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Optimal Design of Gorlov Turbine Using Computational Fluid Dynamics and Taguchi Method

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ABSTRACT

Wind energy for electricity generation presents a promising alternative to fossil fuels, driving the development of renewable energy technologies. Computational Fluid Dynamics (CFD) stands out as a powerful tool in this domain. This study focuses on optimizing the design of Gorlov turbines through a combination of CFD simulations and the Taguchi method. The research identifies four key factors influencing turbine performance: twist angle, chord length, number of blades, and aspect ratio. These factors are systematically varied using an orthogonal array, resulting in nine distinct blade configurations. Subsequently, simulations are conducted using ANSYS Fluent software under transient conditions at a wind speed of 5 m/s. Simulation results reveal that the maximum angular velocity achieved is 29.8187 deg/s, accompanied by a torque of 0.426 Nm, leading to a calculated maximum power output of 12.73 Watts. Furthermore, Taguchi analysis and ANOVA are employed to assess the significance of each factor. The analysis highlights the aspect ratio as the most influential factor, accounting for 99.7% of the observed variation. This study underscores the potential of CFD and the Taguchi method in optimizing wind turbine design for enhanced performance. The findings emphasize the critical role of the aspect ratio in determining turbine efficiency, paving the way for more efficient renewable energy generation.

Keywords: Wind Turbine, Computational Fluid Dinamics, Gorlov, Taguchi Method

INTRODUCTION

Energy is one of the basic needs for humans, which continues to increase and is in line with the level of life [1][2]. Renewable energy is an alternative energy source that has been provided by nature and can be utilized continuously so that it can be used for both household and industrial purposes. To get electrical energy, we only need to convert or change this form of energy into other energy [3][4][5].

Indonesia is a country that has potential renewable energy sources. The amount of renewable energy potential in Indonesia is quite large [6][7][8], reaching 417.8 gigawatts (GW). The Ministry of Energy and Mineral Resources (ESDM) states that this potential comes from ocean currents of 17.9 GW, geothermal 23.9 GW, bioenergy of 32.6 GW, wind of 60.6 GW, water 75 GW, and sun or solar 207.8 GW [9][10].

The development of renewable energy technology in the world has quite a high potential for increasing electrical energy, so many researchers are researching how to develop this potential renewable energy source as well as developing technology for the application of renewable energy [11][12]. To date, there have been many studies using the Robust Design method or Taguchi calculation method.

In the Taguchi method, determining the combination of design factors is necessary to get the best design combination and obtain the highest power results from that design combination. This research was carried out by determining the combination of factors, including the combination of factors includes; number of blades, twist angle, chord length, and aspect ratio [13][14].

This combination of design factors is also applied to the Computational Fluid Dynamic (CFD) method. CFD is a simulation software for analyzing fluid flow, where in this research the fluid flow is analyzed from rest to moving with steady-state conditions. This research was carried out under transient simulation conditions at specified wind speeds. As the newest computational method in CFD simulation, it uses a User Defined Function (UDF) with 6 Degrees of Freedom (6-DOF). In this CFD method, the simulation results will show object data, namely the Gorlov wind turbine, from rest to steady state rotation. So this simulation research aims to obtain and increase the efficiency of electricity generation from the Gorlov wind turbine model and contribute to sustainable renewable energy technology before printing or producing wind turbine blades.

RESEARCH METHOD

This research was carried out using a simulation method using Computational Fluid Dynamic (CFD) software, namely ANSYS R.18, to test the influence of various design factors on the performance of the Gorlov wind turbine, with a focus on analyzing the process flow results. Before simulating ANSYS software, the researcher first determines the design of the data that will be computationally used using the Taguchi method.

The blade design of the NACA Airfoil 6049[17] geometry is shown in Figure 1 and the initial data used is shown in Table 1.

