ARIV
International Journal of Technology
Paper ID: AIJT12092020 Vol1 Issue 2 2020

Feasibility study of Horizontal-Axis Wind Turbine

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Abstract

Wind energy is an abundant renewable energy source all around the world as it is always available and said to be infinite. This research paper investigated the possibility of successfully installing wind turbines in certain parts of Malaysia as an alternative energy source. Generally, there are two types of wind turbines, namely the Vertical-Axis Wind Turbine (VAWT) and the Horizontal-Axis Wind Turbine (HAWT). The study includes the advantages, disadvantages, practicality, implementation cost, and comparison between the two types of the wind turbine. An investigation has been done to figure out which type of wind turbine is suitable and sustainable for East Malaysia. The general wind conditions in East Malaysia were included in the analytical calculations of power and efficiency of the HAWT, which further demonstrates why it is more suitable for East Malaysia than the VAWT. Thus, it is evident that Malaysia would truly benefit from implementing a wind turbine as a renewable energy source. A simulation of HAWT and VAWT wind turbine was done on SolidWorks to further investigate the overall efficiency of wind turbines in offshore areas of Malaysia. Moreover, a few recommendations have been added such as making efforts to raise awareness of the need to implement wind turbines by reaching out to government bodies, non-government associations, and the public, for the future and benefit of the people.

Keywords: Wind energy, renewable, sustainable Vertical-Axis Wind Turbine, Horizontal-Axis Wind Turbine.

Introduction

This paper presents in-depth research on the background of wind energy and the suitability of implementing a wind turbine in Malaysia. The need of implementing an alternative energy source is becoming more crucial as non-renewable energies are rapidly diminishing to meet the demand of the population (Khandakar, 2012, Hasan et al., 2010, Khandakar et al., 2014, Alammari et al., 2017, Islam et al., 2015). Researchers had looked into replacing the need for conventional fuels with renewable resources such as solar, wind, hydro, and so on. Wind energy has been used for thousands of years for purposes such as sailing, electricity generation, grinding mechanisms, and so on. The wind is formed when the air moves from the higher-pressure region to a lower pressure region. As hot air has a low density, it will rise from the ground and cool air will displace the vacuum space left by the hot air. Wind power can be defined as the conversion of wind energy to other useful forms of energy such as electrical and mechanical energies. Wind power is relatively clean, as it does not trigger greenhouse gas emissions. Furthermore, wind power generation plant does not take up a lot of space as compared to other forms of renewable energy.

Nowadays, the energy demand for developing countries is to keep increasing because of new technologies and the consumption of electrical energy rising. Besides that, the carbon footprint of the world also kept is increasing and all the resources available on the earth will be concerned, if the resident on the earth keeps on using the resources at this rate. This is why the reduction of this issue is needed and to have a healthy environment. To reduce this incident happen in the future, the use of renewable energy is highly recommended for the residents on the earth. Renewable energy is a kind of energy that can be gained from the natural resource that could be kept renewing within a lifespan of the human. The natural resource could be wind, sunlight, and water. Besides, various types of renewable energy exist in today's world, for example, wind energy, solar energy, tidal energy, and hydroelectric energy.

To date, several wind turbines had been successfully implemented in Malaysia. Some of these examples are located in Sabah, East Malaysia, and Terengganu in West Malaysia. The very first solar and wind hybrid turbines implemented in Malaysia is in Pulau Perhentian in the state of Terengganu of West Malaysia. The project is said to be funded by a project funding initiative under the Federal Government Electricity Supply Industrial Trust Account and State Government of Terengganu (Rahman, 2007), with the total cost of the solar and wind generation plant around RM12.7 Million. The hybrid turbines had been a major success as it has efficiently cut down the total cost for electrical power, which was initially provided by diesel generators. With the hybrid wind turbines, it has cut down a whopping 40% of the total cost of generating power with the fuel generators. Moreover, this provides the benchmark for other possible projects in the future, to install more wind turbines around Malaysia to help reduce the usage of non-renewable energy sources.

According to Yusoff (2006), the application of wind energy is for water supply, irrigation using the wind pumps, and using the wind generators to generate electrical energy. Back in 5,000 B.C., the ancient Egyptians are the first ones who use the wind power to sail their boat. Later, Iran had invited the windmills to grind their grain; the early windmills looked like a large paddle wheel. Centuries later, the basic design of the windmills had been redesigned by the people of Holland. Throughout the design, the blade of the propeller on the windmills was made by fabric sails and they also had made the direction of the windmills can be changed easily so that the windmills can also facing the direction of the wind. On the other hand, the people of America also use windmills to pump water, grind wheat, and cutting wood. Besides that, the American also had to use the concept of windmills to generate electricity in the rural area where it does not have any electrical service in the year of 1920. In the 1930s, the use of windmills becomes less after the power lines had begun to supply electric service to the rural areas.

This research project aims to study more detail on wind energy and wind energy as an alternative renewable energy source in the region of Malaysia. The Objectives are outlined below:

- To determine the site description in Malaysia.
- To determine various types of Wind turbines in today’s world.
- To perform the analytical calculation of the energy output for the modification design
- To compare the difference between modification design and the existing wind turbine design
- To develop teamwork, with many professionals involved.

