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Performance Analysis of Wind Turbine

Author
[1]Denny Irawan (Orcid ID. 0000-0002-8337-2509)
[2]Zizin Anggun Kinanti (Orcid ID. 0000-0002-0194-4375)

Correspondence
[1,2]Universitas Muhammadiyah Gresik
Email: den2mas@umg.ac.id, zizinanggunkinanti@gmail.com

Abstract:
Geographical conditions Indonesia has natural resources with good potential for the development of renewable energy. One of them is wind, wind is one of the natural resources in Indonesia that can be utilized because Indonesia is an archipelagic country that has a coastline of 81000 km. The largest wind energy resources are located at sea and near the coast. This wind resource can be used to generate electricity using a wind turbine, so this research is a prototype that can simulate a wind power plant (PLTB). The prototype of this wind power plant was tested by simulating the average wind speed in several regions of Indonesia. The wind speed is between 3 m/s – 7 m/s. The wind speed of the blower is regulated by using a dimmer in order to lower and accelerate the wind speed that sweeps the surface area of the wind turbine. From the rotation of the wind turbine, it directly rotates the rotor so that the generator can produce electrical voltage. The output of the generator is connected to the load. The total load in this study is 15 Watt. By comparing the power that comes out of the generator and the power calculated using the formulation of the power that can be issued by the wind turbine, the efficiency of the generator used in this study can be obtained. The highest generator efficiency is when the wind speed is 6 m/s, with a value of only reaching 6.86%. The working efficiency of the generator can be stable above 5% when the wind speed is from 5 m/s – 7 m/s. The cause of the poor working efficiency of the generator is that the number of rotations produced by the wind turbine is not able to maximize the work of the generator.

Keywords: Natural Resources, Renewable Energy, PLTB, Generator Efficiency

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Introduction

Indonesia is the largest archipelagic country in the world. This country has a coastline of 81000 km. Natural geographical conditions in Indonesia have good potential in the development of renewable energy, one of which is wind energy. Wind energy can be used as an alternative energy that can reduce fossil fuels in the use of electricity [1]. Electricity is an energy source which can transfer energy into another electronic form. This electrical energy is needed by various levels of society. Technological developments lead to an ease in the procurement of electrical energy. With the development of technology, there are various ways to generate electrical energy. This electrical energy can be generated by a power generation system, for example wind, sunlight, fossil fuels, and so on [2]. PLTB (Wind Power Plant) is a system that requires wind as a source to be converted into electrical energy. The simple concept of PLTB is wind as a source to rotate the pinwheel which is connected to a generator where the generator has a copper coil so that an emf (electromotive force) occurs. After the emf generates electricity, the electricity is stored through the battery so that it can be used for loads, for example lights or fans [3]. The topic that will be used in this final project is the manufacture of a wind power generation system (PLTB) with a capacity of 100 watts. Wind power is an unlimited natural resource.

By utilizing wind power, we can produce electricity that is environmentally friendly [3]. Basically this PLTB is included in renewable energy. Therefore, the author's final project is the manufacture of a PLTB system in the form of a prototype that was tested using the average wind speed in several regions of Indonesia. Assuming that the average wind speed in some areas of Indonesia is around 3 m/s – 7 m/s [4], the wind simulation in the manufacture of wind power generation systems has a variable limit of wind speed, namely 3 m/s – 7 m /s. Based on the wind potential and geographical conditions in Indonesia that can be used to generate electricity, this final project is related to the manufacture of a wind power generation system with a generator with a capacity of 100 watts. This PLTB system is designed to facilitate the use of electricity in household electrical installations.

Literatur Review

In 2013, Sumiati [3] discussed the problem of the effect of the number, variations of wind speed and the effect of the number of turns on the work of a savonis wind turbine with the resulting current. The method used is to conduct an experiment. The experiment uses a miniature turbine which has 3 independent variables as a reference to determine the effect of each variable on the work of the wind turbine. The independent variables are the number of blades, the number of turns and the wind speed.

There are two results from the main test. First, there is a relationship between wind speed and the resulting voltage. The faster the wind speed, the greater the wind momentum that produces the rotation of the windmill.

As a result of the rotation of the windmill causes an increase in the voltage and current generated by the turbine generator. Second, there is a correlation of the number of turns on the generator to the resulting voltage. When a generator has more turns, the output voltage is greater. Third, the correlation of the number of blades to the resulting voltage, the more the number of blades, the greater the voltage. This is because the more the number of blades, the greater the thrust at the turbine rotation so that the resulting motor rotation increases. In 2016, Hidayatullah and Ningrum [2] discussed the problem of increasing the efficiency of the output power ratio of wind power plants. Wind power plants have low power efficiency, so that only about 30% to 40% of wind energy can be processed. The method used is Maximum Power Point Tracker (MPPT). MPPT is a method for optimizing the output power of wind power plants. The MPPT can be used to optimize the power that comes out of the generator. In addition, the MPPT function can be used to control excessive power when the wind speed exceeds the load on the wind turbine. The result of this MPPT method is that this system can increase the efficiency of the output power. Higher output power ratio using MPPT.

