ranging from 15–20%, its omnidirectional operation makes it ideal for small-scale applications such as water pumping and off-grid power generation. In contrast, the Darrieus turbine, patented by Georges Darrieus in 1931, utilizes lift forces and achieves higher efficiencies (30–40%) but requires external starting mechanisms and experiences greater structural stress.

Modern VAWT configurations—including H-rotor, Giromill, and vortex bladeless designs—continue to evolve, integrating advanced materials and control systems to enhance performance and reliability. These innovations address key limitations such as starting torque, fatigue life, and maintenance complexity, making VAWTs increasingly competitive with Horizontal Axis Wind Turbines (HAWTs), especially in environments where space constraints or wind variability pose challenges. These day as the modern technological advanced, wind turbine like Horizontal-axis wind turbines (HAWTs) and Vertical-axis wind turbine (VAWTs) are participated in global energy sector along with solar and other renewable energy. Despite its benefits, wind energy faces challenges due to its intermittent nature, necessitating advancements in energy storage technology. The horizontal and vertical axis wind turbine are shown in Figure 1.

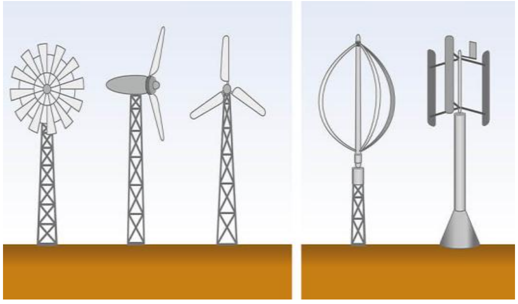

Figure 1. Horizontal and vertical axis wind turbine

In the context of smart and green cities, where individuals seek localized energy solutions, VAWTs offer a promising pathway for sustainable development. Their adaptability to urban landscapes and potential for integration into building infrastructure make them an attractive option for future energy systems. This paper focuses on the theoretical design and analysis of a helical Savonius-type VAWT, exploring its aerodynamic characteristics, structural components, and suitability for decentralized power generation in regions like Myanmar, where wind resources are abundant yet underutilized.

Vertical Axis Wind Turbines (VAWTs) come in various designs, each tailored to harness wind energy effectively. The two main types are the Savonius turbine, known for its scoop-like structure that captures wind from any direction, and the Darrieus turbine, which features curved blades designed for efficient energy capture as they rotate around a vertical axis. By modernizing these designs offer distinct advantages, making VAWTs suitable for diverse applications in renewable energy generation. Types of Vertical Axis Wind Turbine can be classified into;

1. Savonius Wind Turbine
2. Darrieus Wind Turbine
3. H-rotor Wind Turbine
4. Giromill Wind Turbine
5. Vortex Bladeless Wind Turbine
6. Helical Blade Wind Turbine

The Savonius turbine is invented by Finnish engineer Sigurd J. Savonius in 1922, is a drag-based vertical axis wind turbine characterized by its S-shaped or semi-cylindrical blades. The Savonius wind turbine are shown in Figure 2.

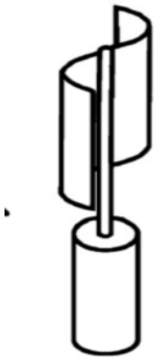

Figure 2. Savonius wind turbine

This design operates on the principle of differential drag, where wind forces are greater on the concave side of the blades compared to the convex side, creating rotational motion. While Savonius turbines exhibit low efficiency typically 15-20% due to their reliance on drag rather than lift forces, they offer significant advantages in terms of mechanical simplicity, self-starting capability even at low wind speeds 3-4 m/s, and omnidirectional operation. These characteristics make them particularly suitable for small-scale applications such as water pumping, ventilation systems, and off-grid power generation in remote areas. Recent studies have explored hybrid configurations combining Savonius with lift-based turbines to improve overall performance.

## II. THEORETICAL BACKGROUND OF SAVONIUS WIND TURBINE

The helical Savonius wind turbine represents a refined evolution of traditional vertical axis wind energy systems, specifically designed to address the limitations of conventional drag-based turbines. At its core, the Savonius turbine operates on the principle of differential drag, where the wind exerts a greater force on the concave side of the blade than on the convex side, generating rotational motion. While this mechanism is inherently simple and effective at low wind speeds, it often suffers from pulsating torque and limited efficiency.

To overcome these drawbacks, the helical configuration introduces a continuous twist—typically 90 degrees—along the vertical axis of the blades. This design innovation ensures that at any given moment, a portion of the blade is optimally aligned with the wind, resulting in smoother torque output and reduced vibration. The twist also enhances the turbine's ability to capture wind energy more uniformly throughout its rotation, improving overall aerodynamic performance.

