CFD SIMULATION OF MICRO HYDRO-KINETIC TURBINE

By

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ENDORSEMENT

I, Muhamad Affiq Iruan Bin Idrus hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

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DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

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Date: 11 July 2021

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CFD SIMULATION OF MICRO HYDRO-KINETIC TURBINE

ABSTRACT

Hydrokinetic energy refers to the energy produced by ocean currents, tidal currents, rivers and artificial water channels from flowing water. Several technologies, such as horizontal axis hydrokinetic turbines, have been developed to extract this energy. Savonius turbine is a cost-effective electric generation used in the low-velocity region. The conventional Savonius wind turbine with semicircular blades has a relatively low power coefficient than other wind turbines that are available out there. Since the turbine itself is not fully explored by researchers, several improvements can be made for this turbine. Some improvements had been made for the turbine to increase performance in terms of coefficient of power and torque coefficient for the best possible result. The main objective of this project is to improve the turbine coefficient of the turbine's performance that will be used in water instead of wind. The Savonius model used in this project is from (Golecha et al., 2011) optimization design since it is already achieving the peak of the power coefficient of the Savonius can be achieved. In this project, the Savonius turbine blade will be used as an optimization to compare with (Golecha et al., 2011) design. This project will also be studied the maximum power coefficient that can be achieved by changing the rotor center of the novel Savonius turbine. The design will be tested through simulation using Ansys pressure-based solver, which is to study the interaction between the structural model and the fluids passing through it. The coefficient of power and coefficient of torque for the different configurations of the blade are studied. The modified Savonius turbine of Design 4 has the highest coefficient of power of all of the designs, 8.53%, at a TSR of 0.68, which is the maximum Cp possible in this experiment. At a tip speed ratio of 0.68, a maximum coefficient of power of 0.1644 is

observed. When the tip ratio is at its maximum power coefficient, the highest coefficient of torque is 0.2430. As for Design 1, Design 2, Design 3, Design 5, and Design 6, the increment for the coefficient of the power is 4.33%, 7.65%, 5.20%, 5.71%, 6.34%, respectively. The study of the fluid flow across the most maximum coefficient of power for the optimization Savonius turbine was also achieved in this project.

SIMULASI CFD MIKRO HIDRO-KINETIK TURBIN

ABSTRAK

Tenaga hidrokinetik merupakan tenaga yang dihasilkan melalui arus lautan, arus pasang surut, sungai dan saluran air buatan dari air yang mengalir. Terdapat beberapa teknologi, seperti turbin hidrokinetik paksi mendatar telah dikembangkan untuk mengekstraksi tenaga ini. Turbin Savonius adalah penjanaan elektrik yang menjimatkan untuk digunakan di kawasan dengan kelajuan rendah. Turbin angin Savonius konvensional dengan bilah separa bulat mempunyai daya yang agak rendah dibandingkan dengan jenis turbin angin lain yang berada di luar sana. Oleh hal yang demikian, turbin itu sendiri tidak dapat diterokai sepenuhnya oleh penyelidik, dan terdapat beberapa penambahbaikan yang boleh dijalankan untuk turbin ini. Terdapat beberapa penambahbaikan yang telah dilakukan keatas turbin ini untuk meningkatkan keupayaan turbin ini dari segi pekali keupayaan dan pekali daya kilas untuk mendapatkan keputusan yang diiginkan. Objektif utama projek ini adalah untuk meningkatkan perkali prestasi untuik turbin ini yang mana turbin ini akan digunakan dalam air berbanding angin. Model Savonius yang akan digunakan dalam projek ini adalah dari reka bentuk optimum (Golecha et al., 2011) kerana ianya sudah mencapai puncak pekali keupayaan yang boleh dicapai oleh Savonius turbin. Dalam projek ini, bilah turbin Savonius akan digunakan sebagai pengoptimuman untuk dibandingkan dengan reka bentuk (Golecha et al., 2011). Dalam projek ini juga, akan dikaji pekali keupayaan maksimum yang dapat dicapai dengan mengubah ukuran pusat pemutar turbin Savonius baru. Reka bentuk ini akan diuji melalui simulasi dengan menggunakan Ansys Fluent solver, iaitu untuk mengkajii interaksi antara model struktur dengan cecair yang melaluinya. Pekali keupayaan dan pekali daya kilas untuk konfigurasi bilah yang berbeza dikaji. Turbin Savonius yang diubahsuai dari Reka Bentuk 4, mempunyai pekali keupayaan yang tinggi berbanding daripada semua reka bentuk, iaitu 8.53% apabila berada pada TSR 0.68, yang merupakan Cp maksimum yang boleh didapati dalam eksperimen ini. Pada nisbah kelajuan hujung 0.68, nilai pekali maksimum 0.1644 diperhatikan. Apabila nisbah hujung berada pada pekali keupayaan maksimum, pekali daya kilas tertinggi dapat diperolehi iaitu 0.2430. Bagi Reka Bentuk 1, Reka Bentuk 2, Reka Bentuk 3, Reka Bentuk 5 dan Reka Bentuk 6, kenaikan bagi pekali keupayaan masing-masing adalah 4,33%, 7,65%, 5,20%, 5,71%, 6,34%. Kajian aliran bendalir mengalir melalui pekali keupayan maksimum untuk pengoptimuman turbin Savonius juga dicapai dalam projek ini.

