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CFD ANALYSIS OF OFFSHORE HAWT BASED ON WIND SPEED PROFILE AT 50 METERS ALTITUDE IN THE SOUTHERN WATERS OF UJUNG PANDANG, SOUTH SULAWESI

Nanang Ali Sutisna[1,a] , Yehezkiel Kusmadi Ritonga[2,b]

[1,2,3] Mechanical Engineering Department, President University, Jababeka Education Park, Jl. Ki Hajar Dewantara, Mekarmukti, North Cikarang, Indonesia.

[a]nanang.ali@president.ac.id, [b]yehezkiel.ritonga@student.president.ac.id

Abstrak.

Turbin angin lepas pantai memiliki banyak keuntungan dibandingkan turbin angin darat, dengan kecepatan angin yang lebih baik, lebih sedikit kendala spasial, dan penurunan efek visual dan kebisingan di daerah padat penduduk. Potensi energi angin darat Indonesia untuk kecepatan angin yang melebihi 4,0 m/s adalah 60,65 GW. Selain itu, kemampuan energi angin lepas pantai Indonesia untuk kecepatan angin yang melebihi 6,0 m/s adalah 94,23 GW. Oleh karena itu, kecepatan angin di daerah lepas pantai lebih menjanjikan dibandingkan daerah daratan, yang secara khusus dapat meningkatkan pembangkitan listrik terbarukan dan mengurangi penggunaan bahan bakar fosil. Penelitian ini dilakukan dengan memodelkan desain 3D HAWT dalam 2 domain, yaitu Stationary dan Rotational, yang akan digabungkan dalam satu interface. Diamati pada kecepatan angin 6 m/s, 6,5 m/s, dan 7 m/s koefisien daya (Cp) turbin berturut-turut sebesar 63,64%, 69,06%, dan 74,19%. Penelitian ini juga berhasil memodelkan interaksi antara aliran angin dan turbin, seperti yang ditunjukkan pada kontur kecepatan yang menunjukkan distribusi kecepatan angin yang lebih tinggi pada ujung blade dan kontur tekanan yang menunjukkan distribusi tekanan yang lebih tinggi pada sisi depan blade dan pada sisi samping blade relatif terhadap arah rotasi.

Kata kunci: Turbin angin lepas pantai, *CFD, HAWT,* dan Parameter kinerja Turbin

Abstract.

Offshore wind turbines have many advantages over onshore wind turbines, with better wind speeds, fewer spatial constraints, and decreased visual and noise effects in densely populated areas. Indonesia's onshore wind energy potential for wind speeds exceeding 4.0 m/s is 60.65 GW. Moreover, Indonesia's offshore wind energy ability for wind speeds exceeding 6.0 m/s is 94.23 GW. Consequently, wind speeds in offshore regions are more promising than onshore areas, which can notably enhance renewable electricity generation and reduce the usage of fossil fuels. This research is conducted by modeling the 3D HAWT design in 2 domains, Stationary and Rotational, which will be combined in one interface. The simulation results indicate a significant increase in turbine performance parameters with increasing wind speed. It is observed that at a wind speed of 6 m/s, 6.5 m/s, and 7 m/s the turbine's power coefficient (Cp) is 63.64%, 69.06%, and 74.19% respectively. It also successfully modelled the interaction between wind flow and the turbine, as shown in the velocity contours that display higher wind speed distribution at the blade tips and in the pressure contours that show higher pressure distribution on the front side of the blades and on the side of the blades relative to the direction of rotation.

Keywords: *Offshore wind turbine, CFD, HAWT, and Turbine performance parameters*

Introduction

All With its plentiful renewable power capacity, Indonesia is strategically positioned to design and enforce sustainable structures, prioritizing using renewable energy resources. A few diverse renewable energy alternatives, such as wind turbines, stand proud as a powerful alternative because of their clean and environmentally pleasant nature, significantly contributing to decreasing dependence on fossil fuels, which can be unfavourable to the environment. Offshore wind turbines have numerous advantages over onshore wind turbines in producing electricity, with higher wind speeds, fewer spatial constraints, and decreased visual and noise effects in populated areas. Horizontal Axis Wind Turbines (HAWT) are the primary technology utilized in offshore wind farms because of their mature design and about 25% better efficiency than Vertical Axis Wind turbines[1]. According to the Global Wind Electricity Council (GWEC), in 2021, 21.1 GW of offshore wind electricity was linked to the global grid, tripling the amount compared to 2020, placing a new report within the offshore wind enterprise. Of the 21.1 GW of the latest offshore installations, 80% of changes contributed via China[2].

