Performance Analysis of Vawt Based on the Number of Blades and Pitch Angle Using Matlab

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PERFORMANCE ANALYSIS OF VAWT BASED ON THE NUMBER OF BLADES AND PITCH ANGLE USING MATLAB

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Abstract: This paper aims to determine the performance of VAWT based on the number of blades and pitch angle. The number of blades used are 2, 3, 4 and the pitch angles used are 0, 5, 10, 15, 20 degrees. Numerical analysis is carried out through the MATLAB application to determine the value of TSR, coefficient power, and turbine power. This paper will also show a graph of the relationship between TSR, coefficient power, and turbine power. The results of this study indicate that a VAWT with 2 blades at a pitch angle of 0 degrees has the highest efficiency of 0.4016 or 40%, which is the maximum limit of turbine efficiency of 16/27 or 59.3%. However, 2 blades are less stable at other pitch angles than 3 and 4 blades.

Keywords: VAWT, TSR, Coefficient Power, Turbine Power

1. INTRODUCTION

The demand for electrical energy has increased significantly along with the increase in population and demand for industry and so on. Currently the fuel used to produce electrical energy is fossil fuels such as coal, gas and non-renewable petroleum [1]. Non-renewable fossil materials will eventually run out. In addition, the use of fossil energy as a supplier of electrical energy also has a relatively large negative impact. Chemical energy from fossil fuels that is converted into electricity generation through combustion is the biggest pollutant producer. The resulting pollutants can be the cause of smog, acid rain, global warming and climate change due to the depletion of the ozone layer [2]. Therefore, special attention is needed to be able to utilize renewable energy such as wind, water, solar cells, geothermal, and biomass because they are more environmentally friendly, low cost, and will never run out.

A wind turbine is a tool used in a wind energy conversion system by utilizing wind energy to convert kinetic energy from the wind into mechanical energy in the form of a rotating rotor or turbine propeller and finally converted into electrical energy by utilizing a generator. Currently, there are two general types of wind turbines which are distinguished based on the direction of their axis, namely the Horizontal Axis Wind Turbine (HAWT) and the Vertical Axis Wind Turbine (VAWT). Both types of turbines are still being developed in order to achieve a high level of efficiency. In terms of generating electricity under a steady wind flow with sufficient speed, HAWT is clearly better and capable of producing much higher energy. While VAWT is efficient in low wind environments and changing wind directions [3]. HAWT is commonly used in large wind farms, remote areas, and offshore where the wind speed is stable and uninterrupted. Wind patterns in urban areas that tend to be unstable with low wind speeds, unpredictable wind directions, and full of turbulence make HAWT relatively ineffective so VAWT can be the best choice [4].

The research conducted in this paper will analyze numerically the effect of the number of blades and pitch angle on VAWT performance. Several previous studies have shown that the number of blades [5], [6] and pitch angle [7] have a significant effect on VAWT performance. In this study, we will discuss further the relationship between the number of blades and the pitch angle in improving the performance of wind turbines using MATLAB.

2. METHODOLOGY

2.1. Literature Review

In the concept of wind turbine efficiency, it is related to the betz limit. The betz limit is the maximum efficiency value that can be achieved on a wind turbine. This concept was first introduced by a physicist from Germany named Albertz Betz in 1919. The value of the betz limit is 16/27 or 59.3%, which means that the maximum limit of wind kinetic energy that can drive a turbine is only 59.3% as shown in **Fig. 1**. But in fact, no wind turbine can reach the maximum limit of this betz limit. The average wind turbine efficiency value is only 35% - 45% [8].

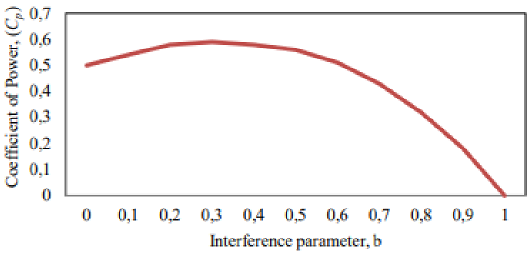

Fig. 1 The power coefficient, C_p functions as a factor b [8]

The power in the wind turbine is the result of the conversion of wind energy that drives the rotor and generator. The amount of power in a wind turbine is highly dependent on the speed of the wind that drives the rotor. The power equation for the wind turbine is as follows [9]:

$$P = \frac{1}{2}\rho C_p A v^3 \quad (1)$$

Where P is wind turbine power (watts), ρ is air density (1.225 kg/m^3), C_p is Coefficient of Power, v is wind speed (m/s), A is rotor area (m^2).

