The Wind Turbine Design and Test

Mark Irwin Paranchis[1] and Hendri Pratama[2*]

[1]Kolej Vokasional Sandakan, Sadakan 90713, Malaysia
[2]Sultan Idris Education University, Tanjong Malim 35900, Malaysia

Article Info

Article history:

Received Feb 12th, 2022
Revised Apr 26th, 2022
Accepted May 16th, 2022

Keywords:

Wind
Turbine
Savonius
Darrieus
VAWT

ABSTRACT

Green energy harvester, known as wind turbine, able to convert mechanical works to electrical power. There are two main type of wind turbine that considered thoroughly, which are the horizontal and vertical axis wind turbine respectively. This project mainly focuses on the design of new wind turbine that can operate well together in low wind speed condition in Malaysia. For the first stage of this project, the problems, purpose, and planning regarding the project were properly determined. Literature survey then further analyzed in order to know the wind power or behavior across the world, and specifically in Malaysia, research on turbine that can work in low wind speed condition, as well as parameter that are often used in designing wind turbine by previous researcher. From the literature survey, the selected turbine was a Three-Bladed Savonius Wind Turbine, which is one type of Vertical Axis Wind Turbine (VAWT). That turbine will be attached to another VAWT turbine system to help generate more power and better performance. Design theoretical calculation and material selection have been properly analyzed before fabrication can be done. Upon completion of the fabrication, Savonius wind turbine section properly tested through experimental works by using simple wind tunnel in Faculty of Engineering Mechanical Workshop, and all readings and data collected using applicable tools and equipment. For the experimental works of Savonius rotor, the variable includes of blades curve angle from its center at different wind speeds. The data collected then interpreted through charts and graph for comparison and performance analysis, and conclude that 1200 blades curve angle from its center was the best among the other type of blades. From this project, it can be concluded that this type of mix wind turbine able to works in low wind speed condition in Malaysia, but a better improvisation and modification of the mix wind turbine will certainly improve its further performance and efficiency.

Corresponding Author:

Hendri Pratama,
Sultan Idris Education University,
Perak 35900, Malaysia
Email: hendripratama.tvet@gmail.com

1. INTRODUCTION

Energy is essential in human life all over the world, in which it comes from many forms of energy including solar, wind, and hydro (water). With energy, many types of works can be done. Energy can help us to wash and dry our clothes, cook our foods, light up cities, as well as power up machinery in factories and devices. These energy demands increase rapidly every years in order to do severe tasks and generate powers, and it can be either harmful or safe. This proposal was done to pin point out the extraction of green and safer wind energy in which wind turbine was selected. Based on the previous wind turbines, especially vertical axis wind turbines, new wind turbines design and test proposed that can operate under low wind speed in Malaysia. Thus, low wind speed operated wind turbines must be further studied and analyzed in order to design and test it. Green energy comes from natural sources such as sunlight, wind, rain, tides, plants, algae and geothermal heat. These energy resources are renewable and naturally replenished. In contrast, fossil fuels are a finite resource that take millions of years to develop and will continue to diminish with use. In Klang Valley, Malaysia, data of pollution produced from fossil fuels were collected and it caused concern due to estimated environmental damage because of increasing level of dangerous chemical composition produced from fossil fuels, although the level still below of acceptable limit by World Health Organization (WHO) [1].

The green energy, or more specifically, renewable energy becomes more important as time goes by as this kind of energy cannot be depleted, or in other words, it can be reuse or renewable. In Iceland, Geothermal and hydropower is the primary energy supply as almost all electricity produced in Iceland derives from hydropower plants and from geothermal plants. The stream flow in rivers used for hydropower energy tends to exhibit a large annual variation, with larger flow during summer than in winter, while the annual cycle of wind in the country has the opposite phase, with stronger winds in winter than in summer. Thus, wind can be harvested and can be use efficiently by combining it with hydropower [2].

Of course, wind can produce mechanical works and electrical power, and it certainly depends on the wind characteristics and energy, and all this matter depends on the availability of wind on the specify place. Insufficient wind energy or power will cause difficulty or failure for machineries or more specifically, wind turbines to efficiently and properly work. As commonly known, high wind speed produced from huge plain field or seashore and low wind speed produced inland. Figure 1 below shows the Global renewable resources available around the globe, and Figure 2 shows the Global wind speed map across the globe.

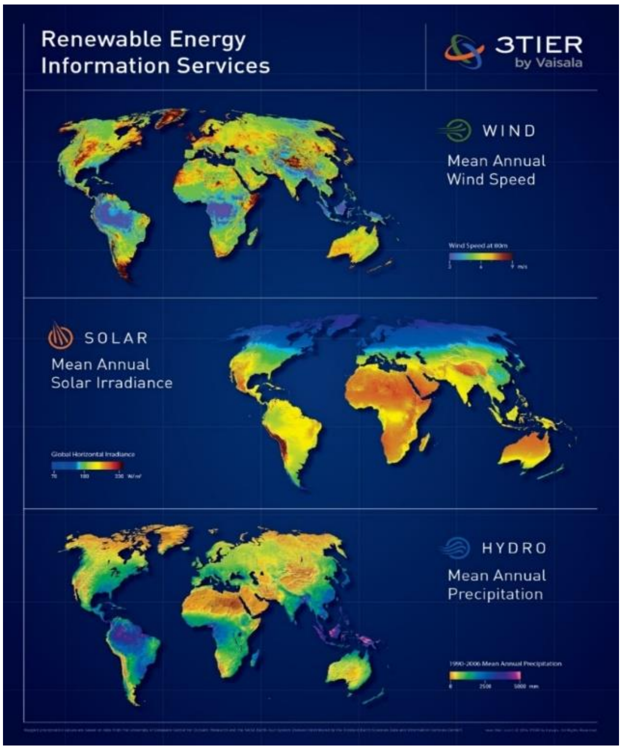

Figure 1: Global Renewable Resources across the Globe [3]

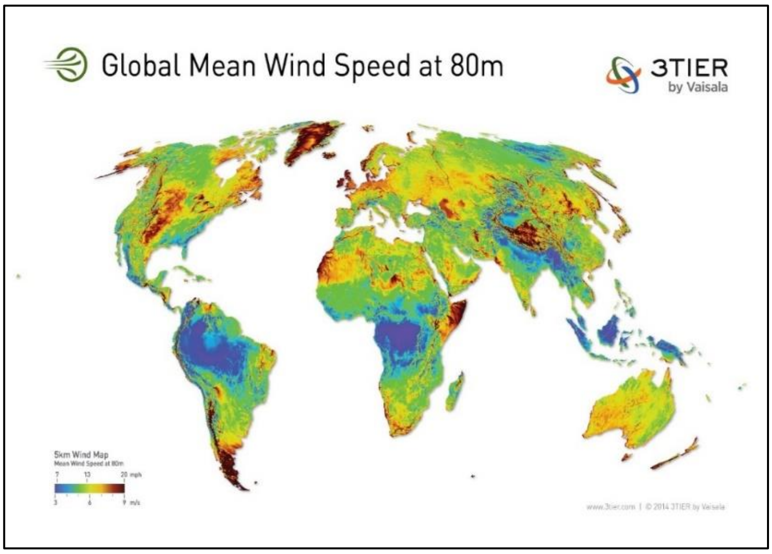

Figure 2: Wind Speed Map across the Globe [3]

Besides of all renewable energy power machine or plants, wind turbine considered and approved as one of the green and renewable energy harvester to generate power and electricity. Since the increasing demand for electricity and reduction of pollution and global warming, the research and improvement of wind turbine were forced and encouraged [4]. Generally, there are two types of wind turbine commonly known, horizontal axis and vertical axis wind turbine with advantages and disadvantages of their own [5]. Horizontal wind turbines can produce high and commercial energy and they were built tall in order to capture fast moving laminar air currents, due to large rotor, the laminar wind pass through it will become turbulent, other than its big weight, high maintenance cost and it is not suitable for residential use. Unlike horizontal wind turbine, vertical axis wind turbines built closer to ground and able to harvest lower wind speed due to its blade as well as suitable for residential use [6].