The latest initiatives have addressed the challenges in creating and renovating offshore wind farms. Improvements along with floating windmills have opened new opportunities for installations in deep waters, wherein fixed-foundation generators are not feasible. Beneath favourable conditions, floating wind foundations, including semi-submersible, barge, and anxiety leg structures, can be mounted at depths as shallow as 30 meters. However, the modern cost of floating foundations is 2-3 instances higher than that of fixed foundations, making them economically unviable for shallow water depths that still permit constant foundations [3].

Senda Hurmuzan [4] of The Central Bureau for Electricity Survey and Testing stated that surveys and mapping of wind turbine capability in Indonesia have been conducted. The entire onshore wind electricity potential for wind speeds exceeding 4.0 m/s is 60.65 GW. Additionally, Indonesia's total offshore wind turbine ability for wind speeds exceeding 6.0 m/s is 94.23 GW. Therefore, wind speeds in offshore regions are more promising than those in the onshore areas, which can appreciably enhance renewable energy technology and reduce fossil gasoline use.

In a previous study on a planned power plant in a remote area of East Nusa Tenggara, where the wind speed is estimated at 6.0 m/s, and the plant has a capacity of 10 M.W., it was decided to use HAWT because it generates 37% more power than VAWT at the same wind speed. Additionally, HAWT's power coefficient (Cp) is 25% higher than that of VAWT, making it a more efficient choice for this location[5].

Methodology

This research is conducted by modelling the 3D HAWT design in 2 domains, Stationary and Rotational, which will be combined in one interface. The stationary domain includes the area around the blades that remains static. Here, the researcher models the airflow approaching the blades without considering the blades' rotation. In this domain, boundary conditions such as inlet velocity, atmospheric pressure, and pressure outlet must be set up. The rotational domain includes the area around the rotating blades. Here, the airflow interacting with the moving blades is modelled. In this domain, boundary conditions are set on the surface of the blades.

Research Framework

As depicted in Fig. 1, the research is started with problem identification, followed by literature review, modelling HAWT in Solidworks, and verification. Next is doing simulation in Ansys, after checking the convergence we did the result data analysis.

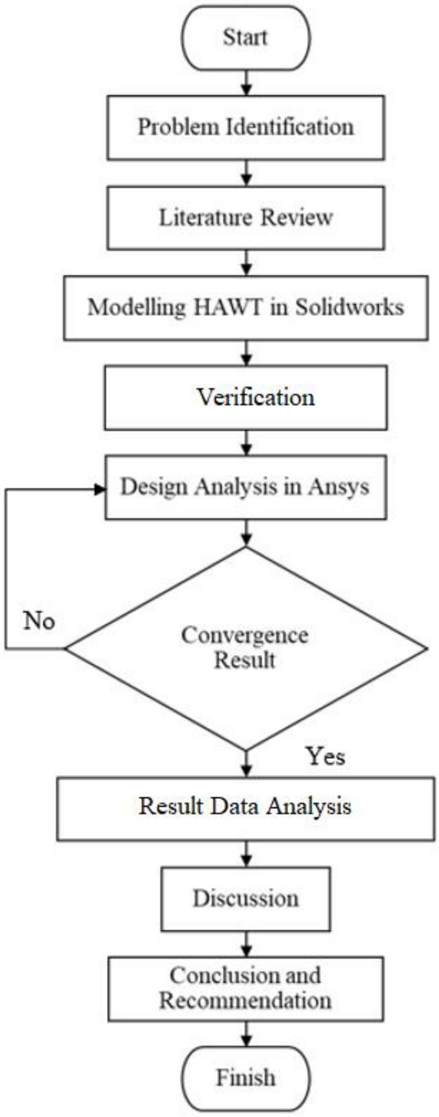

Figure 1. Research Flowchart

Horizontal Axis Wind Turbine Specifications

Fig 2 exhibit HAWT with 3 blades, the specific shape of HAWT used in this research is the HAWT, using the NACA 4412 airfoil.

