STUDY OF WIND ENERGY POTENTIAL AT SELECTED WIND SPEED STATIONS IN PENINSULAR MALAYSIA USING WEIBULL DISTRIBUTION FUNCTION

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ABSTRACT

Wind energy is considered one of the fastest-growing and most used renewable energy sources which can produce electricity without any harm to the environment. However, the application of wind energy is not thoroughly undertaken all over the world. In this study, wind characteristics and wind energy potentials in three different wind stations in Peninsular Malaysia located in Chuping, Kuantan, and Melaka have been analysed at different altitudes starting from the standard 10 m height up to 150 m height above sea level. Wind speed seasonable variations and prevailing wind directions are also thoroughly studied. The analysis technique was based on two-parameter Weibull distribution function over three recent consecutive years starting from 2018 up to 2020 to identify the potentiality of the wind as a source of energy generation in these respective sites. The results show that the monthly highest mean wind speeds were 4.42 m/s, 2.96 m/s, and 2.17 m/s in Melaka, Kuantan, and Chuping, respectively. The highest most probable wind speed was 4.70 m/s and the wind speed carrying maximum energy was 1.74 m/s, both occurred in Melaka in 2019. The yearly highest Weibull shape parameter was 1.69 and the scale parameter was 2.96 m/s. Among the three stations studied, Melaka has shown the highest wind power potentials with an average value of 26.10 W/m^2, followed by Kuantan with 12.71 W/m^2 and Chuping with 6.80 W/m^2 wind power densities. The corresponding wind energy densities were 595.58 kWh/m^2/year, 111.37 kWh/m^2/year, and 228.65 kWh/m^2/year for Chuping, Kuantan, and Melaka stations respectively. The prevailing wind directions are northeast at both Kuantan and Melaka stations, and west and southwest direction at Chuping station. It is therefore concluded that although the potential of the wind power of the sites covered in the present study is considerable, they are suitable for small-scale power generation applications only.

ABSTRAK

Tenaga angin dianggap sebagai salah satu sumber tenaga boleh diperbaharui yang paling pesat berkembang dan paling banyak digunakan serta boleh menghasilkan tenaga elektrik tanpa memudaratkan alam sekitar. Walau bagaimanapun, penggunaan tenaga angin adalah masih tidak menyeluruh. Dalam kajian ini, ciri-ciri angin dan potensi tenaga angin di tiga stesen angin berbeza di Semenanjung Malaysia, bertempat di Chuping, Kuantan, dan Melaka telah dianalisis pada ketinggian berbeza bermula pada ketinggian standard 10 m hingga 150 m dari aras laut. Kelajuan dan variasi arah angin dikaji dengan mendalam. Teknik analisis adalah berdasarkan teknik dikenali sebagai *two-parameter Weibull distribution function* untuk tempoh tiga tahun berturut-turut bermula dari 2018 hingga 2020 untuk mengenal pasti potensi angin sebagai sumber penjanaan tenaga di kawasan yang telah dikenal pasti ini. Keputusan menunjukkan bahawa purata kelajuan angin bulanan tertinggi ialah 4.42 m/s, 2.96 m/s, dan 2.17 m/s masing-masing di Melaka, Kuantan, dan Chuping. Kelajuan angin tertinggi ialah 4.70 m/s dan kelajuan angin yang membawa tenaga maksimum ialah 1.74 m/s kedua-dua berlaku di Melaka pada tahun 2019. Parameter bentuk Weibull tertinggi tahunan ialah 1.69 dan parameter skala ialah 2.96 m/s. Antara tiga stesen yang dikaji, stesen Melaka telah menunjukkan potensi kuasa angin tertinggi dengan nilai purata 26.10 W/m2 diikuti Kuantan dengan 12.71 W/m2 dan Chuping dengan ketumpatan kuasa angin 6.80 W/m2. Ketumpatan tenaga angin yang sepadan ialah 595.58 kWh/m2/tahun, 111.37 kWh/m2/tahun, dan 228.65 kWh/m2/tahun masing-masing untuk stesen Chuping, Kuantan, dan Melaka. Arah angin semasa adalah timur laut di kedua-dua stesen Kuantan dan Melaka, arah barat dan barat daya di stesen Chuping. Oleh itu, disimpulkan bahawa walaupun potensi kuasa angin di kawasan yang diliputi dalam kajian ini adalah besar, namun ia sesuai untuk aplikasi penjanaan kuasa skala kecil sahaja.