In Malaysia, particularly in Sabah region, the wind speed can be considered low at 5 km/h to 7 km/h [7]. Based on this wind speed condition, vertical wind turbine able to deal with this situation as it able to harvest low wind speed easily. The other benefit of this turbine includes of its lightweight and low cost maintenance. The operational work system of vertical axis wind turbine is simple where rotary motion of the blade and shaft produced energy and stored onto battery. This power will be use later by supplying the electrical current from the battery itself which store the charge from the wind turbine [8]. Although vertical axis wind turbines have the ability to capture wind from many angles, the speed of the wind caused trouble and difficulty for this turbine to works smoothly.

Generally, there are several types of wind turbines, and two types of vertical wind turbines that commonly known were Darrieus and Savonius Wind Turbine. Darrieus wind turbines was the first aerodynamic vertical axis wind turbine developed by Georges Darrieus in France and first patented in 1927. The wind that passing through the turbines blade will determine its speed, and resulting apparent wind throughout whole revolution coming in as a head wind with only a limited variation of angle. Meanwhile, Savonius wind turbine introduced by Finnish Engineer S.J. Savonius in 1922. The operational work for this type of turbine is simple, in which, each cups that fixed to a central shaft in opposing directions, will capture wind and rotating the shaft, and the energy will go through the generator [9].

As technology keep advancing, researches have been done in order to improve the aerodynamic system of the turbine. One of the blades type that very common was the airplanes airfoil. The performance and thickness of this airfoils are not necessarily good for wind turbine airfoils. However, it do have benefits from extensive laminar flow and associated low drag [10]. Size of the airfoils will depends on the machine size as the Reynold numbers must be considered to avoid significant laminar separation bubbles that will causes noise, excessive drag, and inconsistent maximum lift. Besides that, helical type blade design also another type of blades for wind turbine, but comes with a bad design which looks like a screw. The twisted design of the blade used to harvest the wind energy but unfortunately eliminating the drag caused by the rotational motion. It also did not produce high annual energy even if the blades rotates faster [11]. Based on this situation, it shows that there were actually many types of wind turbine blades but not used by manufacturer due to its efficiency.

Other than that, the number of blades used for the wind turbines also affect its performance and efficiency. According to the previous research done for savonius wind turbine blades, it shows that two blades savonius wind turbine have higher torque coefficient and power coefficient rather than three blades savonius wind turbine [12]. This analysis can be done by using FEM and CFD analysis. In this project, three-bladed savonius rotor used instead of two-bladed savonius rotor to investigate its impact on performance and efficiency.

Moreover, the angle of the blades surely will affect the performance of the turbines especially in the process of harvesting winds. According to the previous research done on vertical axis wind turbine, specifically, the savonius wind turbine rotor or blade, the static and dynamic torque coefficient, velocity and the pressure across the blades were determined according to different angle of the rotor or blades. All the simulation were done by using simulation software. The aim of all this simulation and calculations is to show the influence of the geometrical parameters on the flow structures in order to increase the efficiency of the Savonius rotors [13].

Vertical axis wind turbine is the most suitable type of wind turbine that can be used in Malaysia, especially in Sabah, because it can deal with low wind speed. A mix turbine must be built with combination of different type of blades so that it will be able to make a self-start and work more effectively. The performance of the mix turbine system will further studied and analysed based on the blades specification or profile, in order to deal with the low wind speed condition. Therefore, this study aims to focus on the design of new wind turbines that can work well in low wind conditions in Malaysia. The turbine in this study was designed to operate at low wind speeds and parameters that were often used by previous researchers in the form of wind turbines. These turbines will later be installed in other VAWT turbine systems to help generate more power and better performance.

2. MATERIAL AND METHODS

In design process, theories and calculations correlated in finding best dimension for the Savonius wind turbine prototype. For this project, there are four stages in the designing process. The first stage is the wind turbine design parameter. The second stage is the Savonius wind turbine drawing and 3D views. The third stage is dimensional analysis of the design and the last stage will be the fabrication of the prototype with specified dimensions and materials [14]. The experiment for Savonius wind turbine done after the fabrication of the wind turbine complete and these data from experiment used to determine the performance of the mix wind turbine.

As this experiment focused more to the Savonius wind turbine section from the mix wind turbine. As for Savonius wind turbine that commonly seen that using two blades to operates, this experiment focus on three Savonius blades to operate. The variables that would be used to determine the performance of the wind turbine was the dimension of the blades, which was the degree of curve of the blades that will differentiate the swept area. The degree of curve of the blades used includes 30º, 60º, 90º, and 120º.

Furthermore, the wind speed will be varied to determine the power that the turbine can produced at specified wind speed. From these variables, the rotation speed of the turbine, torque, and power generated by the turbine can be determine. The main purpose of this experiment is to determine the performance of the mix wind turbine, and focused more to Savonius wind turbine section. The experiment conducted in Engineering Faculty Mechanical Workshop by using simple wind tunnel system.

2.1 Test procedure

The first variable that most important in this experiment was the wind speed. The wind speed from the wind tunnel was adjusted based on the distance of the turbine with the wind tunnel. The wind speed from wind tunnel adjusted using anemometer and the ground marked or pointed after required wind speed achieved. The wind speed that used in the experiment were 1 m/s, 2 m/s, and 3 m/s. The second variable examined was the angle of curve from center of the blades for the Savonius wind turbine. The blades' angle of the curve from its center used in this experiment were 30º, 60º, 90º, and 120º. This blade can be changed from the turbine with the bolt and nuts feature. For the entire experiment, the Savonius wind turbine section were tested for several value of wind speed according to the blades curve degree angle.

2.2 Data collection and equipment

For the experimental work, tools and equipment for measuring, calibration and data collection must be determined for a smoother operation during experimental work. Data was collected through observation and documentation of images and videos as reporting and evaluation material. The turbine is placed on different distances from the simple wind tunnel and the distances between them determined from measured wind speed using anemometer. Besides that, the amount of rotation per minutes produce from the rotating Savonius wind turbine section can be determined by using bicycle rotation sensor. Mobile video camera would be used if there is difficulty to take readings from the sensor. The RPM would be counted properly based on the slow-motion turbine rotation from the video. The power generated from the wind turbine motor can be calculated using wind turbine controller. Digital multimeter used in case the controller malfunction. Wiring circuit used as alternative in case the power generated from the motor not sufficient for the controller to work [25]. The wiring circuit included with rectifier, capacitor, wires, wiring hub, and light bulb with 5 W of power.

2.3 Design parameters

2.3.1 Wind power

Since selecting a suitable wind turbine for specific location is important, thus, the wind power must be also important to be considered. The wind power, Pw can be defined as the multiplication of mass flow rate, pAV and the kinetic energy per unit mass, ½V^2 [15], and can be denoted as,

$$P_w = \frac{1}{2}\rho A V^3 \quad (1)$$

Where, P_w is wind power, ρ is density of air, A is swept area and V is velocity.

