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Analytical Review of Material Criteria as Supporting Factors in Horizontal Axis Wind Turbines: Effect to Structural Responses

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Abstract

The potential of wind energy sources in Indonesia is quite large, with a potential of 60 GW. This fact shows that wind energy has great potential to be developed into a major energy source in Indonesia, especially in the development of wind energy power plants. The growth of wind energy power plants is in line with government regulations, where the government is targeting that in 2050 new renewable energy can supply national energy by 25%. This research, a literature review has been carried out on the supporting components of the turbine structure that affect wind turbine performance. The turbine performance is influenced by several things, including turbine materials, turbine rotors, and turbine structure. Turbine structures that need to be considered include generators, batteries, and gearboxes. Horizontal type wind turbines are recommended using washing machine motors and treadmill motors generators. Materials recommended for wind turbine components include Aluminum Alloy, natural Composite, Copper-Aluminum-Nickel, Copper-Zinc-Aluminum, and Nickel-Titanium. Then the factor of damage to the turbine installation in the coastal area is dominated by ship collisions. Some factors that must be considered are velocity, type of vessel, collision direction, and Collision angle.

Keywords: Wind turbine; HWAT; material; renewable energy

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1. Introduction

The government is targeting that in 2050 new renewable energy can supply national energy by 25%. Much research has been done to support the development of EBT in Indonesia, such as biofuels (Sartomo et al., 2020; Prabowoputra et al., 2020), hydro-energy (Prabowoputra et al., 2020), wind energy (Wicaksono et al., 2018), and the solar energy (Khuzaini et al. 2020). Most of the use of EBT in Indonesia is used for electricity generation, and most of it is used for the transportation, industrial and commercial sectors. In 2018, Indonesia had a power plant with a capacity of 64.5 GW. The condition increased by 7% from 2017. However, of the total capacity, only 14% coming from new energy sources was renewed in Fig. 1. Of the 14%, new energy renewed, consisting of 50% hydro-energy, 20% biomass, and 30% from energy other renewable new. On the other hand, the potential of wind energy sources in Indonesia is quite large, with a potential of 60 GW. Shows that wind energy has great potential to be developed into the primary energy source in Indonesia (Suharyati et al. 2019).

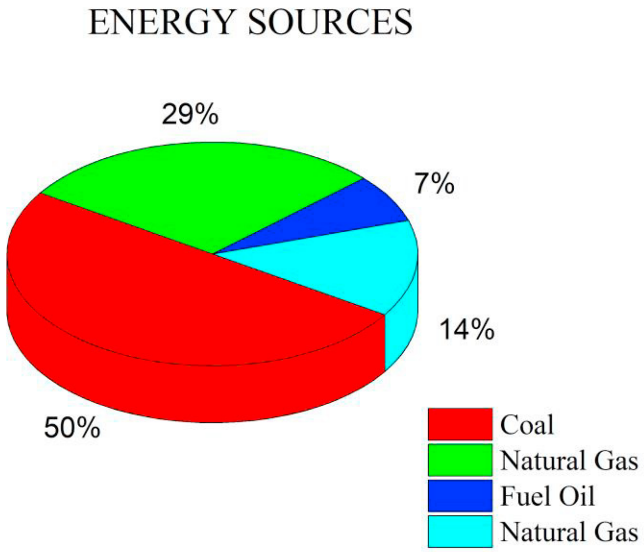

Fig. 1. Energy Sources (Suharyati et al., 2019).

One of the obstacles in developing EBT-based technology requires a relatively high cost. However, wind turbines are proven technology and are cheaper than some other power generation systems. The development of power plants sourced from the wind has done a lot. One of the developments carried out is researching the effect of rotor design on turbines (Prabowoputra et al., 2020). Modifications that have been made have the aim of improving the performance of the turbine. Rotor has several parameters that influence its performance. The design parameters have been tested both experimentally and in CFD simulations (Prabowoputra et al., 2020). Some aspects that have been tested are material type, number of blades, aspect ratio, overlap ratio, and blade shape (Nadhief et al., 2020). In addition to rotor geometry, many components affect turbine performance. This research, a literature review has been carried out on the supporting parts of the turbine structure that affect turbine performance.

