Numerical study of savonius wind turbines performance at Demak coastal area, Indonesia: a comparative study of savonius wind turbines without fin and with fin

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Abstract. The coastline of Demak city shows an increase in the need for electrical energy every year, in line with an increase in pond production. Currently, electricity needs are supplied from diesel generators. However, the use of diesel generators as electricity generators causes pond production costs to increase. On the other hand, the coastal location of Demak has wind potential, which can be used as a power plant. In this study, a numerical study was carried out using the savonius wind turbine as a power plant in the coastal area of Demak city. This research’s initial stage was to collect data on wind characteristics during the day and night conditions. Wind speed data are then used as input parameters in the numerical simulation using the ANSYS R.15 software. This study compares simulations between Savonius wind turbines without using fins and using fins for placement on the coast of Demak. The simulation results show that the wind speed on the coast of Demak ranges from 2 to 3.5 m/s. In these wind conditions, the savonius wind turbine with one fin has a power coefficient ($C_p$) better than without the fin. The relationship between wind speed and the electric power produced has been simulated and discussed in depth in this paper.

1. Introduction

Currently, pond farmers in the coastal city of Demak face obstacles related to electrical energy availability around the ponds. Besides functioning as lighting, electricity in the area is also used to support energy in the processing of pond products. Farmers complain about problems with the supply of electrical energy. If the pond farmers use a generator set, the fuel costs will become the operational costs, and the pond operational costs will be high. This problem needs to find a solution because pond cultivation has become a legacy of residents from generation to generation in the Coastal Coast of Demak city.

On the other hand, the coastal city of Demak has the potential for wind as a new energy source that can be used to generate electricity. The researchers have supported energy consumption to switch from non-renewable energy to renewable energy, such as waste to energy [1][2][3][4][5], turbine [6][7], and biofuel [8][9][10][11]. In this research, a numerical study has been carried out using the Savonius wind turbine as a power plant in the coastal area of Demak city.

Wind energy is an environmentally friendly renewable energy source [12]. Wind turbines are divided into two based on their axis: Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT). The savonius wind turbine included in the Vertical Axis Wind Turbine (VAWT) has...
good potential in meeting small-scale energy needs. This savonius wind turbine’s potential applications include home or building electricity needs (lights, air conditioning, space heating) and water pumping for irrigation. The savonius wind turbine itself has several advantages, including a compact design and low construction costs. Savonius wind turbines can also operate at low wind speeds with massive starting torque [13]. Savonius wind turbines can also receive wind from all directions and have good starting characteristics because they can rotate at low wind speeds.

The problems encountered in savonius wind turbines are efficiency and relatively low rotational speed [14]. Numerical investigations were carried out to improve the performance of savonius wind turbines. This refers to their relatively low efficiency compared to other turbine types [15]. Attempts to improve savonius wind turbines’ performance by modifying the design have been carried out both experimentally and numerically. Modifications to the S-type savonius design, such as fins on the turbine blades, can increase the Savonius wind turbine [6]. Fins can increase turbine $C_p$ by adding one fin to obtain the highest $C_p$. Some of these design modification experiments have succeeded in improving the performance of the savonius wind turbines.

This study compares the savonius wind turbine simulation without using fins and using one fin within the coastal city of Demak. The parameters used include wind speed as the input to the CFD simulation process. The wind speed used is 2-3.5 m/s. This study’s design parameters are the variation of fins that are used without fin and one fin. Each of these design variations has been analyzed, both in terms of performance and aerodynamic characteristics.

2. Research Method

In this study, a numerical study was carried out on utilizing the savonius wind turbine as a power plant in the coastal area of Demak, as shown in Fig. 1. The initial stage of this research was to collect wind characteristic data both at daytime and night conditions. The wind characteristics on the coast of Demak can be seen in Fig. 2. The savonius wind turbines installed in the ponds, to be precise in the village of Berahan Kulon, Demak city, have a cut-in speed of 2.0 m/s. Therefore, the wind speed of 2.0 m/s can only rotate to move the generator (Fig. 3). The average wind speed measurements within 12 hours for three consecutive days obtained 4596 data. Detailed data can be seen in Figure 2. These data are then used as input parameters in the numerical simulation using the ANSYS R.15 software. This study’s independent variable is the variation of fins’ addition to the blade, namely: no fin and one fin. Design details and variations of the fin can be seen in Fig. 4 and Fig. 5.

