ON THE GEOMETRICAL EFFECT OF VERTICAL AXIS WIND TURBINE ON ITS AERODYNAMIC OUTPUT

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I hereby declare that the thesis submitted to University Malaysia Sabah is entirely the result of my own work except the citation and summaries which I have clarified their resources. The thesis has not been submitted to any others university. I declared that I read this thesis and in our point of view this thesis is qualified in term of scope and quality for the purpose of the requirement for the degree of Bachelor of Mechanical Engineering.

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ABSTRACT

Renewable energy resources are becoming more attractive for sustainable energy development globally. Wind energy has a significant potential as an alternative energy source as a result of the effects of global modernization. Over the years, the demand for a small-scale wind turbine in built environments has increased to reduce urban areas' carbon emissions. Vertical axis wind turbine (VAWT) has development potential because VAWT is suitable for low wind speed condition, high turbulence, and wind direction variations. However, these wind rotors generally have lower efficiency. The current number of studies and publications and the basic understanding of VAWT under unfavourable conditions are limited. Based on the literature reviews, two relevant factors of the critical parameters that positively impact the VAWT power performance are the aspect ratio and solidity. Therefore, a comprehensive numerical analysis has been conducted in this study to understand the aerodynamic phenomena and wind flow characteristics around turbine's blades that influence the VAWT's performance with different aspect ratios and solidities in low Reynolds number conditions (100000, 150000 and 200000). The numerical investigation was carried out using ANSYS Fluent software using high-fidelity Computational Fluid Dynamics (CFD) technology. Current research employs various aspect ratios (0.4, 2.0 and 4.0) with rotor radii of (2.50 m, 0.50 m, and 0.25 m), respectively and with a different chord length of air foil which is (0.1 m and 0.20 m). The blade height was fixed at 1.0 m to achieve various solidity. For low Reynolds numbers of wind conditions, a two-dimensional CFD model of H-Darrieus VAWT with different solidities was simulated corresponding to TSR values (2.0, 2.5, 3.0). Various computational settings in CFD simulation are considered based on previous studies' experiences and data. For verification purposes, the initial results were compared and validated against published simulation and experimental data to ensure the accuracy of the simulation results obtained in this study. This research also consists of 54 simulations in total. This study aims to provide an overview and understanding of the effect of changes in rotor diameter on VAWT power performance and a preliminary review for future research into improving the optimal VAWT design for urban areas.

Keywords: Wind energy; Renewable energy; H-Darrieus vertical axis wind turbine; Urban area; Reynold number; Aspect Ratio; Tip Speed Ratio; ANSYS Fluent (CFD).

ABSTRAK

KAJIAN KEATAS KESAN GEOMETRI TURBIN ANGIN PAKSI MENEGAK PADA OUTPUT AERODINAMIKNYA

Sumber tenaga boleh diperbaharui menjadi lebih menarik untuk pembangunan tenaga mampan di seluruh dunia. Tenaga angin mempunyai potensi yang besar sebagai sumber tenaga alternatif akibat kesan pemodenan global. Selama bertahun-tahun, permintaan untuk turbin angin berskala kecil di persekitaran binaan telah meningkat untuk mengurangkan pelepasan karbon di kawasan bandar. Turbin angin paksi menegak (VAWT) mempunyai potensi dalam bidang pembangunan kerana VAWT sesuai untuk keadaan kelajuan angin rendah, pergolakan tinggi, dan variasi arah angin. Walau bagaimanapun, pemutar angin ini secara amnya mempunyai kecekapan yang lebih rendah. Bilangan kajian dan penerbitan semasa dan pemahaman asas VAWT di bawah keadaan yang tidak baik adalah terhad. Berdasarkan ulasan literatur, dua faktor relevan dari parameter kritikal yang memberi kesan positif kepada prestasi kuasa VAWT adalah nisbah aspek dan kekukuhan. Oleh itu, analisis berangka yang komprehensif telah dijalankan dalam kajian ini untuk memahami fenomena aerodinamik dan ciri-ciri aliran angin di sekitar bilah turbin yang mempengaruhi prestasi VAWT dengan nisbah aspek dan kekukuhan yang berbeza dalam keadaan Reynolds number rendah antara (100000, 150000 dan 200000). Penyiasatan berangka dijalankan menggunakan perisian ANSYS Fluent menggunakan teknologi Dinamik Bendalir Pengkomputeran (CFD) kesetiaan tinggi. Penyelidikan semasa menggunakan pelbagai nisbah aspek (0.4, 2.0 dan 4.0) dengan radius rotor (2.50 m, 0.50 m, dan 0.25 m) masing-masing dan dengan panjang kord yang berbeza kerajang udara iaitu (0.1 m dan 0.20 m). Ketinggian bilah ditetapkan pada 1.0 m untuk mencapai pelbagai kekukuhan. Untuk bilangan keadaan angin Reynolds yang rendah, model CFD dua dimensi H-Darrieus VAWT dengan kekukuhan yang berbeza telah disimulasikan sepadan dengan nilai TSR (2.0, 2.5, 3.0). Pelbagai tetapan pengiraan dalam simulasi CFD dipertimbangkan berdasarkan pengalaman dan data kajian sebelumnya. Untuk tujuan pengesahan, keputusan awal telah dibandingkan dan disahkan terhadap simulasi yang diterbitkan dan data eksperimen untuk memastikan ketepatan hasil simulasi yang diperolehi dalam kajian ini. Penyelidikan ini juga terdiri daripada 54 simulasi secara keseluruhan. Kajian ini bertujuan untuk memberikan gambaran keseluruhan dan pemahaman tentang kesan perubahan diameter pemutar pada prestasi kuasa VAWT dan kajian awal untuk penyelidikan masa depan untuk meningkatkan reka bentuk VAWT yang optimum untuk kawasan bandar.