Equation 2.5 is an equation of ideal power of wind turbine in case of no aerodynamics and any other loses in energy conversion. Unfortunately, it is impossible that all energy can be converted into useful energy as

DOI: https://doi.org/10.24036/teknomekanik.v5i1.12672

stated by Betz Limit [16]. The maximum power coefficient, C_p for Savonius rotor is 0.30, and thus the power output, P by considering the power efficiency can be denoted as,

$$P_w = 0.15\,\rho A V^3 \quad (2)$$

2.3.2 Swept Area

Swept area is a method to know and calculate the amount of wind energy intercepted by turbines, specifically Savonius wind turbine which then can have a better comparison between turbines in similar wind regimes. Simply say, swept area is the section area in which turbines hit by wind to generate rotating force. It is found that swept area for Savonius wind turbine calculated by multiplication of rotor diameter, D and rotor height, H [17]. The equation donated as,

$$A = DH \quad (3)$$

Where, A is swept area, D is rotor diameter and H is rotor height.

2.3.3 Wind Speed

Power output affected by wind speed as it is the major element for it. There are three main parameters which includes cut-in speed, rated wind speed, and cut-out speed [18], and can be denoted as follow:

$$V_{cut-in} = 0.5\, V_{avg} \quad (4)$$

$$V_{rated} = 1.5\, V_{avg} \quad (5)$$

$$V_{cut-out} = 3.0\, V_{avg} \quad (6)$$

2.3.4 Aspect Ratio

Aerodynamic performance of Savonius rotor can be evaluated by considering the aspect ratio [19] and [20], in which the rotor height is twice of the rotor diameter for better stability and efficiency. The equation can be denoted as,

$$AR = H/D \quad (7)$$

2.3.5 Tip Speed Ratio

Another important thing has to be considered is tip speed ratio. Tip speed ratio, λ can be described as the ratio of rotor blade, $\omega.R$ to the undisturbed wind speed, V [21]. The maximum tip speed ratio can be achieve is 1 and the performance of wind turbine improves when tip speed ratio increase, by increasing the rotational rate of rotor [16]. The equation denoted as:

$$\lambda = \omega.R/V \quad (8)$$

Where, λ is tip speed ratio, ω is angular velocity, R is the radius revolving part of the turbine, and V is the undisturbed wind speed.

2.3.6 Solidity

Solidity best described as the ratio of blade area to the turbine rotor swept area. Solidity can be related and inversely proportional with tip speed ratio, in which, a higher tip speed ratio will result in low solidity. For vertical axis wind turbine, the equation denoted as,

$$\sigma = nd/R \quad (9)$$

Where, n is the number of blades, d is chord length or diameter of each half cylinder, R is the radius of wind turbine. According to many research, number of blades is directly proportional to performance of turbine. However, some researchers found that two-blade Savonius rotor resulting in better turbines performance than three-blade Savonius rotor [22] and [23].

DOI: *https://doi.org/10.24036/teknomekanik.v5i1.12672*

2.3.7 Moment of Inertia

The other important parameter in designing savonius wind turbine is moment of inertia. This parameter will tells us the amount of energy stored or required to rotate rotor to a particular velocity [12]. The equation can be denoted as,

$$I = I_b + 2I_p + I_s + I_d \quad (10)$$

Where, I_b is the blades moment of inertia, I_p is the end plates moment of inertia, I_s is shaft moment of inertia, and I_d is torque measuring disc moment of inertia.

The moment of inertia for two bladed and three bladed Savonius wind turbines respectively given as:

$$I_{2b} = \frac{8}{3\pi} m.d^2 \quad (11)$$

$$I_{3b} = \frac{4}{\pi} m.d^2 \quad (12)$$

2.3.8 Torque

Torque can be defined as the force acting tangentially over the rotor blade operating at a distance of rotor radius, d from the Centre [12], and denoted as,

$$\tau = I\alpha \quad (13)$$

But, in this project the torque formula that would be used for easier and better calculation and result given as:

$$\tau = \frac{P}{\omega} \quad (14)$$

Based on the theories and calculations decided and made for the design, the main dimensions and three-dimensional views via SolidWorks software for the design have been made. The shaft fabricated using PVC pipe, the riveted hinges made of light stainless steels, and all type of blades used made of thin aluminum sheets.

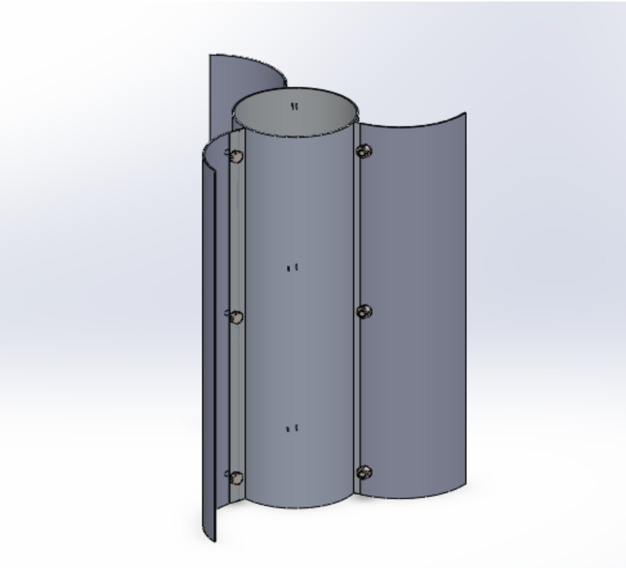

Figure 3: Three-Dimensional View of Savonius Wind Turbine

As what can be seen in Figure 3, it was a three-dimensional view of the Savonius wind turbine. The purposed of this project is to build a mix wind turbine with combination of Savonius wind turbine operating system and darrieus wind turbine operating system. In this project, only Savonius wind turbine which placed on top of the darrieus wind turbine for the mix wind turbine will be further study and focused. Moreover, the assembly of the top part of the mix wind turbine, which was the Savonius wind turbine can be looked closer and specifically via exploded view that can have been done by using Solid works Software. Figure 4 shows the exploded view of the Savonius wind turbine.