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LIST OF SYMBOLS AND ABBREVIATIONS

ρ	-	Air density
AC	-	Alternating current
z	-	Anemometer level
$\bar{V}$	-	Average wind speed
η	-	Betz limit
L	-	Blade length
r	-	Blade radius
λ	-	Combination of scale and shape parameter
$F(U)$	-	Cumulative distribution
DC	-	Direct current
E	-	East
EL	-	East longitude
$P(Vi)$	-	Frequency of wind speed falls within a bin
Γ	-	Gamma function
z_a	-	Height of anemometer
HAWT	-	Horizontal axis wind turbine
HOMER	-	Hybrid optimisation model for electric renewable
V_{max}	-	Maximum wind speed
V_m	-	Median wind speed
V_{mp}	-	Most probable of wind speed
n	-	Nonzero of wind speed
N	-	North
NL	-	North latitude
NW	-	Northwest
d	-	Number of the day
$p(U)$	-	Probability density / frequency distribution
A	-	Rotor swept area

c	-	Scale parameter
k	-	Shape parameter
SL	-	South latitude
σ	-	Standard deviation
t	-	Time
i	-	Timestep
VAWT	-	Vertical axis wind turbine
τ	-	Weibull location parameter
α	-	Weibull scale parameter
β	-	Weibull shape parameter
WECS	-	Wind energy conversion system
Ew	-	Wind energy density
$Pw(V)$	-	Wind power
Pw	-	Wind power density
WRPLOT	-	Wind rose plot
V	-	Wind speed
$V_{\max E}$	-	Wind speed carrying in maximum energy

CHAPTER I

INTRODUCTION

1.1 Background

Renewable energy sources such as solar, hydro, geothermal, and wind are receiving more attention nowadays from researchers, manufacturers, policymakers, and developers as they are becoming promising alternative sources of energy. They are being explored and considered globally in the effort to decrease the dependency on fossil fuels which are depleting, finite, producing GHG emissions, and rising in price. In particular, wind energy is considered one of the fastest-growing and most used renewable energy sources which can produce electricity without any harm to the environment. This is because wind energy is clean, renewable and possesses economically viable characteristics (Didane et al., 2019).

Current advancement in windmill technologies for design and development made the production of electricity through wind turbines more efficient than ever before with an economically viable process (Al-Ghriybah et al., 2019; Didane et al., 2016). Thus, to get the utmost benefits from the energy that comes from wind resources, further investigations are needed for the economical utilisation of wind energy. In addition, wind turbines have a good potential to be developed in future as the wind flows continuously around us to make it a better choice compared to solar power generation and fossil fuel (Cho et al., 2017).

Wind turbines are generally a chosen solution for large-scale applications such as the national grid for commercial-scale power production. There are two common types of wind turbine designs which are horizontal-axis (HAWT) and vertical axis wind turbine (VAWT). The vertical axis wind turbine is claimed as the most preferred wind turbine model for relatively low speed applications because it is efficient, quiet, suitable to set up in any place, and it is able to operate well in turbulent wind (Didane et al., 2019; Didane et al., 2020; Pagnini et al., 2018). The other design, which is the horizontal axis wind turbine, is the most built wind turbine. It can generate electricity more than the vertical axis wind turbine but heavy in weight and may not be able to operate well in the turbulent wind (Deisadze et al., 2013). The factor of heavier weight can cost more to undergo maintenance and do the set-up process.