Status of renewable energy in Malaysia

Malaysia is currently implementing the strategy of Five- Fuel Diversification Strategy to produce the energy demand for the country (Ong et al., 2011). The Five- Fuel Diversification resources consist of natural gas, coal, oil, hydro, and renewable energy. The electricity in Malaysia is mostly generated by using non-renewable resources such as coal, fuel, and natural gas (Mekhilef et al., 2014). Coal and fuel are also known as a kind of non- renewable energy and it will pollute the living environment of the human. Besides, the prices of coal and fuel are kept increasing in the global market because of the volume of coal and fuel will be decreased or finished at the current rate of usage. To overcome the problem related to the environment polluted and the depletion of Coal and Fuel the Malaysian government had formulated the National Green Technology policy in April 2009. On the other hand, the Malaysia government had taken action on exploring the resource of renewable energy as alternative energy to generate the demand for electrical energy for the country. According to Albani et al. (Albani et al., 2013), wind energy was the fastest-growing energy technology than other kinds of renewable energy in today's world. Besides, wind energy also meets the needs of the country and it can reduce the use of burning fossil fuel to generate energy and it could provide more a clean environment for the people.

Geographic aspect

Malaysia is known as a country, which was located in the region of Southeast Asia and the land of Malaysia is mostly surrounded by water. Besides, Malaysia can divide into two regions, which were called as West Malaysia where it is also called as peninsular Malaysia and East Malaysia. Malaysia is located roughly between 1 to 6 degrees on the north latitude and 100 to 104 on the east longitude (Chiang et al., 2003). Malaysia is also boarded by Thailand in the north part of Malaysia, and the country of Indonesia and the Philippines is in the south and east part of Malaysia. The land size of this country is about 329,758-kilometer square and the separated distance between West Malaysia and East Malaysia is about 640 kilometers [5].

Weather and wind speed

Malaysia is humid tropical with warm and uniform temperature country. Throughout the year the temperature and the humidity were high, but the temperature on the mountain will be slightly cooler (Sopian and Khatib, 2013). The weather of Malaysia is influenced by two monsoons, which were called as Northeast monsoon and Southwest monsoon. Northeast monsoon will be occurring between November and March, where the Southwest monsoon will be occurring between May and September. Besides that, the wind speed during the period of Northeast monsoon can reach up to 15 m/s and the wind speed during Southwest monsoon can be below 7 m/s. Due to the effect of typhoons which is striking in the country such as Vietnam and the Philippines, the strong wind will be blowing to East Malaysia and the speed of the wind could be more than 10 m/s. According to Azhar (Aziz, 2011), the annual average wind speed of Malaysia is low and it will not more than 2 m/s. Even though the wind speed is low in Malaysia, but it is still possible to install a small wind turbine in which the wind turbine can be operated below the wind speed of 3 m/s facing to the side of the South China Sea.

Technology Overview of Wind Turbine

Nowadays, the wind turbine is widely used in many countries across the globe as well as Malaysia. The wind turbine has functioned when the wind passes by the wind turbine. The electricity will be generated when the wind turbine spin and power up the generator. The wind turbine is a sustainable and environmentally friendly device due to the wind as the clean main power source. Due to the advanced knowledge and technologies nowadays, the wind turbine has been designed into any kind of shape and design. The wind turbine can be divided into two main types which are the Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Figure 1 (Kumara et al., (2017)) shows the difference between HAWT and VAWT.

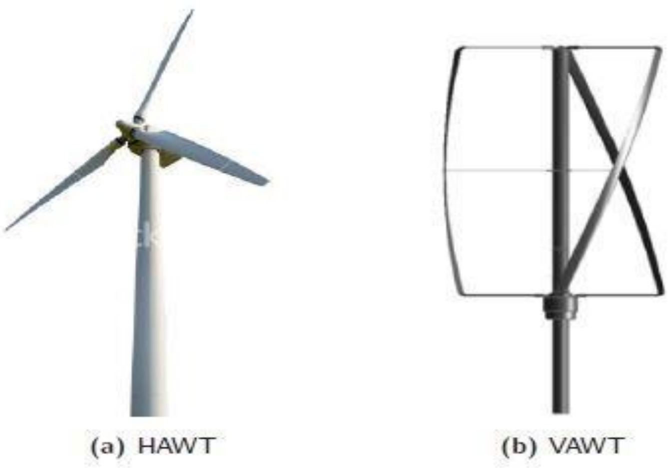

Figure 1 HAWT & VAWT

Technologies Overview of HAWT

The Horizontal Axis Wind Turbine (HAWT) generally has a height of 90 meters due to the strength of the wind at a high altitude. A nacelle is located at the top of the tower and it houses the main components of the wind turbines such as the main rotor shaft, electrical generator, and the 3-blade or 2-blade rotor which have equal or more than 100 meters in diameter. The blades will spin the rotor and the rotor will spin rotates the shaft that fitted to the nacelle when the wind blows. The shaft is connected with the generator and the generator can convert the rotation of the shaft into electrical energy. Besides, a transformer is located inside the tower and it is used to raise the voltage and the current and transported via the electric grid power lines. The minimum required annual wind speed for the functioning of the wind turbine is 10-15 km/h. The HAWT consists of a safety device that been used to stop the rotation when the wind speed exceeds 90 km/h. The HAWT has more than 2 blades but generally is 2 to 3 blades. The main principle behind the HAWT is the principle of wind turbine aerodynamic lift and this only occurs during the wind flows over the aerofoil shaped blades. The aerofoil shaped blades will cause the velocity of the airflow at the upper side of the blades to become high and this will leads the low pressure at the high-velocity side and high pressure at the low-velocity side. Thus the aerodynamic lift will be created due to the pressure difference at the top and the bottom of the blades (Darling, 2015).