2. Wind turbine

Wind turbines are turbines that convert wind energy into electrical energy, where wind energy is the kinetic energy of the airflow. The value of kinetic energy depends on the density of air and air velocity. Available wind energy is shown in equation 1.

$$\dot{w}_{available} = \frac{d(mV^2/2)}{dt} = \frac{\rho A V^3}{2} \tag{1}$$

where ρ is the air density, A is the swept area, and V is the velocity (Zhao et al., 2019).

Wind turbines generally consist of two types, namely Horizontal Axis and Vertical Axis. Fig. 2 shows the distribution of types of wind turbines and Fig. 3 shows the Performances of the main conventional wind machines. Horizontal axis wind turbine (HAWT) is a turbine that rotates on the horizontal axis and parallels the direction of airflow. The Vertical Axis Wind Turbine (VAWT) is a turbine that rotates in a vertical direction and is perpendicular to the direction of the airflow (Zhao et al., 2019). HAWT has a higher efficiency than VAWT (Cengel and Cimbala, 2017). HAWT has several advantages over VAWT is (Zhao et al., 2019):

- HAWT is the most stable wind turbine design to be applied
- HAWT can operate at relatively lower cut-in wind velocity and result in higher energy conversion efficiency.
- HAWT has excellent performance at fluctuating wind velocity, due to better attack angle control.

HAWT has disadvantages, among others (Zhao et al., 2019):

- HAWTs require yaw drives to turn the turbine toward the oncoming wind.
- More substantial structural support is needed for massive generators and gearboxes.
- Installation and maintenance costs are higher because of the taller tower height.

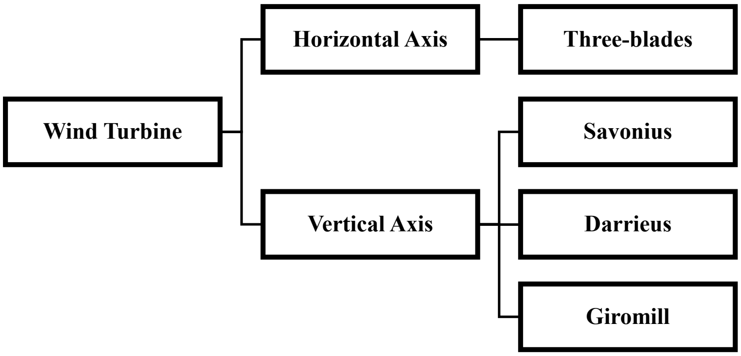

Fig. 2. Classification of Wind Turbine (Zhao et al., 2019).

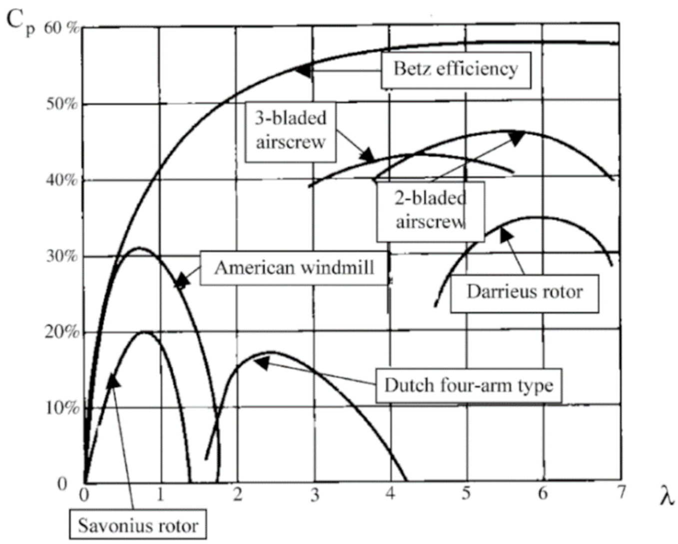

Fig. 3. Performances of primary conventional wind machines (Menet, 2004).

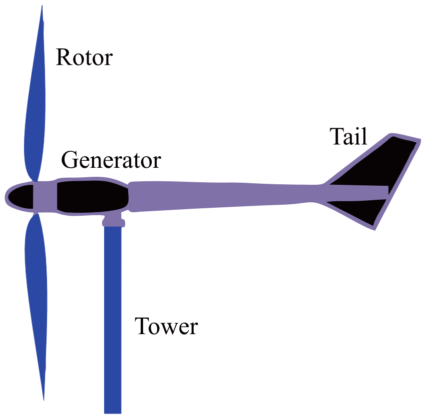

Fig. 4. Drawing of a small wind machine showing the basic components (Clark, 2014).