Figure 2. HAWT with 3 Blade

Wind turbine blades using NACA 4412 airfoils provide an exciting possibility for offshore applications. The NACA 4412 profile, characterized with the aid of a maximum camber of 4%, placed 40% along the chord from the leading side, and a max thickness of 12%, offers a balance between lift and drag force, as it is shown in Table 1,

Table 1. Horizontal Axis Wind Turbine Specifications

Blade length	60 m
Rotor Diameter	130 m
Swept Area	13266.5 m^2
Number of Blade	3
Type	NACA 4412 airfoil
Developed	National Advisory Committee for Aeronautics (NACA)

Wind Speed Data
The wind speed data used in this research is sourced from three sources: BMKG-OFS interactive OFS map [6], Global Wind Atlas [7], and Indonesia Wind Prospecting [8]. The data collection location is -5.592222°, 119.421919°. There are three wind speeds from the data obtained at the exact location for data collection. The data for the wind speed from the three sources are as follows, from smallest to biggest: (6.38, 6.62, and 7.96) in unit m/s. The wind speed of 7.96 m/s is the average daily wind speed as of 15 July 2024. Thus, according to the wind speed mentioned above, speed distribution data, only 6.0 m/s, 6.5 m/s, and 7.0 m/s wind speeds will be used.

First Stage Calculation

Maximum Power Calculation
The maximum power can be known by calculating the power using this equation:

$$P_{max} = \frac{1}{2}.\rho.A.U^3 \quad (1)$$

Table 1. Maximum Power Calculation Result

Wind Speed (m/s)	Power Produced (MW)
6	1.76
6.5	2.23
7	2.79

Angular Velocity Calculation
Since the available data only includes wind speed, the tip speed ratio (TSR) must be used to obtain the angular speed value. The wind speed should be multiplied by the TSR value to achieve this. The TSR for HAWT with 3 blades is 7.

$$\omega = \frac{V.TSR}{R} \quad (2)$$

Table 2. Angular Velocity Result

Wind Speed (m/s)	Angular Velocity (rad/s)
6	0.65

6.5	0.7
7	0.75

Rotation Speed
Rotation speed can be calculated by using this equation:

$$n = \frac{60}{2\pi} . \omega \quad (3)$$

Table 3. Revolutions Per Minute Result

Wind Speed (m/s)	Revolution Per Minute (RPM)
6	6.21
6.5	6.69
7	7.16

Meshing
Mesh quality significantly affects computational results as equations are analysed through cells. There are standards for mesh quality, including orthogonal quality and skewness values as it is shown in Fig. 3.

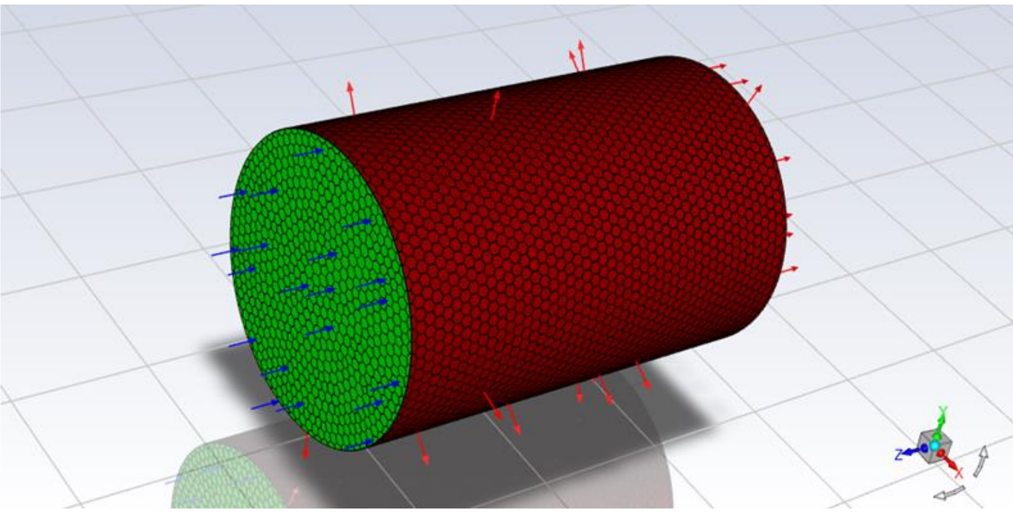

Figure 1. Meshing HAWT in Ansys

Ideally, the orthogonal quality value should be 0.1 or above, while the skewness value should be below 0.95. Mesh quality meets the required value to minimize errors [9].

Table 4. Meshing Quality

Total Number of Faces	243047
Maximum Skewness	0.85
Total Number of Cells	1975485

Minimum Orthogonal Quality	0.16

Analysis Result

Torque

The resulting torque that rotate the wind turbine is obtained based on the input parameters.

Table 6. Torque Parameters

Wind Speed (m/s)	Torque (N.m or J)
6	1717870
6.5	2198570
7	2765530

Power Output Calculation

Power output can be calculated by using this equation:

$$P_{out} = \tau . \omega \tag{4}$$

Table 7. Power Output Result

Wind Speed (m/s)	Power Output(MW)
6	1.12
6.5	1.54
7	2.07

Discussion

The data obtained from the simulation and calculations, including maximum power, angular speed, revolutions per minute (RPM), torque, and power output, as summarized in Table 7, will then be plotted into graphs.