Wind turbines basically generate electricity by converting kinetic energy to mechanical energy. Then, a generator will convert the mechanical energy to electric energy. Wind turbines can generate electricity when the rotors capture the wind flow (Lin et al., 2017). As the wind flows, the rotor or blade will rotate continuously when the wind is present. A shaft that is connected to the rotor and generator will spin to generate electricity. Wind turbines can also be used at home, school or office to supply electricity sufficiently in our daily lives.

In Malaysia, the primary energy demand is highly dependent on the technology utilised as well as the price of fuels used in providing the energy to various sectors. Therefore, the energy demand is more sensitive due to the changes in energy type, price of fuels used in different industries or sectors, and the pace of technological change which can impact directly or indirectly the energy demand and supply. As such, the energy prices and government policies will influence the pace of deployment and development of new technologies and take into account the global market conditions and economic factors.

The wind is a form of solar energy that is made of the uneven heating of the sun to the atmosphere, the irregularities of the earth's surface and the rotation of the earth (Akwa et al., 2012). The amount of wind energy varies according to the cube of wind speed. Therefore, it is important to understand the characteristic of the wind source in every aspect of wind energy exploitation starting from the identification of suitable sites and the design of wind turbines for the prediction of the economic viability of wind farm projects. It is also important to understand their effect on electricity distribution networks and consumers (Tjiu et al., 2015).

The potential of wind energy for a site is typically determined by the strength of the wind in the site of interest. Wind speed persistence and wind speed frequency are varying significantly at the very same terrain due to wind regime characteristics and that may lead to varied power output.

Malaysia has two different seasons, which are the southwest monsoon (May to September) and the northeast monsoon (October to March). Generally, Malaysia has a non-uniform flow of wind and experiences low-speed wind. Only certain places or areas in Malaysia experience strong wind. The success of a wind power project shall relate to two main factors; the proper site assessment and choosing the appropriate wind turbine for the particular site.

There are numerous numerical and statistical methods used to evaluate the wind potentials of a site since the meteoritical wind speed data alone is not sufficient to give an accurate appraisal. Among the widely used technique is the two-parameter Weibull distribution method known for its simplicity, suppleness, and accuracy to fit the meteorological data (Didane et al., 2017; Hassane et al., 2018a; Islam et al., 2011a).

In this study, the two-parameter Weibull distribution function is adopted to study the potential of the wind as a source of power generation in the three geographically different stations in Malaysia, namely Chuping station in the state of Perlis, Kuantan station in Pahang, and Melaka station in the state of Melaka.

1.2 Problem Statement

Malaysia lies close to the equatorial line and has two different seasons, the southwest monsoon which starts from May up to September and the northeast monsoon which starts from October up to March. In other words, Malaysia has a non-uniform flow of wind and experiences low-speed wind. Only certain places or areas in Malaysia experience strong wind. Therefore, the success of a wind power project for such sites depends on two things; firstly, the proper site assessment including wind speed persistence, variation with altitude, and wind speed frequency which varies significantly at the very same terrain due to wind regime characteristics and that may lead to varied power output. Secondly, choosing an appropriate wind turbine for the particular site.

There are various numerical and statistical methods used to evaluate the wind potentials of a site since the meteorological wind speed data alone is not sufficient to give an accurate appraisal. The two-parameter Weibull distribution method is among the widely used technique due to its simplicity, suppleness, and accuracy to fit the meteorological data. In this study, the two-parameter Weibull distribution function is adopted to identify the potential of the wind as a source of energy generation at three different stations in Malaysia, namely Chuping station in the state of Perlis, Kuantan station in Pahang, and Melaka station in the state of Melaka.

1.3 Objectives

The main objectives of this study are as follows:

1) To study and establish the potential of wind energy at three different wind stations in Malaysia using Weibull distribution.
2) To provide and compare the seasonal variations between the stations studied including the variation of wind speed with altitudes.
3) To determine the prevailing wind direction of the three stations for 2018, 2019 and 2020.

