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CFD Analysis Of Wind Turbine For 10 MW Electrical Power Generator In East Nusa Tenggara

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Abstrak.

Energi listrik mempunyai peranan yang vital dalam aktivitas manusia sehari-hari. Sumber energi yang saat ini digunakan dalam suatu pembangkitan adalah sumber energi tak terbarukan. Energi angin merupakan sumber energi terbarukan yang dapat dimanfaatkan menjadi energi mekanik atau listrik melalui suatu konversi yang disebut Sistem Konversi Energi Angin. Pada pembangkit listrik tenaga angin, komponen yang cukup penting adalah turbin angin; angin akan menggerakkan turbin dan menghasilkan listrik dari generator. Penelitian ini menganalisis kesesuaian desain turbin untuk diterapkan pada pembangkit listrik tenaga angin di Nusa Tenggara Timur, khususnya di tiga wilayah yang memiliki potensi angin cukup tinggi dibandingkan wilayah sekitarnya. Pemilihan turbin angin yang tepat untuk pembangkit listrik di Nusa Tenggara Timur merupakan penelitian tahap pertama yang membandingkan dua desain turbin angin, yaitu Turbin Angin Sumbu Horizontal (HAWT) dan Turbin Angin Sumbu Vertikal (VAWT). Dilanjutkan dengan menganalisis kinerja turbin yang dipilih menggunakan data sekunder dan perangkat lunak analisis yaitu Ansys untuk mengetahui torsi yang dihasilkan turbin angin yang diteliti. Hasil simulasi menunjukkan bahwa Turbin Angin Sumbu Horizontal menghasilkan daya sebesar 259,491 kW pada kecepatan angin 5,86 m/s dan 271,447 kW pada kecepatan angin 6,13 m/s. Berdasarkan hasil yang diperoleh, kebutuhan Turbin Angin Sumbu Horizontal untuk menghasilkan 10 MW sebanyak 56 unit..

Kata kunci: Turbin Angin, Pembangkit Listrik, Turbin Angin Sumbu Horisontal, Turbin Angin Sumbu Vertikal

Abstract.

Electrical energy has a vital role in daily human activities. The energy sources currently used in a generation are non-renewable energy sources. Wind energy is a renewable energy source that can be utilized as mechanical or electrical energy through a conversion called the Wind Energy Conversion System. In wind power plants, a somewhat important component is a wind turbine; the wind will drive the turbine and generate electricity from the generator. This study analyzed the suitability of turbine designs to be applied to wind power plants in East Nusa Tenggara, especially in three areas with a reasonably high wind potential compared to the surrounding area. Selection of appropriate wind turbine for electrical power generation in East Nusa Tenggara is the first phase of the study, it compared two wind turbine designs, namely Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Followed by analyzing the performance of the selected turbine using secondary data and analysis software, namely Ansys, to determine the torque generated by the wind turbine under study. The simulation results showed that the Horizontal Axis Wind Turbine produced power of 259.491 kW at a wind speed of 5.86 m/s and 271.447 kW at a wind speed of 6.13 m/s. Based on the results, the Horizontal Axis Wind Turbine needed for generating 10 MW is 56 units.

Keywords: *Wind Turbine, Electrical Power Plant, Horizontal Axis Wind Turbine, Vertical Axis Wind Turbine.*

Introduction

Electrical energy has a vital role in daily human activities. Recorded in the third quarter of 2021, electricity consumption in Indonesia reached 1,109 kWh per capita, according to the Ministry of Energy and Mineral Resources (Kementerian ESDM); this figure is equivalent to 92.2% of the target set in 2021 of 1,203 kWh [1]. For now, power plants use fossil fuels (coal and petroleum), Diesel Power Plants which are the most potent plants to produce electrical energy in Indonesia; from data by PT Perusahaan Listrik Negara (Persero) or PLN, there are around 5,258 units of Diesel Power Plant in 2021 [2].

The energy sources currently used in a generation are non-renewable energy sources. Coal and petroleum are examples of non-renewable energy sources used in power generation from the past until now. However, it is known that non-renewable energy sources have a harmful environmental impact, which has been the main concern in our society. Cleaner energy is needed to maintain human survival. Renewable energy sources become alternative energy to replace non-renewable energy sources.