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LIST OF ABBREVIATIONS

μ-HKT	Micro Hydro-Kinetic Turbine
2D	Two Dimension
3D	Three Dimension
AR	Aspect Ratio
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
FPS	Frame Per Second
GHG	Green House Gas
HKT	Hydro-kinetic Turbine
HAWT	Horizontal Axis Wind Turbine
IEA	International Energy Agency
RPM	Revolution Per Minute
Re	Reynolds Number
TSR	Tip Speed Ratio
VAWT	Vertical Axis Wind Turbine

LIST OF NOMENCLATURE

ρ	Density
η	Viscosity
º	Degree
A	Area
$C0_2$	Carbon Dioxide
$\boldsymbol{C_p}$	Coefficient of Power
Cp_{max}	Maximum Coefficient of Power
Ct	Coefficient of Torque
d	Rotor Diameter
$F_{concave}$	Concave Force
F_{convex}	Convex Force
F_D	Drag Force
F_L	Lift Force
h	Rotor Height
k-ε	K-Epsilon
l	Length
P_{max}	Maximum Stream Power
T	Temperature
v	Velocity

CHAPTER 1

INTRODUCTION

1.1 Overview

Hydrokinetic energy refers to the energy produced by ocean currents, tidal currents, rivers, and flowing water using artificial water channels. Over the past few decades, several turbine technologies, such as horizontal axis hydrokinetic turbines, have been studied and developed to extract this wind energy from valuable sources. Therefore, the water turbines can be considered two main categories: horizontal axis water turbine (HAWT) and vertical axis water turbine (VAWT). In the later section, the details of each phrase will be discussed and the study's objectives.

1.2 Background

From the global energy usage report, almost 90% of the total energy sources worldwide are coming from burning fossil fuels, such as coal, petroleum oils, natural gas, and so on. Fossil fuels can be considered one of the most significant contributors to energy needs. The energy resources produced by the earth are minimal and will come beyond their peak volume availability in the following decades. Some countries may use fossil energy as their primary energy resource. It also has a significant drawback regarding global climate change because of carbon dioxide and sulfur dioxide emissions from fossil fuel combustion. More than 40% of all carbon dioxide (CO_2) emissions from burning fossil fuels and about 25% of total greenhouse gas (GHG) emissions are attributed to the power sector. Renewable energy is the most effective way to replace harmful energy as their primary source and significantly reduce carbon dioxide emissions in the power sector (Torresi et al., 2014). With the advancement of economics and technologies, energy scarcity and pollution problems are becoming more severe as renewable energy is getting much more attention because it can solve all countries' main problems about energy sources. Since the rapid advancement in developing the use of wind energy worldwide, the development of the Savonius wind turbine has recently become a hot topic among researchers. In 1928, the Finnish scientists known as Sigurd J. Savonius had invented the Savonius wind turbine (Zhipeng et al., 2013).

Renewable energy with low-carbon energy and cost-effective solutions for the energy source is becoming the main goal for the global energy policy. Renewable energy can be a climate-friendly energy source because it produces no harmful emissions during energy extract (Wenehenubun et al.,2015). The advancement of technology has prompted people to seek out modern and alternative energy sources to replace traditional energy sources (Utomo et al., 2018). The interest in this subject has grown in tandem with the potential market opportunities in the recent decade (Rathore et al., 2016). As wind energy technologies are well known worldwide, it is becoming the most contributor to renewable energy is wind energy, which has lowered global emissions by around 400 million tonnes in 2012. This finding is proven from the annual global market trend, which shows that wind power installation increased by about 45GW in 2012, about 10% of increment over the cumulative installation through 2011(Torresi et al., 2014).

Since wind energy is available everywhere and has very plentiful and can renew all the resources, it will significantly affect the economy, society, and climate change (Chan et al., 2018). Wind energy can be considered one of the newer energy sources discovered from the earth. These energies have begun to be used to produce electricity for use in other applications. Wind turbines are one of the instruments used to harness wind energy (Utomo et al., 2018). Even though the wind turbine industry's developments move toward large-scale onshore and offshore turbines, small-scale wind turbines have many promises (Marzec et al., 2021). Based on projections in the 2004 World Energy Outlook report, the International Energy Agency (IEA) showed the global cumulative wind power capacity in Figure 1.1. Wind turbines convert wind energy into mechanical energy (such as windmill and moving height) (Wenehenubun et al., 2015).

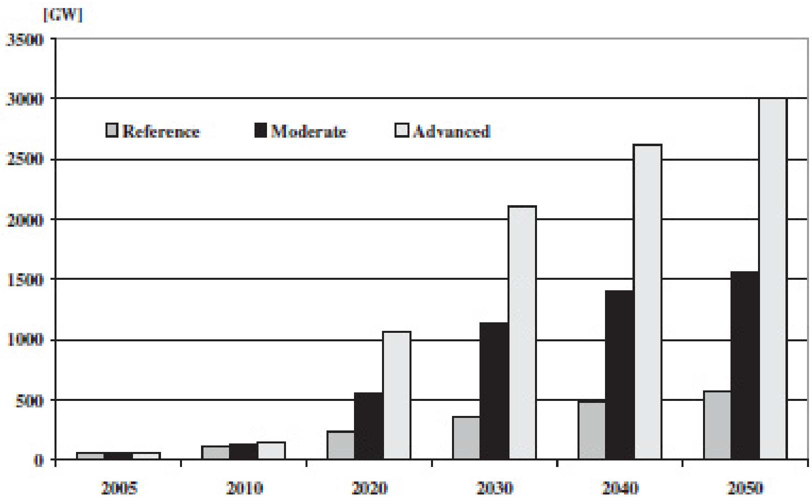


Figure 1.1 Global cumulative of wind power capacity globally (Wenehenubun et al., 2015)

For the current water turbines, the electricity can be produced by using the energy from natural water resources flowing through the riverside with different shapes and types of rotors. These rotors will be attached to a riverside platform or floating pontoons. Hydro-kinetic turbine energy generation is intended chiefly for use in areas that placed far from conventional power grids. It is a helpful tool since it can enhance people's quality of lifestyle and boost local economies, especially in rural areas. Tides, tidal waves, the river flows, and water flows from manufacturing operations are only a few examples of applications for these turbines (Golecha et al., 2011). Water current turbines come in a variety of designs for extracting energy from river water or canals.