DOI: *https://doi.org/10.24036/teknomekanik.v5i1.12672*

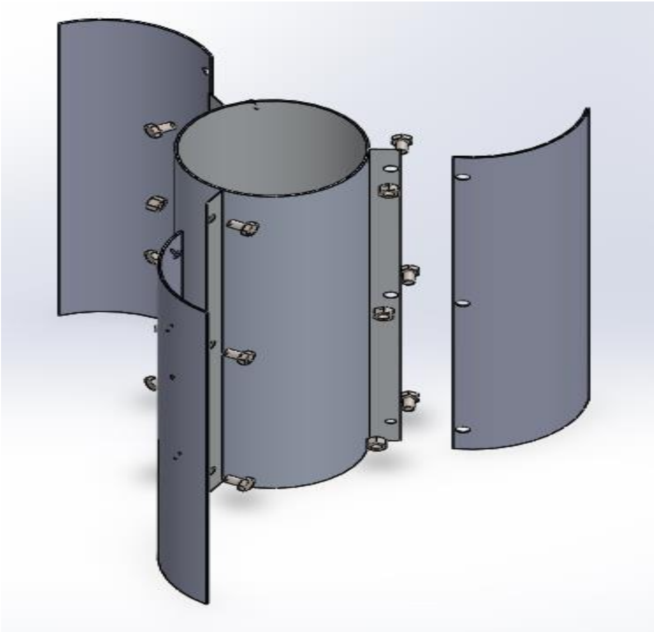

Figure 4: Exploded View of Savonius Wind Turbine

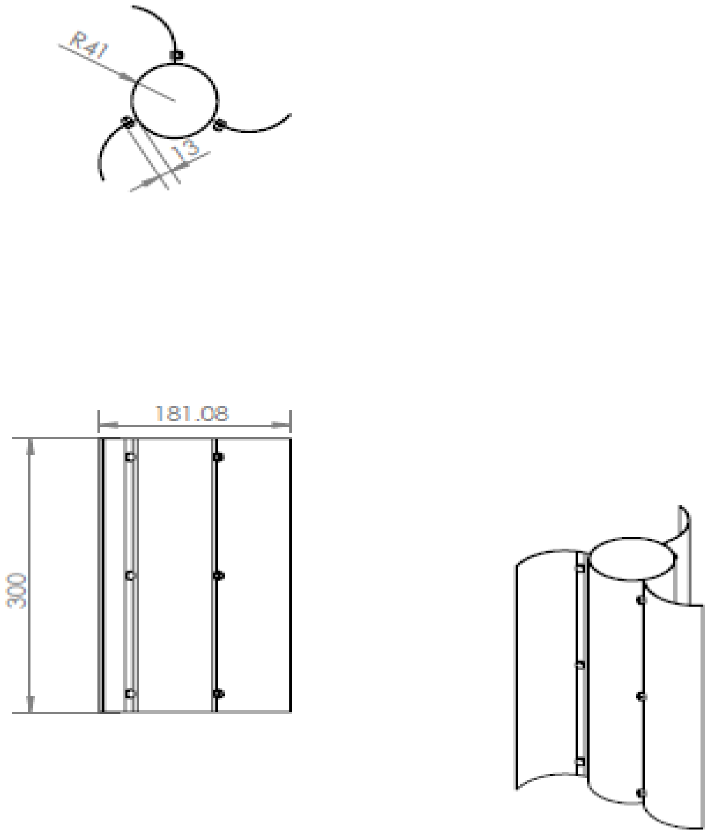

Figure 5: Two-Dimensional Drawing of Savonius Wind Turbine

In addition, the two-dimensional drawing with the main dimensions also shown in Figure 5. This allow reader or fabrication engineers to understand more regarding for this design, and the drawing was made by using Solid works Software which is beneficial to its user.

DOI: *https://doi.org/10.24036/teknomekanik.v5i1.12672*

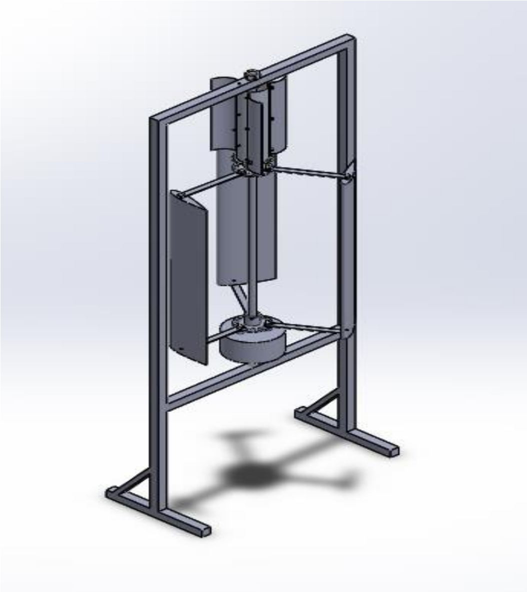

Figure 6: Three-Dimensional Drawing of Mix Wind Turbine

Meanwhile, Figure 6 shows the 3D view of the whole assembly of the mix wind turbine that will be tested. Figure 7 also shows the fabricated prototype during on experimental works.

Figure 7: Mix Wind Turbine full assembly during experimental works

3. RESULTS AND DISCUSSION

Further study and calculation was focused on the savonius rotor section, specifically for the theoretical tip speed ratio, torque and power that can be produced from only savonius section without any additional load. From the calculation result obtained for the design, a three-dimensional savonius wind turbine, as well as the whole assembly of mix wind turbine model modelled through CAD/CAM software, called SolidWorks. From the assembly, a simple simulation was done to the savonius rotor, as well as the whole mix wind turbine structure to determine the potential of the savonius rotor to be workable, as well as mix wind turbine as a whole. Based on the design proposed, fabrication of mix wind turbine can be proceed. Then, The mix wind turbine, specifically for the savonius rotor, undergo several tests with its blades curve angle from its centre and wind speed as the variables. All readings and data was taken and noted down.

3.1 Design Calculation

As for design calculation, the calculation will focus on the performance availability from only the savonius wind turbine system alone. Specific design parameters considered for the Savonius wind turbine rotor, that will be synchronized with Darrieus wind turbine rotor. These parameters also done by refering to Betz limit as shown in Figure 8.

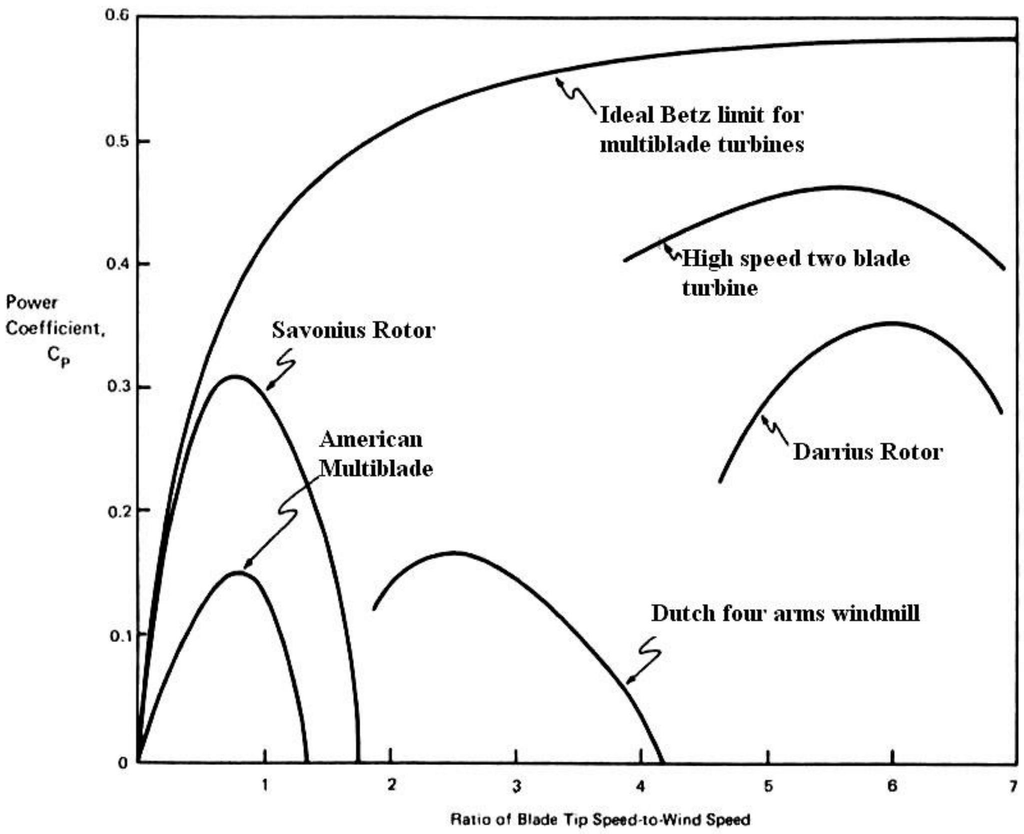

Figure 8: Betz Limit Chart [24]

Meanwhile, the design calculation result summary is shown in Table 1 below.