Table 8. Calculation and Simulation Result

V (m/s)	P_{max} (MW)	ω (rad/s)	n (rpm)	τ $(Nm\ or\ J)$	P_{out} (MW)
6	1.76	0.65	6.21	1717870	1.12
6.5	2.23	0.7	6.69	2198570	1.54
7	2.79	0.75	7.16	2765530	2.07

Based on the results obtained and shown in the comparison graph between maximum power and power output (Fig.4), it is found that as the wind speed increases, the value of the power coefficient (Cp) also increases (directly proportional).

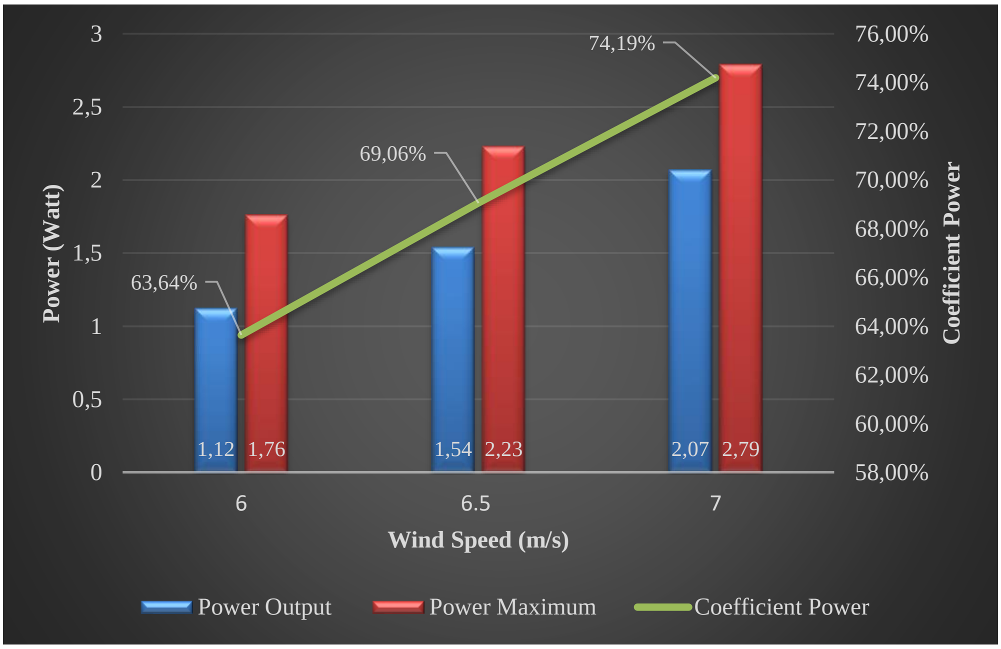

Figure 2. Comparison Graph of Maximum Power Value to Power Output

It is observed that at a wind speed of 6 m/s, the turbine's Cp is 63.64%; at 6.5 m/s, the turbine's Cp reaches 69.06%; and at a wind speed of 7 m/s, the turbine's Cp increases to 74.19%.

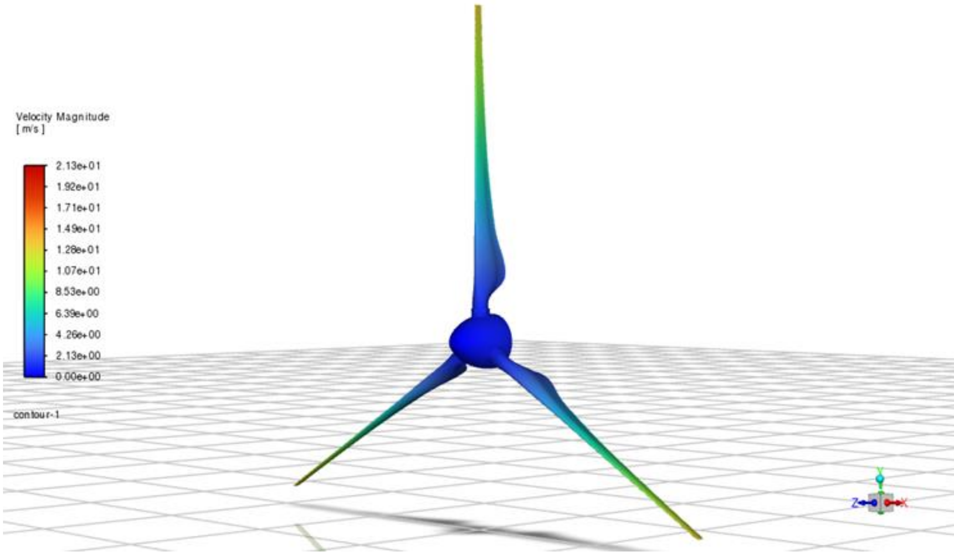

Figure 3. Velocity Contour on HAWT

The velocity contour on the HAWT above shows a higher velocity distribution at the blade tips, reflecting an increase in linear speed as the distance from the centre of rotation increases.