![Figure 1](image1.png)

**Figure 1.** The research location (coastal area of Demak, Jawa Tengah, Indonesia)

![Figure 2](image2.png)

**Figure 2.** The installation of the wind turbine in the coastal area of Demak
3. Result and Discussion

3.1 Modeling of the Savonius Wind Turbine Type S

The meshing process for modeling S-type savonius wind turbines uses triangular mesh. In the modeling domain, sizing is applied, as shown in Table 1. The sizing used in this study is included in the smooth setting category. The purpose of selecting the sizing is to obtain a more accurate simulation result and a smoother visual appearance. The amount of division in this sizing greatly determines the accuracy of the simulation results. The smooth meshing yields more accurate results but requires longer computation time. Face sizing is applied to modeling to make the mesh on the rotating domain and the blade tighter because these sections show the distribution of velocity and pressure visually. This study uses CFD by applying face sizing to produce meshes of different sizes in the rotating and stationary domains. The meshing results in this simulation are shown in Figure 6.

Table 1. Sizing modeling

| Sizing          | Value  |
|-----------------|--------|
| Relevance center | Fine   |
| Smoothing       | High   |
| Transition      | Slow   |
| Span angle center | Fine   |
The domain used in the savonius wind turbine modeling is divided into two parts, namely the rotating domain and static domain. The rotating domain consists of wind turbines and fluids affected by the rotating turbine conditions, while the static domain is a constant wind condition. In the rotating domain, a mesh motion is applied to model the turbine in a rotating state with variations in angular velocity according to the Tip Speed Ratio (TSR) used. The determination of the domain size is adjusted to the turbine’s rotor diameter, as shown in Figure 7. This study’s domain size is 7.6 m x 3.6 m x 4.25 m, and the rotating domain size is 1.35.

Figure 6. Meshing results of Savonius Wind Turbine Type S

Figure 7. Savonius wind turbine modeling domain
The boundary conditions applied in this modeling are divided into three parts, i.e., inlet, outlet, and wall. The inlet is the part where air enters through space. A constant velocity of 3.5 m/s is applied to the inlet, assuming the inlet wind speed. At the boundary outlet, a relative static pressure of 0 Pa was applied, while the boundary wall on the blade was applied with a no-slip wall. The determination of the turbulence method used in this savonius wind turbine modeling is to look for the \( C_p \) data of several turbulence models in the one fin addition variation that is closest to the \( C_p \) data on the baseline (experiment). Some of these turbulence models are set on boundary conditions and uniform settings with the settings, as shown in Table 2. The results of the computation of variations in the turbulence modeling used are shown in Table 3.

Table 2. The connection settings of the savonius wind turbine modeling domain

| Angular velocity | 6.54 m/s |
|------------------|----------|
| Wind velocity    | 4.5 m/s  |
| TSR (\( \lambda \)) | 0.8 |
| Time step size   | 0.001    |
| Number of time steps | 2 |
| Number of literacy/time step | 2000 |
| Residual criteria | \( 10^{-5} \) |

Table 3. Comparison of the results of several turbulence models

| Turbulence Model   | \( C_p \) (power coefficient) |
|--------------------|--------------------------------|
| Baseline (experiment) | 0,181                      |
| k-epsilon standard | 0,221                      |
| k-epsilon RNG      | 0,228                      |
| k-epsilon realizable | 0,233                    |
| k-omega standard   | 0,218                      |
| k-omega SST        | 0,222                      |

Based on the data above, the results show that the standard k-omega modeling, which has a power coefficient (\( C_p \)), is closest to the baseline (experimental). However, this modeling takes a relatively longer computation time. Considering the computation time, yield resistance, and the resulting power coefficient (\( C_p \)), close to the experimental baseline, the standard k-epsilon turbulence model was chosen. The results’ resistance referred to here results from the \( C_p \) value consistent with the other TSR variations. The turbulence model choice depends on several factors, such as airflow characteristics, the accuracy of the results, computational resources (related to the computer hardware used), and the time available for the simulation process [16]. The standard k-epsilon turbulence model is a semi-empirical model with robustness and accuracy of results over a large turbulence flow area.