The turbine performance is influenced by several things, including turbine material, turbine rotor, and turbine structure. Turbine structures that need to be considered include generators, batteries, and gearboxes. Horizontal Axis Wind Turbine structure is shown in Fig. 4.

3. Supporting factors in wind turbines

Rodrigo et al. have conducted research that produced recommendations for the set of guidelines for the construction of wind turbines. A generator is one of the main components in electricity generation using a wind turbine. Four types of generators have been tested, namely washing machine motors, treadmill motors, centrifuge motors, and car alternators. Washing machine motors have the best performance, and this is shown in Fig. 5. The picture shows that the washing machine motor can achieve maximum power with a smaller RPM compared to other types of generators (Rodrigues et al., 2016). The result of the comparison between the RPM and the power generated is the recommendation of using a washing machine motor and treadmill motor for HAWH while the centrifuge motor and car alternator for VAWH.

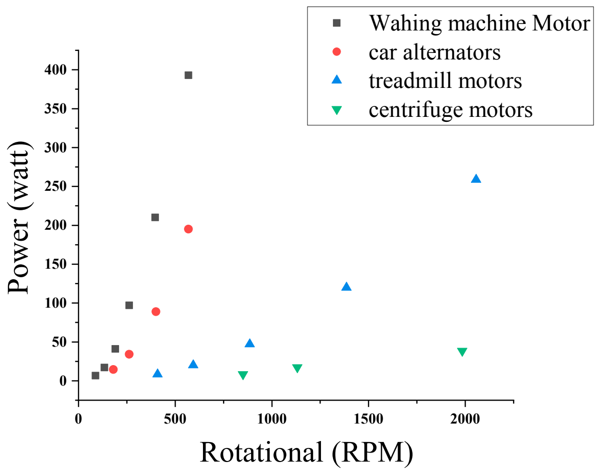

Fig. 5. Power output vs. RPM for the tested generators (Rodrigues et al., 2016).

Pradeep et al. stated that the turbine building material must have excellent mechanical properties but be environmentally friendly. Research has been grouping four types of composite materials that are good for turbine materials, including natural composites, hybrid composites, thermoplastic composites, and nanocomposites (Pradeep et al., 2019; Thomasa and Ma, 2018). Natural composites have the advantage of having excellent mechanical properties, low cost, environmentally friendly, and the major disadvantage is moisture absorption. Composite hybrids have the advantage of producing static tensile loads and good fatigue. The difficulty of hybrid composite materials is that they cause the mechanical properties of high carbon fibers to become simple composite properties. Then the advantage of Thermoplastic composites is that it has stiffness and high strength. Nanomaterial has the same advantages as Thermoplastic composites, which has stiffness and high strength (Pradeep et al. 2019). These materials are environmentally friendly, so materials like natural bio-composite materials and thermoplastics are useful for making wind turbine blades (Thomasa and Ma, 2018).

Okokpujie et al. (2020) conducted a quantitative study to find out good material for wind turbine blades. A numerical approach does justification of quantitative analysis. Criteria used in material valuation include price, corrosion resistance, weight, and durability level. The assessment was carried out using a scale of 1-5, in this study conducted with variations in mild steel, Glass fiber, Stainless steel, Aluminum alloy (Okokpujie et al. 2020). This questionnaire was given to 130 materials science engineers. Where the resource persons come from the Aluminum roll mill company, Ajaokuta Steel Company Limited and Nigeria foundry limited. This research focus uses MCDM for selectable material for developing a horizontal wind turbine blade. The results of the study are shown in Figs. 6 and 7. Fig. 6 shows the comparison of durability, corrosion resistance, and density factors with the type of material. The result indicates that Mild Steel has the highest density value, Stainless Steel has the highest durability, and Aluminium Alloy has the highest corrosion resistance. Fig. 6 shows that SS has the highest price, and MS has the lowest price. Then in Fig. 7 shows a score chart of the combination of all factors and shows that AA has the highest score. Where in this study indicates that AA material is the right material for wind turbines (Okokpujie et al. 2020).

Fig. 6. The comparison type of material with Criteria (Okokpujie et al., 2020).