From the picture below, it can be seen a cross-section of a wind turbine type ENERCON Wind Energy Converters type E82. From the picture above, it can be seen that there are 6 main components in a win turbine: the main carrier, yaw drive, annular generator, blade adapter, rotor hub, and rotor blade.

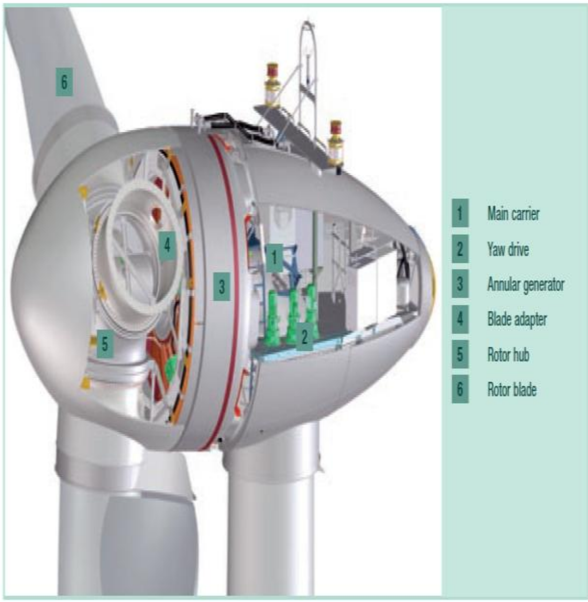

Figure 1. Components Wind Turbine ENERCON Wind Energy Converters type E82

And the technical specifications of the ENERCON Wind Energy Converters type E82 wind turbine as follows :

Technical specifications E-82 E3

Rated power:	3,000 kW	**Drive train with generator**	
Rotor diameter:	82 m	Hub:	Rigid
Hub height:	78 m / 85 m / 98 m / 108 m / 138 m	Main bearing:	Double-row tapered/cylindrical roller bearings
Wind class (IEC):	IEC/NVN IA and IEC/NVN IIA	Generator:	ENERCON direct-drive annular generator
WEC concept:	Gearless, variable speed Single blade adjustment	**Grid feed:**	ENERCON inverter
Rotor		**Brake systems:**	– 3 independent pitch control systems with emergency power supply – Rotor brake – Rotor lock
Type:	Upwind rotor with active pitch control		
Rotational direction:	Clockwise		
No. of blades:	3		
Swept area:	5,281 m²	**Yaw system:**	Active via yaw gear, load-dependent damping
Blade material:	GRP (epoxy resin); Built-in lightning protection	**Cut-out wind speed:**	28 – 34 m/s (with ENERCON storm control*)
Rotational speed:	Variable, 6 – 18.5 rpm		
Pitch control:	ENERCON single blade pitch system; one independent pitch system per rotor blade with allocated emergency supply	**Remote monitoring:**	ENERCON SCADA

*For more information on the ENERCON storm control feature, please see the last page.

Figure 2. Technical specifications of Wind Turbine ENERCON Wind Energy Converters type E82

Next, the specifications of the induction generator are obtained from a book (11) as table 1 :

Tabel.1 Parameter Generator Induksi, 1.45 MW, 575 V, 50hz

Generator Type	SCIG, 1.45 MW, 575 V, 50 Hz	
Rated Output Power	1.45 MW	
Rated Mechanical Power	1.4707 MW	1.0 pu
Rated Apparent Power	1.72 MVA	1.0 pu
Rated Line-to-line Voltage	575 V (rms)	
Rated Phase Voltage	331.98 V (rms)	1.0 pu
Rated Stator Current	1723 A (rms)	1.0 pu
Rated Stator Frequency	50 Hz	1.0 pu
Rated Power Factor	0.8439	
Rated Rotor Speed	1007.2 rpm	1.0 pu
Rated Slip	−0.0072	
Number of Pole Pairs	3	
Rated Mechanical Torque	13.944 kN·m	1.0 pu
Rated Stator Flux Linkage	1.063 Wb (rms)	1.006 pu
Rated Rotor Flux Linkage	0.9757 Wb (rms)	0.9233 pu
Stator Winding Resistance, R_s	1.354 mΩ	0.007 pu
Rotor Winding Resistance, R_r	1.39 mΩ	0.0072 pu
Stator Leakage Inductance, L_{ls}	0.1044 mH	0.1706 pu
Rotor Leakage Inductance, L_{lr}	0.0498 mH	0.0814 pu
Magnetizing Inductance, L_m	1.77016 mH	2.8931 pu
Base Flux Linkage, Λ_B	1.0567 Wb (rms)	1.0 pu
Base Impedance, Z_B	0.1922 Ω	1.0 pu
Base Inductance, L_B	0.61187 mH	1.0 pu
Base Capacitance, C_B	16599.34 μF	1.0 pu

Before plotting wind turbine curves vs induction generator (speed vs power curves), c_p value must be obtained as table 2.