Wind energy is a renewable energy source that can be utilized as mechanical or electrical energy through a conversion called the Wind Energy Conversion System [3]. Indonesia is one of the countries rich in wind energy sources. This is supported by geographical conditions as an archipelagic country on the equator, providing Indonesia's abundant wind energy potential [4]. NTT province also has a reasonably good wind energy potential. Two of the three locations on Timor Island are Aeu'ut Village, South Central Timor Regency, and Wini Village, North Central Timor Regency. In contrast, one location is Waingapu, East Sumba Regency, Sumba Island. The windfall varies between 4.5 to 5 m/s, so using the latest wind power plant technology can develop the location as a wind farm [5].

In wind power plants, a somewhat important component is a wind turbine; the wind will drive the turbine and generate electricity from the generator. In terms of technology, wind turbines have several standard designs: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). HAWT is the most common wind turbine design in use today. HAWT uses aerodynamic blades (or wings) attached to a rotor that can be positioned upwind or downwind [6]. In VAWT, the main rotor shaft is arranged vertically. The main advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective; this is an advantage in areas where the wind direction changes significantly [7]. Each of the wind turbine designs has advantages and disadvantages; which of these wind turbine designs adapts to the environmental conditions of installing wind power plants.

Methodology

As illustrated in Fig. 1, this study started with identification of problem, where wind potential is very supportive of building a Wind Power Plant in the East Nusa Tenggara area to be channeled to villages that have not been electrified. The goals of this study is to determine the most suitable turbine design for 10MW power plant.

Wind Turbine Selection

After identifying the problem, the next phase is selection of wind turbine type. There are two distinct types of wind turbine, namely Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT).

HAWT is a wind turbine whose main shaft rotates according to the wind direction. For the rotor to rotate well, the wind direction must be parallel to the turbine's axis and perpendicular to the rotor's rotation direction. Turbines of this type usually have airfoil blades resembling an aircraft wing's shape. In general, the greater the number of blades, the higher the turbine speed [8].

The number of blades in the HAWT depends on the application and expected wind conditions. Based on the number of blades, HAWT rotors can be classified into single-blade, two-blade, three-blade, and multi-blade rotors [9]. There are also several variation of HAWT rotor found in application such as contra-rotating double rotor, flettner, sail wing, ring generator, multi rotors, and many more.

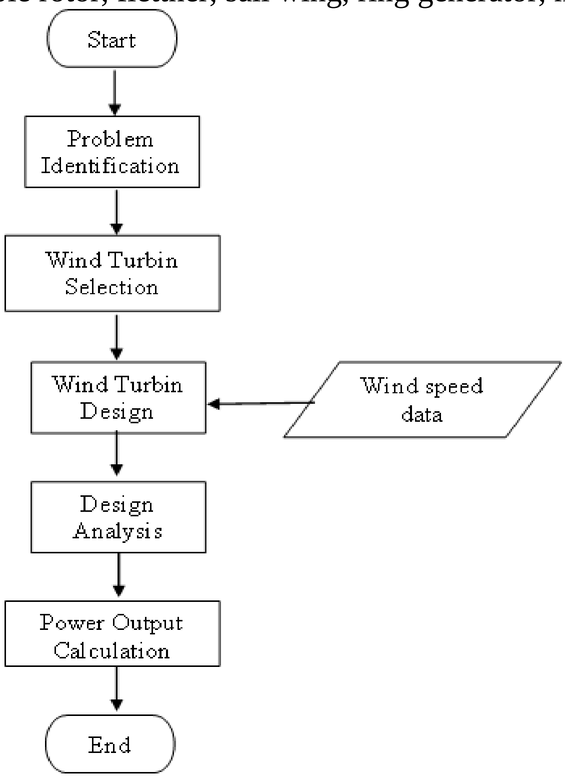

Fig. 1 Research flowchart

VAWT is a vertical-axis wind turbine in which the movement of the shaft and rotor is parallel to the direction of the wind, and the rotor can rotate in any wind direction. This type of wind turbine has three types of rotors: Savonius, Darius, and H rotors. The Savonius turbines used an inhibitory force, while the Darrieus and H rotors used a lifting force [8]. Table 1 shows the advantages and disadvantages of HAWT and VAWT, and Table 2 shows the comparison of power generated by HAWT and VAWT in several wind speed.