With,

$$A = hd \quad (2)$$

Where h is the height of the wind turbine (m), d is the diameter of the rotor (m).

Coefficient of power (C_p) is a coefficient that determines the amount of power performance of the wind turbine. This C_p is basically influenced by two factors, namely the yield power of the wind turbine and the kinetic energy of the wind flow itself. This C_p has a directly proportional relationship with the performance of the wind turbine, the greater the C_p, the better the performance of the wind turbine [10]. The Coefficient of Power (C_p) equation is as follows:

$$C_p = \frac{Pr}{Pw} \quad (3)$$

Where: C_p is the Coefficient of Power, Pr is the actual turbine power (Watts), Pw is the Power of the theoretical wind speed (Watts)

With,

$$Pw = \frac{1}{2}\rho A v^3 \quad (4)$$

C_p equation based on the value of TSR (λ) and pitch angle (β)

$$C_p = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{-\frac{C_5}{\lambda_i}} + C_6\lambda \quad (5)$$

The coefficient values C_1 to C_6 are: C_1 = 0.5176, C_2 = 116, C_3 = 0.4, C_4 = 5, C_5 = 21 and C_6 = 0.0068 [11]

With,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (6)$$

Tip speed ratio (TSR) is one of the important factors in determining wind turbine design. TSR refers to the ratio between wind speed and wind turbine blade tip speed. TSR is a dimensionless quantity that states the relationship between wind speed and the average rotation of the rotor [12]. The equation is as follows:

$$TSR\ (\lambda) = \frac{\omega R}{v} \quad (7)$$

Where λ is Tip speed ratio, ω is turbine rotor rotation speed, R is rotor radius (m), v is wind speed (m/s)

$$(\lambda max) = \frac{4\pi}{n} \quad (8)$$

Where n is the number of blades.

2.2. Numerical Analysis

MATLAB is a programming platform that uses a matrix-based language so it is generally used to analyze data, create algorithms, and create models and applications [13]. In this study, MATLAB is used to determine the value of TSR, power coefficient, and turbine power. MATLAB is also used to plot comparison charts based on the number of blades and pitch angles.

Table 1: Parameters of VAWT

Parameters	Value
Air density	1.225 kg/m^3
Wind velocity	5 m/s
Swept area	3.14 m^2
Blade number	2, 3, 4
Pitch angle	0°, 5°, 10°, 15°, 20°
Radius	0.5 m

Some of the parameters entered in this study are shown in **Table 1**. The main parameters in this study are the number of blades and pitch angle.

```
lambda1 = 4*pi/2          %tsr for 2 blades
lambda2 = 4*pi/3          %tsr for 3 blades
lambda3 = 4*pi/4          %tsr for 4 blades
y = [lambda1, lambda2, lambda3]
x = [2, 3, 4]             %number of blades
plot(x, y)
```