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CHAPTER 1

INTRODUCTION

1.1 Overview

For future generations, sustainable energy is a promising source of energy. The earth's natural energy source is depleting on a daily basis due to the increased of energy usage. One of the most important sources of renewable energy is wind. Wind turbines can transform mechanical energy into electrical energy, making them a viable source of energy. Vertical axis wind turbines have the benefit of being able to capture wind from any direction without the use of a yawing device. Vertical axis wind turbine (VAWT) has an axis of rotation perpendicular to the oncoming wind flow. (Mohammad et al., 2014)

Wind turbines have been widely installed in open space in rural areas. Iran is one of the countries that has begun to install wind turbines. The horizontal axis wind turbine (HAWT) was employed in the initial installation, which took place in the cities of Manjil and Roadbar. Every year, 1.8 million kWh of electricity was generated at a wind speed of 15 m/s for 3700 hours (Xin J et al.,2015). This technique has sparked interest in urban development (Elkhoury M et al., 2015). Therefore, the on-site renewable energy generation concept is widely applied to the populated area such as installing wind turbines on top of tall buildings. Furthermore, according to some study, VAWT performs better in urban areas than HAWT. The VAWT gave lower noise emission, insensitivity to yaw and better integration in agriculture projects (Mojtaba AB et al., 2015). It also requires low manufacturing cost while ease for the installation and maintenance as it is installed on the ground compared to HAWTs.

Aerodynamic problems in low Reynolds numbers (Re) flows are among the most crucial research areas that have been extensively studied recently to explore new energy potentials, especially in urban areas. For wind energy generation, the study of airflow and aerodynamics of the airfoil blades of a wind turbine is essential, especially for low wind speed application, hence low Reynolds number conditions. It is, therefore, necessary to investigate and analyze the aerodynamic characteristic of different geometrical ratios and their impact on the wind turbine characteristic as a whole. The purpose of this research is to assess the aerodynamic behavior of the rotating airfoils at various diameters on low Reynolds numbers and to establish the correlation between the performance and the geometry of a vertical axis wind turbine.

In this research, the aerodynamic analysis of VAWT is complicated due to their orientation in the oncoming wind. It has a rotational axis that is perpendicular to the direction of flow. Therefore, the wind flow interacting with the turbine blades will be analyses through numerical analyses. This assesses the interrelationships of the governing parameters such as the angle of attack, lift force, rotor diameter to height ratio, torque coefficient, power generation against tip speed ratio, and torque distribution. The research will be a step forward into the progress of wind turbine design, especially on the low Reynolds number effects in the aerodynamic performance of rotating airfoils and the interrelationship between airfoil dynamics and the wind turbine geometrical ratios. In the VAWT analysis, the symmetric airfoils have been commonly used in VAWTs, due to ease of manufacturing. These airfoils have zero lift coefficients (C_L) at zero angle of attack, while cambered airfoils tend to have positive lift coefficients (C_L) at zero angle of attack and above, until stall. This analysis will focus on the NACA0021 (National Advisory Committee for Aeronautics) airfoil. A 2D numerical simulation will be run through ANSYS Fluent software to calculate the aerodynamics characteristics and the performance of the VAWT.

