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Numerical Simulation of the Effect of Wind Velocity on the Diffuser Augmented Wind Turbines Performance

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Abstract

The study was conducted on GE 1.5 XLE wind turbine blades with a blade length of 4.32 m. This study uses a numerical simulation method with the help of ANSYS Workbench 19 software. Simulation is carried out at wind speeds of 3 m/s, 5 m/s, and 8 m/s. The DAWT (Diffuser Augmented Wind Turbines) research model uses the same wind turbine blade as a conventional wind turbine model which is the same GE 1.5 XLE model. The size of the diffuser added to the construction of the wind turbine is 9 m in addition to flanged on the side of the inlet and outlet diffuser. Based on numerical simulations carried out, for wind speeds of 3 m/s, the highest increase in DAWT performance is 115.6%. For wind speeds of 5 m/s, the highest increase in DAWT performance is 99.2%. For wind speeds of 7 m/s, the highest increase in DAWT performance is 91.8%. Based on the simulation results it can be said that the addition of diffuser in the construction of wind turbines will produce effective performance at wind speeds of 3 m/s. The increase in DAWT performance is relatively small on TSR 1-4, and some even experience a decrease in performance. So that it can be said that DAWT is not suggested to be operated on a low TSR, DAWT is recommended to operate above TSR 5.

***Keywords**: wind turbine, diffuser, GE 1.5 XLE model, DAWT, TSR*

1. INTRODUCTION

The consumption of energy in Indonesia in particular and in the world in general continue to increase due to population growth, economic growth and energy consumption patterns that are constantly increasing. Meanwhile, the availability of fossil energy which has been the main source of energy is depleting. When considering energy needs that continue to increase and the availability of fossil energy continues to dwindle, of course in the not too distant future there will be an energy crisis (4).

Efforts to find alternative energy sources other than fossil energy encourage researchers in various countries to look for other energy that we know today with the term renewable energy (8). Renewable energy can be defined as energy that can quickly be reproduced through natural processes. Wind energy is a renewable energy that is clean and free to use. Wind energy is a very flexible renewable energy source, because the use of wind can be done anywhere (4). Therefore, the potential of kinetic energy contained in wind must be maximized to produce electrical energy or other mechanical energy.

The application of wind energy technology in Indonesia is still quite low when compared to the available wind energy potential. The most widely used wind turbine models are horizontal axis wind turbine or HAWT and vertical axis wind turbine or VAWT. The cause of the underdevelopment of wind energy utilization in Indonesia is the relatively small wind speed which results in very expensive wind energy production costs (4). Based on the background above, it is necessary to develop a wind turbine model to improve the efficiency of the power produced.

One method of wind turbine research is numerical study of fluid flow. Fluid flow is used as a wind turbine mover. These studies are known as Computational Fluid Dynamic (CFD) (9). CFD is the study of ways to predict fluid flow, chemical reactions, heat transfer, and other phenomena by solving mathematical equations (mathematical models). The mathematical model contains partial differential equations that present laws of conservation of mass, momentum, and energy. Computers with high specifications are needed in analyzing fluid flow using CFD (9).

The concept of a diffuser augmented wind turbines or DAWT has been found more than a decade ago. Some DAWT concepts that have been created cannot compete in the market due to higher manufacturing costs than conventional wind turbine models. Research on DAWT continues to be developed to improve its performance so that it can offset its relatively high manufacturing costs (5). Diffuser is one of the enhancements in the wind turbine that is used to increase the power of the wind turbine by changing the pressure outside and inside the diffuser. The pressure inside the diffuser is lower than the outside pressure, so the wind speed will move into the diffuser, so that there is an increase in wind speed at the diffuser inlet. With increasing wind speed, the mass flow rate that passes through the wind turbine rotors will also increase, so that the power generated by the wind turbine rotor will also increase (6,7).

The general theory of disk actuators that have long been used for mathematical modeling of wind turbine performance is used to model DAWT with the addition of several empirical equations (3). The results of this modeling show closeness to the validation of other methods that have been used previously and also the results of CFD simulations. Study of the characteristics of a single type horizontal rotor wind turbine with diffuser addition have conducted to find the influence of diffuser in wind turbine construction. The study used experimental and simulation methods to determine performance improvements due to the addition of diffuser (1). The results showed an increase in wind turbine output power characteristics with the addition of a diffuser (DAWT). Wind speed rises to 1.7 times faster in the diffuser. The addition of a diffuser increases the power and energy curves that can be produced by wind turbines 2.4 times higher than conventional wind turbines. Diffuser is very useful if the wind direction is constant from one direction only.