Advantages and Disadvantages of HAWT

There are two main types of HAWT which are the upwind wind turbine and downwind wind turbine. The differences between these two types can be known by looking at the direction of the rotor face. The upwind turbine rotor is facing the wind direction or against the wind flow direction as shown in Figure 2 (Hitachi, 2014). The benefit of the upwind turbines is to avoid the wind flow from the opposite direction or behind the tower. The disadvantage of the upwind turbine is the rotor must be fixed in the direction that the rotor against the direction of wind flows. Other than that, a yaw mechanism is required to keep the rotor facing the wind flow direction (Hitachi, 2014).

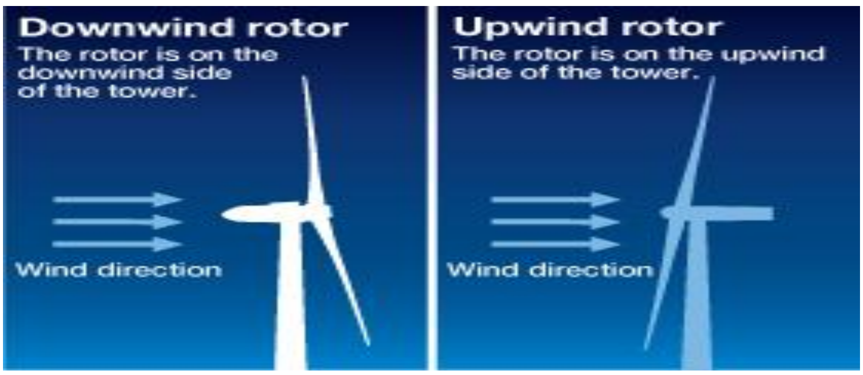

Figure 2 Upwind and Downwind Rotor

The downwind turbine functions when the wind flows from the back of the tower. The advantage of the downwind wind turbine is the wind turbine can be built without the yaw mechanism and flexible. Thus, the rotor and nacelle will be designed the way it can follow the direction of wind flow passively. The downwind turbine has lesser weight than upwind due to the no yaw mechanism design. This can make the blades rotate at a higher speed and generate more electricity. Unfortunately, the fluctuation in wind power will be occurred due to the direction of the rotor and this can lead to the increases of fatigue loads on the turbine when compared with the upwind turbine (TeacherGeek, 2006)

Installation of HAWT

A flat foundation will be used depending on the site situation for the stability of the wind turbine. The reason is the foundation is used to hold the self-weight of the tower, nacelle, rotor blades, and hold the rotation movement of the rotor blades caused by the wind flow. Then, the tower will be built on the foundation and the nacelle placed on the top of the tower. The nacelle is used to hold all the turbine machinery and it orients the machine in the best wind flow direction. At last, the hub is placed in front of the rotor and completes the installation of HAWT.

Cost Information about HAWT

The factors that governing the wind turbine cost are investment costs and operational & maintenance costs. The amount of the investment cost is different depending on the capacity of the wind turbine that wants to be installed. The cost of investment will become high if want to install a high capacity wind turbine. The cost of the wind turbine is referring to the size, diameter of the turbines and the tower height. The estimated cost of investment of windmill in Malaysia is RM1.4 billion with a land area of 18977 KM^2. and able to set up the wind turbine to generate the wind power in Malaysia (Azhar, 2011). Wind turbine nowadays generally consists of 20 years lifetime and able to operates 120,000 hours within the life time[7]. Other than that, the maintenance fee will be estimated as 2% of the investment cost of wind turbines per year (Azhar, 2011). The Tenaga Nasional Berhad in Malaysia cooperates with the renewable energy firm from Argentina and Industries Metalurgicas Pescarmo to generate 500 to 2000MW by the wind turbine to meet the demand of 4 to 14% by 2020. The calculation below is to calculate the amount of power that can be generated:

Average wind speed = 3m/s,

Height of wind tower = 32m,

The diameter of the wind turbine = 25m,

The circular area of the turbine is $491m^2$

The energy per m^2 area of wind turbine

= (0.5)*(air density)*(average wind speed)^3

= $(0.5)*(1.3)*(3)^3$

= $17.55W/m^2$

Therefore, the total wind power

= $17.55W/m^2$ x $49m^2$ = 8615W

Assume the minimum efficiency as 50%, the actual output will be = 4308W

Potential Challenges

The potential challenge for the upwind and downwind turbine is the wake effect that occurred between both of them. A wind wake effect will be created by the upwind turbines when the wind flows through the turbines. The wind will flow to adjacent downwind turbines and affect the performance of the downwind turbines. This will cause the reduction of energy production and mechanical loads may increase. The wind speed at the downwind of the turbine has a lower speed than the free stream with high turbulence when the wind flows through the turbine. The free stream at the upstream from the turbine is traveling with the natural velocity. Therefore, the wind at the turbine will have lower kinetic energy than the wind before passing the turbines and this causes the reduction of the energy generation. The environmental, atmospheric, and model of the wind turbine are the main factor that causes the differences in wind speed, turbulence, and atmospheric stratification. Therefore, the consideration of the impact of the wake effect placement, operation, and performance of wind turbines must be done by the developers and engineers during the construction of the wind turbine (Diamond, 2015).