1.4 Scopes

To achieve the main objectives of this study, these scopes are considered:

1) The study involves only three wind speed stations in Peninsular Malaysia.
2) The statistical Weibull two-parameter distribution method is used to analyse the data.
3) The data used is for the last three years (2018, 2019, and 2020).

4) The data collected involves daily and monthly average data.

1.5 Significance of the Study

The study of potential wind energy could provide an overview and a wind potential map in several different locations in Malaysia. The study would also serve as relevant wind characteristic data to meet the possibility to implement the types of wind turbine system at those wind stations. The determination of a suitable location together with the prevailing wind direction is very important and a crucial step in planning a wind energy project. Likewise, detailed knowledge of the wind characteristics at these three sites is needed to estimate and to lead to a deeper understanding of the performance of a wind energy project. The study shall become a reference on the issues of the wind resource areas specifically in Malaysia as it would be beneficial to society, project players of the renewable energy sector, and any future researcher.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a comprehensive review and discussions of previous works related to wind energy in Malaysia are discussed. The chapter also covers a discussion on the typical renowned methods of assessing the potential of wind power at a particular site. Moreover, an extensive review and discussion on the devices used to harvest wind energy are also presented including both horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT).

2.1 General Climate of Malaysia

Malaysia comprises Peninsular Malaysia, Sabah, and Sarawak which are part of Borneo Island. Malaysia lies in the equatorial zone and the climate was affected by the northeast and southwest monsoons which blow alternately during the year as mentioned by Sopian et al. (1995). The wind over the country of Malaysia is light and variable, but there have been some uniform periodic changes in the pattern of wind flow as highlighted by the Malaysian Meteorological Department (MMD) in 2011. Four seasons of monsoon can be found and classified through these changes, which are the southwest and northeast monsoon and including two inter-monsoon seasons in shorter periods.

Early June and the end of September go through southwest monsoon season, and its wind flow is generally light. November or end of March undergo southwest monsoon season.

During the inter-monsoon seasons, the winds become light and generally variable. However, during these seasons in Malaysia, the equatorial trough (quasi-continuous situation of low atmospheric pressure) occurs. There is also a significant effect of the land and sea breezes influence the wind flow pattern, especially during the day times. Sea breeze often occurs during the sunny noon, and it can reach up to several tens of kilometres to the land. That would be the reverse process which is the land breeze takes place in the night-time, and land breezes of weaker strength can also develop over the coastal areas.

Malaysia's total land area is 329,847 square kilometres, the 66th largest country in the world in terms of area. It is the only country to contain land on both mainland Asia and the Malay Archipelago. Peninsular Malaysia makes up 132,090 square kilometres or almost 40% of the country, while East Malaysia covers 198,847 square kilometres or 60%. Of the total land area, 1,200 square kilometres or 0.37% is made up of water such as lakes, rivers, or other internal waters. Malaysia has a total coastline of 4,675 kilometres, and Peninsular Malaysia has 2,068 kilometres, while East Malaysia has 2,607 kilometres of coastline.