The theoretical analysis of this system is the understanding of parameters such as solidity, angle of attack, and drag coefficients. Solidity, defined as the ratio of blade area to the swept area, influences the balance between torque generation and aerodynamic resistance. An optimal value around 0.3 is often targeted to maximize performance. The angle of attack varies dynamically as the turbine rotates, with maximum torque typically occurring when the concave surface directly faces the wind. The difference in drag coefficients commonly around 2.1 for the concave side and 0.3 for the convex side forms the basis for torque calculations and power estimation.

In addition to aerodynamic considerations, structural and material aspects play a crucial role. The use of lightweight, flexible materials for blades and robust metals for the shaft and supports ensures mechanical stability while maintaining ease of fabrication. Theoretical modeling of these components allows for precise prediction of performance under varying wind conditions, making the helical Savonius turbine a promising solution for decentralized, small-scale energy generation in diverse environments.

## III. DESIGN CALCULATION OF VERTICAL AXIS WIND TURBINE

$P_t = 1500$ W (required optimal power)

$$C_P = \frac{P_t}{P_w} \qquad \text{Equation 1}$$

$$P_w = \frac{P_t}{C_p}$$

$$= \frac{1500}{0.3}$$

$$= 5000\text{W}$$

Based on the given wind conditions, the theoretical maximum power output is first determined. Using this value, the required swept area of the turbine can then be calculated by applying the standard wind power equation.

$$P_t = 0.5 \text{ x } \rho \text{ x } A \text{ x } V_{rated}^3 \qquad \text{Equation 2}$$

$$A = \frac{P_t}{0.5\text{x}1.225\text{x}12^3}$$

$$= \frac{1500}{0.5\text{x}1.225\text{x}12^3}$$

$$= 1.4172 \text{ m}^2$$

The calculated frontal area of the helical wind turbine is 1.4172 m². With an aspect ratio (AR) of 2, the relationship between the turbine's height and diameter can be derived using the area formula. By applying this ratio, the height is set to twice the diameter, allowing both dimensions to be determined directly from the known swept area.

$H/D = 2$

$H = 2D$

$A = H \text{ x } D$

$= 2D \text{ x } D$

$= 2D^2$

$$D = \sqrt{\frac{A}{2}} = \sqrt{\frac{1.4172}{2}} = 0.8417 \text{ m}$$

$H = 2 \text{ x } D = 2 \text{ x } 0.8417 = 1.6835$ m

The helical wind turbine is designed with a diameter of 0.8417 meters and a corresponding height of 1.6835 meters, based on the selected aspect ratio. To determine its rotational performance, the number of revolutions per minute (RPM) is calculated using the tip speed ratio and angular velocity equations, providing insight into the turbine's operational speed under rated wind conditions.

$$\lambda = \sqrt{\frac{\omega\text{x}R}{V}} \qquad \text{Equation 3}$$

$$\omega = \sqrt{\frac{\lambda\text{x}V}{R}}$$

$$= \sqrt{\frac{1x12}{0.8417/2}}$$

$$= 28.51 \text{ rad/s}$$

If, $\omega = \frac{2\pi N}{60}$,

$N = 272.25 \text{ rpm} \approx 273 \text{ rpm}$

At a tip speed ratio (TSR) of 1, the helical wind turbine achieves a rotational speed of approximately 273 revolutions per minute (rpm). To evaluate the aerodynamic performance, the lift force acting on the blades is determined using standard aerodynamic equations, which consider factors such as lift coefficient, air density, swept area, and wind velocity.

$F_L = C_L \text{ x } ½ \text{ x } \rho \text{ x } A \text{ x } V^2$

$= 0.6 \text{ x } 0.5 \text{ x } 1.225 \text{ x } 1.4172\text{x } 12^2$

$=74.99$ N

Therefore, the lift force is 56.25 N.

$F_D = C_D \text{ x } ½ \text{ x } \rho \text{ x } A \text{ x } V^2$

$= 1.8 \text{ x } 0.5 \text{ x } 1.225 \text{ x } 1.4172 \text{ x } 12^2$

$= 224.99$ N

The calculated drag force acting on the turbine is 224.99 N. To determine the blade chord length, the solidity equation is applied. Given a solidity value (σ) of 0.3 and a two-blade configuration (B = 2), the chord length (c) is derived to ensure optimal aerodynamic performance and appropriate blade coverage across the rotor's swept area.

$$\sigma = \frac{Bxc}{\pi xD} \qquad \text{Equation 4}$$

$$c = \frac{0.3x\pi x0.8417}{2}$$

$$= 0.3966 \text{ m}$$

The resulting blade chord length is determined to be 0.3966 meters. Following this, the blade pitch angle is computed using the geometric relationship between the blade twist and rotor dimensions, providing a critical parameter for optimizing aerodynamic performance and structural alignment.