Two generic types exist and popular among the researchers that determine based on the orientation of the rotor axis concerning the water flow. These types are axial turbines with horizontal and vertical axis turbines (crossflow turbines). Horizontal axis turbines use to draw electricity from the sea or river (Elbatran et al., 2017). Vertical turbines are deployed in places with the non-steady flow of water directions or turbulent flows in another term because water direction is unsuitable for the vertical turbine because of its design. Since the water flow direction does not affect the vertical turbine operation. Figure 1.2 shows a simple sketch to illustrate the forces that are acting on the turbine, which is the drag, F_D and lift, F_L forces that will act differently according to the water flows. Vertical turbines are designed in accordance with the acting force type. The Savonius type turbines operated based on the action of drag forces, while the Darrieus type turbines were based on lift forces' action. However, for the Hybrid turbines between Savonius and Darrieus, both forces are being used as acting forces (Lates & Velicu, 2014).

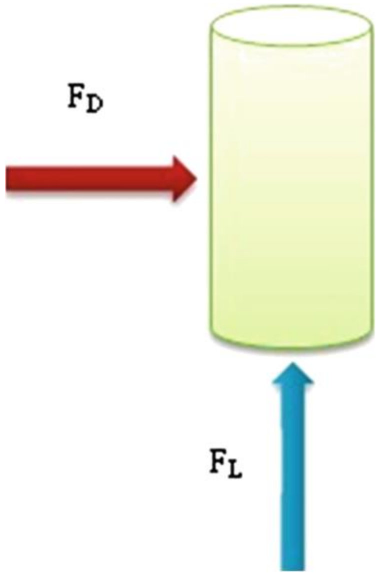


Figure 1.2 The forces of drag F_D and lift F_L acting on a general shaped system (Lates & Velicu, 2014)

1.3 Problem Statement

Given that micro hydro-kinetic turbine technology is regarded as a feasible choice for sustainable, green, and low-cost power generation compared to conventional turbines, there is an immediate need for demand to accelerate this trend. Additionally, shifting to a predominantly renewable energy source will reduce carbon emissions over the following decade (Niebuhr et al., 2019). The installation of the technology and the possibilities for using this turbine are entirely appropriate in light of the climate review of a specific country with higher annual rainfall. Several countries are already using μ-HKT as their energy sources, and the main contribution in terms of energy sources from the micro hydrokinetic turbine is expected to increase more in the future (M. B. Salleh et al., 2018). Energy can be extracted from the ocean and river currents using submerged turbines similar to wind turbines, harvesting energy by hydrodynamic processes rather than aerodynamic, lift, or drag processes. Turbines may have axes of rotation that are horizontal or vertical (Guney, 2011).

The designation of the turbine is essential to have a good performance, but the Savonius turbine has a relatively low coefficient of power and coefficient of torque (Golecha et al., 2011). Computational fluid dynamics is required to check whether the design is suitable for flow conditions to be used. The chosen type of blade with the different blade propeller spanning and angle will also affect the efficiency. As stated by (Saha et al., 2008), the twisted blades in the vertical direction provide better performance than conventional cylindrical blades. The change of the blade design can be used to improve the coefficient of power (Hassan Saeed et al., 2019). Simulating the turbine performance varies with the Savonius blade configuration using a neural network algorithm (Sargolzaei & Kianifar, 2009). The Savonius rotor with two rotor blades produces the highest power coefficient compared to three rotor blade under identical test conditions (Zemamou et al., 2017).

Many analytical investigations, numerical analyses, and experimental data may be required for finding the optimum configuration of a Savonius turbine. Test the propeller in constant input power for rotating propeller in quiescent water to test its efficiency. Flow field analysis is critical in determining the turbine's efficiency by checking at levels of unsteadiness and deformation rate (Mabrouki et al., 2014). The pressure field around a Savonius turbine is needed to relate the relationship between the streamlines and the torque-contributing pressure (Shigetomi et al., 2011). In addition, the flow field analysis determines the fluctuation of torque due to the shape of the blade (Al-Faruk & Sharifian, 2017). The pressure distributions, and velocity contour distributions for modified design blades, as given by (Kacprzak et al., 2013) and (Roy & Ducoin, 2016), prove that they improve the turbine performance can be seen clearly by using these contours. By measuring the pressure distributions with flow visualization can easily describing the power production mechanisms for the rotor (N. Fujisawa & Gotoh, 1992).

1.4 Objectives

This study will examine the performance of the Savonius water turbine from previous research to the new design. The project objective will study the improvement that can be achieved using a different type of blade shape design. Objectives that are to be achieved in this project include:

1. To improve the turbine efficiency and performance coefficient for the micro hydro-kinetic turbines using CFD simulation.

2. To evaluate the design and CFD simulation test for suitable improvement can be made from the new design of Savonius turbine.

3. To study the effect and flow field analysis features around the turbine.

1.5 Thesis Outline

This thesis is subdivided into five chapters and structured as stated below:

Chapter 1 summarises the research problem, including background information, a problem statement, the study's objectives, and significance.