Table 1 Advantages and disadvantages of HAWT and VAWT [8,10,11]

	Advantages	**Disadvantage**
HAWT	▪ High efficiency and low cut-in wind speed ▪ Higher power coefficient ▪ High torque as result of high power and blade length .	▪ HAWT exploits yaw control to increase the intake of wind power because the rotor can only take the wind from one direction ▪ Should be installed away from the area s of buildings and cities
VAWT	▪ High torque makes it possible to rotate at low wind speeds ▪ Generator can be placed under the turbine for easier maintenance ▪ The turbine works even if the wind affects the direction is not affected ▪ Can be installed in city areas due to less noise and did not need yaw control	▪ Lower efficiency ▪ The wind speed on land is very low. Thus, when the tower is not in use, it rotates less and less efficient than HAWT

Since the planned power plant is in the remote area of East Nusa Tenggara where the wind velocity is estimated to be 6 m/s and to have power capacity of 10 MW, it is decided to use HAWT due to it produce power 37% higher the that of VAWT at the same speed [10] and the power coefficient 25% higher than the VAWT [11].

Table 2. Comparison between the power, for the HAWT and the VAWT in several wind velocity [11]

Wind velocity [m/s]	HAWT power [kW]	VAWT power [kW]
3	0	0
6	3	1.8
9	7	6
12	20.2	15
15	22	30

Next phase is designing the wind turbine and hence there is a need to know the wind velocity in the area where the power plant to be built. The wind data that was taken come from global wind atlas [12], and the speed that was used in the analysis is the average wind speed. Sample for wind velocity data taken in Pambotanjara Village, Waingapu, East Nusa Tenggara, with latitude and longitude of -9.684014° and 120.113848° respectively.

After the design of turbine completed, it was followed by analysis using computational fluid dynamic (CFD). The software used in the analysis is Ansys which, in this stage, will analyze the structure of the wind turbine and calculate the efficiency and output that each wind turbine type can produce. Based on the analysis results, the appropriate wind turbine design is selected by comparing the number of each turbine will be installed to produce 10 MW electrical power.

Result and Discussion

Wind Velocity Data

The wind data was taken from global wind atlas [12] and the sample for wind velocity data was taken in Pambotanjara Village, Waingapu, East Nusa Tenggara (NTT), with latitude and longitude of -9.684014° and 120.113848°respectively. On an area of 9 km^2, data for 10% of windy areas have a potential wind speed of 6.13 m/s and a mean power density of 256 W/m2 at 50 m as exhibited in Fig. 2. Monthly wind speed data shows that a reasonably high wind speed index occurs in the middle of the year, namely in May-August with a value of 1.28 to 1.34, and the highest wind speed index in June - July with a value of 1.42 (Fig. 3).

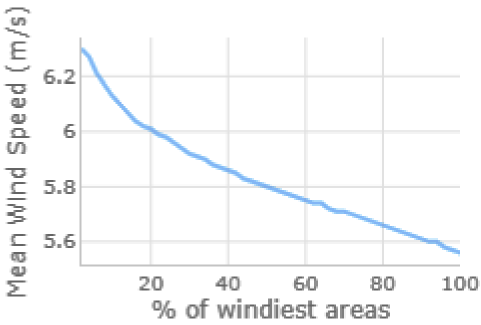

Fig. 2 Mean wind speed at height 50m

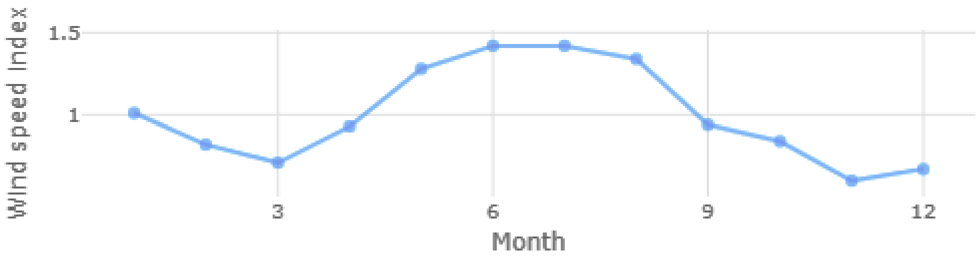

Fig. 3 Monthly wind speed index

Table 1 shows the average wind speed in the area that will be used in the analysis, wind data is taken from the global wind atlas [12], located in Pambotanjaran Village, Waingapu, NTT.