Table 1: Design Calculation Result Summary Table

Parameter	Design Calculation Result
Swept Area, A	$0.0657\ m^2$
Aspect Ratio, AR	1.37
Cut-In Wind Speed, $\boldsymbol{V_{cut-in}}$	$1\ m/s$
Rated Wind Speed, $\boldsymbol{V_{rated}}$	$3\ m/s$
Cut-out wind speed, $\boldsymbol{V_{cut-out}}$	$6\ m/s$
Tip Speed Ratio, $\boldsymbol{\lambda}$	2.19
Solidity, $\boldsymbol{\sigma}$	1.37
Moment of Inertia, $\boldsymbol{I}$	$8.226\ \times 10^{-3}\ kg/m^2$
Torque, $\boldsymbol{\tau}$	$25\ Nm$
Power, P	1kW
Wind Power, $\boldsymbol{P_w}$	$0.2205\ W$

Based on the experimental works for Savonius turbine and mix wind turbine as a whole, the summarization of the data result as well as data analysis are shown as in the next tables, figures, and graphs respectively.

Table 2: Savonius RPM Without Load Based on Blades Curve

wind speed, V (m/s)	**Revolution Per Minute Without Load (RPM)**			
	30	**60**	**90**	**120**
1	62	73	91	103
2	81	89	112	115
3	114	130	153	217
wind speed, V (m/s)	Revolution Per Minute with Load (RPM)			
	30	60	90	120
1	51	69	82	91
2	70	81	93	101
3	99	121	140	184

Table 3: Result Calculated for Savonius Wind Turbine system at wind speed of 1 m/s with Savonius blades at 30°,60°,90°, and 120°

No	Voltage, V (V)	Resistance (Ω)	Resistance Voltage, V_Ω (V_Ω)	Current, I (A)	Power, P (W)	Rotational Speed (RPM)	Angular Speed, ω (rad/s)	Torque, T (Nm)	Tip Speed Ratio, λ
Savonius, 1 m/s, 30°									
1	0.543	0.22	0.003	0.013636364	0.007404545	51	5.431	0.001386359	0.514044545
2	0.327	0.22	0.0013	0.005909091	0.001932273	40	4.189	0.000461273	0.403170305
3	0.433	0.22	0.0025	0.011363636	0.004920455	48	5.027	0.000978805	0.483823615
4	0.545	0.22	0.0032	0.014545455	0.007927273	51	5.341	0.00148423	0.514044545
Average	0.462	0.22	0.0025	0.011363636	0.005546136	47.5	4.9745	0.001077667	0.478770753
Savonius, 1 m/s, 60°									
1	0.611	0.22	0.0054	0.024545455	0.014997273	61	6.388	0.002347726	0.6234688
2	0.659	0.22	0.0059	0.026818182	0.017673182	65	6.807	0.002596325	0.66443632
3	0.594	0.22	0.0046	0.020909091	0.01242	58	6.0734	0.002044983	0.59276384
4	0.667	0.22	0.0064	0.029090909	0.019403636	69	7.226	0.002685253	0.7052576
Average	0.63275	0.22	0.005575	0.025340909	0.016123523	63.25	6.6236	0.002418572	0.64646336
Savonius, 1 m/s, 90°									
1	0.679	0.22	0.0075	0.034090909	0.023147727	72	7.54	0.00306999	0.81432
2	0.682	0.22	0.0089	0.040454545	0.02759	75	7.854	0.00351286	0.848232
3	0.699	0.22	0.0097	0.044090909	0.030819545	78	8.168	0.003773206	0.882144
4	0.703	0.22	0.0099	0.045	0.031635	80	8.378	0.003775961	0.904824
Average	0.69075	0.22	0.009	0.040909091	0.028298068	76.25	7.985	0.003533004	0.86238
Savonius, 1 m/s, 120°									
1	0.732	0.22	0.014	0.063636364	0.046581818	83	8.692	0.00535916	1.0047952
2	0.753	0.22	0.035	0.159090909	0.119795455	90	9.425	0.012710393	1.08953
3	0.741	0.22	0.022	0.1	0.0741	85	8.901	0.008324907	1.0289556
4	0.749	0.22	0.03	0.136363636	0.102136364	88	9.215	0.011083707	1.065254
Average	0.74375	0.22	0.02525	0.114772727	0.085653409	86.5	9.05825	0.009369542	1.0471337

Table 4: Result Calculated for Savonius Wind Turbine system at wind speed of 2 m/s with Savonius blades at 30°,60°,90°, and 120°

No	Voltage, V (V)	Resistance (Ω)	Resistance Voltage, V_Ω (V_Ω)	Current, I (A)	Power, P (W)	Rotational Speed (RPM)	Angular Speed, ω (rad/s)	Torque, T (Nm)	Tip Speed Ratio, λ
Savonius, 2 m/s, 30°									
1	0.778	0.22	0.046	0.209090909	0.162672727	61	6.388	0.025465361	0.30740653
2	0.799	0.22	0.067	0.304545455	0.243331818	68	7.121	0.034171018	0.342680323
3	0.785	0.22	0.054	0.245454545	0.192681818	65	6.807	0.028306423	0.327569858
4	0.79	0.22	0.061	0.277272727	0.219045455	67	7.016	0.031220846	0.33762746
Average	0.788	0.22	0.057	0.259090909	0.204432955	65.25	6.833	0.029790912	0.328821043
Savonius, 2 m/s, 60°									
1	0.831	0.22	0.075	0.340909091	0.283295455	74	7.749	0.036558969	0.3781512
2	0.798	0.22	0.067	0.033155153	0.243027273	70	7.33	0.033155153	0.357704
3	0.855	0.22	0.083	0.040005976	0.322568182	77	8.063	0.040005976	0.3985984
4	0.86	0.22	0.084	0.040201229	0.328363636	78	8.168	0.040201229	0.3985984
Average	0.836	0.22	0.07725	0.037480332	0.294313636	74.75	7.8275	0.037480332	0.381982
Savonius, 2 m/s, 90°									
1	0.903	0.22	0.095	0.045971683	0.389931818	81	8.482	0.045971683	0.458028
2	1.201	0.22	0.119	0.069702985	0.649631818	89	9.32	0.069702985	0.50328
3	1.11	0.22	0.103	0.058384655	0.519681818	85	8.901	0.058384655	0.480654
4	0.922	0.22	0.098	0.047251391	0.410709091	83	8.692	0.047251391	0.469368
Average	1.034	0.22	0.10375	0.055327679	0.492488636	84.5	8.84875	0.055327679	0.4778325
Savonius, 2 m/s, 120°									
1	1.45	0.22	0.139	0.094068833	0.916136364	93	9.739	0.094068833	0.5629142

2	1.322	0.22	0.122	0.077783458	0.733109091	90	9.425	0.077783458	0.544765
3	1.509	0.22	0.146	0.058384655	1.001427273	96	10.053	0.099614769	0.5810634
4	1.498	0.22	0.142	0.047251391	0.966890909	95	9.948	0.097194502	0.5749944
Average	1.44475	0.22	0.13725	0.055327679	0.904390909	93.5	9.79125	0.092165391	0.56593425