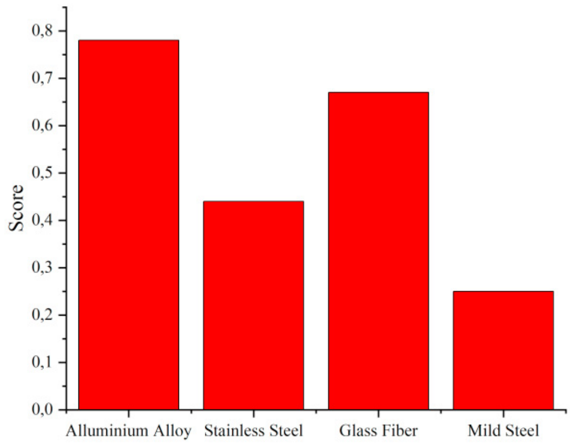

Fig. 7. The performance value analysis of alternatives materials (Okokpujie et al., 2020).

Research has been conducted a study comparing the properties of materials used as blade material in HAWT (Dathu and Hariharan, 2020). This research has been done to compare the effect of material on wind speed. The materials used are glass fiber, polyester, Copper-Aluminum-Nickel (Cu-Zn-Ai), Copper-Zinc-Aluminum (Cu-Ai-Ni), and Nickel-Titanium (Ni-Ti). Table 1 shows the properties of each material. Fig. 8 graph shows the correlation between Shear stress & Wind speed. The chart shows that polyester and glass fiber has experienced a large increase in shear stress along with increasing wind speed. This indicates that turbines are less stable compared to turbines with Cu-Zn-Ai, Cu-Ai-Ni, and Ni-Ti materials. A small increase in shear stress means more durable metal. Where the blade is rotating more stable can produce more power (Dathu and Hariharan, 2020).

Table 1. Property of the material (Dathu and Hariharan, 2020).

Material	Property	
	Critical Temperature	Density
Glass Fiber	110°-180°C	Approx 2.11 g/cc
Polyester	130 °C	Approx 1.38 g/cc
Cu-Zn-Ai	15°-25°C	Approx 7.12 g/cc
Cu-Ai-Ni	35°C	Approx 7.64 g/cc
Ni-Ti	30 °C	Approx 6.45 g/cc

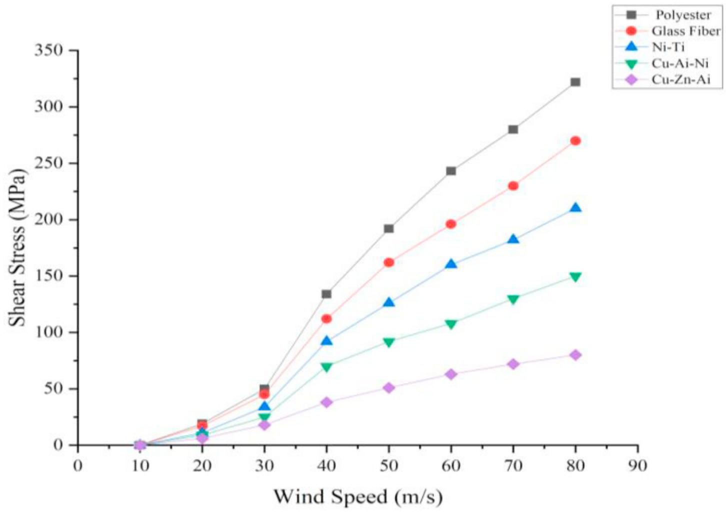

Fig. 8. Correlation between shear stress and wind speed (Dathu and Hariharan, 2020).

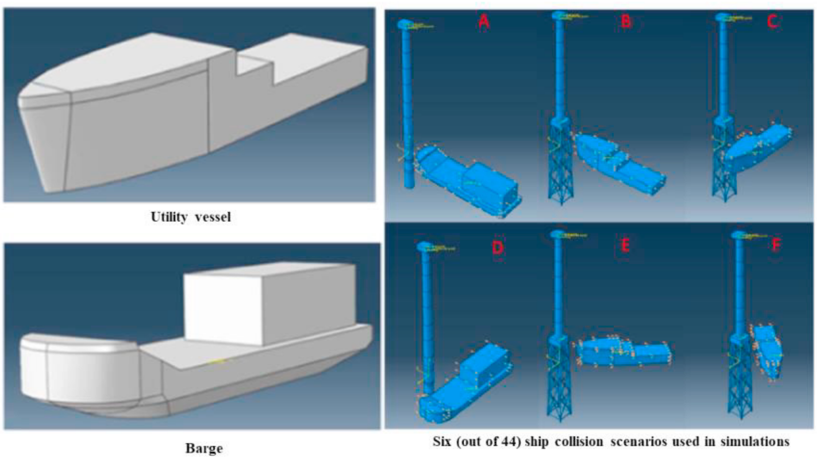

Fig. 9. Type of Ship and Scenario used in simulation (Moulas et al., 2017).