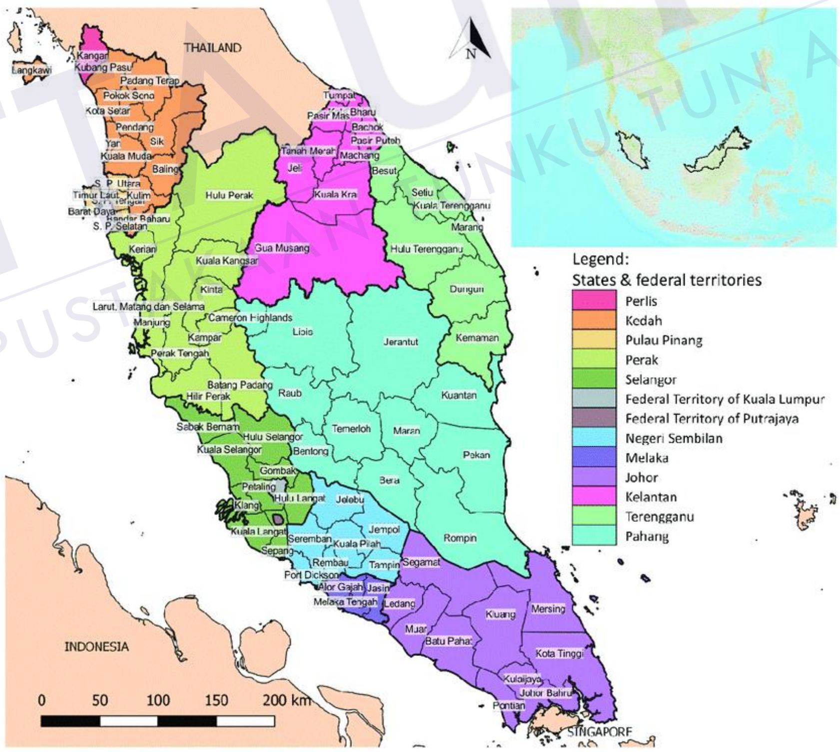

Figure 2.1: Map of Peninsular Malaysia

2.2 Energy Status in Malaysia

Dependence on fossil fuels has given an adverse impact on the availability of resources and the environment. The decline comes from the growing population in developing countries and its lack of energy supply, especially in rural or remote regions. This creates pressure to generate more energy supply structures to meet the current and future needs for electricity demands. Permanent electricity supply is considered one of the major factors responsible for the sustainable economic and social development of a nation (Mohammed et al., 2013).

Due to the decline in fossil fuels, alternative sources are derived from renewable energy sources such as solar, biomass, wind, tidal, and hydropower. Wind as a source of sustainable energy is one of the most common resources used. From being unlimited and free, it has the capacity to contribute for technology advancement and performance around the world and especially so towards the rural and remote regions that fall out of the national grid from electricity (Borhanazad et al., 2013).

Wind assessments studies have been carried out in Malaysia since the 1990s. As Malaysia is located at the equator, land and sea breezes may influence the wind regime. The wind does not blow uniformly and varies according to the month and region. Therefore, studies on wind speed behaviour and characteristic have dominated wind studies in Malaysia. The southern and East coast of Peninsular Malaysia shows higher potential in terms of wind velocity as compared to other parts primarily due to the monsoon seasons that affect such area exposed to the South China Sea (Sopian et al., 1995).

The most effective way to reduce the impact of power generation on global climate change is the divestment of the fossil fuel-related business and extreme reduction of electricity usage. However, this way is impossible without practical alternative sources of energy that can provide service to human activities, seen purposely made difficult by a fossil fuel industry that profits and will continue to profit from the status. It has been seen that the future of climate change has been dominated by controlling the power generation from the economy and politics of fossil fuels. The other way that may encourage some resistance to the status is the long and slow process of educating those who do not directly gain the profit or benefits from the fossil fuel industry, at least from the energy demand is concerned. However, the net world electricity consumption raised from about 7000 billion kWh in 1980 to more than 15000 billion kWh in 2011 has been doubling due to the development of technology as well (EIA, 2013).

Since the 1980's Malaysia has experienced a rise in carbon dioxide (CO_2) emissions from energy usage. Hence, Malaysia becomes one of the fastest-growing CO_2 emissions rate countries in the world. A report from the United States Energy Information Administration (2013) stated that in 1980, 26 million metric tons of CO_2 was released from the energy consumption in Malaysia. The emissions rose to 195 million metric tons in 2011. At the same time, the electrical consumption in Malaysia rose to about 106 billion kWh. In the year 2009, Malaysia's Prime Minister had made a voluntary commitment to the reduction of CO_2 emissions by 40% in 2020 from 2005. This commitment further reinforced Malaysia's ratification of the Kyoto Protocol in 2002 (*EIA*, 2013).