Researcher tried to improve DAWT performance by adding a vortex generator to reduce pressure on the exit diffuser so that the incoming mass flow rate increases (7). The results of the research conducted show that the use of vortex generators in the diffuser can increase DAWT power by 9%. Shroud and flanged are added to DAWT to improve DAWT performance. Flanged on DAWT serves to accelerate the incoming wind through the diffuser by making a low pressure on the exit diffuser area so that the incoming air flow rate of the diffuser increases (1). Based on the tests carried out, it can be seen that the addition of shroud and flanged to the diffuser increases wind speeds from 1.6 to 2.4 times in the diffuser area. Some researchers also conducted a study to determine the aerodynamic interactions in DAWT with a multi-rotor system (MRS) (1). The study was conducted by testing the DAWT model in a wind tunnel. Fluid interaction at the DAWT gaps is the focus of observation in addition to improving the performance produced by the MRS system in DAWT. The results of the research that has been conducted show an increase in performance of 5% - 9% in the multi-rotor DAWT model of the single-rotor model. In the future, to find out the details of the aerodynamic phenomena that occur, research will be carried out using the CFD method to obtain complete visualization results (2).

In this study we will discuss the development of horizontal axis wind turbines namely Diffuser Augmented Wind Turbines (DAWT), where the wind turbine model is added with a diffuser to increase the air flow rate that passes through the rotor. The study was conducted using numerical simulation methods using ANSYS Fluent software. Simulations are carried out at low, medium, and high wind speeds to determine the increase in wind turbine performance with the addition of a diffuser.

2. METHODS

The study was conducted on GE 1.5 XLE wind turbine blades with a blade length of 4.32 m. This study uses a numerical simulation method with the help of ANSYS Workbench 19 software. Simulation is carried out at wind speeds of 3 m/s, 5 m/s, and 8 m/s. The research model is shown in Figure 1, in this study the object studied was only a wind turbine blade.

The DAWT research model uses the same wind turbine blade as a conventional wind turbine model which is the same GE 1.5 XLE model. The size of the diffuser added to the construction of the wind turbine is 9 m in addition to flanged on the side of the inlet and outlet diffuser.

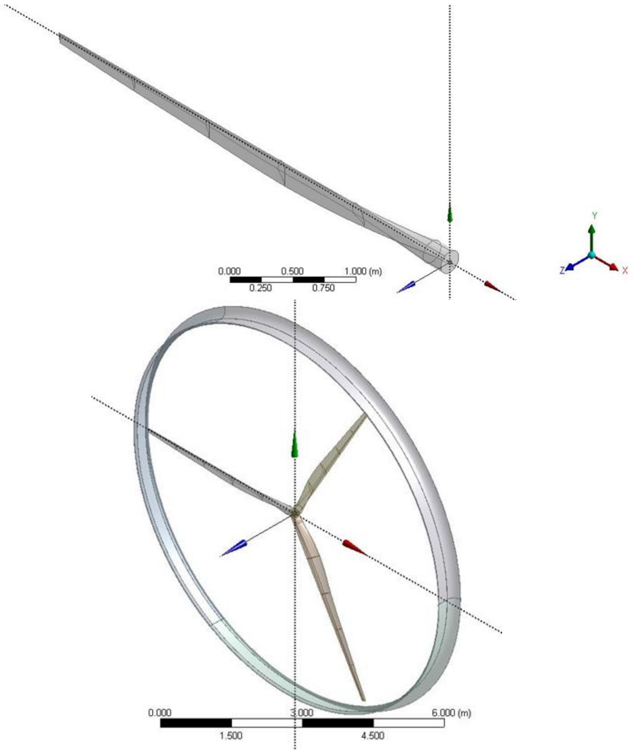

Figure 1. Research model

This simulation uses the multiple-rotating reference frame (MRF) method, with rotation data obtained from a predetermined TSR (Tip Speed Ratio). TSR values used in this study are TSR 1 to TSR 10.