Table 2. The value of the coefficient of cp on wind speed and wind turbine power

Wind [m/s]	Power P [kW]	Power coefficient Cp [-]
1	0.0	0.00
2	3.0	0.12
3	25.0	0.29
4	82.0	0.40
5	174.0	0.43
6	321.0	0.46
7	532.0	0.48
8	815.0	0.49
9	1,180.0	0.50
10	1,580.0	0.49
11	1,900.0	0.44
12	2,200.0	0.39
13	2,480.0	0.35
14	2,700.0	0.30
15	2,850.0	0.26
16	2,950.0	0.22
17	3,020.0	0.19
18	3,020.0	0.16
19	3,020.0	0.14
20	3,020.0	0.12
21	3,020.0	0.10
22	3,020.0	0.09
23	3,020.0	0.08
24	3,020.0	0.07
25	3,020.0	0.06

$\rho = 1.225\ kg/m^3$

From the table above, a plotting of the power change curve and the value of cp for changes in wind speed is generated, where the power curve in the specifications will be programmed in MATLAB and compared the results with calculations. The following are the results of plotting the resulting curve in the specifications and modeling results in MATLAB :

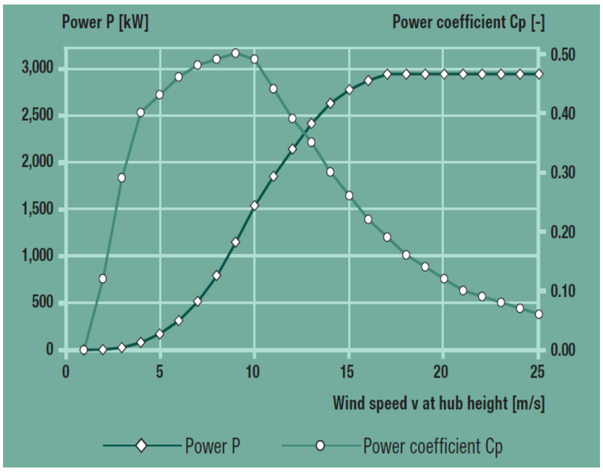

Figure 3. The curve of the change in the value of power and the coefficient of cp to changes in wind speed

From the curve above, it can be seen that the power rating value produced by the wind turbine is 3 MW at a speed of 17 m/s. Wind speed (cut in 2 m/s) and (cut out 25 m/s). In MATLAB, the mechanical power generated by the wind turbine is calculated. By using the following equation:

$$P_{wt} = \frac{\rho}{2} A c_p(\lambda, \theta) v_w^3$$

Dimana:
ρ = Kerapatan udara (kg/m^3)
A = Luas area turbin (m^2)
c_p = Koefisien daya turbin
v_w = Kecepatan angin (m/s)

dari persamaan 1, kita menentukan persamaan nilai c_p menggunakan perhitungan sebagai berikut:

$$c_p(\lambda, \theta) = 0.5176\left(116 \times \frac{1}{\lambda_i} - 0.4\beta - 5\right) e^{\frac{-21}{\lambda_i}} + 0.0068\lambda$$

$$\lambda = \frac{r \times \omega_r}{v_w}$$

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

Dimana:
χ = tip speed ratio dari turbin angin

ω_r = kecepatan angular turbin (*rad/s*)
r = jari-jari rotor turbin (m)
β = pitch angle pada blade

One of the important parameters in determining the value of cp is the pitch angle of the blade . The specifications show that this turbine uses active pitch control, but does not provide data on changes in based on changes in wind speed. Therefore it is assumed that = 0 to produce the optimum so that it is obtained at the maximum cp. The following is a comparison of cp based on data (red) and cp based on calculation (green).