Study on renewable energy becomes significant as part of the effort to combat the climate issues due to the CO_2 emissions. The potential of renewable energy includes hydropower, geothermal power, solar power, and wind power. This work focuses on study of wind energy potential at selected wind stations in Malaysia. The objective of this study is to analyse the wind power potential in Malaysia and to help in giving awareness and encouragement for using the renewable energy in the power generation sectors.

2.3 Wind Energy Conversion System (WECS)

Wind energy conversion system (WECS) or referred to as a wind turbine which utilises the potential of wind to generate energy. It is a device used to convert kinetic energy from wind movement into mechanical energy and finally produce electric energy. With wind turbine generators, mechanical energy is converted into electricity and in windmills this energy is used to do work such as pumping water, mill grains, or drive machinery. The advantages of this system are it can work continuously as long as there is a potential for wind energy in the area. Wind energy is environmentally friendly and it will not cause negative effects on the environment (Ananta & Purbawanto, 2014).

2.3.1 Power Control of Wind Turbine

The wind turbine turns and converts wind energy into electricity by mean aerodynamic force from the rotor blades. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity. Usually, energy produced is saved in a battery before it can be used (Sumiati & Amri, 2014).

Wind turbine design is the process of defining the form and configuration of a wind turbine to extract energy from the wind. An installation consists of the systems needed to capture the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and other systems to start, stop and control the turbine. The net efficiency of the wind turbines is depending on input power of wind turbine and the rated velocity. The net efficiency shall reduce after reaching its maximum before rating the wind speed and due to the pitch control, it starts to waste the energy after this point maintaining power under limits. The pitch control is the electric tool in the turbine which checks the power output several times. If the output power is too high, it will give order to the blades and the blades immediately turn the rotor slightly out from the wind direction. But this mechanism will be back to actual when the wind drops again. Hence, the pitch control can be run at a variable speed and makes it a mechanical process. It will be controlling the torque and makes the gearbox and generator not overload by using pithing the blades (Wagner, 2018).

2.3.2 Classification of Wind Turbine

Based on the constructional design, the wind turbine can be divided into two types, which are vertical axis wind turbine and horizontal axis wind turbine. This classification is more feasible and commonly used.
Vertical axis wind turbine (VAWT) is the oldest model of wind turbine. In the beginning, VAWT is just like drag type rotors. Based on the rotor, VAWT can be divided into three types namely Savonius-rotor, Darrieus-rotor, and the H-rotor.

The Savonius design is usually used for the small and simple wind rotor like in the water pump because this design is not compatible to use in electric generators due to its low tip speed ratio. Savonius turbines can work because the concave part of the blades accepts wind and causes the blade to rotate at the shaft which can also produce force. Hence, the concave blades can force the rotor to rotate with the force generated in the blades. Then, the Darrieus is usually used in the aerodynamics sector, with the rotation in the pattern of surface line or rotation in the vertical axis. But to make the geometric blades is complicated and preferably this design is built with two or three blades.

The variation of Darrieus is H-rotor with straight blades that are connected to the rotor shaft and this is the simple design of VAWT with a permanent generator integrated into the rotor without the intermediary gearbox. Although the VAWT does not produce large electrical energy, with more development, it is expected that the VAWT can be a serious rival for the Horizontal axis rotor in future (Hau, 2013; Wenehenubun et al., 2015).