$$\Phi = 90°$$

$$\Phi = 90° \text{ x } \frac{\pi}{180}$$

$$= 1.57 \text{ rad}$$

$$L^2 = H^2 + (R\ \Phi)^2 \qquad \text{Equation 5}$$

$$= 1.6835^2 + (0.42 \text{ x } 1.57)^2$$

$$= 3.27$$

$$L = 1.8 \text{ m}$$

$$H = L \text{ x } \sin \delta$$

$$\delta = 69.28°$$

Therefore, the blade pitch angle is 69.28°. Shaft Design of the Savonius turbine can be calculated by

$$D_s = 3 \text{ x } \sqrt[3]{\frac{2 \text{ x } T_T}{\pi \text{ x } \tau_s}} \qquad \text{Equation 6}$$

$$A_{curved} = \pi \text{ x r x H} = \pi \text{ x } 0.42 \text{ x } 1.6835 = 2.221 \text{ m}^2$$

$$A_{flat} = \text{D x H} = 1.417 \text{ m}^2$$

$$A_{total} = A_{curved} + A_{flat} \qquad \text{Equation 7}$$

$$= 2.221 + 1.417$$

$$= 3.638 \text{ m}^2$$

Since number of blade = 2, volume of the turbine is

$$V_{blade} = A_{total} \text{ x t} \qquad \text{Equation 8}$$

$$= 3.638 \text{ x } 0.001$$

$$= 0.003638 \text{ m}^3$$

For mass calculation for weight of blade,

$$m = \rho_{ZA} \text{ x } V_{blade} \qquad \text{Equation 9}$$

$$= 3800 \text{ x } 0.003638$$

$$= 13.824 \text{ Kg}$$

$$W_b = \text{m x g} \qquad \text{Equation 10}$$

$$= 13.824 \text{ x } 9.81$$

$$= 135.617 \text{ N}$$

Since number of blade = 2,

$$W_b = 2 \text{ x } 135.617$$

$$= 271.23 \text{ N}$$

To figure out the centrifugal force the Weight of generator, connecting rod and turbine should be calculated at first.

Weight of generator,

$$W_g = \text{m x g}$$

$$= 2 \text{ x } 9.81$$

$$= 19.62 \text{ N}$$

Weight of connecting rod,

$$W_r = 12.343 \text{ x } 9.81$$

$$= 121.08 \text{ N}$$

Weight of turbine,

$$W_t = W_b + W_g + W_r$$

$$= 271.23 + 19.62 + 121.08$$

$$= 411.93 \text{ N}$$

$$C.F = \frac{W_t \text{ x } \frac{\lambda}{2}}{\text{g x R}} \text{ x } V_{rated}^{2}$$

$$= 7198.427 \text{ N}$$

Therefore, Centrifugal force due to rotor weight is 7198.427 N.

Shaft Torque,

$$T_1 = \frac{\text{R x } P_W}{V_{rated} \text{x } \lambda}$$

$$= \frac{0.42 \text{ x } 5000}{12 \text{ x } 1}$$

$$= 175 \text{ N}$$

Torque due to Centrifugal force,

$$T_2 = \text{C.F x R}$$

$$= 7198.427 \text{ x } 0.42$$

$$= 3023.339 \text{ N}$$

Resultant Torque,

$$T_T = T_2 - T_1$$

$$= 3023.339 - 175$$

$$= 2848.339 \text{ N}$$

To determine the shaft diameter, the calculated resultant torque of 2848.339 N is applied to the torque-based design equation. This substitution allows for accurate sizing of the shaft to ensure it can withstand the mechanical stresses generated during turbine operation,

$$D_s = 3 \times \sqrt[3]{\frac{2 \times T_T}{\pi \times \tau_s}}$$

$$= 3 \times \sqrt[3]{\frac{2 \times 2848.339}{\pi \times 400 \times 10^6}}$$

$$= 0.04965 \text{ m}$$

As a result of the calculated torque, the required shaft diameter is determined to be approximately 0.04965 meters, ensuring sufficient strength to withstand operational stresses during turbine rotation..

Theoretical power output of generator is calculated by

$P_g = P_t + \eta_g$

$P_g = 1500 \times 0.95$

$= 1425$ watt

Therefore, the output power of the generator is 1425 watt at a wind speed of 12m/s.

## IV. CONCLUSIONS

This study presents a comprehensive theoretical design and analysis of a helical Savonius Vertical Axis Wind Turbine intended for small-scale power generation. Through detailed calculations, the parameters such as rotor dimensions, blade chord length, pitch angle, lift and drag forces, and shaft torque were determined to optimize turbine performance under varying wind conditions. The turbine was designed with a rotor diameter of 0.8417 m and a height of 1.6835 m, yielding a frontal area of 1.4172 m². At a wind speed of 12 m/s, the turbine achieves a rotational speed of approximately 273 rpm and generates a theoretical output of 1425 watts, assuming a generator efficiency of 95%. The calculated shaft diameter of 0.04965 m ensures structural integrity under centrifugal and torque loads. These results confirm the viability of the helical Savonius design for decentralized energy applications, particularly in regions with moderate wind resources like Myanmar. The simplicity, self-starting capability, and adaptability of this turbine make it a promising solution for urban, coastal, and remote installations.

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