Table 1 Wind Data for Simulation

% of the windiest area	Wind Speed (m/s)
10	6.13
20	6.01
40	5.86

From the data above, simulations in the wind turbine design will use wind speed in 10% of the windiest area, namely, 6.13 m /s, as a parameter in this research

Wind Turbine Design

The design analysis uses data from several sources, such as journals, books, official websites, and online stores. The blade design specifications were taken through the online store. The turbine model for analysis were created using CAD Software, HAWT model was redrawn from the V52 wind turbine Rotor made by Vestas [13] as it is shown in Fig. 4. The specification of HAWT models is shown in Table 3 respectively.

Figure 4 Horizontal Axis Wind Turbine CAD model

Table 3 HAWT V52 Wind Turbine by Vestas [13]

Diameter	52 m
Swept Area	2,124 m^2
Number of Blades	3
Rotor Speed, max	3.14 U/min
Tip-speed	85 m/s
Type	-
Material	GFK
Manufacture	Vestas

Meshing

The meshing process is one of the essential processes in CFD. The quality of the mesh has a significant impact on the simulation output. Meshing is the process of dividing a domain into multiple cells. Meshes can be divided into two types: structured grids and unstructured grids.

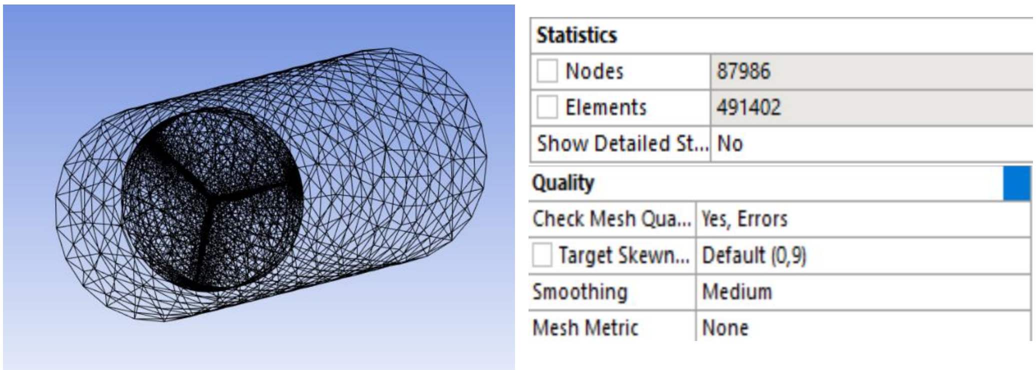

Fig. 5 Meshing Result of Horizontal Axis Wind Turbine

The mesh quality greatly affects the computational results because the equations are analyzed through the cells. If there is no error or failed mesh, that could continue to the next process.

Setup

After the meshing process is done and there is no problem or error, it could continue until the following process is set up. In this process need input some data to run the simulation. Before inputting data, make sure the geometry is ready, such as making the domain of the geometry and name selection of the domain.

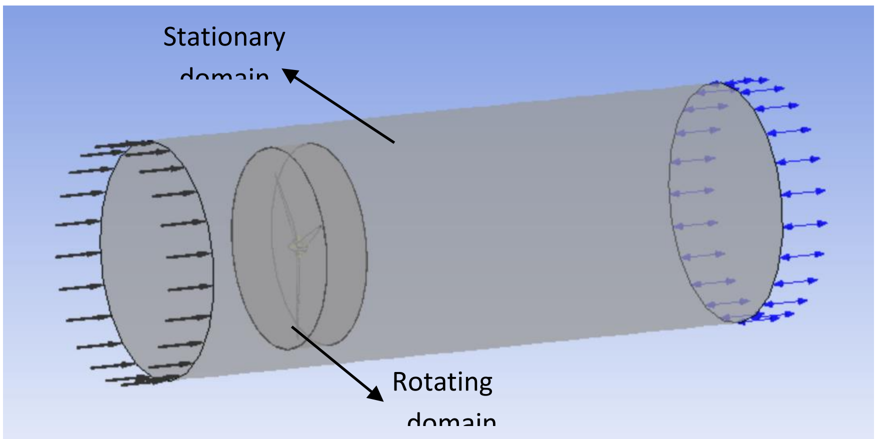

Fig. 6 Domain for Simulation

After the domain has been created, it is necessary to create boundaries such as inlets to enter the fluid flow, wall boundaries as boundaries, and outlets as the fluid flow exit.