Nowadays, renewable energy is the world's most pressing issue. It was discovered that the world's fossil fuel reserves are diminishing rapidly, and there are far fewer fresh reserves being discovered. Furthermore, energy production from fossil fuels has the potential to generate a slew of environmental issues, including greenhouse gas emissions, global warming, and acid rain. In this sort of circumstance, renewable energy sources play a crucial role. Winds, sunshine, rain, tides, waves, geothermal heat, and other renewable energy sources are used to generate renewable energy. Renewable energy is often used to power four different regions. Electricity generating, air and water heating/cooling, transportation, and rural (off-grid) energy services are the four categories (Ellabban et al., 2014). For example, Iceland and Norway already generate their electricity using renewable energy. Denmark's government has also pledged to move to 100 percent renewable energy for total energy supply, mobility, and heating or cooling by 2050. (V. Mathiesen et al., 2015).

The increase of carbon emissions in developing countries such as China and India have led to a significant shift in conventional energy generation by burning of fossil fuels such as coal, petroleum, and natural gas, into greener and environmentally friendly renewable energy sources such as solar energy, wind energy, and hydropower (Ramlee, 2020). It is estimated that renewable energy sources such as wind, solar, and hydropower will account for more than half of global electricity by 2035. Wind energy has been identified as a promising renewable option. Many nations have identified and formulated policies to ensure that wind power has a growing role in energy resources.

Wind energy is a rapidly growing and mature renewable energy technology because it is recognized as a natural, clean, and cheap power source. It has increasingly become a favorable renewable energy technology in many countries. Wind power is harvested and converted as electricity or mechanical energy, in which wind turbine does the power conversion.

Wind power development is exploding all over the world. Due to significant scientific advancements, industry maturation, and growing concerns about greenhouse emissions connected with fossil fuel combustion, the use of wind for power generation is rapidly developing. Despite the vast wind resources, only a small part of the available wind potential is now being utilized. Wind power adoption is influenced by government and electrical sector restrictions, as well as government incentives.

As wind energy sustainability gradually increases, researchers and manufacturers have reignited significant development efforts for wind energy harvesting devices (Muzammil, 2018). The harvesting devices are broadly divided into two different rotation axes of wind turbines, horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). In contrast with horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs), HAWTs are better than VAWTs because of their high wind energy extraction capacity, increasing power generation, and reduced system expenses per kilowatt of power generation. Therefore, HAWTs have become the dominant technology in modern wind energy technologies. However, VAWTs can satisfy specific energy generation requirements that cannot cultivate in some situations (Pope et al., 2010). HAWTs can only accomplish higher efficiency when the wind's energy quality is high. Simultaneously, VAWTs can extract wind energy from omni-direction, easier to install, have low maintenance costs, have better robustness and scalability, and produce low noise emissions (Rezaeiha et al., 2018b). The complex features of urban wind involve unstable, unsubstantial, and unsteady wind flow due to many obstacles (i.e., buildings). Therefore, Vertical axis wind turbines (VAWTs) like the Darrieus turbine appear to be promising for the conditions of unsteady and complex air flows (Balduzzi et al., 2012). The increase in energy demand automatically requires the development of more fields of land for wind farms. However, the number of vacant lands suitable for a wind farm is limited, which has become one of the main constraints for securing wind energy resources. Besides, this indirectly leads to massive land development and land acquisition costs, increasing the total cost of energy production. Therefore, a specific built-in environment in urban regions can be set aside to deploy a small wind power generation area to benefit cities and urban households.

1.2 Problem Statement

The global energy issue has concerned all country and has become the primary concern. Overall, all countries rely on fossil fuels (natural gas, crude oil) as an energy source for generating power, transportation, and other purposes. However,people tend to utilise excessive amounts of fossil fuels due to the depletion of fossil fuel supplies. This will not only give impact on the country, but it also had a terrible impact on the environment. Fossil fuels pollute the air, particularly carbon dioxide (CO_2), which is the primary driver of global warming and increasing sea levels (Anxo CS et al.,2015).