The related literature is reviewed in Chapter 2 to present what researchers have done so far to improve the conventional Savonius turbine. The reviews cover the conventional Savonius turbine and how new design implementations can improve power coefficient in different applications. To study the challenges and feasibility of the Savonius turbine in real-life scenarios, explanations of the Savonius turbine's specifications in conjunction with its flaws. Additionally, the research difficulties are discussed in greater detail.

Next, Chapter 3 discusses the implemented methodology and techniques used in this project. A novel model (Golecha et al., 2011) turbine model's modified configuration is illustrated and shown in this chapter. The numerical simulation process is explained in detail, including meshing, the turbulence model for the flow around the turbine, the wall function at the near wall and boundary layers, the solver, and solution controls. The turbulence model is used to solve the Reynolds averaged Navier-Stokes’s equations in this section.

Chapter 4 showed the simulation results, such as pressure contours, velocity vectors, torque, and power coefficient, and validated them using previous data. A series of experiments with the suggested model was reported, which included pressure distribution measurements. Several comparisons were made between the (Golecha et al., 2011) model of Savonius and the modified model. The advantages at low current speeds were discussed. Numerous critical parameters of the turbine gained through simulation were discussed in this chapter. The final section of this chapter investigates the innovative turbine's design parametric research numerically.

Finally, Chapter 5 will present the study's significance as the foundation for the future production of a better improvement for the Savonius water turbine. The conclusion is to be drawn based on the parameter correlation in the research and modified based on (Golecha et al., 2011) design. The primary conclusions, which include a summary of the debate and findings from the current study. Additionally, several future works were indicated for additional inquiry.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The turbine that uses wind energy, like windmills, uses kinetic energy from the wind flows and converts it into a different form of energy to be used in the turbines. The electrical energy will be produced from the conversion of the kinetic energy produce by the turbines. Wind turbines serve various uses, from harnessing energy for a large city to generating small amounts of electricity for personal use. Small wind turbines are typically chosen for local applications. They are typically put in isolated, rural, and off-grid places that hard to get the grid connection with the national grid and can produce less than 100kW of electricity. Wind turbine technology is now employed for various purposes, not just for generating electricity (Johari et al., 2018).

There are two most popular wind turbine types: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). As for the VAWT, it can be classified into two types which are drag driven for the Savonius turbine and lift driven that mostly use for the Darrius turbine that is commonly recognized based on the difference of the pressure across the blade surface (Al-Shammari et al., 2020). HAWT has a rotation axis in horizontal, while VAWT has a rotation vertically. Furthermore, HAWT's structure and installation are more complicated than VAWT's. The VAWT generator is mounted on the ground at the bottom of the central shaft; therefore, the system for the tower installation is not required to support it. Wind turbines are beneficial in a variety of wind speeds and directions. VAWTs, on the other hand, have poor pressure coefficients. Hence considerable study on VAWT rotors is needed to increase their performance (Wenehenubun et al., 2015). Despite their low cost and ease of fabrication, drag-driven blades collect air from any direction and self-start, but their efficiency is restricted.

The VAWT type is the most popular now, but a developing market demands machines with various capabilities to meet a variety of needs. The design of VAWT turbines has constantly been abused by literature and the market with little knowledge about the turbines. However, with the rapid development of the technologies and falling of the values of the raw materials like permanent magnets, combined with the unique ability of VAWT turbines to operate where other types have problems, this turbine can have a significant competitive advantage in the current market (Rathore et al., 2016). Due to numerous undeniable advantages over HAWTs, VAWTs are widely regarded as a promising research method. VAWTs are particularly well suited to household applications due to their lower noise emission, higher cutoff wind speed, lower minimal operational wind speed, reduced susceptibility to wind turbulence, omnidirectionality, and more compact design. However, compared to HAWTs, VAWT constructions have some disadvantages, primarily more inadequate efficiency and material strength difficulties (Marzec et al., 2021). The shape of VAWTs and HAWTs of the turbine can be identified as shown in Figure 2.2. From the picture, it clear that the different types of wind turbines available.