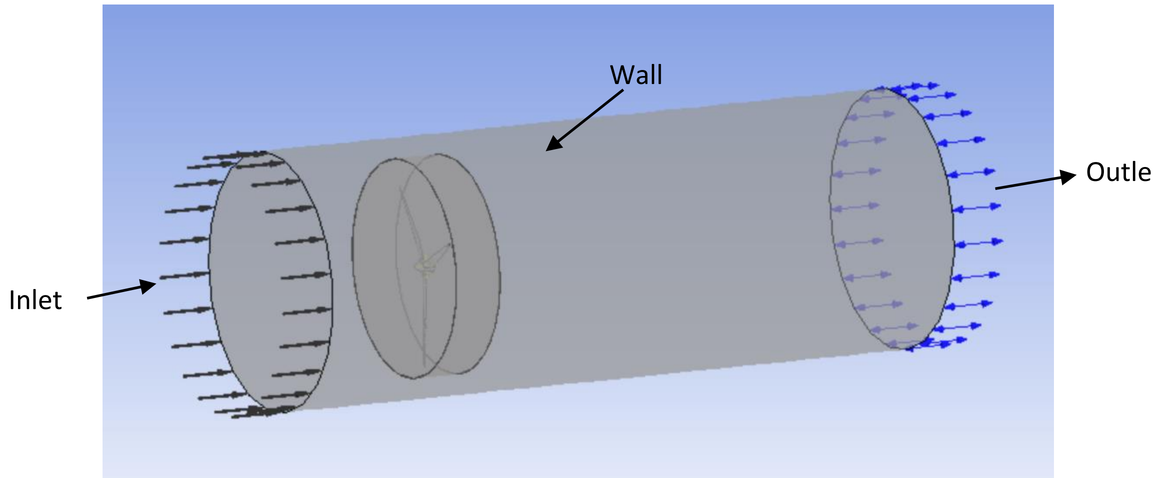

Fig. 7 Placement of boundaries

Fig. 8 shows the setting for inlet boundary. The "Normal Speed" uses the average wind speed in Pambotanjara Village, Waingapu, East Nusa Tenggara, and Fig. 9 shows the settings for rotating domains, where this domain will rotate together with the wind turbine and get the wind turbine's torque value. Angular Velocity uses 480 RPM as the value.