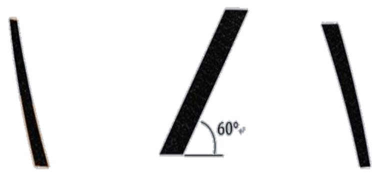

Figure 1. Blades

Table 1. Blade dimension

Material	Size		
Chord lenght	60 mm	80 mm	100 mm
Span (H)	300 mm	400 mm	500 mm
Twist angle	60^0	76^0	90^0
Number of blade	3	4	5
Aspect ratio	0,6	0,8	1

The factors or levels used in the Gorlov wind turbine are shown in Table 2.

Table 2. Factors or level

Factors / Levels	Twist angle (degree) A	Chord length (cm) B	Number of blade C	Aspect ratio D
1	60	6	3	0,6
2	75	8	4	0,8
3	90	10	5	1

The Taguchi method provides an experimental strategy using orthogonal array (OA) to efficiently determine the influence of design factors or levels on the quantitative quality of a product [14][18]. The factors designed to influence the power produced in this research are the number of blades, twist angle, chord length, and aspect ratio, where the value of each influencing factor is in Table 1 above. The Taguchi method in this study uses the L9 orthogonal array so that the combination of factors or levels is shown in Table 3.

Table 3. Orthogonal array

Factors / Levels	Twist angle (degree) A	Chord length (cm) B	Number of blade C	Aspect ratio D
1	60	6	3	0,6
2	60	8	4	0,8
3	60	10	5	1
4	75	6	4	1
5	75	8	5	0,6
6	75	10	3	0,8
7	90	6	5	0,8
8	90	8	3	1
9	90	10	4	0,6

The combination of factors in Table 3 was designed in SolidWorks and then carried out computationally with the simulation conditions shown in Table 4.

Table 4. Simulation conditions

Simulation conditions	
Velocity inlet	5 m/s
Pressure outlet	0 bar
Turbulent model	k-epsilon with model realizable
General time	Transient
Initialization solution	Standard
Time step size	0.001 sec

RESULT AND DISCUSSION

Based on the data from the simulation results carried out on the combination of Gorlov turbine factors, the speed contours shown in Figure 2 are obtained.

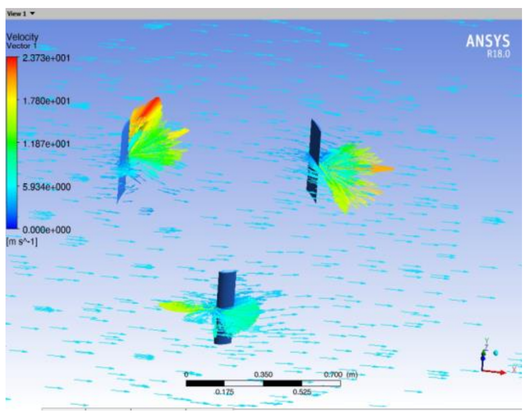

Figure 2. Speed contour around the blade

Meanwhile, the torque obtained from computational results with 2 tests in each case is shown in Table 5.

Table 5. Data from simulation results 1 and 2

Case	Angular velocity 1 (deg/s)	Angular velocity 2 (deg/s)	Torsi 1 (Nm)	Torsi 2 (Nm)
1	28,64804	28,56571	0,12489	0,14178
2	26,56721	25,56102	0,32099	0,31995
3	18,62914	18,34672	0,38298	0,32526
4	8,579096	8,493376	0,79277	0,79342
5	15,19781	15,95334	0,34948	0,34521
6	17,18163	17,98561	0,37472	0,31032
7	10,81412	10,11638	0,52778	0,55523
8	29,89114	29,74634	0,43267	0,42126
9	24,96439	23,96482	0,12104	0,13105

By obtaining simulation data for each combination of factors, the resulting power can be calculated using the formula: $P = T \times \omega$ [19][20] where P is power, T is torque, ω is angular velocity. By using the formula above, the power obtained is shown in Table 6.