The emission of CO_2 is expected to increase in future drastically. Therefore, the need to look into alternative forms of energy sources. As a result, renewable energy (RE) has emerged as one of the most promising alternatives for reducing reliance on fossil fuels as a primary energy source. Wind energy is abundant, clean, and was used by humanity for centuries. Moreover, wind energy has been established as a mainstream form of energy in electrical power generation and has seen an increasing trend in its diffusion.

This study focuses on vertical axis wind turbines in low Reynolds number conditions to emulate urban on-site wind energy devices. Much research has shown that the VAWTs are more suitable for low wind speed flow that is typically found in urban areas. However, the efficiency and low self-start ability of VAWTs are their main drawbacks, especially for the lift-type VAWTs. One research area that can be explored is to improve the performance of the VAWT in the low Reynolds numbers (Re) aerodynamics. Research in the low Reynolds numbers aerodynamics has resolved many significant aerodynamic problems. For example, to improve the performance of a wind turbine, one could look to using an appropriately designed wind turbine (i.e. aspect ratios) utilising a high lift-to-drag ratio airfoil shape to increase its torque output.

Therefore, the study of airflow and aerodynamics of the airfoil blades of a wind turbine with various aspect ratios is crucial, especially for low wind speed applications, hence low Reynolds numbers. However, there is minimal research in the investigations on the effects of the airfoil blade spanwise positions wind turbine geometrical aspect ratio on the performance of the rotor during rotation. Computational Fluid Dynamics (CFD) is an adequate and often the best investigative tool for studying and analysing the aerodynamic performance of VAWTs under the influence of various geometrical and operational parameters. The benefit of CFD is that it provides a platform to explore various geometrical aspect ratios for optimum VAWT performance. Hence, the study will focus on numerical simulation in determining the performance of vertical axis wind turbines based on the variation of their geometrical aspect ratios.

1.3 Research Objective

Based on the problem statement, this research investigates the impact of various geometry parameters on the aerodynamic performance of straight-bladed VAWT under low Reynolds number wind conditions. The research is based on a numerical simulation method to carry out the analyses. In order to achieve these goals, two objectives of this research were set as follows:

a. To investigate the aerodynamic behaviours of the vertical axis wind turbine at the various diameter of rotors and airfoil chord length in low Reynolds number conditions.

b. To establish the correlation between the performance and the geometry of a vertical axis wind turbine.

1.4 Scope of Works

The project's work scope is planned to accomplish the objectives accordingly. The strategic scope of work is as follow

a. Carry out the literature review on the existing and past research on the aerodynamics performance characteristics of VAWTs of different geometrical parameters from different sources (i.e., journals, books, and articles).
b. Thorough literature survey of wind turbine geometric condition and performance on low Reynold number conditions (i.e., aspect ratio, angle of attack, lift force, drag force) as ultra-low Reynold number wind condition affect the performance of vertical axis wind turbine.
c. Understanding the Computational Fluid Dynamic (CFD) methodologies and the tools (i.e., ANSYS CFX or ANSYS Fluent) that can be used to carry out the studies, especially in the computational setting and parameters of the study.
d. Modelling of wind turbine rotor with selected airfoil blades with different aspect ratios, and various range of Reynolds number airflow for Computational Fluid Dynamic (CFD) simulation.
e. Carry out measurement and validation of Computational Fluid Dynamic (CFD) settings through benchmarking process with previous studies.
f. Performing CFD simulation analysis, and correlation of various wind turbine geometrical configurations (i.e., geometrical ratio, shape, size, airfoil) with its performance.
g. Selection of airfoil blades and range of optimized aspect ratios based on low Reynolds number wind conditions.
h. Verification of numerical analysis through comparison with past studies using CFD simulation.

1.5 Thesis Outline

Wind energy research and aerodynamic research are very complex. Therefore, it requires advanced numerical analysis and theoretical investigations. As a result, the study on various sources and materials should be carried out to grasp the research project title. The thesis is organised in the following way in order to illustrate the study's findings effectively:

In Chapter 1, a brief introduction to the renewable energy source, the impact of using non-renewable sources, the growth of wind energy, and wind turbines suitable for urban areas are presented. The problem statement, research objectives, and scope of work have also been established.

Chapter 2 presents the literature reviews where the state-of-the-art surveys of related studies regarding wind turbines are conducted. This chapter includes the wind turbine configuration, impact of geometry parameters on a VAWT and numerical simulation methodologies to measure aerodynamic performance. This chapter is vital to reveal the basis for conducting this research.