Technology Overview of VAWT

The Vertical Axis Wind Turbine (VAWT) can accept the wind flow from any direction without repositioning the rotor. The rotor blades will turn and sweep a three-dimensional surface as long as the wind is flow in the direction of perpendicular to the axis of the rotation of the blades. Compare with the traditional vertical axis wind turbine, the modern vertical axis wind turbine able to extract most of the power from the wind when it passes across the blades. The rotor set for the VAWT is set vertically and as opposed to its counterpart technology which is the HAWT because the main components are installed at the base area. The reason locating the main components at the base area is allowing convenience during maintenance. The rotor blades of VAWT have the aerofoil design and suspended perpendicular to the ground. The blades are attached at the top and the bottom of the rotor shaft and form a natural parabolic shape. Furthermore, the blades will experience less stress and it can be fabricated lighter at a lower cost. The remarkable cost and complication of equipment and controls required for orientation can be reduced because the blades are arranged vertically with the Omni-direction to allow the wind to rotate them.

The benefit of using the VAWT is no worry about the direction of the wind flows. The blades still rotate and generate electrical energy from the kinetic energy regardless of which way of the wind blows or changing direction frequently. The VAWTs are not as widely used as the HAWTs. Furthermore, the VAWT can generate electrical power at the low wind speed or frequently speed changing conditions. Other than that, the balanced approach for the wind tower design produces less stress on the support structure and the height of the tower is under the average collectible zone. These factors can help to reduce the construction cost for the towers. Since the generator speed is not constant due to the low wind speed and frequently speed changing condition, an inverter is used in the VAWT to change the three-phase voltage which is produced by the generator into single-phase AC voltage at 60Hz for the residential area or three-phase AC voltage at 60Hz for commercial or industrial area. Most of the smaller VAWTs are used in the urban area because the wind turbine is operated quietly and vibration-free. The factor that caused the turbine can be operated quietly is the blade tips are close to the axis of rotation and it travels a shorter distance per revolution.

Installation of VAWT

The installation of VAWT is similar to the installation of HAWT. A flat foundation will be required for the stability of the tower by depending on the condition of the site. The generator and the gearbox will be located at the bottom of the tower. The fiberglass monopole of the turbine will be installed into the foundation for the stability after the construction. The monopole must be secured tightly to avoid turbine tower instability hazards. After that, the coupler will be installed to link the monopole to the rotor blades. Then, the generator is connected with the main shaft at the bottom of the tower (Ragheb, 2015). The blades will be assembled with screws and bolts. At last, the assembled blades lifted and placed at the top of the tower by using a crane. Furthermore, three cables are used and attached from the top of the tower to the ground for further stabilization.

Cost of Implementation and Economy

An economic analysis is done by D'Ambrosio and Medaglia (2010) to compare between 200KW and 2MW for VAWT. The estimated costs are listed in Table 1. Table 1 showed that the payback periods have a similar value although the initial installation cost for the 2MW is almost 13 times more than 200KW. This means that the initial cost required being 13 times more to get 10 times more power. Although the 200KW VAWT looks economic the 2MW VAWT still be the best choice for the large scale power production. The economic analysis is done with the cost of VAWT and data from Europe. The cost of VAWT and other data will vary by depending on different locations globally. Other than that, the payback period can be shortened if the material can be sourced locally.

Table 1 Estimated Cost of implementation of VAWT

DESCRIPTION	**COST (€)**	
	200KW	**2MW**
OPERATION AND MAINTENANCE COST		
Measurement	750	750
Service	430	4,300
Telecommunication	215	215
Insurance	860	8600
Commission Fee	110	110
Administration	540	540
Tax	720	7200
TOTAL (PER YEAR)	3,625	21,715
CONSTRUCTION COST		
Land	5,000	10,000
Grid Connections	16,000	160,000
Project Development	40,000	400,000
Road & Miscellaneous	2,000	20,000
Foundation Construction	10,000	100,000
Green Certificate (20 Years)	-14,620	-194,370
TOTAL	58,380	495,630
Wind Turbine Cost	62,700	1,643,000
TOTAL	193,580	2,572,930
Energy Production (KWh/yr)	423,700	5,633,900
Tariff Rate (per KWh)	0.0484	0.0484
Profit (per year)	20,507.08	272,680.76
Payback Period (years)	9.4397	9.4357

Potential Challenges

The potential challenge for VAWT is that some of the turbines are not self-starting. Therefore, a motor will be required to help and make them turn initially. The backup battery or power-up system is required to start the motor. Other than that, the VAWT has low efficiency when compared to the HAWT due to the wind at the lower levels is not that strong and not consistent. Therefore, the cost of a kilowatt-hour of power is higher than HAWT. Furthermore, the VAWTs require wires for stability and this will be caused problems if install the VAWTs in small residential area or farm field due to the disturbance.