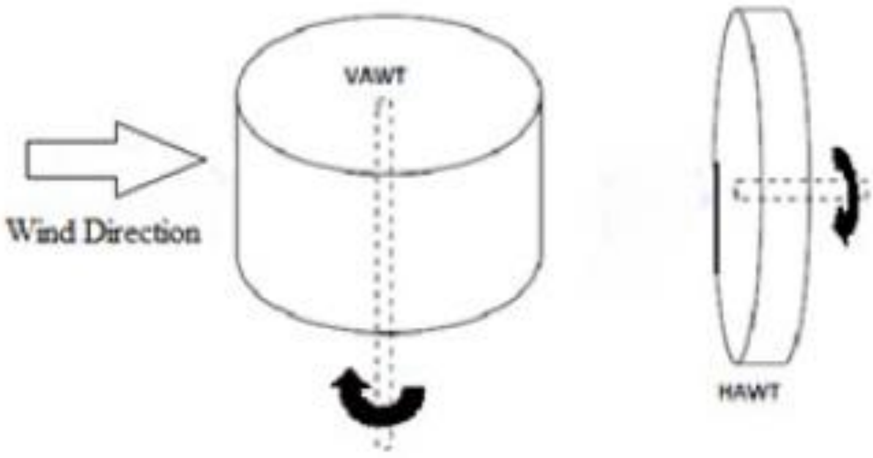
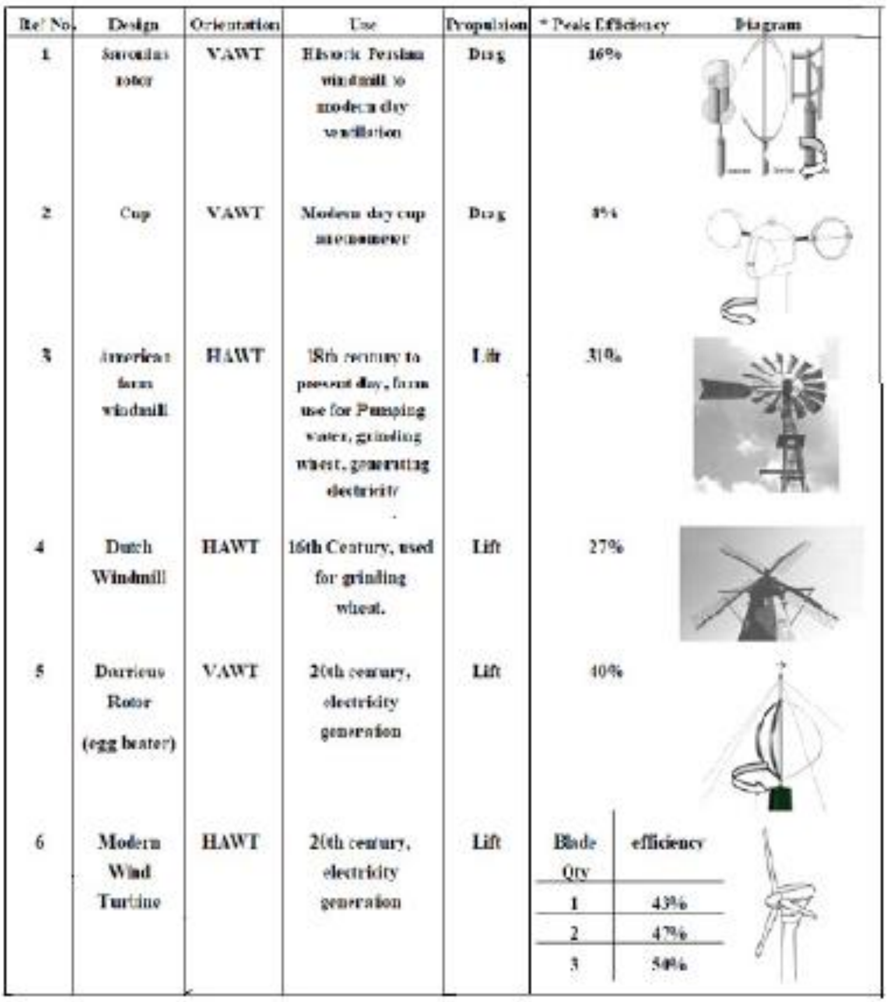


Figure 2.1 Shaft and rotor orientation configurations (Agbezudor et al., 2014)



Ref No.	Design	Orientation	Use	Propulsion	* Peak Efficiency	Diagram
1	Savonius rotor	VAWT	Historic Persian windmill to modern day ventilation	Drag	16%	
2	Cup	VAWT	Modern day cup anemometer	Drag	8%	
3	American farm windmill	HAWT	18th century to present day, farm use for Pumping water, grinding wheat, generating electricity	Lift	31%	
4	Dutch Windmill	HAWT	16th Century, used for grinding wheat.	Lift	27%	
5	Darrieus Rotor (egg beater)	VAWT	20th century, electricity generation	Lift	40%	
6	Modern Wind Turbine	HAWT	20th century, electricity generation	Lift	Blade Qty / efficiency: 1 – 43%; 2 – 47%; 3 – 50%	

Figure 2.2 Comparison of different types of wind turbines (Agbezudor et al., 2014)

2.2 The Betz Law

There is a potential of doing work if there is energy. Wind turbines generate electricity by extracting energy from the wind. The theoretical maximum efficiency of other types of turbines and propellers is 100 percent. This implies that they may be able to transfer all of the energy given to the propeller into energy derived from the airstream. Wind turbines cannot convert all the energy into labour and, unlike other generators, can only create energy that is instantly available in reaction to the wind. It is impossible to store wind in order to use it later. The wind that blows along the axis and the circle area traced by the blades is the capture area in a horizontal axis wind turbine.

In an open flow, the Betz law calculates the maximum power that may be harnessed from a wind turbine.

Wind energy is the kinetic energy of moving air, where *m* denotes mass and *v* denotes velocity.

$$\boldsymbol{E_{kin} = \frac{1}{2} m v^2} \qquad (1)$$

The mass *m* (*kg*) can be defined from density ρ (kg/m^3) of the air and volume *V* (m^3) by

$$\boldsymbol{m = \rho V} \qquad (2)$$

Equation 3 shows then the kinetic energy of wind,

$$\boldsymbol{E_{kin,wind} = \frac{1}{2}\rho V v^2} \tag{3}$$

Energy divided by time equals power. A brief period of time, Δt, during which air particles travel a distance of $s = v\Delta t$ in order to pass through. The distance is then multiplied by the distance of the capture area, or rotor area, of the wind turbine, yielding a volume of

$$\boldsymbol{\Delta V = Av\Delta t} \tag{4}$$

Then there is the power connected with the wind travelling through the capture region, which grows as the cube of the wind speed. When the wind speed is doubled, the wind power is increased by eight times. Therefore, the positioning of wind turbines is crucial.