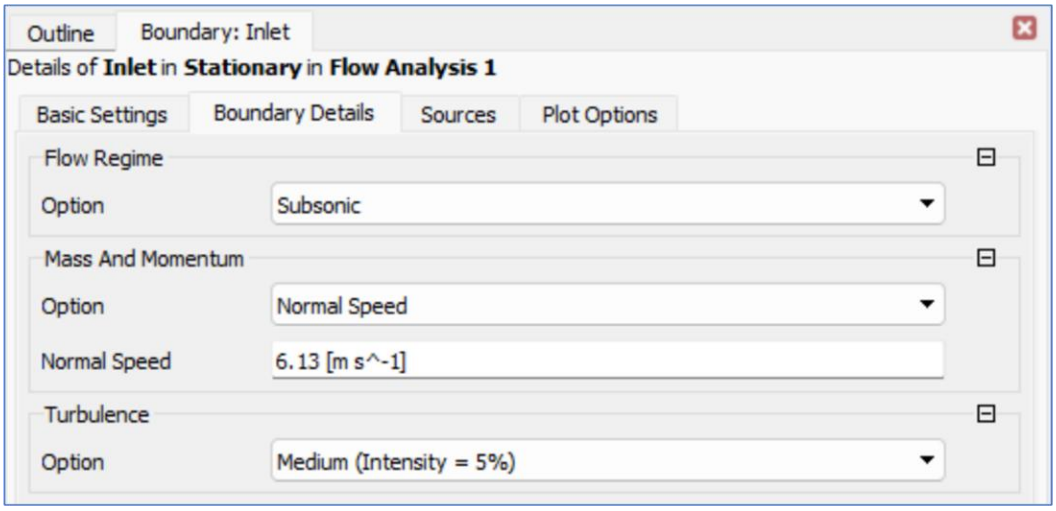

Fig. 8 Setting up for Inlet Boundary

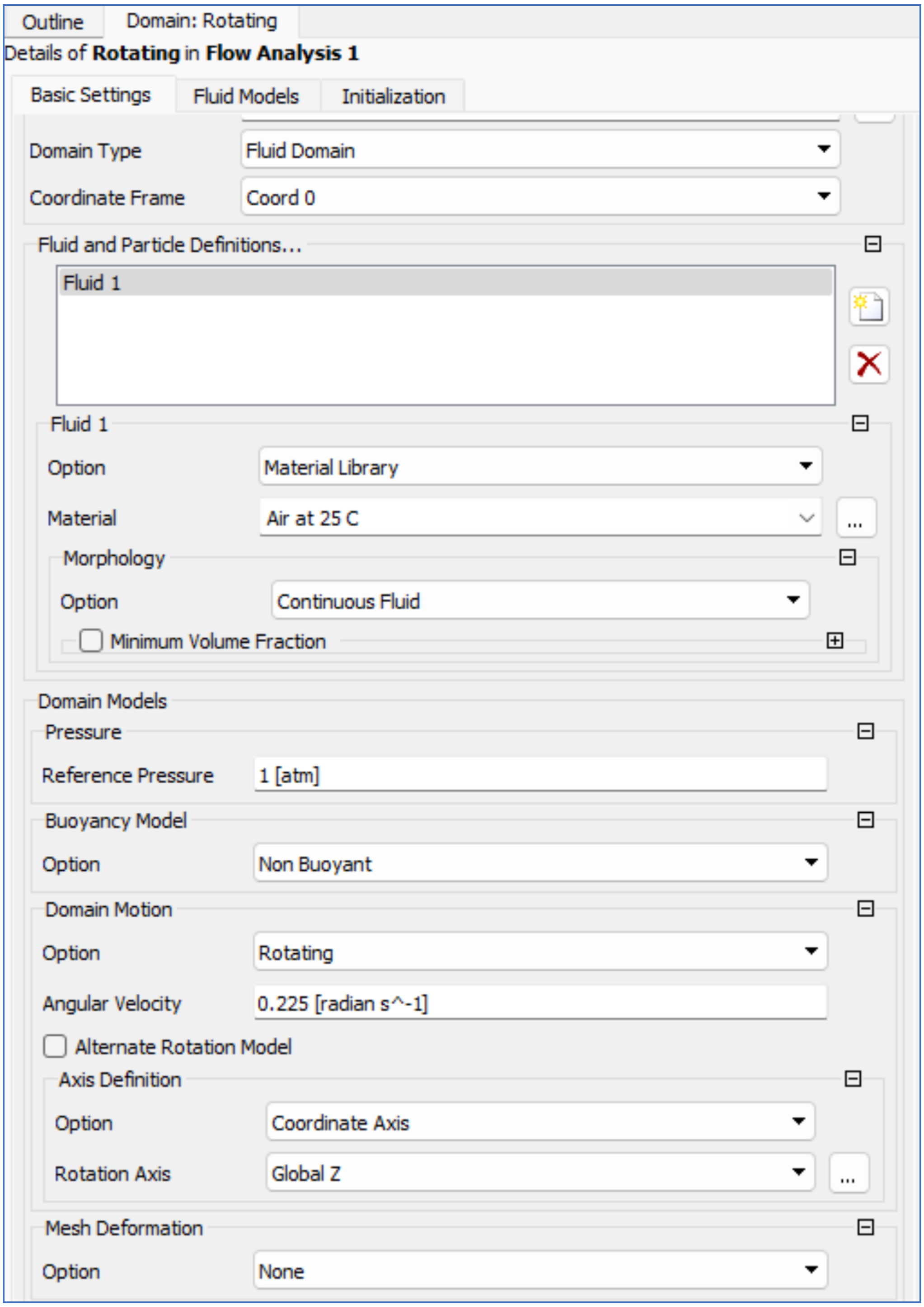

Fig. 9 Rotating Domain's Setting

Analysis Result

The CFD simulations are carried out to obtain torque values of the HAWT turbines. Fig. 10 shows the simulation result of torque of HAWT. The Horizontal Axis Wind Turbine has a torque value of 1150,2 J.