Results and Analysis

This section will discuss the analytical approach and result of the analysis.

Analytical Approach

Based on the information from the literature review it is decided to select the horizontal axis wind turbine (HAWT) as a suitable wind turbine. Nonetheless, those are just expressed in terms of words. Hence, the power output by the upwind HAWT for multiple locations in Malaysia will be calculated.

Derivation of Betz's limit

By assuming the fluid flow of the model is ideal and simplified, it will be easier and simpler to obtain the maximum attainable efficiency of the wind turbine. The mass of air is assumed to be one unit (1 ATM) and the upstream velocity (v_u) which flows perpendicular to the turbine blade area (v_d). Other than that, some velocities flow below the blade will then provide an acting force on the rotor blade which is the flowing air at a lower velocity (v_t) and downstream velocity (v_d). Hence, the product of area and the rate of change of momentum between the upstream and downstream fluid will yield as this formula:

$F = \rho A_t v_t (v_u - v_d)$ ------------------------------(1)

After replacing power in terms of velocity and force:

$P = \rho A_t {v_t}^2 (v_u - v_d)$-----------------------------(2)

Bernoulli's Principle is applied and assumed incompressible and irrational flow:

${P_t}^+ + \frac{1}{2}\rho {v_t}^2 = p + \frac{1}{2}\rho {v_u}^2$--------------------(3)

${P_t}^- + \frac{1}{2}\rho {v_t}^2 = p + \frac{1}{2}\rho {v_d}^2$--------------------(4)

Where,

p = ambient pressure

P_t^+ = pressure at the upstream of the rotating blades

P_t^-= pressure at the downstream of the rotating blades

ρ = density of fluid

v_u = upstream velocity

v_d= downstream velocity

The equation will produce a formula that due to the force on the disc and factoring the product of area and pressure drops:

$F = A_t \Delta p = A_t(P_t^+ - P_t^-)$---------------------(5)

$F = \rho A_t((v_u - v_d)(\frac{v_u - v_d}{2})$-------------------------(6)

By comparing equation (5) and (6), subtracting $v_u$from both sides and rearranging, is it shown that:

$v_t = \frac{(v_u - v_d)}{2}$---------------------------------------(7)

$(v_u - v_d) = 2(v_u - v_t)$-------------------------(8)

Therefore, power output is obtained as:

$P = 2\rho A_t v_t^2 (v_u - v_t)$-------------------------------(9)

Upstream flow is defined as:

$P_u = \frac{1}{2}(\rho A_t v_u^2)$-----------------------------------(10)

Power coefficient can be obtained by dividing power in the upstream flow to power output:

$\eta = \frac{P}{P_u} = 4(\frac{v_t}{v_u})^2 \left[1 - \frac{v_t}{v_u}\right]$----------------------(11)

To find the maximum possible power coefficient, the power coefficient is partially differentiated with respect to turbine blade velocity. In this process, the end differential product is set to 0, which hence $v_t = \frac{2}{3v_u}$ and:

$$\frac{\delta \eta}{\delta v_t} = 0 \rightarrow \eta_{max} = 4\left(\frac{2}{3}\right)^2 \left[1 - \frac{2}{3}\right] = 0.593$$

The greatest achievable power efficiency is otherwise called Betz efficiency. It is the most extreme achievable efficiency as far as aerodynamics and despite the turbine outline. As far as the limit is not indisputably the imperative not at all like the Carnot's efficiency for a heat pump for instance. It is considered as the general guideline which misuses the predominant physical sensational. For this situation, around 40% of the power is a loss because of gearbox friction and electrical dissemination [15].

Formulation of total power production by wind turbine

According to WWEC (2014) with the help of the fundamental governing equations and understandings, the maximum power, torque, thrust, and maximum achievable efficiency of the wind turbine is calculated.

Table 2 Formula Table

Air density	$\rho = \frac{P}{RT}$	P = Absolute pressure R = Gas constant T = Fluid temperature (K)
Total power density	$\frac{P_{total}}{A} = \frac{1}{2g_c}\rho {v_i}^2$	g_c= Conversion factor P_{total}=Total power v_i=Wind velocity A=Area perpendicular to wind direction
Maximum obtainable power density	$\frac{P_{max}}{A} = \frac{8}{27g_c}\rho {v_i}^2$	g_c= Conversion factor P_{max}=Maximum power v_i=Wind velocity A=Area perpendicular to wind direction
Obtained power density	$\frac{P_{max}}{A} = \eta \frac{P_{total}}{A}$	η =Efficiency (Max = Betz limit) P_{max}=Maximum power A=Area perpendicular to wind direction
Total power produced	$P_{net} = 245 \times \frac{\pi D^2}{4}$	D= Turbine diameter
Maximum torque	$T_{max} = \frac{2}{27g_c}\frac{\rho D {v_i}^2}{N}$	D= Turbine diameter v_i = Wind velocity N=Turbine operating speed (RPS)
Axial thrust	$F_{x,max} = \frac{\pi}{9g_c}\rho D^2 {v_i}^2$	D= Turbine diameter v_i = Wind velocity