3. Result and Discussion

3.1. Wind Turbines Rotor Torque

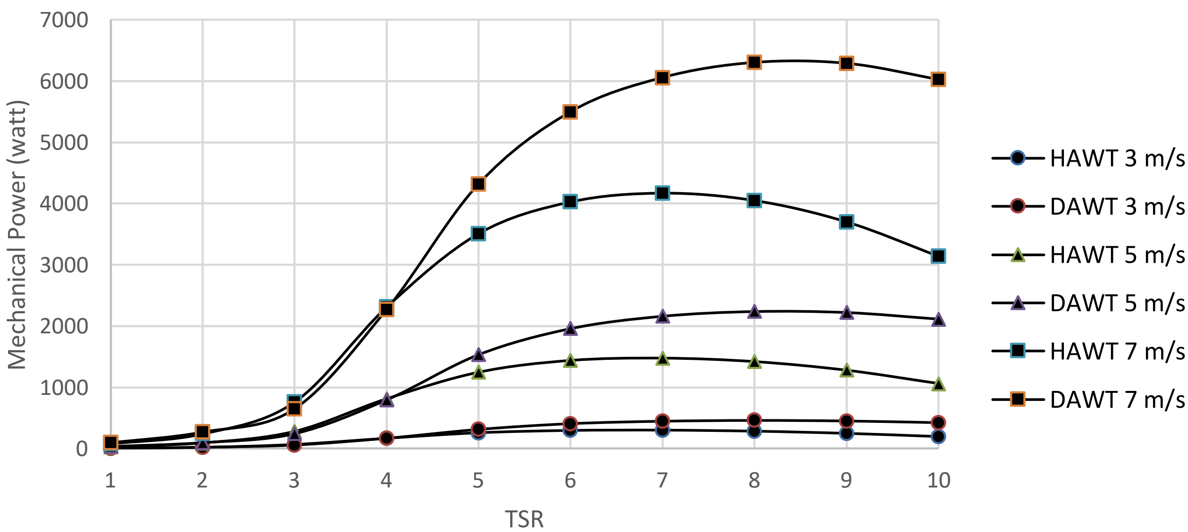

Figure 2. Wind Turbine Rotor Torque

Figure 2 shows the torque produced by wind turbine rotors on various simulated TSRs. For conventional wind turbine rotors (HAWT) produce the highest torque of 74.79 Nm on TSR 5. For the DAWT rotor produces the highest torque of 97.92 Nm on the TSR 6. From Figure 2, we can also see that DAWT in wind speed of 3 m/s will show an increase in torque if operated on a TSR higher than 5. If DAWT at a wind speed of 3 m/s is operated at a TSR below 5, then the DAWT does not provide increased performance and only adds production costs.

The torque produced by HAWT and DAWT models at wind speeds of 5 m/s can be seen in Figure 2 too. In TSR 1 to 4 the torque produced is relatively the same but in the TSR 5 - 10, the torque produced by the DAWT model is greater than the conventional wind turbine model. HAWT models begin to experience a decrease in torque on the TSR 6 while the DAWT model begin to experience a decrease in torque on TSR 7. Based on the simulation results it can be said that at wind speeds of 5 m/s, the addition of diffuser in wind turbine construction will provide additional performance on the TSR 5 and above. The addition of performance can be seen from the torque produced, where the torque produced by the DAWT model wind turbine is higher than conventional wind turbines at the same wind speed of 5 m/s. Although on the 7-10th TSR both wind turbine models both experienced a trend of decreasing torque, but the torque value produced by the DAWT model remained larger than HAWT models.

At wind speed of 7 m/s, the torque produced by HAWT and DAWT models have a different pattern, where in HAWT models, the highest torque is achieved on the TSR 5. While in the DAWT models, the highest torque is achieved on the TSR 6. Almost at all rotating speeds, DAWT produce more torque than HAWT models, only on TSR 3 and TSR 4 torque produced by DAWT model is slightly smaller than the torque produced by HAWT model. The highest torque that can be achieved by HAWT models at 7 m/s wind speed is 433.32 Nm in TSR 5. As for the DAWT model, the highest torque that can be achieved at 7 m/s wind speed is 565.47 Nm at TSR 6. On high TSRs, namely TSR 7 - TSR 10 both wind turbine models show a trend of decreasing torque value, however the torque produced by DAWT model remains higher when compared to conventional HAWT model.