In Chapter 3, the research methodology using CFD simulations is presented in detail. This includes developing the numerical model, various computing settings, and comparing the study's obtained simulation results with published data. Moreover, mesh independent and transient analyses will also be carried out to achieve a higher fidelity data output.

Chapter 4 presents the data collected through the simulation and are discussed based on the methodology outlined in Chapter 3. This chapter includes the analysis of the vertical axis wind turbine performance based on the various geometrical aspect ratios, solidities, and Reynolds numbers. The numerical performance evaluation includes comparisons with previous studies and a detailed analysis of the blades' aerodynamic flow with varying parameters set in Chapter 3.

Lastly, Chapter 5 concludes the thesis with a summary of the present work with recommendations for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this rapidly developing nation, technology is an invention or tool that would improve the lives of humankind. Human beings are distinctly dependent on electricity and natural gas for their daily needs. As electricity increases, a reliable energy supply is essential to meet the demand. This energy mainly originates from non-renewable energy sources, such as fossil fuel combustion and increasing net carbon dioxide emissions. This scenario has intensified the development of renewable energy and environmentally friendly energy. This chapter outlines the demand for renewable energy sources, especially the characterisation of wind energy. It is focusing on the type of wind turbines and the design parameters of vertical axis wind turbines (VAWT) with the limitation on their performances. This chapter also introduces the factors that limit wind turbine performance and the application of computational fluid dynamic techniques.

2.2 Renewable Wind Energy

Wind energy is a by-product of the sun. The uneven solar heating of the atmosphere, the earth's irregular surfaces of mountains and valleys, and the planet revolve around the sun combine to *create* wind. Since wind is in plentiful supply, it is a sustainable resource for as long as the sun rays heat the planet. Renewable energy can be defined as greener energy from natural sources such as solar, geophysical, or biological sources that are naturally replenished at a rate that equals or exceeds its use rate. By considering sustainability requirements, renewable energy refers to modern technologies and approaches that convert energy from renewable sources into energy carriers that humans can use (Turkenburg et al., 2012). Example of renewable energy resources includes biomass energy, hydro energy, solar energy, wind energy, geothermal energy, and ocean i.e tidal, wave, current, ocean thermal.

Wind power is an attractive and alternative power source for large-scale and small-scale distributed power generation applications. Wind turbines generate electricity by converting wind energy into electricity (Wenehenubun et al., 2015). Onshore wind is a cost-effective electric power source that can compete with coal or gas plants (Walwyn et al.,2015). Offshore wind farms are more stable and resilient than onshore wind farms, and they have a lower aesthetic effect, but their construction and maintenance costs are substantially greater. Onshore wind farms have substantially greater development and maintenance expenses. With mainly untapped wind energy potential throughout the world and falling wind energy costs, an attempt to accelerate wind technology advancement and lower costs while enhancing environmental quality is needed.

2.3 Wind Energy Study in Malaysia

Malaysia is located in Southeast Asia that suffers from a low wind speed condition due to its weather climate and geographic position. In the early 1990s, the Malaysian Metrological Department conducted a wind speed investigation study, specifically for specific cities and regions. Those are Petaling Jaya, Melaka, Mersing, Kuala Terengganu, Sabah and Sarawak. Those locations have a higher wind speed rate than any other region in the country, giving rise to some potentials for wind turbines to be deployed in those areas (L. WahHo, 2016).

In comparison to other nations, Malaysia is recognised for having low wind speeds. The average annual wind speed in Malaysia is 1.8 m/s. Winds are stronger at places along Peninsular Malaysia's east coast, such as Mersing, Kota Kota bharu, and Kuala Terengganu. The average monthly wind speed in these areas might surpass 3 m/s. Wind energy has not been effectively harnessed in Malaysia since the average yearly wind speed is roughly 2 m/s, while most wind turbines require a minimum wind speed of 4 m/s to generate power (Chinnasamy, 2015).

Figure 2.1 shows the average monthly wind speed for some places in Malaysia and the mean wind speed in Malaysia through a global wind map. From this data, it can be concluded that Malaysia has low wind power resources.