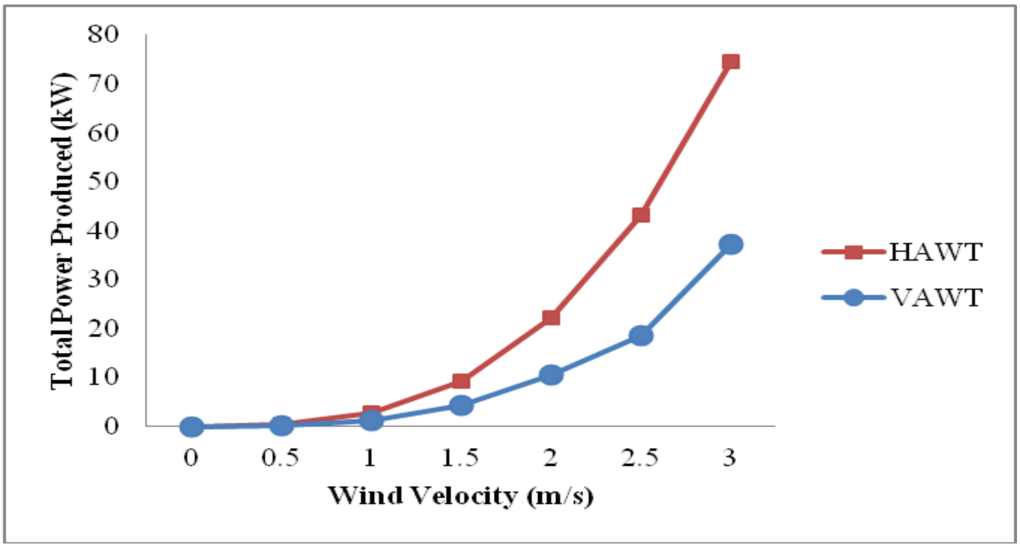

Figure 3 Total Power Produced vs Wind Velocity

Graphical results based on calculations

By taking an example of only one wind turbine,

- Diameter of 140m
- 40 RPM velocity
- Assume maximum efficiency
- 1 standard ATM pressure
- 1 square meter swept area

Figure 3 is the plotted graph of total power produced versus wind velocity of both HAWT and VAWT.

Table 3 Calculated Theoretical Values for HAWT

Wind velocity (m/s)	Total power density (W/m^2)	Maximum obtainable power density (W/m^2)	Actual obtainable power density (W/m^2)	Total power produced (kW)	Torque (N)	Axial thrust (N)
0.0	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.0764	0.0453	0.0306	0.3456	2.0367	1535.8096
1.0	0.6110	0.3621	0.2444	2.7645	12.2933	6143.2384
1.5	2.0621	1.2220	0.8249	9.3300	54.9900	13822.2864
2.0	4.8880	2.8966	1.9552	22.1157	130.3467	24572.9536
2.5	9.5469	5.6574	3.8188	43.1946	254.5833	38395.2400
3.0	16.4970	9.7760	6.5988	74.6403	439.9200	55289.1456

Table 4 Calculated Theoretical Values for VAWT

Wind velocity (m/s)	Total power density (W/m^2)	Maximum obtainable power density (W/m^2)	Actual obtainable power density (W/m^2)	Total power produced (kW)	Torque (N)	Axial thrust (N)
0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.5	0.0467	0.0217	0.0173	0.1643	1.0239	759.7030
1.0	0.3010	0.1701	0.1297	1.1017	6.1297	3046.8200
1.5	1.0451	0.7299	0.4142	4.2360	298.6480	6814.7500
2.0	2.7410	1.3436	0.9368	10.4573	61.0315	12746.8500
2.5	4.5743	2.8297	1.9097	18.4690	121.0300	19137.6000
3.0	8.2374	4.7140	3.2687	37.1600	215.0630	27674.1600

Tabular Data of Potential Wind Energy in Malaysia

Wind speed is one of the important factors for the wind turbine to work as it is the main source of this renewable energy. In this segment, based on Weather Spark (2014), the yearly maximum, minimum, and average wind speed data is obtained. Several potential locations in Malaysia are chosen here to analyze their respective annual average wind speed to estimate the total power produced.