3.2 Model Validation

Validation of the savonius wind turbine modeling was carried out by simulating the variation in the addition of 1 fin in the TSR range 0.4 to 0.8 with a wind speed of 4.5 m/s. The results obtained are then compared with the baseline (experiment) that has been carried out by Pamungkas et al., 2018 [6], as shown in Figure 8. In comparing the results of the power coefficient (\( C_p \)) obtained by CFD and experiments, in the data above, the power coefficient (\( C_p \)) value of CFD results is greater than the experiment. This result is because the experimental power coefficient (\( C_p \)) results are reduced by installing a generator device on the savonius wind turbine. Meanwhile, the modeling of this savonius wind turbine ignores this efficiency. The slight difference between CFD modeling and experimental results makes this validation appropriate.
3.3 Speed distribution on turbine blades

The distribution of wind speed in the savonius without the addition of fins can be seen in Figure 9. Wind speed is inversely proportional to pressure. The higher the wind speed, the lower the air pressure in the turbine, and vice versa. The distribution of wind speed in the savonius without fins’ addition shows the maximum wind speed value of 8.998 m/s. This wind speed is seen hitting the sides of the endplate at the top and bottom of the turbine. Also, the wind speed that enters the turbine section gradually decreases its speed. The darker blue color indicates this. In this simulation, the wind speed in the environment outside the turbine section is around 3.5 m/s.

The savonius wind turbine with a variation of the addition of 1 fin shows the wind conditions in the environment around the fin have a greenish-blue color, which indicates a lower speed. The air environment in blue around the turbine in this variation shows a broader variation area without fins. The low speed will make wind pressure high. The maximum wind speed in this one fin addition variation is 9.44 m/s (Fig.10).
3.4 Pressure distribution on the blade

The pressure distribution in the variation without fins’ addition shows a maximum pressure of 92,050 Pa, shown in dark red (Figure 11). The blade’s inner side has the highest pressure, while on the outside, the pressure gradually decreases, it can be seen from the increasingly bright yellow color. This variation without the addition of fin has a drag coefficient ($C_d$) of 1.25. Seen from the top view, the concave part of the blade experiences high pressure, shown in red, while the convex part of the blade experiences low pressure is indicated by a mixture of dark blue and light blue. In the concave part, the pressure is dominated by red, namely the value of 67.50 - 92.050 Pa. The pressure is dominated by low pressure in the range of -6 to -6 values in the convex section, -37 Pa.

In the variation of 1 fin addition, the pressure on the turbine blade shows a maximum value of 92.014 m/s (Figure 12). In this variation, the blade’s inner pressure also shows a high value compared to the outside. The drag coefficient ($C_d$) for the variation in the addition of 1 fin shows a value of 1.65.
The concave area in this one fin variation is under high pressure, shown in red. Meanwhile, the convex area experiences low pressure with a predominance of dark blue. In the high-pressure concave area, it is in the range 72 - 92.014 Pa, while in the convex area dominated by low pressure, it is in the range of -46 Pa.

Figure 12. Pressure distribution on a savonius wind turbine with the addition of one fin

3.5 Comparative analysis of variations in the addition of fins in savonius wind turbines

The value of the power coefficient ($C_p$) between variations without adding and adding fins at a wind speed of 3.5 m/s and TSR ($\lambda$) 0.8 results from the CFD ANSYS R 15 simulation is shown in Fig. 13. The results showed that the $C_p$ value in the turbine savonius with the addition of 1 fin increases 0.03 for each 0.1 m/s increase in wind speed. Meanwhile, in the savonius turbine without a fin, the increase in $C_p$ ranges from 0.02 for each additional 0.1 m/s wind speed. These results indicate that the savonius wind turbine with the addition of 1 fin is better than without fins.

Figure 13. Effect of adding fins to the savonius wind turbine on the power coefficient
4. Conclusion
Based on the data obtained, it can be seen that the variation of adding one fin has better performance than without adding fins. This is shown in this model, obtained a power coefficient of 0.218. The pressure distribution in the variation of 1 fin in the blade concave area shows a relatively even pressure from the top to the bottom compared to the variation without fins. In variation one fin area, concave and convex have a significant pressure difference. The concave area, which has a red color with the highest pressure, is 92.014 Pa, and the convex area is shown in dark blue with the lowest pressure -46.145 Pa. The occurrence of negative pressure causes a pressure difference between the turbine’s concave and convex surfaces, which causes the turbine to rotate. The value of the Savonius wind turbine’s power coefficient from the numerical test increases by 0.3 for every 0.1 m/s increase in wind speed.

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