The wind power is then,

$$\boldsymbol{P_{wind} = \frac{E_{in,wind}}{\Delta t} = \frac{\Delta V \rho v^2}{2\Delta t} = \frac{\rho A v^3}{2}} \tag{5}$$

Wind power is lower than shown in the equation above. The wind speed behind the wind turbine cannot be zero since no air could follow. As a result, only a fraction of the kinetic energy is available for use. The effective power is the difference between the two wind powers, shown in Equation 6, is

$$P_{eff} = P_1 - P_2 = \frac{\rho A}{4}(\boldsymbol{v}_1^2 + \boldsymbol{v}_2^2)(\boldsymbol{v}_1^2 - \boldsymbol{v}_2^2) \quad (6)$$

If the difference between the two speeds is zero, there is no net efficiency. The difference in speed is too great if the airflow through the rotor is too restricted. The power coefficient is equal to

$$\boldsymbol{C_p} = \frac{\boldsymbol{P_{eff}}}{\boldsymbol{P_{wind}}} = \frac{(\boldsymbol{v_1}+\boldsymbol{v_2})(\boldsymbol{v_1^2}-\boldsymbol{v_2^2})}{\boldsymbol{2v_1^3}} \quad (7)$$

2.3 Type of Wind Turbines

2.3.1 Horizontal Axis Wind Turbine (HAWT)

As shown in Figure 2.3, the HAWT configurations have been in use for a very long time, about 5000 B.C., since their first appearance, with people harvesting energy from the wind to set sail their boats along the river. Wind turbines have a very long history journey that undergone important invention and customization in their design to achieve optimal performance since then. The HAWT design incorporates horizontally oriented rotors that seem perpendicular to the surface and gather wind energy. The blades work and turn due to aerodynamic lift while facing the wind flow perpendicularly. Because it has a considerable benefit over VAWT, HAWT is the most popular wind turbine and has been gained through enhanced research and development expenditure. When both of the turbines are placed in a constant wind flow, HAWT is more efficient in capturing energy from the wind compared to the VAWT. It is because of its design, which enables it to extract energy throughout the blades' revolution. Additionally, it is susceptible to the backtracking effect (Johari et al., 2018).

Figure 2.3 Vertical axis wind turbine (Johari et al., 2018)

Any number of blades can be used in a HAWT, and the odd number of blades are more encouraged since it is provided to its excellent balance in the energy efficiency and structural stability. Adding blades to a massive turbine may cause increases in its cost production, but on the other hand, it will help reduce the amount of time each blade has before it collides with its wake; consequently, the fewer blades, the better. Turbines that have an even number of blades place a great deal of load on the system that allows them because, when the blades are vertical, the top experiences the maximum wind because of its elevation. At the same time, the bottom receives the least wind due to the proximity to the pole or tower that supports it. This imbalanced force distribution may cause the machine to deteriorate and eventually fail. Three-bladed turbines are the most commonly used because they have both requirements for the turbine to maintain its performance: an odd number of blades and a small number of blades. (Digital Commons & Winslow, 2017).

HAWTs are by far the most efficient type of turbine due to their horizontal motion that generates energy throughout their rotors' rotation. However, one limitation of HAWTS is that the blades should always confront the direction of the wind, necessitating frequent direction changes for maximum efficiency. A weathervane-like tail can be employed on smaller systems turbines to orient the turbine in the appropriate position. Larger systems, on the other hand, require more complex mechanical yawing systems that are both expensive and time-consuming to maintain the rotors' rotation. HAWTs thrive in places with little turbulence and consistent wind, as they are rarely directional changes. (Eriksson et al., 2008).

2.3.2 Vertical Axis Wind Turbine (VAWT)

In contrast to HAWT, the blades of VAWT rotate perpendicular to the ground and around the vertical axis, as shown in Figure 2.4, the blade shape of the HAWTS. This type of turbine uses either drag-driven, lift-driven, or combining these two forces to make it operate perfectly. VAWT has been around for a long time compare to HAWT, and the first windmills that people ever designing are VAWT to take advantage of the wind flow to their usage. Before HAWT appeared and became famous at some point in the history of wind turbines, VAWT becomes a phenomenon. VAWT is divided into two primary designs, each of which operates on different principles. The first shape of the VAWT is Savonius, which works like a water wheel that makes use of drag forces, and the second design is Darrieus, which uses aerodynamic blades to generate lift force and drive the turbine to rotate (Johari et al., 2018).

Figure 2.4 Horizontal axis wind turbine (Johari et al., 2018)

VAWTS were the earliest known windmills. Horizontal mills, on the other hand, appeared and became the standard at some point. This choice was made by chance and that one technique is not always superior to the other (Eriksson et al., 2008). As a result of this shift, vertical axis turbines have stayed on the fringe of development, while HAWTs have received the majority of attention. Because their blades move in the same direction as the wind, VAWTs are less efficient due to backtracking. Every time a blade rotates, it must return to the wind before being driven around again (Digital Commons & Winslow, 2017).

VAWTs have a number of advantages that make them ideal for use in advance places, and it is very suitable for urban application. Compared to HAWTs, where the rotor blade must always face the wind direction, VAWTs are omnidirectional systems by utilizing wind from any direction. Due to the vertical orientation of the turbine, the transmission and other equipment can be located closer to the ground, thus, reducing maintenance expenses considerably. On the contrary, a HAWT must position all mechanical components at the top. Finally, VAWTs may generate electricity at lower wind speeds, making them ideal for urban areas that have slower and more turbulent winds because of several factors like building and more people living than rural areas. (Toja-Silva et al., 2013). Higher efficiencies can be achieved with HAWT, but only if the wind energy quality is good. A HAWT can have severe difficulty with severe wind turbulence, wind variations, and high directional variability, although VAWTs can perform effectively in these conditions (Darhmaoui & Sheikh, 2017). Table 1 is the summary of the comparison characteristics and performance of both types of wind turbines.