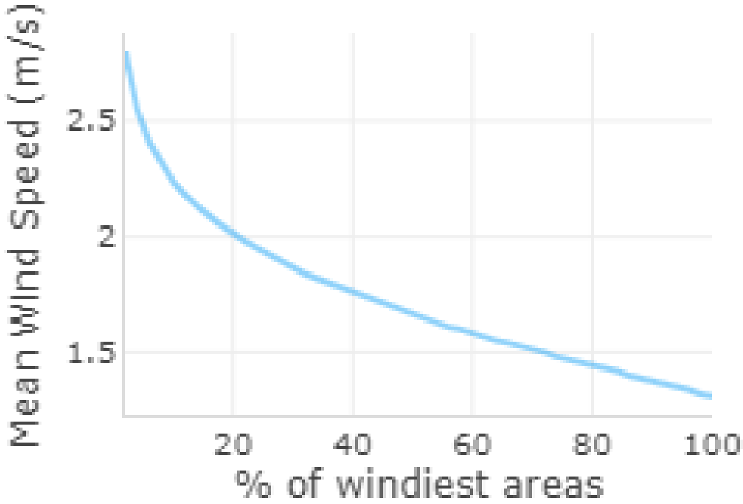

Figure 2.1 : Average wind speed in Malaysia
Source: (Globalwindatlas.info,2021)

Although many sites in Malaysia are not ideal for wind energy, the common belief is that some place, particularly along the coast and in windier areas, have a high potential for wind energy generation. Wind energy potential was discovered in studies undertaken in Kuala Terengganu, Kudat and Mersing. However, because wind speed varies greatly from season to season due to the monsoons, using wind energy in these areas may not be simple. (2017, B. Firdaus). In Malaysia, this has become a significant barrier for wind energy. Because Malaysia's government is still exploring the country's wind energy potential as a renewable energy source, wind turbines have only been built for educational and research purposes. In Malaysia, no wind energy power generation projects have been completed because the Malaysian government is still looking into the possibility of including wind energy as one of the country's eligible energy sources for power generation in order to reduce the country's carbon footprint and greenhouse gas emissions (The Star, 2017).This is further corroborated by a remark made by Tun Dr Mahathir Mohamad, Malaysia's Prime Minister which state that the government has proposed to build wind turbines in the sea on East Coast of Malaysia (Wong Ee Lin, 2019). However, incorporating wind energy as one of the country's renewable energy sources is not as simple as it would appear.

Tenaga Nasional Berhad (TNB) erected a 150 kW of wind turbines at Terumbu Layang Layang, Sabah, demonstrating some success in wind turbine construction. It is considered as having one of the Malaysian island's highest wind energy potential (A. Albani & M.Z. Ibrahim, 2017). Aside from that, on Perhentian Island, Terengganu a 100 kW wind turbine was combined with a 100 kW solar PV system and a 100 kW diesel generator. However, investigations revealed insufficient evidence for wind energy to be generated there.(Lip Wah Ho, 2016).

Moreover, some wind turbines having a capacity between 3.3 kW to 25 kW were installed in Kudat, Kuching, and Kuala Perlis. Thus, several investigations and research into the possibilities of wind energy were conducted, although many of the studies were inadequate. The Malaysian Government said in 2017 that Sabah, in Kota Marudu and Kudat, had been designated for wind energy development. (The Star,2017).

2.4 Vertical Axis Wind Turbine for urban areas

Many researchers have carried out numerous studies to develop innovative designs for generating electricity from turbines in urban areas. Often in urban areas, the wind speed is very low, and this can provide a barrier and affect the energy generation of electricity from wind turbines. Other than that, a very high wind speed coming out from an air conditioning cooling tower can generate electricity. A wind turbine can be placed on the mouth of the cooling tower where kinetic energy from the unnatural wind produced by the high-speed fan rotation can be extracted (S.C Poh et al.,2014). Moreover, the VAWT can be suitably placed on the cooling tower since the VAWT still can be functioning without the need of yaw mechanism (Mathew S et al.,2012). The size of VAWTs also is not too big and does not require a large area to install. Moreover, even though the wind source is low quality or in high turbulence, the VAWT still can be operated to capture wind energy.

The VAWT has a unique omni-direction blade arrangement that causes the blade to rotate in a constant speed, and did not need to be pointed to the wind direction. Because of this, the VAWTs generate more power than HAWTs in urban areas. In brief, the VAWT system consists of the main rotor and has several vertically oriented blades attached. Wind flows through the blades (i.e. airfoils) to create torque, and then the rotor will rotate when there is enough speed (Pope K et al., 2010). In certain VAWT, a small power motor is required to start the rotation since VAWT is not a self-starting turbine due to its original characteristics that require high wind speed for operation. Here, a variable pitch VAWT has been suggested to improve the wind turbine. This could be carried out by simply changing the angle of attack corresponding to various wind conditions (Pope K et al., 2010).