Table 5: Result Calculated for Savonius Wind Turbine system at wind speed of 3 m/s with Savonius blades at 30^o,60^o,90^o, and 120^o

Savonius, 3 m/s, 30°									
No	Voltage, V (V)	Resistance (Ω)	Resistance Voltage, V_Ω (V_Ω)	Current, I (A)	Power, P (W)	Rotational Speed (RPM)	Angular Speed, ω (rad/s)	Torque, T (Nm)	Tip Speed Ratio, λ
1	0.993	0.22	0.097	0.440909091	0.437822727	90	9.425	0.04645334	0.302369708
2	0.798	0.22	0.083	0.377272727	0.301063636	89	9.32	0.032302965	0.299001133
3	1.132	0.22	0.128	0.581818182	0.658618182	93	9.739	0.06762688	0.312443352
4	0.809	0.22	0.089	0.404545455	0.327277273	91	9.529	0.034345395	0.305706202
Average	0.933	0.22	0.09925	0.451136364	0.431195455	90.75	9.50325	0.045182145	0.304880099
Savonius, 3 m/s, 60°									
1	1.534	0.22	0.151	0.686363636	1.052881818	102	10.681	0.09857521	0.347488533
2	2.01	0.22	0.198	0.9	1.809	114	11.938	0.15153292	0.388382933
3	2.772	0.22	0.279	1.268181818	3.5154	120	12.566	0.279754894	0.408813867
4	2.544	0.22	0.253	1.15	2.9256	116	12.147	0.240849592	0.3951824
Average	2.215	0.22	0.22025	1.001136364	2.325720455	113	11.833	0.192678154	0.384966933
Savonius, 3 m/s, 90°									
1	2.974	0.22	0.298	1.354545455	4.028418182	124	12.985	0.310236287	0.46746
2	3.331	0.22	0.349	1.586363636	5.284177273	131	13.718	0.385200268	0.493848
3	4.055	0.22	0.403	1.831818182	7.428022727	146	15.289	0.485840979	0.550404
4	3.65	0.22	0.373	1.695454545	6.188409091	137	14.347	0.431338196	0.516492
Average	3.5025	0.22	0.35575	1.617045455	5.732256818	134.5	14.08475	0.403153932	0.507051
Savonius, 3 m/s, 120°									
1	4.531	0.22	0.457	2.077272727	9.412122727	163	17.069	0.551416177	0.657725467
2	4.377	0.22	0.381	1.731818182	7.580168182	153	16.022	0.473109985	0.617381067
3	4.83	0.22	0.612	2.781818182	13.43618182	198	20.735	0.647995265	0.798988667
4	4.652	0.22	0.588	2.672727273	12.43352727	170	17.802	0.698434292	0.6859704
Average	4.5975	0.22	0.5095	2.315909091	10.7155	171	17.907	0.59273893	0.6900164