Table 2.1 Comparison between VAWTs and HAWTs

	VAWTs	**HAWTs**
Tower Sway	Small	Large
Tower Mechanism	No	Yes
Overall Formation	Simple	Complex
General Placing	On ground	Not on ground
Height from Ground	Small	Large
Blade's operation space	Small	Large
Noise Generating	Low	Relatively high
Wind direction	Independent	Dependent
Obstruction	Low	High

2.4 Savonius Wind Turbine

The Savonius wind turbine is made up of two staggered semi-cylindrical blades that combine together. As for the modified shape of the turbine is the resistance type turbine that is moved sideways along the cutting plane in the shape of a letter of S. In a simple term, the rotor can be said to have a set of two buckets that are hinged to the rotor shaft. The basic difference between these two wind turbines is that Savonius rotors have a gap (overlap) between the two buckets, whereas S shape rotors do not have a gap between the hinge. (Torresi et al., 2014). These twin semicircular surfaces, referred to as blades or buckets, are positioned on a vertical axis parallel to the direction of the wind, and a gap or overlap separates it at the axis (Wenehenubun et al., 2015). The turbine rotates due to varying pressure on both sides of the blades and varied torque between the blades. When the rotor maintains a steady speed, the torque coefficient varies regularly. This turbine has several benefits, including the ability to accept wind from any direction of the blades long fatigue life, high starting torque, a wide working wind speed range, and the ability to generate power at high wind speeds, ease of installation, manufacture, maintenance, and low noise (Zhipeng et al., 2013).

As a primary turbine, the Savonius wind turbine has exerted a difference in forces on each blade. Due to the concave section facing the wind direction, the turbine's blade is forced to rotate around the shaft. However, when the blade rotor comes into contact with the air, its convex section will be deflected sideways around the shaft. As illustrated in Figure 2.5, when traveling against the wind (F_{convex}), the curvature of the blades will produce less drag compare when it is traveling with the wind ($F_{concave}$). The concave part will trap the air and accelerates the turbine to rotate as the flow that encounters the convex side of it will generate less drag than the flow that encounters the concave part. This turbine rotates due to the imbalance of the drag force. As a result, the rotor is forced to rotate by concave blades that generate a more significant drag force than the other half-cylinder (Wenehenubun et al., 2015). This turbine has a lesser efficiency and speed than the Darrieus turbine, but it produces much torque. Because of the high torque at low speeds, Savonius turbines are self-starting. A Savonius wind turbine's power coefficient is dependent on wind velocity, with maximum performance at wind velocity (Puspitasari & Sahim, 2019).

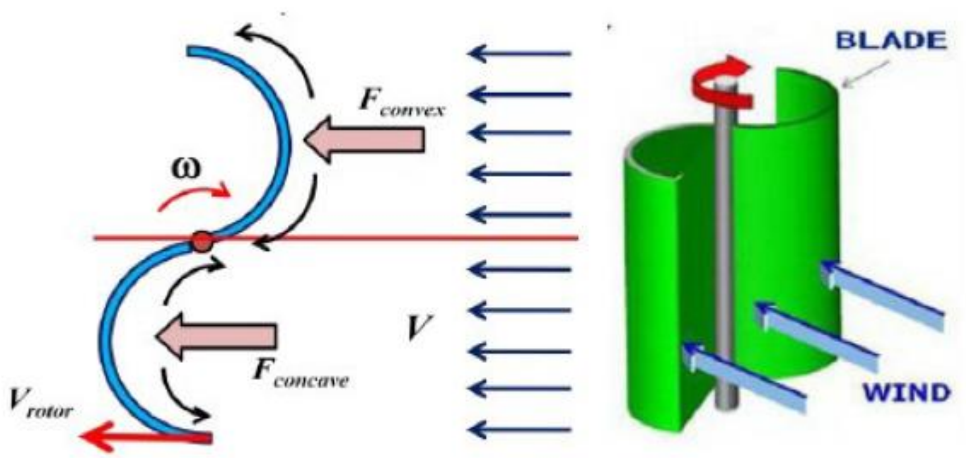


Figure 2.5 S blades Savonius wind turbine and drag force (Wenehenubun et al., 2015)

For the Savonius turbine, Butaud and Besnard have emphasized the concept of a drag wind turbine. It is about the influence of lift force can be seen in the dynamic study of its operation. The Savonius defies easy classification into either of these categories, which is drag-driven or lift-driven. Since its initial efficiency is determined mainly by drag, and sometimes the rotating efficiency is primarily determined by lifting force, it might sometimes be unclear for the researchers (Zemamou et al., 2017).

The value of a turbine power coefficient is frequently used to assess its performance. In essence, this term refers to a level of efficiency. It is comparable to the retrieved energy to the wind energy flowing across the turbine's anticipated zone. The power coefficient (C_p) is a form of mathematical notion that is used to calculate the wind turbine's output power and determine its performance (Bhadra et al., 2020). As in the Figure 2.5 shows that the power performance of typical wind turbines in comparison.