Table 6. Power from calculation results

Case	A	B	C	D	Power 1 (Watt)	Power 2 (Watt)
1	60	6	3	0,6	3,577911	4,050046
2	60	8	4	0,8	8,527968	8,178248
3	60	10	5	1	7,134607	5,967454
4	75	6	4	1	6,800881	6,738814
5	75	8	5	0,6	5,311407	5,507253
6	75	10	3	0,8	6,438369	5,581294
7	90	6	5	0,8	5,707496	5,616918
8	90	8	3	1	12,93306	12,53094
9	90	10	4	0,6	3,021889	3,140589

Based on the calculations above, the amount of power produced can be compared based on factors/levels as shown in Figure 3. Figure 3 shows the amount of power generated in each case or combination of factors. From the picture, the maximum power in the case or a combination of factors 8 is obtained because the highest value of angular velocity is obtained in case 8.

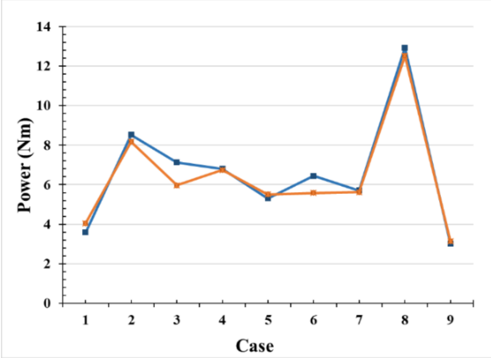

Figure 3. Generated power graph

Taguchi orthogonal arrays are used to identify the optimal combination of process parameters. From these results, the signal-to-noise ratio (S/N ratio) can be obtained as a parameter selection criterion where the S/N response in this study depends on the characteristics of the quality of the response, namely the greater the better so that in this study the characteristic of quality is the maximum power seen from the highest ratio of twist angle, number of blades, chord length, aspect ratio. The optimal combination chosen in this study was selected from factors with greater S/N values which are shown in Table 7 and Figure 4.

Table 7. Maximum power variation analysis (ANOVA)

ANOVA	Power			
Factor	A	B	C	D
level 1	15,4105	14,4159	16,3944	12,0019
level 2	15,5936	18,3948	14,9374	16,3336
level 3	15,6410	13,8344	15,3133	18,3095
AVG	15,5484	15,5484	15,5484	15,5484
SS	0,08894	36,9673	3,43285	62,4535
DOF	2	2	2	2
Var	0,04447	18,4836	1,71642	31,2267
Factor	0,48208	200,37	18,6067	338,510
Confidence	0,32527	0,99503	0,94899	0,99705
significant	No	Yes	Yes	Yes

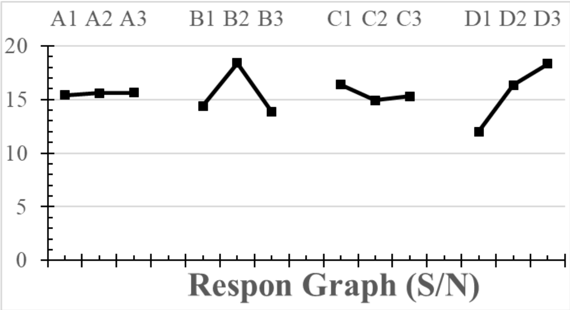

Figure 4. Response graph (S/N) max power

From Table 7 and Figure 4, the best factor combination based on Taguchi analysis is A3, B2, C1, and D3 (twist angle 90 degrees; chord length 8 cm; number of blades 3; aspect ratio 1) where this combination is identical to the combination in case 8.

CONCLUSION

Based on the CFD simulation results on the combination of factors (Taguchi orthogonal array), the highest power was obtained in the 8th case combination, namely 12.73 Watts, and based on Taguchi's analysis, the best factor combination was also in the 8th case, namely a twist angle of 90 degrees; chord length 8 cm; number of blades 3; aspect ratio 1. So it can be concluded that the combination of factor 8 is a more efficient geometric design than other combinations.

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