Fig. 2 MATLAB code for TSR function

Fig. 2 is a code to find the TSR value or tip speed ratio based on the 2, 3, 4 of blades. After that, a graph of the TSR relationship with the number of blades will be displayed with a plot function.

```
clear
clc
%number of blades
%pitch angle(beta) = [0, 5, 10, 15, 20]
lambda2 = 4.1888
oneperlambda1 = 1/(4.1888 + 0.08*0) - 0.035/(0^3 + 1)
oneperlambda2 = 1/(4.1888 + 0.08*5) - 0.035/(5^3 + 1)
oneperlambda3 = 1/(4.1888 + 0.08*10) - 0.035/(10^3 + 1)
oneperlambda4 = 1/(4.1888 + 0.08*15) - 0.035/(15^3 + 1)
oneperlambda5 = 1/(4.1888 + 0.08*20) - 0.035/(20^3 + 1)
%Cp
cp1 = 0.5176*(116*oneperlambda1 - 0.4*0 - 5)*exp(-21*oneperlambda1) + 0.0068*4.1888
cp2 = 0.5176*(116*oneperlambda2 - 0.4*5 - 5)*exp(-21*oneperlambda2) + 0.0068*4.1888
cp3 = 0.5176*(116*oneperlambda3 - 0.4*10 - 5)*exp(-21*oneperlambda3) + 0.0068*4.1888
cp4 = 0.5176*(116*oneperlambda4 - 0.4*15 - 5)*exp(-21*oneperlambda4) + 0.0068*4.1888
cp5 = 0.5176*(116*oneperlambda5 - 0.4*20 - 5)*exp(-21*oneperlambda5) + 0.0068*4.1888
y = [cp1, cp2, cp3, cp4, cp5]
x = [0, 5, 10, 15, 20]
plot(x, y)
xlabel('pitch angle')
ylabel('Coefficient power')
```

Fig. 3 MATLAB code for Coefficient Power

Fig. 3 shows a code to display the value of the coefficient power based on the previously obtained TSR and pitch angle. It first looks for one per lambda, then the result is plugged into the C_p equation. Since there are five pitch angles being compared, there will be five C_p per number of blades. After that, a comparison graph will be displayed using the plot function. If there is a C_p value that exceeds the value of 0.593 or 59.3%, then the equation used is not correct.

```
%P = 0.5*rho*cp*A*v^3
rho = 1.225
A = 3.14
v = 5
p1 = 0.5*rho*0.1622*A*v^3
p2 = 0.5*rho*0.1263*A*v^3
p3 = 0.5*rho*0.1381*A*v^3
p4 = 0.5*rho*0.1391*A*v^3
p5 = 0.5*rho*0.1253*A*v^3
y = [p1, p2, p3, p4, p5]
x = [0, 5, 10, 15, 20]
plot(x, y)
xlabel('pitch angle')
ylabel('Turbine Power')
```

Fig. 4 MATLAB code for Turbine Power

Fig. 4 shows a code to display the value of the turbine power which is influenced by C_p, wind density, wind speed, and swept area. Since there are five pitch angles being compared, there will be five Powers per number of blades. After that, a comparison graph will be displayed using the plot function.

3. RESULTS AND DISCUSSION

3.1. TSR (λ)

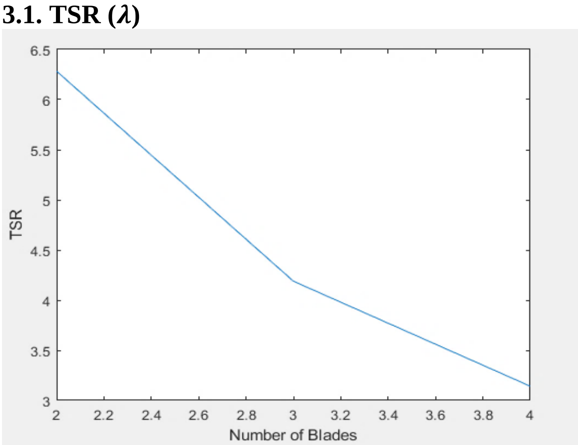

Fig. 5 The Correlation TSR and Number of Blades

Based on **Fig. 5**, it is known that the TSR graph is decreasing. The TSR of 2 blades is 6.283, TSR of 3 blades is 4.1888, and TSR of 4 blades is 3.1416. This shows that the more the number of turbine blades, the smaller the turbine TSR value. The relationship between TSR and the number of propellers is inversely proportional. Wind turbine performance will be better by using only 2 blades, this is evidenced by the largest TSR value.