HAWT more widely applied in the area of the beach/sea than on the field because the wind in the sea is more stable than other regions. But the location at sea has several disadvantages. One of the disturbances to the installation of the sea is the ship's collision (see the variety of this phenomenon in Sèbe et al., 2020; Wu et al., 2019; Khan et al., 2020; Jia et al., 2020; Prabowo et al., 2016; 2017; 2018), so a collision-friendly foundation construction is needed (Moulas et al. 2017). Moulas et al. (2017) conducted a ship collision study using a turbine using two parts of collision analysis, namely Collision likelihood analysis and Collision damage analysis. Collision likelihood analysis is the possibility of a collision that depends on the type of collision, namely a powered collision or a flying collision. Subsequent analysis Collision damage analysis is an analysis of the magnitude of damage caused by collisions between ships and offshore wind structures, including tonnage, average speed, stiffness, structural properties of wind turbines, foundation, toughness, friability, etc. (Moulas et al. 2017).

Moulas et al. (2017) conducted a numerical test, in which the turbine foundation collision occurred on two types of ships shown in Fig. 9. The collision scenario between the ship and the foundation is shown in Fig. 9. The test is carried out in 24 scenarios, where the effect of the collision scenario is shown in Table 2. The table shows that in the Barge scenario, there is a more significant plastic deformation than in the utility. Table 3 shows the analysis of variance on factors, which shows that the greatest effect on plastic deformation is speed, and is followed by collision direction. The damage assessment of collisions between ships and offshore wind structures is an important area.

Table 2. the effect of the collision scenario (Moulas et al., 2017).

Scenario	**Type of vessel**	**Collision direction**	**Ship velocity (m/s)**	**Collision angle (°)**	**Plastic deformation**	**Failure**	**Rupture**
1	Utility	Head on bow	1	0	10	0	0
2	Utility	Head on bow	2	0	14	0	0
3	Utility	Head on bow	4	0	27	3	1
4	Barge	Head on bow	1	0	5	0	0
5	Barge	Head on bow	2	0	18	0	0
6	Barge	Head on bow	4	0	51	4	4
7	Utility	Sideway	1	0	8	0	0
8	Utility	Sideway	2	0	21	4	0
9	Utility	Sideway	4	0	49	2	6
10	Barge	Sideway	1	0	8	0	0
11	Barge	Sideway	2	0	21	4	0
12	Barge	Sideway	4	0	53	2	6
13	Utility	Head on bow	1	45	1	0	0
14	Utility	Head on bow	2	45	10	0	0
15	Utility	Head on bow	4	45	33	4	0
16	Barge	Head on bow	1	45	2	0	0
17	Barge	Head on bow	2	45	18	0	0
18	Barge	Head on bow	4	45	37	2	4
19	Utility	Sideway	1	45	5	0	0
20	Utility	Sideway	2	45	23	0	0
21	Utility	Sideway	4	45	51	10	4
22	Barge	Sideway	1	45	6	0	0
23	Barge	Sideway	2	45	19	0	0
24	Barge	Sideway	4	45	38	3	4

Table 3. Analysis of variance on the selected factors.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F0
Velocity	5.594	2	2.797	10.57707
Type of vessel	24	1	24	0.090754
Collision direction	241	1	241	0.910059
Collision angle	74	1	74	0.277933

4. Conclusions

This research guides determining the materials and generators in making wind turbines. This study shows that the factors that need to be considered are the generator, turbine material, and turbine buffer structure. From the review, it was obtained to bring for horizontal type wind turbines using a generator washing machine motors and treadmill motors. Both types of generators have high efficiency. Excellent materials used for making wind turbines are Aluminum Alloy, natural Composite, Copper-Aluminum-Nickel, Copper-Zinc-Aluminum, and Nickel-Titanium. Several factors caused by ship collisions are affected by velocity, type of vessel, collision direction, and collision angle. Deploying calculation using the factorial design method, it is found that the factors that have significant influence are velocity and collision direction.

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