Table of Design Points						
	A	B	C	D	E	F
1	Name	P5 - Expression 1	P4 - TorqueZ	Retain	Retained Data	Note
2	Units	radian s^-1	J			
3	DP 0 (Current)	0,236	1150,2	☑	✓	
*				☐		

Fig. 10 Torque Value Result

The power output generated from wind turbines becomes a parameter in the construction of wind power plants. The wind turbine torque value obtained in previous simulations can be used to obtain the power output produced by the wind turbine. By using the following equation, the power output can be obtained.

Power [kW] = Torque [Nm] x Angular velocity [rad/s]

Therefore, the power output based on the simulation results are shown in Table 5 below

Table 5 Power Output Based on Simulation Result

Wind Speed [m/s]	**Power Output Result**
5.86	259.491 kW
6.13	271.447 kW

The above results are potential, which can change based on environmental conditions at the power plant, such as wind speed, technology applied to power plants, optimized turbine designs, and also the type of generator used. Considering the power coefficient for three-bladed rotor as it is shown in Fig. 11, we take 0.5 as the power coefficient. Therefore, by taking the lowest wind speed (5.86 m/s) the output power become 179.75 kW.

After finding the power from the wind turbine design analysis, it needs to simulate how many turbine units are needed to meet the needs of power generation of 10 MW, which is 10 MW / 179.75 kW. So that the number of wind turbine needed to generate 10 MW is 56 units.

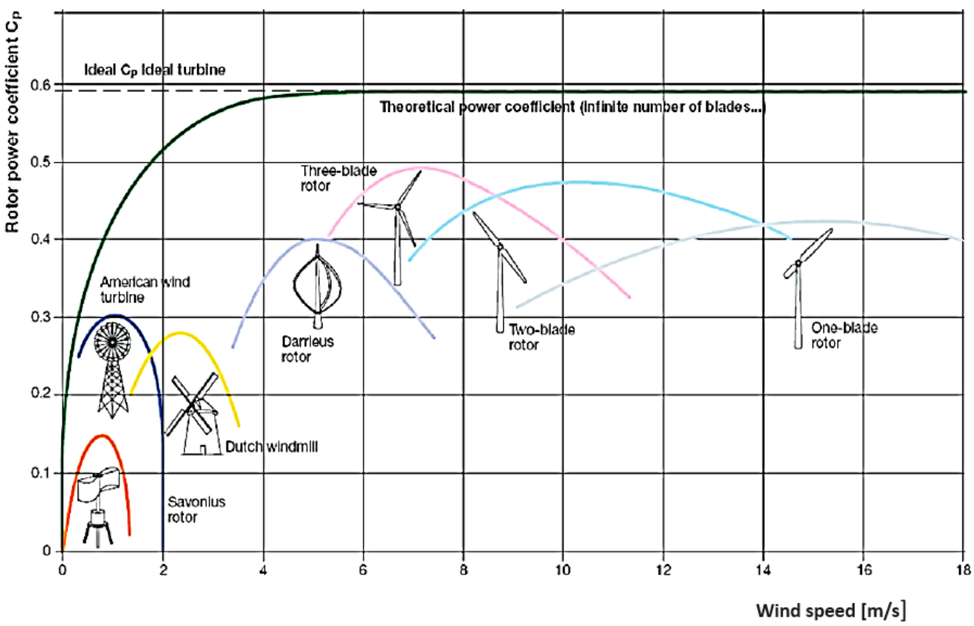

Fig.11 Power rotor coefficient of different types of rotor at different speed [11]

Conclusion

Based on the study, a Horizontal Axis Wind Turbine is a wind turbine that is suitable to be a component in wind power plants compared to a Vertical Axis Wind Turbine.

The results of CFD analysis shows that the wind turbine produce power of of 259.491 kW at a wind speed of 5.86 m/s and 271.447 kW at a wind speed of 6.13 m/s. Therefore, the number of wind turbines used in power plants 56 units HAWT to achieve the power capacity of 10 MW for the power plant in East Nusa Tenggara.

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