3.2 Mechanical Power of Wind Turbine Rotor

Figure 3 shows the simulation results of MRF in the form of mechanical power, where the torque from the simulation results is multiplied by the angular velocity of the wind turbine rotor during simulation to obtain the value of the mechanical power of rotor. For HAWT generating mechanical power of 302.68 watts on TSR 7, while for DAWT models, maximum power at wind speed of 3 m/s is achieved at TSR 8 which is equal to 461.37 watts. Addition of diffuser on the wind turbines construction that operating at wind speed 3 m/s will provide a significant performance increase if the wind turbine operates on the TSR above 5. At low TSR DAWT performance is almost the same as HAWT performance, in Figure 2 it can also be seen that in TSR 3 the mechanical power produced by DAWT is lower than HAWT models.

The simulation results in the form of mechanical power of HAWT and DAWT models at wind speeds of 5 m/s can be seen in Figure 3 too. For HAWT models, the greatest mechanical power is achieved at a TSR 7 of 1478.9 watts. As for the DAWT model, the greatest mechanical power is achieved at the TSR 8 of 2240.2 watts. Based on Figure 3, it can be said that the addition of a diffuser in the construction of a wind turbine will provide additional performance in the form of an increase in mechanical power on a high TSR (TSR 5-10). At low TSR (under TSR 5), the addition of a diffuser on the construction of a wind turbine does not provide additional performance, and only increases production costs and construction costs. So it can be said that for wind speeds of 5 m/s, the addition of a diffuser in the construction of wind turbines operating at low TSR (under TSR 5) is not recommended because it does not increase the performance of the wind turbine itself.

For wind speed 7 m/s, DAWT model produces greater mechanical power compared to HAWT model at almost all simulated rotating speeds, except for TSR 3 and TSR 4. The smaller mechanical power of the DAWT wind turbine is due to the torque generated on the TSR 3 and TSR 4 which is also smaller compared to the torque produced by HAWT model on the same TSR. The highest mechanical power produced by HAWT model is 4171.12 watts on TSR 7. Meanwhile for DAWT model, the highest mechanical power is produced at TSR 8, which is 6301.17 watts. At low TSR (TSR 1-4), the mechanical power produced by both wind turbine models is almost the same. It can be concluded that for wind speeds of 7 m/s, the addition of a diffuser on a wind turbine or DAWT construction will be effectively operated at a rotating speed above TSR 4. For wind speeds of 7 m/s, it can be said that the addition of a diffuser in wind turbine construction will increase performance if the wind turbine is operated on a high TSR (above TSR 4).