2.5 Basic Type and Component of Vertical Axis Wind Turbine

As mentioned, vertical axis wind turbines are a type of wind turbine where the main rotor shaft is set to traverse and not necessarily vertical. In addition, the major components are situated at the base of the turbine. This configuration places the generator and gearbox near the ground, making servicing and repair easier. Because VAWTs do not need to be directed into the wind, wind sensors and orientation systems are not required. The early designs (i.e. Savonius, Darrieus, and H-Darrieus) had major problems, such as significant bending moments on the blades and high torque fluctuation throughout each revolution. Basic components of a wind turbine, i.e. the generator, nacelle (for horizontal axis wind turbine), rotor and gearbox, are shown in Figure 2.2.

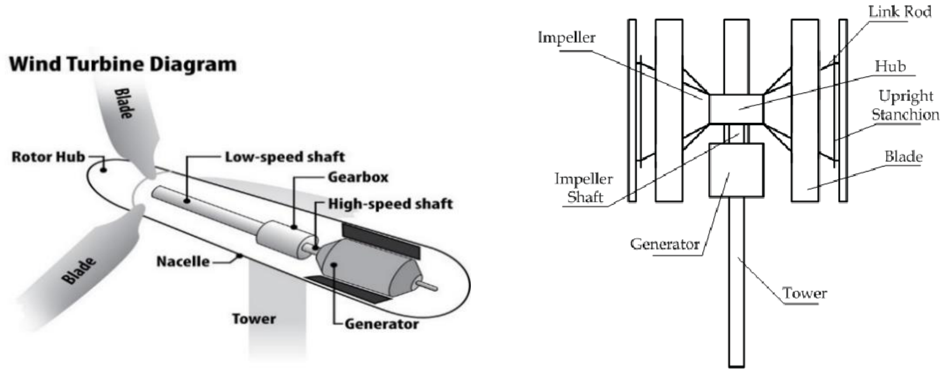

Figure 2.2 : Basic component of wind turbine
Source: (Hasan Shahariar, G.M., & Hasan, M.R. (2014)

2.5.1 Savonius and Darrieus VAWT

The rotor component is considered a significant component in a vertical axis wind turbine. The reason is that many types of rotor configurations have been studied and developed based on the literature survey. A suitable configuration rotor must be appropriately selected depending on the purpose of the wind turbine installation. This would enhance the performance of the system and the overall generation of energy. Besides, the parameter such as torque, power and the rotational speed of the rotor play essential roles in the performance of the VAWT system.

There are many types of configuration for the Darrieus rotor concept consisting of straight blades. Each type of configuration has a different shape and reliability. Figures 2.3 shows a Straight bladed Darrieus rotor and Figure 2.4 show the Variable Geometry Oval Trajectory (VGOT) Darrieus rotor. Meanwhile Figure 2.5 shows a egg beater shape Drrieus rotor. Lastly, Figure 2.6 shows the Savonius rotor a (A.Hamdan, 2014).

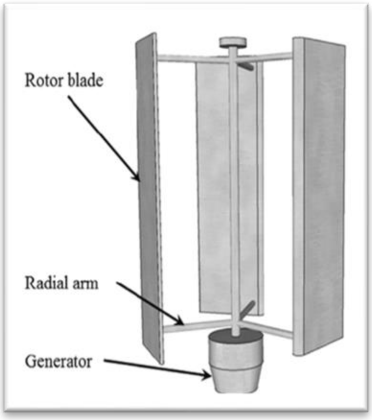

Figure 2.3 : Straight Bladed Darrieus rotor.

Source: (Hamdan, Ahmad et al., (2014)

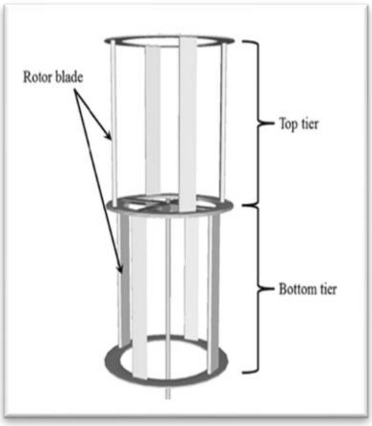

Figure 2.4 : Variable Geometry Oval Trajectory (VGOT) Darrieus rotor

Source: (Hamdan, Ahmad et al., (2014)