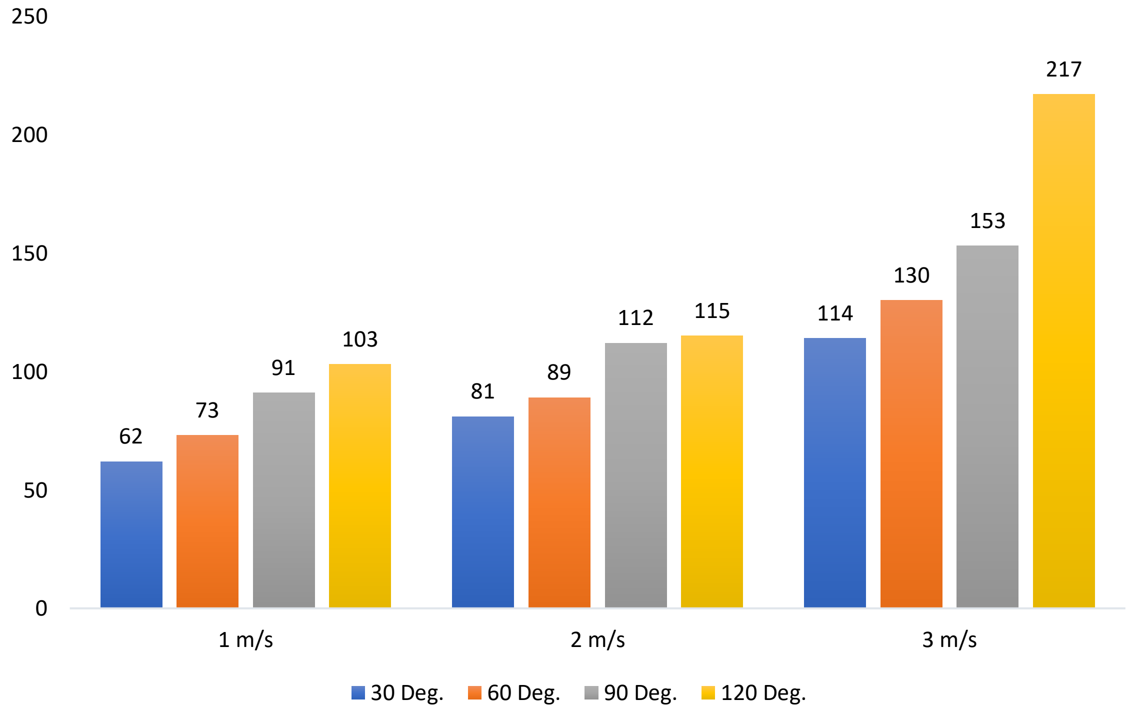

Figure 9: Savonius RPM Without Load Based on Blades Curve

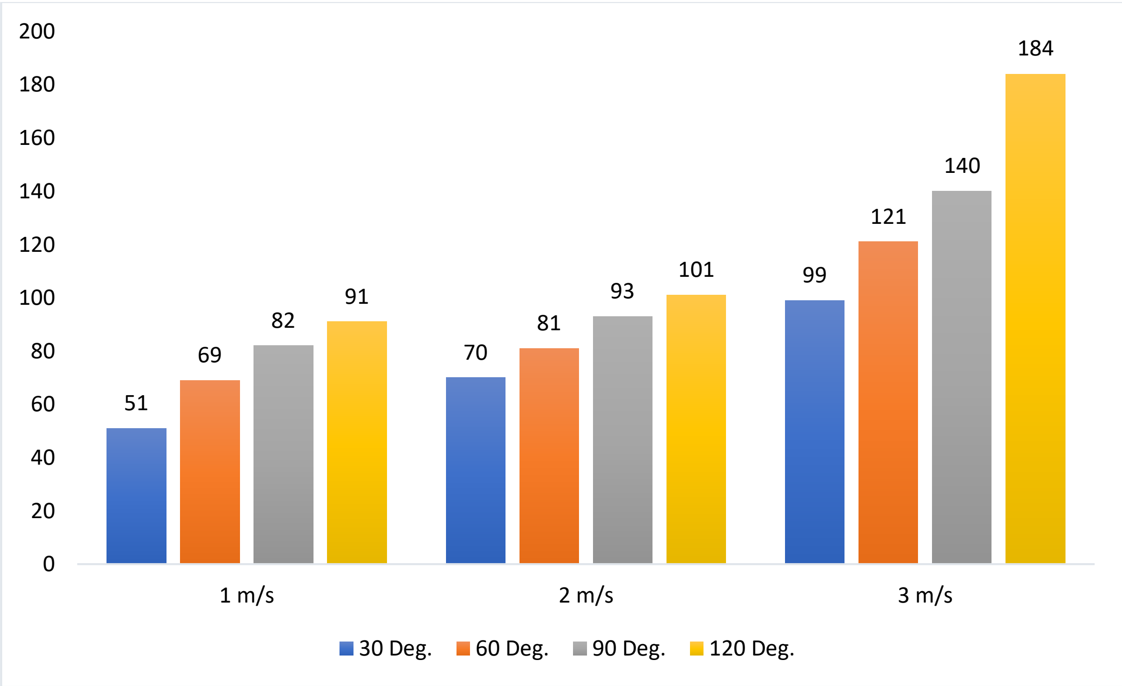

Figure 10: Savonius RPM With Load Based On Blades Curve

Based on the bar chart in Figure 9 and 10 for Savonius RPM without load and with load respectively, it shows that by overall all types of blades able to produce higher RPM if there is any load including motor attached to it. From those two figures, it shows that 120º of blades curve angle from its center produce the highest among the other blades while 30º blades curve angle from its center shows lowest RPM generated. By mechanical theory and concept, higher RPM means higher torque and power able to be produced, and thus 120º curve of blades would be able to produce highest power among the other blades. The reason on why the RPM of all the blades decreased when having load attached on it was because of the weight of the other part of the turbine that the blades and whole assembly of the Savonius wind turbine have to counter. The coupling mechanism also influenced the smoothness of the system. Besides that, the wind distribution also biased to the surrounding as the test did not run inside a total enclosed area.

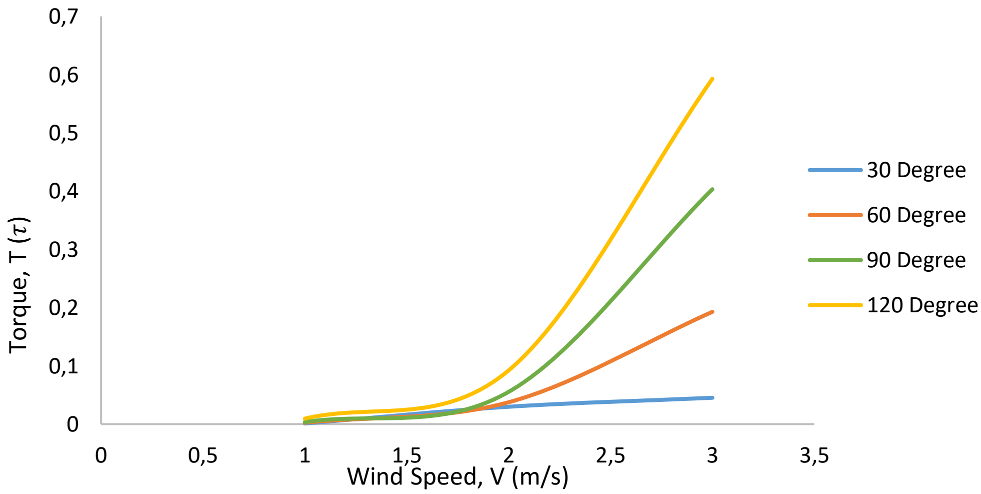

Figure 11: Graph of Torque, τ Against Wind Speed, V Produce for Savonius Rotor

DOI: https://doi.org/10.24036/teknomekanik.v5i1.12672

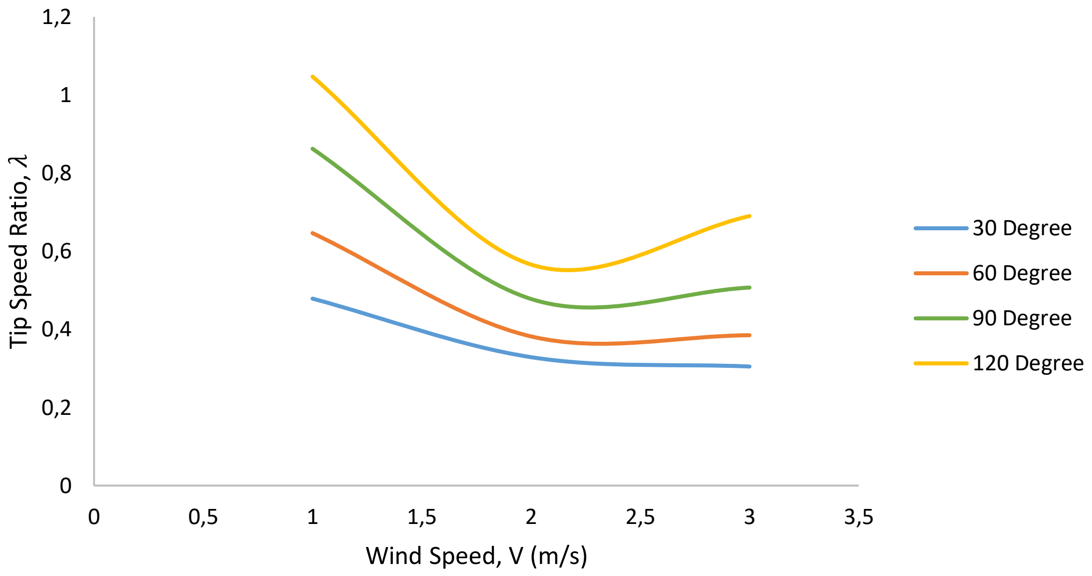

Figure 12: Graph of Tip Speed Ratio, λ Against Wind Speed, V for Savonius Rotor

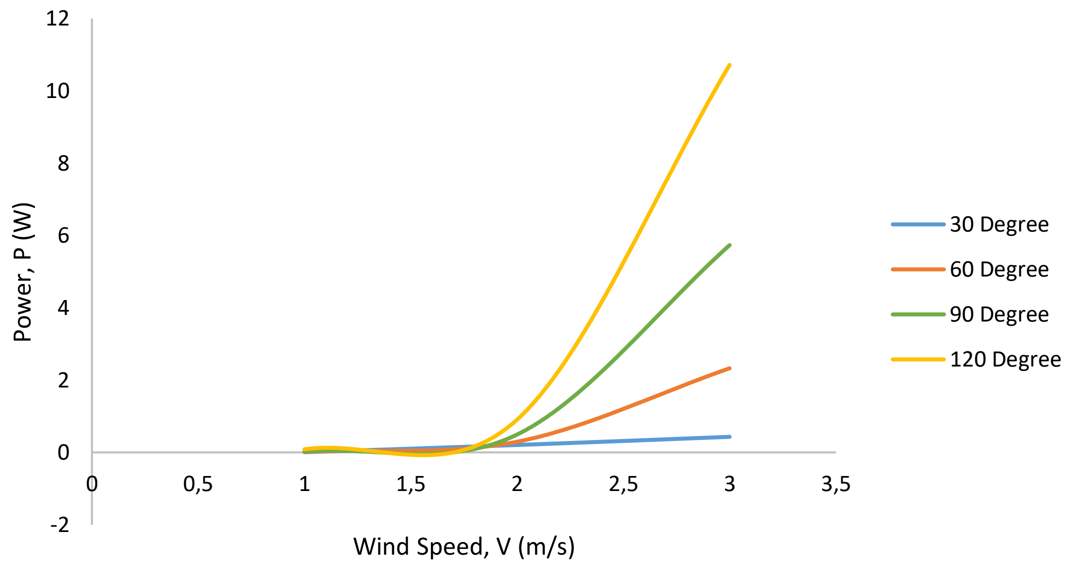

Figure 13: Graph of Power, P Against Wind Speed, V for Savonius Rotor

By referring to Fig. 11, Fig. 12, and Fig. 13, it clearly shows that the torque, tip speed ratio, and power generated at its best when mix wind turbine - Savonius turbine blades at 120^o and at its worst performance at blades curve degree angle of 30^o.