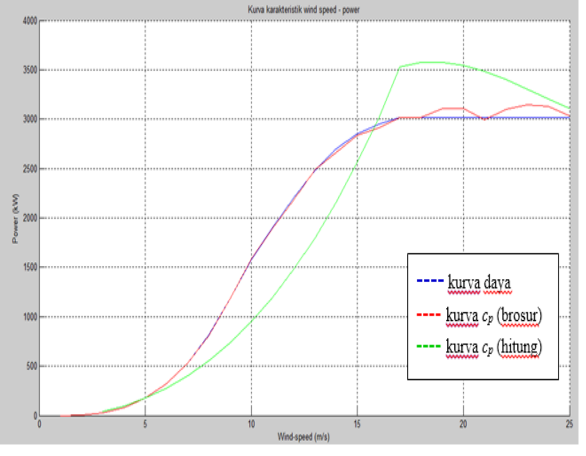

Figure 3. The curve of the change in the value of power and the coefficient of cp to changes in wind speed (MATLAB results)

In Figure 4 obtained 3 curves. The first curve (blue) is the curve of the change in power with the change in wind speed. The second curve (red) is the wind turbine output power curve based on the cp value in the brochure. The third curve (green) is the wind turbine output power curve based on the calculated value of cp

Table 3. Comparison of the results of the cp coefficient value of spesification data and calculations

Cp	Cp1
0	0
0	0
0,16	0,474
0,34	0,468
0,43	0,432
0,48	0,394
0,49	0,362
0,5	0,334
0,5	0,312
0,5	0,293
0,48	0,277
0,44	0,265
0,39	0,253
0,33	0,243
0,28	0,234
0,24	0,227
0,2	0,211
0,17	0,189
0,14	0,161
0,12	0,136
0,11	0,116
0,09	0,098
0,08	0,084
0,07	0,071
0,06	0,062

The next step is plotting the power characteristic curve against the speed of the induction generator. In the brochure data, it can be seen that the output power rating is 3 MW at a wind speed of 17 m/s. The turbine rotor will rotate at a maximum speed of 18.5 rpm while the generator rotor rotates at a speed of 1025.2 rpm, so that the gearbox will increase the speed by a factor of 29.5. The following is a power-to-rotor speed curve for an induction generator.

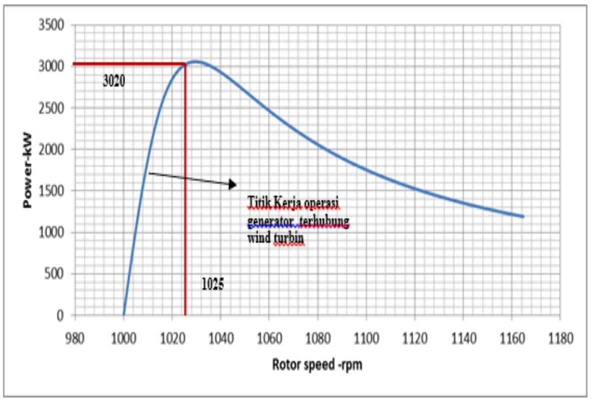

Figure 4. The curve of the ratio of the generator output power to the rotor speed and the operating point of the generator connected to the wind turbine

The power rating of this type of induction generator is 1.45 MW at a speed of 1007.2 rpm with a slip of 0.0072. While the generator operating area when applied to a wind turbine designed to operate at a speed of 1000 rpm to 1025.2 rpm which produces a power of 3 kW to 3020 kW. When plotting the characteristic curve of the rotor speed of the wind turbine and the rotor of the induction generator against the power generated, it can be stated as follows:

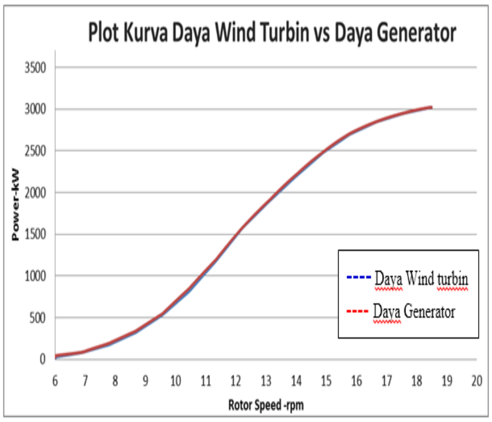

Figure 5. The ratio between the power generated by the generator (red) is slightly different (larger) compared to the power generated by the wind turbine (blue).

Conclusion

Based on the results of research and testing, it can be concluded as follows: the value of Cp produced by the rotor reaches 0.009 to 0.205. This indicates that the turbine which is being experimented as a wind converter is still not considered good. The cause of the low Cp value is possible because the rotor balancing is still not perfect as a result of the limited tools available to balance the wind turbine rotor. For further development, the authors provide very useful suggestions and can help develop existing tools for the future, namely: a. At the time of testing the Wind Turbine, it is better to pay attention to the weather conditions in the field because the performance of the Wind Turbine can function properly if the weather is favorable. b. In making the Horizontal axis Wind Turbine, it is better to pay attention to the important factors that affect the performance of the Wind Turbine.

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