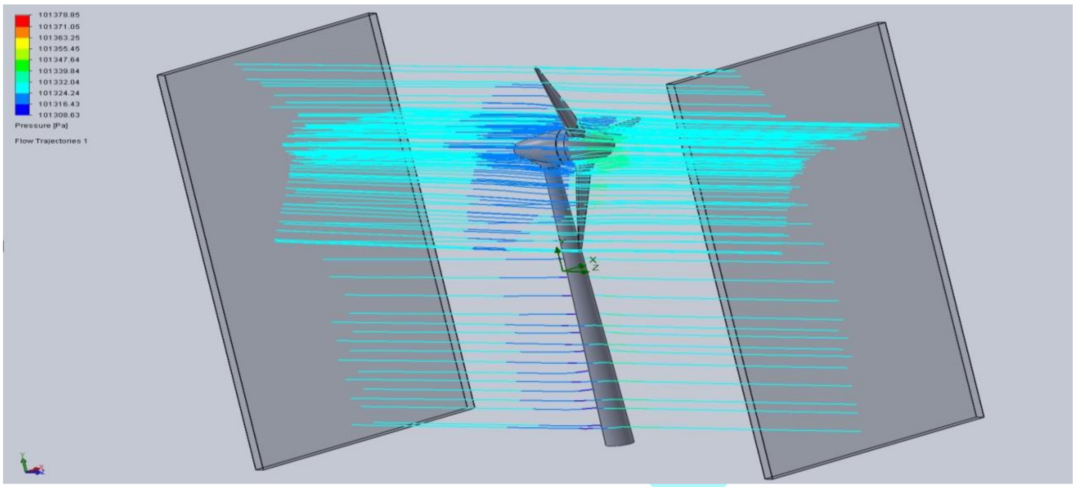

Figure 4 Isometric view of the flow simulation (HAWT)

Table 5 2013 Annual Wind Speed at Several Location in Malaysia

Location	**Maximum Wind Velocity (m/s)**	**Minimum Wind Velocity (m/s)**	**Average Wind Velocity (m/s)**	**Total Power produced (kW)**
Kuching	1.70	1.43	1.565	10.4769
Sandakan	2.91	1.52	2.215	29.1335
Bintulu	1.92	1.70	1.810	15.9827
Kota Kinabalu	2.32	2.01	2.165	29.1862
Tawau	1.88	2.15	2.015	19.7394
Kudat	2.15	2.68	2.415	37.6459

The result of the total power produced is obtained by using the related equations as mention before. As observed from the result obtained, it is logical to build the wind turbine in areas like Sandakan, Kota Kinabalu, and Kudat because their wind speed is more relevant. For other places like Kuching, Bintulu, and Tawau are they not so suitable due to the lower wind speed of their locations. It is not suitable in a sense where to build a wind turbine in these areas is not very practical and economical.

SolidWorks Simulation Results

Based on current wind turbine design and using them as a reference, the team came up with a similar design as the prototype of this project. By using SolidWorks, the project design is created and also demonstrated the flow simulation to determine the pressure difference between the three blades of a HAWT and VAWT. Wind velocity of 6m/s and environmental pressure is used as the boundary condition. Besides that, to simulate both of these wind turbines (HAWT and VAWT) the wind is coming from the front which is facing the wind turbine. This is because when the wind is applied at the front, the wind turbine will receive the maximum wind.

After flow simulation is done, the pressure lines can be seen at both of the wind turbines (HAWT and VAWT). The pressure lines are from blue to turquoise color showed that the pressure from the wind on the blades is still under the maximum pressure and concluded that is it able to withstand the wind speed.

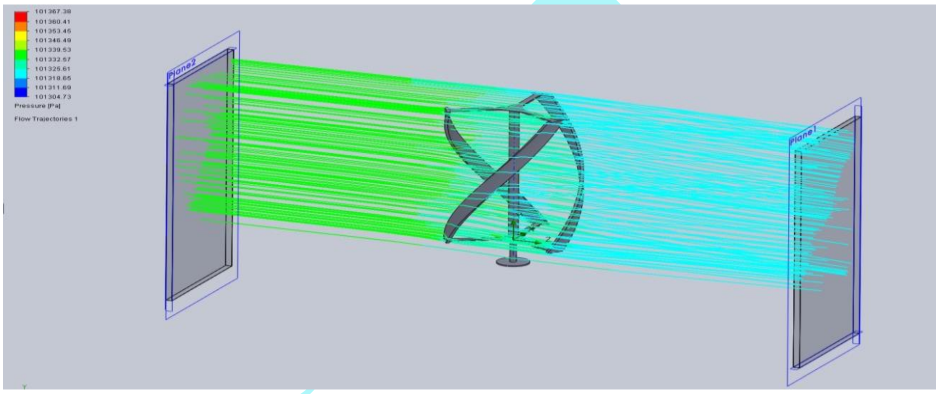

Figure 5 Isometric view of flow simulation (VAWT)

Discussion

Based on the information in the literature review, coupled with the calculation done in results and analysis which includes theoretical calculation and simulation results, we can deduce that the horizontal axis wind turbine (HAWT) is the best type of wind turbine to be implemented in Malaysia as an alternative and renewable energy source. Through the results and analysis section, we are able to construct a simplified information table below to conveniently demonstrate why the horizontal axis wind turbine (HAWT) is much suitable than the vertical axis wind turbine (VAWT).