3.2. Coefficient of Power (C_p)

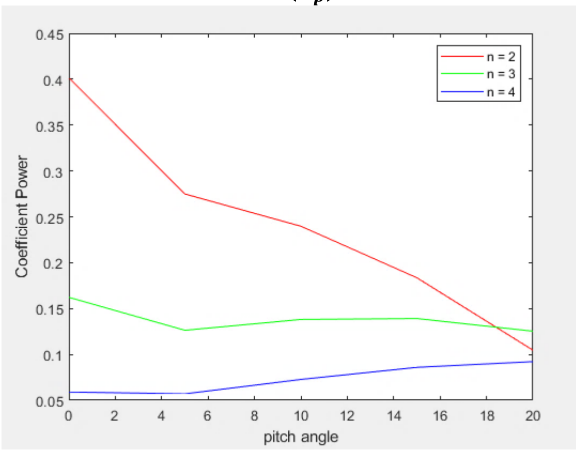

Fig. 6 The Coefficient Power ratio

Fig. 6 is a comparison of the coefficient power values of 2, 3, and 4 blades at pitch angles of 0, 5, 10, 15, 20 degrees. The C_p value on the 2 blades decreases with the largest C_p value with a pitch angle of 0 degrees is 0.4016 or 40% and the smallest at an angle of 20 degrees is 0.1046 or only 10%. The C_p value on the 3 blades is quite stable where the C_p value is the largest with a 0 degree pitch angle is 0.1622 or 16.2% and the smallest at a 20 degree pitch angle is 0.1253 or 12.5%. The C_p value on the 4 blades tends to increase, with the largest C_p value with a 20 degree pitch angle is 0.0921 or 9% and the smallest with a 5 degree pitch angle is 0.0570 or 5.7%.

These results indicate that the equation used in this study is correct because there is no C_p value that exceeds the value of 59.3%. In addition, **Fig. 6** shows that the efficiency of the turbine with 2 blades is very good but less stable, while the efficiency of the turbine with 3 and 4 blades is rather low but quite stable.

3.3. Turbine Power (P)

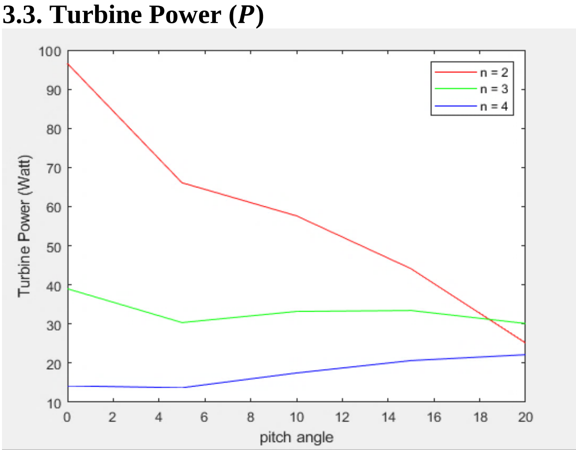

Fig. 7 The Turbine Power Ratio

Fig. 7 is a comparison of turbine power values of 2, 3, and 4 blades with varying pitch angles of 0, 5, 10, 15, 20 degrees. The P value on 2 blades decreased, where the largest P value with a pitch angle of 0 degrees was 96.5472 W and the smallest at an angle of 20 degrees was 25.1465 W. The P value for 3 blades was quite stable where the P value was the largest with a pitch angle of 0 degrees. is 38.9939 W and the smallest at a pitch angle of 20 degrees is 30.1229 W. The P value on 4 blades tends to increase where the largest P value with a pitch angle of 20 degrees is 22.1414 W and the smallest with a pitch angle of 5 degrees is 13.7032 W.

These results indicate that a wind turbine with 2 blades produces very good power output but is less stable, while a wind turbine with 3 and 4 blades has a rather low power output but is quite stable.

CONCLUSION

Based on the result, so it can be concluded that the greater the value of TSR and C_p, the greater the power generated. Wind turbines with 2 blades produce the greatest power output and 4 blades produce the smallest power output. Wind turbines with 2 and 3 blades are most efficient at a pitch angle of 0 degrees, while wind turbines with 4 blades are at an angle of 20 degrees. Based on the comparison graph, it can be seen that the VAWT with 2 blades produces the most power but tends to be unstable, while the VAWT with 3 and 4 blades produces lower power but is quite stable. If the VAWT design has a dynamic blade design that can adjust the wind direction, then 2 blades with a 0 degree pitch angle are preferred. If the VAWT design has a static blade design that cannot adjust the wind direction, then 3 blades with a 0 degree pitch angle are preferred.

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