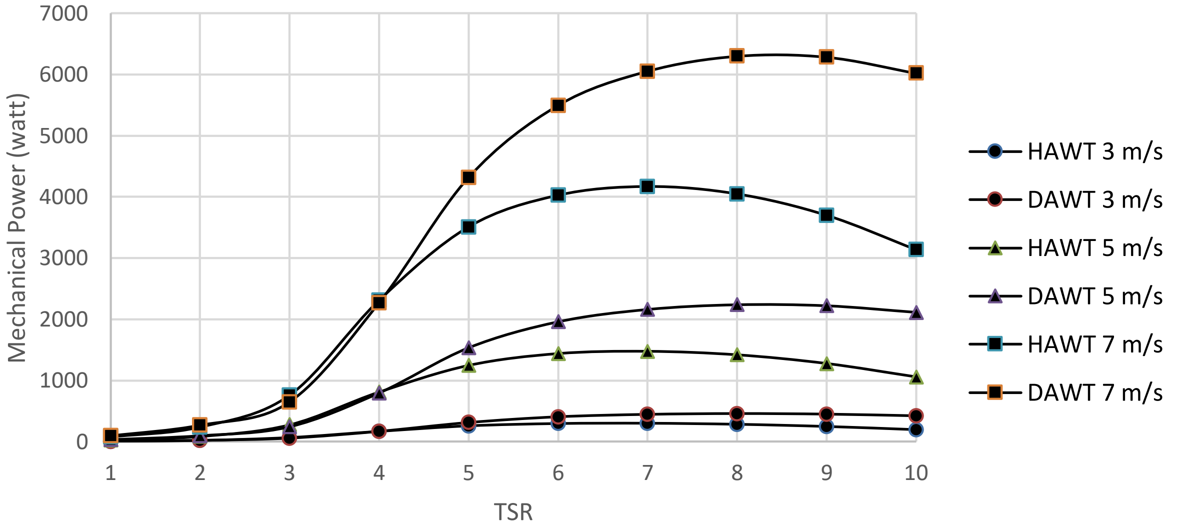

Figure 3. Mechanical Power of Wind Turbines Rotor

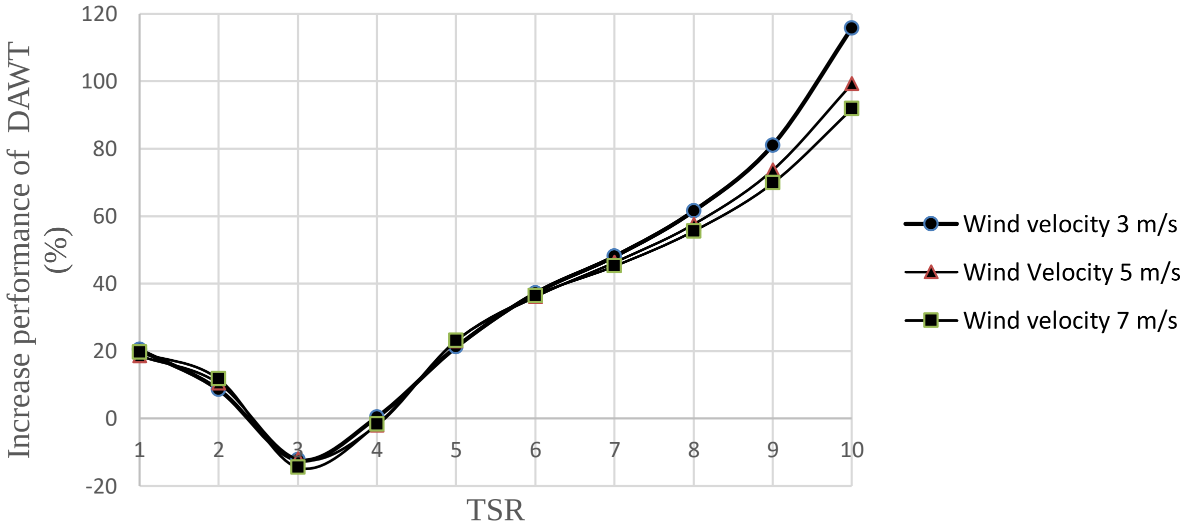

Figure 4. Increase Performance of DAWT

Figure 4 shows an increase in DAWT performance against HAWT model as seen from the percentage increase in mechanical power produced. At three simulated wind speeds there is a trend of almost the same performance increase. In TSR 1 - 3 the addition of a diffuser on the construction of wind turbines provides a decrease in performance, so it is not advisable to operate a DAWT model wind turbine on a TSR of 1 - 3. Even though the TSR 4 shows a trend in increasing the performance of DAWT wind turbines, but its performance is relatively small, which is around 1%. So that the operation of DAWT is also not recommended on TSR 4 because the increase in performance is not in accordance with production costs and operational costs. In the 5 - 7 TSR the increase in DAWT performance ranged from 21% - 48%, for the highest increase in performance obtained when DAWT operated at wind speeds of 3 m/s which was equal to 48.02%. In the TSR 8 the performance improvements achieved were 61.48%, 57.56%, and 55.57% for wind speeds of 3 m/s, 5 m/s and 7 m/s. For wind speeds of 3 m/s, 5 m/s and 7 m/s, the increase in performance achieved by DAWT on TSR 9 was 81%, 73.65%

and 69.81%. In TSR 10, the increase in performance achieved by DAWT is 115.6%, 99.2% and 91.8% for wind speeds of 3 m/s, 5 m/s and 7 m/s.

4. CONCLUSION

Based on numerical simulations carried out, it can be concluded that: HAWT model will get increased performance when adding a diffuser to the construction. This increase in performance occurs because of the function of the diffuser which increases the mass flow rate that flows inside. For wind speeds of 3 m/s, the highest increase in DAWT performance is 115.6% on TSR 10. For wind speeds of 5 m/s, the highest increase in DAWT performance is 99.2% on TSR 10. For wind speeds of 7 m/s, the highest increase in DAWT performance is 91.8% on TSR 10. Based on the simulation results it can be said that the addition of diffuser in the construction of wind turbines will produce effective performance at wind speeds of 3 m/s. on TSR 1 - 4, the increase in DAWT performance is relatively small, and some even experience a decrease in performance. So that it can be said that DAWT is not suggested to be operated at a low TSR, DAWT is recommended to operate above TSR 5.

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