4. CONCLUSION

The mix wind turbine project main objectives were to analyze the outcome based on three-bladed savonius blade design, and to study the torque and power produced by the turbine based on the savonius blade profile or specification. The data and analysis show that this kind of turbine, mix wind turbine is workable as it able to rotate even in low wind speed from 1 m/s to 3 m/s. Furthermore, it able to generate power from kinetic mechanical energy as a result from rotation. All this objective intended to determine the best dimension or type of savonius blade for the three-bladed savonius section of the mix wind turbine. Based on the data analysis of

DOI: https://doi.org/10.24036/teknomekanik.v5i1.12672

the experimental works, it shows that 120º blades curve angle from its centre shows highest RPM in increasing wind speed compared to the other blades either in without load or with load condition, and 30º blades curve angle shows the lowest RPM among the other type of blades. Furthermore, 120º blades curve angle of Savonius wind turbine from its centre shows the best production of power, torque and tip speed ratio among the other types of blade starting from 1 m/s to 3 m/s. Meanwhile, 30º of blades shows the worst performance among the other types of blade. There are difference between the value obtained from design theoretical calculation results and experimental results and it might cause by some errors in material and design, or test tools and equipment. Based on the experimental data analysis, by overall, it shows that three-bladed wind turbine able to works as well as two-bladed savonius rotor as the performance was quite good, and tip speed ratio can be reached slightly more than ideal tip speed ratio with value of 1. 120º blades curve angle from its centre is the best and most suitable type of blade that can be used for savonius wind turbine and mix wind turbine itself for better performance and efficiency.Future works should focus more on the design of the mix wind turbine, or more specifically to the synchronization mechanism between two types of wind turbine system. A more thorough design calculation should be endorsed and a better selection of material for fabrication should be upgraded for a better result outcome, but still have to considered for all required and relative cost.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to the faculty of mechanical and manufacturing, and also to innovation committee, of Sandakan Vocational College for their financial and facility supports provided upon completion of this research project.

REFERENCES

[1] Lodhi, M. A. K., Abidin, A. Z., & Sulaiman, M. Y. Pollutant emissions from fossil fuel use in Kuala Lumpur and environmental damage. *Energy conversion and management*. 1997; *38*(3), 213-216.
[2] Nawri, N., Petersen, G. N., Bjornsson, H., Hahmann, A. N., Jónasson, K., Hasager, C. B., & Clausen, N. E. The wind energy potential of Iceland. *Renewable energy*. 2014; *69*, 290-299.
[3] 3Tiers. (2014). Wind Speed Map across the Globe Retrieved November 28, 2014, from http://www.3tier.com/static/ttcms/us/images/support/maps/3tier_5km_global_wind_speed.jpg
[4] Roy, S., & Saha, U. K. Review on the numerical investigations into the design and development of Savonius wind rotors. *Renewable and Sustainable Energy Reviews*. 2013; *24*, 73-83.
[5] Type of Wind Turbines. (2006). Retrieved from http://www.teachergeek.org/wind_turbine_types.pdf
[6] Shen, C., & Meisen, P. Various wind turbine technologies. *Global Energy Network Institute, San Diego, CA, Sci*. 2012.
[7] Malaysian Meteorological Department. (2014). Retrieved October 6, 2014, from http://www.met.gov.my/index.php?option=com_weathertimeseries&purpose=dailyBulletin&Itmid=1154
[8] Sathiyamoorthy, S., & Bharathi, N. Hybrid energy harvesting using piezoelectric materials, automatic rotational solar panel, vertical axis wind turbine. *Procedia engineering*. 2012; *38*, 843-852.
[9] Johari, M. K., Jalil, M., & Shariff, M. F. M. Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). *International Journal of Engineering and Technology*. 2018; *7*(4.13), 74-80.
[10] Tangler, J. *The evolution of rotor and blade design* (No. NREL/CP-500-28410). National Renewable Energy Lab. (NREL), Golden, CO (United States). 2000.
[11] Liu, X., Wang, L., & Tang, X. Optimized linearization of chord and twist angle profiles for fixed-pitch fixed-speed wind turbine blades. *Renewable Energy*. 2013; *57*, 111-119.
[12] Ali, M. H. Experimental comparison study for Savonius wind turbine of two & three blades at low wind speed. *International Journal of Modern Engineering Research (IJMER)*. 2013; *3*(5), 2978-2986.
[13] Menet, J. L., & Bourabaa, N. Increase in the Savonius rotors efficiency via a parametric investigation. In *European Wind Energy conference & exhibition* (pp. 22-25). 2004, November.
[14] Harun, F., Suparman., Hairun, Y., Machmud, T., & Alhaddad, I. Improving Students' Mathematical Communication Skills through Interactive Online Learning Media Design. *Journal of Technology and Humanities*. 2021; *2*(2), 17-23.
[15] Dent, C. M. Wind energy development in East Asia and Europe. *Asia Europe Journal*. 2013;*11*(3), 211-230.
[16] Henderson, C. R., Manwell, J. F., & McGowan, J. G. A wind/diesel hybrid system with desalination for Star Island, NH: feasibility study results. *Desalination*. 2009; *237*(1-3), 318-329.

[17] Li, T., Hayashi, Y., Hara, Y., & Suzuki, K. Wind tunnel test on a three stage out phase Savonius rotor. In *Proceedings of European Wind Energy Conference and Exhibition*. 2004.
[18] Jain, P. Wind Energy Engineering, McGraw-Hill, New York. 2011.
[19] Johnson, C. Practical wind-generated electricity. 1998.
[20] Mentis, D., Siyal, S. H., Korkovelos, A., & Howells, M. Estimating the spatially explicit wind generated electricity cost in Africa-A GIS based analysis. *Energy strategy reviews*. 2017; *17*, 45-49.
[21] Solanki, C. S. *Renewable energy technologies: A practical guide for beginners*. PHI Learning Pvt. Ltd. pp. 103-106. 2008.
[22] Saha, U. K., Thotla, S., & Maity, D. Optimum design configuration of Savonius rotor through wind tunnel experiments. *Journal of Wind Engineering and Industrial Aerodynamics*. 2008; *96*(8-9), 1359-1375.
[23] Zhao, Z., Zheng, Y., Xu, X., Liu, W., & Hu, G. Research on the improvement of the performance of Savonius rotor based on numerical study. In *2009 International Conference on Sustainable Power Generation and Supply* (pp. 1-6). IEEE. 2009, April.
[24] Eldridge, F. R. Wind machines. New York: Van Nostrand Reinhold Co. 1980.
[25] Pratama, H., Zakaria, N. A., Azman, M. N., & Khairudin, M. Development of Programmable Logic Controller Teaching Aids on Electrical Motor Installation Course Among Vocational School Students in Aceh, Indonesia. *Materials of International Practical Internet Conference "Challenges of Science"*. Issue IV, 2021, 117-127.

DOI: *https://doi.org/10.24036/teknomekanik.v5i1.12672*