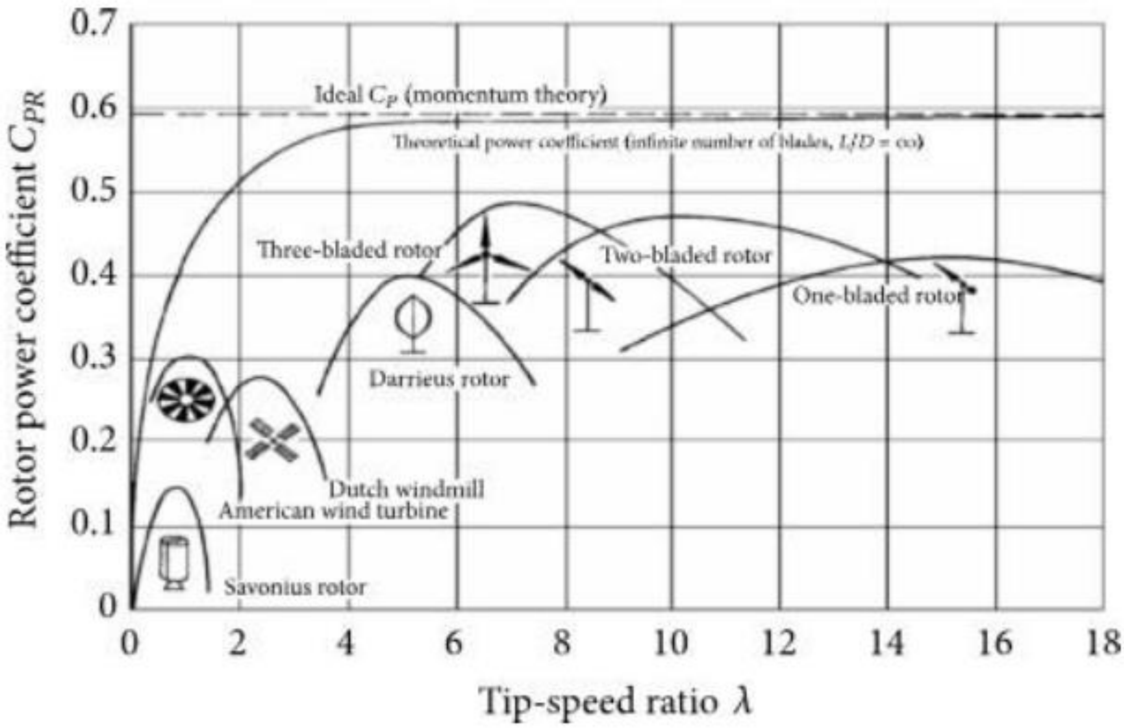


Figure 2.6 Performance of typical wind turbines (Bhadra et al., 2020)

2.5 Improvement Conducted on Savonius Turbine

Various scholars have conducted numerous performance improvement studies on the Savonius rotor due to the inefficiency of a standard Savonius rotor. Experiments on Savonius rotors are conducted in the outdoors or a wind tunnel. Wind tunnels have been used in the great majority of the studies presented here. It is unusual for thorough research to occur after installing a system (Abraham et al., 2012). Experiments show that Savonius wind turbines work effectively in low-wind conditions (Darhmaoui & Sheikh, 2017). The power coefficient (C_p), which defines as a wind turbine aerodynamic efficiency, is the fundamental metric that characterises it, and wind turbine research is frequently focused on developing new solutions that integrate to increased and improve the aerodynamic efficiency by using a simple design as a reference. (Lates & Velicu, 2014).

Compared to Savonius rotors with more blades, the Savonius rotor with two rotor blades produces the highest power coefficient. Under identical test conditions, the blades of the two under identical test conditions, the Savonius turbine of the two blades can be considered most efficient and has a more significant power coefficient than the three-bladed wind turbine (Zemamou et al., 2017). The coefficient of power for the two-blade design will also be higher than the three-blade design when it is compared side by side. Researchers also discovered that four-blade outperform two-blade at low tip speed ratios (TSRs) while three-blade outperform three-blade at higher TSRs (Darhmaoui & Sheikh, 2017). The use of defectors or curtains can cause the increment of the performance of a traditional Savonius wind turbine. These deflectors are essentially meant to collect the wind flow toward the rotor of the advancing blade while also directing it away from the returning blade. The deflector uses a flat plate that will be placed upstream of the returning blade, and its position and orientation are optimized using evolutionary algorithm principles (Chan et al., 2018).

When compared with the turbine that does not has a deflector, the turbine optimized using the plate deflector at its optimally positioned is improved the time-averaged of the power coefficient (C_p) by more than 27% more. (Golecha et al., 2011) has carried out experiments to prove its confirmation of this approach. (Altan & Atilgan, 2008) also experimented by installing two straight plates upstream of the Savonius turbine, forming a convergent channel used to gather the approaching wind. From (El-Askary et al., 2015b) built on this principle by channelling a portion of the airflow into the inner side of the returning blade through the use of a smooth channel while resulting in enhanced negative pressure there. At TSR 0.82, the maximum power coefficient is significantly enhanced up to C_p = 0.52, which consider as a substantial improvement. Nonetheless, these deflectors create a very turbulent wake, making the turbine system more complicated and direction-dependent (Chan et al., 2018).

The Bach-type blades are used for the blade of the Savonius turbine by (Golecha et al., 2011) and (Kacprzak et al., 2013), who investigated the influence of geometrical characteristics on performance. Compared to the conventional turbine (Kacprzak et al., 2013), semi-elliptical blades outperformed the Cp of the conventional Savonius turbine. (Tartuferi et al., 2015) study blades with varying thicknesses and different airfoils as turbine blades by a significant margin. The coefficients force, pressure distributions, and velocity contour distributions for the modified designed blades, as provided by (Kacprzak et al., 2013) and (Roy & Ducoin, 2016), prove that they improve the turbine performance because of the increase in the lift force produce that gives an elongated momentum arm.

On the other hand, (Driss et al., 2015) investigated the effects of arc angle of the edge blade that happen due to the turbulent wake. (Yang et al., 2016) have developed a turbine with four deflectable at the arc of the blades that can alter their incidence angle relative to the wind flow during its rotation. From Table 2.2 shows all summarized based on the previous researchers by changing the shape of blades of the Savonius turbine for the studies of the improvement of power coefficient.