Table 6 Summarized comparisons between HAWT and VAWT

Criteria for one turbine	HAWT	VAWT
Efficiency	High	Low
Cost (Per kWh)	High	Low
Ease of manufacture	Complex	Simple
Space required	High	Low
Self-start ability	No	Yes
Yaw mechanism	Yes	No
Operating mechanism	Complex	Simple
Rotor blade bending stress	Low	High
Turbulent condition performance	Unstable	Stable
Visibility	High	Low
Noise production (per kWh)	Low	High
Durability	High	Low
Working speed	Low	High

Table 7 Rating scale

Rating	Definition
Low	Significantly below performance standards
High	Significantly exceeds performance standards
Complex	Involvement with complicated connection or arrangements
Simple	Not complicated
Yes	Existence of certain part or criteria
No	No existence of a certain part or criteria
Unstable	Not stable, inconstant or liable to fail

Other than comparisons in Table 6, it is also clearly seen in Figure 4 that the power produced from the HAWT is higher than VAWT. Therefore, the wind speed of VAWT will also eventually lower than HAWT. This is because wind power generator (wind turbine) has a high relationship with wind velocity. This can be also said that the wind turbine is driven by wind velocity. When deciding and comparing any products or systems, the efficiency level is often seen as the first and foremost important element to be considered. From the table above, we can see that based on efficiency alone, the HAWT boasts a much higher efficiency level compared to the VAWT. This is due to the positions of the blades in the VAWT, which are not positioned at an optimum angle to the wind. Thus, drag and stall force affects the overall efficiency of the VAWT.

Also, due to the low wind speed in most parts of Malaysia, the VAWT would have been a more feasible option. However, due to the practical disadvantages of the VAWT in other criteria, it overpowers the theoretical advantages that it brings to the table (Barnard, 2013). Based on the theoretical analysis of the VAWT, it may seem ideal as it shows very promising results. But in truth, due to the fact that the wind acts in one direction, the blades of the VAWT undergo a fatigue failure in large-scale power generation scenarios. This is unlikely for the HAWT as it works well with the one direction wind, which does not negatively affect the blades directly.

Next, the HAWT does not require manual starters, unlike the VAWT. In recent research and developments, a new hybrid VAWT is now able to self-start which eliminates the need for a manual starter. However, the overall efficiency of the new VAWT is still lower than that of the HAWT.

Apart from the overall efficiency, another important consideration that needs to be taken into account is the installation and maintenance cost. As shown in the table above, the cost of a HAWT is higher than that of the VAWT. This is mostly due to the larger surface area required and the complexity of its manufacturing structure of the HAWT. Also, the noise level produced by the HAWT had considerably decreased in recent times. Thus, the noise level produced by HAWT is now lower than that of the VAWT (Barnard, 2013).

Lastly, from the results and analysis obtained, HAWT may not be well suited to some parts of Malaysia due to the low mean wind speed. Thus, favors the VAWT. However, VAWT is only applicable for the amount of power generation, which has been used by some on top of their houses. Overall, for a large-scale generation of electrical power, the HAWT is the best-suited choice to be implemented in Malaysia.

Recommendation

Due to the success of the installment of wind turbines in Terengganu West Malaysia, the government should look more into the research and development planning in installing more wind turbines in other parts of Malaysia to fully take advantage of the ever-present wind energy. The government should take initiatives in forming and funding groups of researchers to look into reducing the cost of implementation of wind turbines as well as maximizing the performance of it. Next, the wind turbine that was successfully installed in Terengganu was hybrid. These hybrid wind turbines incorporate various renewable energy technologies to produce electrical power that may well be more efficient than a single renewable energy powered wind turbine. As seen in this hybrid wind turbine used, it collaborates with both the solar and wind energy by implementing solar photovoltaic cells in a wind turbine to further improve the system's efficiency level.

Due to the high cost of implementation of these renewable energies in Malaysia, not many private investors would have the financial means to invest in such a project despite having a successful project previously implemented in West Malaysia before. Due to the high risk of long payback periods and high-interest fees from banks, many would-be discouraged in attempting to invest in these projects. The technological references for renewable energies in Malaysia are still relatively new and limited. Hence, potential investors will lose their interest in providing the funds needed to fund the project as they may see the project as too high a risk. Thus, the governing bodies should take the initiative to help lessen the burdens of the investors in order to help promote the project in Malaysia. The Government bodies could provide a lease of financial aid to investors to lessen the burden on them.

Furthermore, the people of Malaysia may be against the idea of implementing wind turbines as it may destroy the natural beauty of landscapes and rivers. This may well lead to several economical issues whereby fewer tourists would be attracted to visit Malaysia due to the affected scenic landscape hot spots. Hence, open land spaces in remote areas of Malaysia should be used for the implementation of the wind turbine to preserve the attractiveness of the scenic landscapes of Malaysia (Ali et al., 2012).

Conclusion

From this research, it has been found that the upwind horizontal axis wind turbine is the much-suited option to be implemented in Malaysia. The design of HAWT and VAWT was drawn by using SolidWorks. Observed from the results, to produce large scale generation of electrical power, HAWT is the best-suited choice to be implemented in Malaysia. However, VAWT is only applicable to a small amount of power generation. As shown and discussed in the report, despite the high installation and maintenance cost of these wind turbines, it provides higher overall efficiency than the vertical axis wind turbine. Due to the fact that Malaysia is heavily dependent on non-renewable energy resources such as crude oil, coal, and natural gas, it is highly important to find a renewable energy source to counteract this problem. As these non-renewable energy resources are slowly but surely depleting, it is the responsibility of both government and non-government bodies to promote, invest and research into using renewable energy resources to help reduce the use of the non-renewable energy.

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