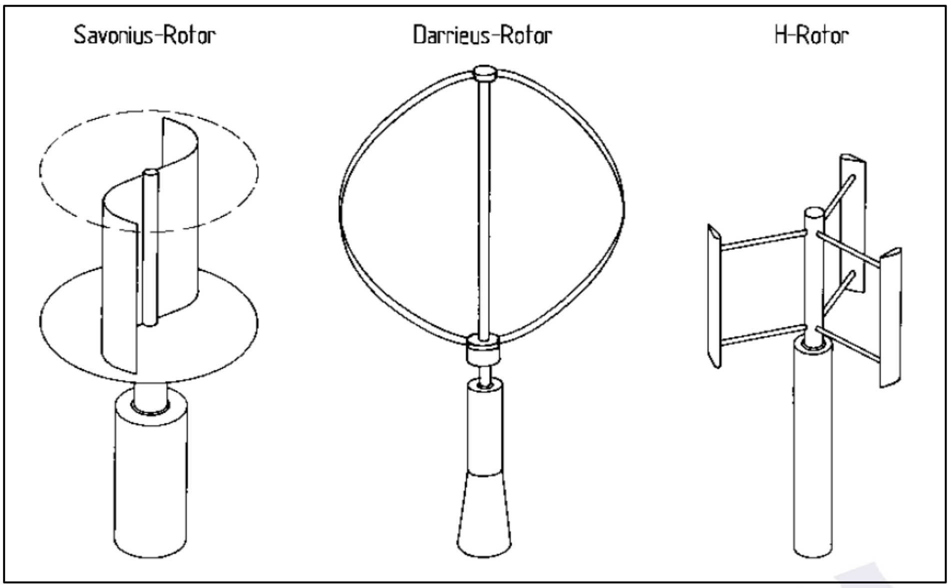

Figure 2.2: Types of vertical axis wind turbine (Hau, 2013)

Horizontal axis wind turbine (HAWT) is the exclusive wind turbine that now has a concept based on the propeller on the horizontal axis. The following characteristics of this turbine: In propeller design, the rotor speed and power output can be controlled by the pitching of the rotor blades. The rotor blade can be optimised by using the maximum exploit of the aerodynamics lift. The technology is the factor in the development of propeller design. From the advantages above, HAWT is a thing used for generating electricity (Hau, 2013).

Figure 2.3: Horizontal axis wind turbine (Hau, 2013)

2.3.3 Wind Turbine Component

Nowadays the wind turbine has variation in size with technological advances. Technology improvement in the wind turbine component is being updated now. Component design improvement is important to ensure a stable wind turbine architecture and to work toward optimum efficiency. The followings are general wind turbine components:

(i) Rotor (which is divided into four parts blades, blade extender, the hub, and the pitch drive system).

(ii) Nacelle (the structure above the tower and housing of controller, gearbox, generator, large bearings, connecting shaft, and electronics part which is to monitor the wind speed and direction).

(iii)Tower (as the foundation and to support the blades and nacelle).

(iv)Other components (include transformers, circuit breakers, fibre optic cables, and ground-mounted electrical equipment)

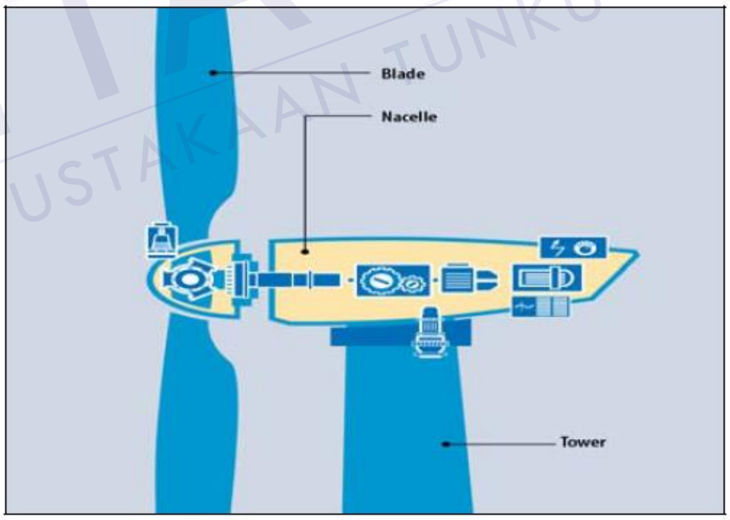

Figure 2.4: General component of wind turbine (Platzer, 2012)

Based on Figure 2.4, we can know the percentages of the cost to build the wind turbine based on the percentages of cost in each component. But not just about it, because the raw materials also influence the costs. But the dominant material used to build the turbine is steel, especially to manufacture the wind blades (Platzer, 2012).

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