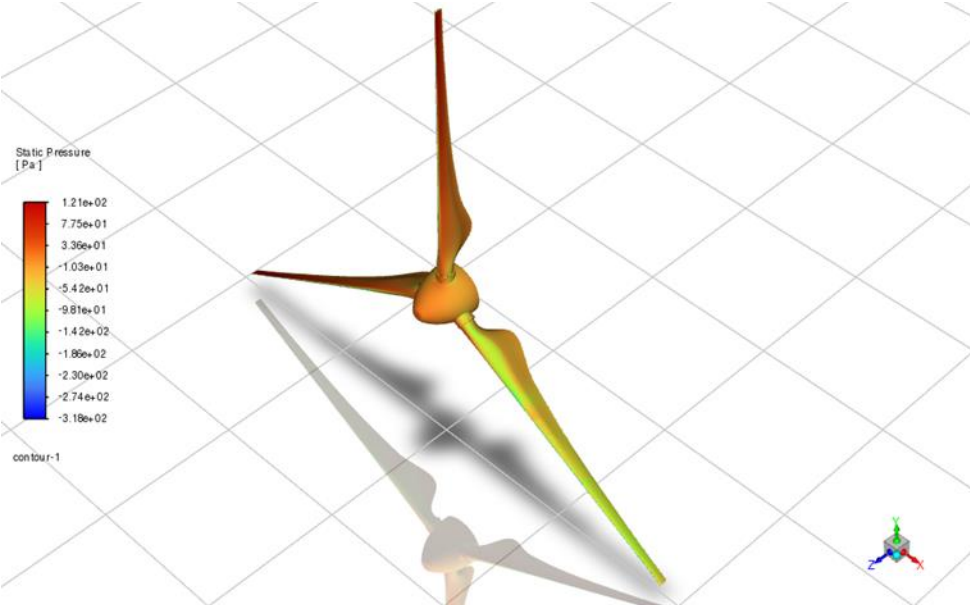

Figure 4. Pressure Contour on HAWT

The pressure contour on the HAWT shows a higher pressure distribution on the front side of the blades and the side of the blades relative to the direction of rotation (in this case, clockwise).

Conclusion

Based on the results of the simulation, data analysis, and discussion conducted in the previous chapter, the following conclusions can be drawn:

1. Simulation Findings: The simulation results indicate a significant increase in turbine performance parameters with increasing wind speed:
   - Output power increased from 1.12 MW at 6 m/s to 2.07 MW at 7 m/s.
   - Power coefficient (Cp) increased from 63.64% at 6 m/s to 74.19% at 7 m/s, indicating high energy conversion efficiency.
   - Turbine RPM increased from 6.21 at 6 m/s to 7.16 at 7 m/s.
   - Torque increased from 1,717,870 Nm at 6 m/s to 2,765,530 Nm at 7 m/s.
2. Site Potential: The data collection location in the southern waters of Ujung Pandang, South Sulawesi, at an altitude of 50 meters, with an average wind speed of 6 m/s and above, based on three reliable data sources, shows good potential for offshore wind energy development (feasible installation).
3. CFD Analysis Result and CFD Methodology: The CFD analysis using the NACA 4412 airfoil design on a wind turbine with a rotor diameter of 130 meters in the southern waters of Ujung Pandang, South Sulawesi, based on wind speed at an altitude of 50 meters, shows good performance in the wind speed range of 6-7 m/s. The CFD method using ANSYS Fluent successfully modeled the interaction between wind flow and the turbine, as shown in the velocity contours that display higher wind speed distribution at the blade tips, consistent with wind turbine aerodynamic theory, and in the pressure contours that show higher pressure distribution on the front side of the blades and on the side of the blades relative to the direction of rotation, consistent with aerodynamic lift principles.

Recommendation

There may still be many factors to consider in the feasibility study of offshore wind turbines at this location. Therefore, the next stage requires analysing the impact of materials on the performance of the HAWT.

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