EXPERIMENTAL STUDY OF VERTICAL AXIS WIND TURBINE WITH PRE-SWIRL AUGMENTED

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ABSTRACT: The paper presents an experimental investigation on a vertical axis wind turbine that utilizes pre-swirl augmentation through a concentric stator and rotor system. The study's main objective is to demonstrate that incorporating a stator as a guide blade can significantly enhance the turbine's performance. The rotor is positioned in the inner region of the turbine and is rotated by the flow induced by the stator surrounding it in the outer region. The stator accelerates the incoming wind before it reaches the rotor. The turbine has five rotor blades and has been tested with stator guide blades varying from zero to six and twelve. Both the guide rotor and blades use a modified cp-100-050-gn cambered plate airfoil. The tests were conducted at an average wind speed of 4 m/s. The results indicate that utilizing a stator with six guide blades leads to a 52% increase in the power coefficient, while a stator with 12 guide blades yields a slightly higher increase of 58%. Moreover, the turbine with a stator comprising 12 guide blades takes less time to attain maximum speed under no-load conditions than the one with a stator with six guide blades.

KEY WORDS: Vertical axis wind turbine, pre-swirl augmented, cambered plate airfoil, power coefficient, starting capability.

1. INTRODUCTION

Wind power is an essential renewable energy source that can significantly reduce greenhouse gas emissions and provide sustainable power for future generations. The technology of wind turbines has undergone significant development over the past few decades, and researchers are continuously exploring innovative ways to improve wind turbine performance [1].

In Indonesia, the government aims to increase the use of new and renewable energy sources to at least 23% by 2025 and 31% by 2050, per the National Energy Policy under PP No. 79 of 2014. Wind energy is one of the potential sources, with areas like Sukabumi, Garut, Lebak, Pandeglang, and Lombok identified as having considerable wind energy potential [2].

One approach to harnessing wind energy is through Vertical Axis Wind Turbines (VAWT) with augmented pre-swirl, which uses fixed stator blades to accelerate fluid flow into the rotor blade arrangement connected to the generator. This concept was initially introduced by Dr. Gecheng Zha and patented in 2011 [3]. The geometric formation of the pre-swirl stator and rotor blades aims to provide greater efficiency than that of conventional VAWTs. Further research has been conducted to optimize VAWT designs using pre-swirl stators, such as the study by Sullivan, who varied the pre-swirl stator's angular orientation and used principles of fluid mechanics and computational analysis [4]. The optimized VAWT design achieved a 57.15% output power and efficiency increase, outperforming similar-sized wind turbines.

Another study in 2020 examined the Savonius-Darrieus turbine combination, where the Savonius wind turbine serves as the starting device [5]. While the combination increased self-starting by 60%, the power obtained was lower than the Darrieus turbine without the combination. These studies demonstrate ongoing efforts to improve VAWT performance, mainly through pre-swirl stators and turbine combinations, which align with Indonesia's renewable energy targets.

VAWTs suffer from lower aerodynamic efficiency compared to Horizontal Axis Wind Turbines (HAWT), which has led researchers to explore ways to improve their power output. Studies have investigated the effects of various design parameters such as airfoil profile [6], Gurney flap [7], pitch angle [8], aspect ratio [9], and solidity [10] on VAWT performance in order to determine optimal parameters that enhance power generation. Flow augmentation devices like deflectors, diffusers, and guide vanes have also been employed to improve VAWT efficiency [11]. One promising approach to address these issues is to use pre-swirl augmentation techniques [12-14]. Pre-swirl augmentation involves introducing a swirl component to the incoming wind flow before it enters the turbine blades.

Vertical axis wind turbines (VAWTs) are a type of wind turbine that can operate effectively in low wind speed conditions and have the potential to be more efficient than traditional horizontal axis wind turbines (HAWTs). However, VAWTs still face some significant challenges, such as low power coefficient and poor starting ability, which limit their effectiveness [15]. The study's main objective is to examine incorporating a stator as a guide blade on the turbine's performance by modified rotor blades using cp-100-050-gn cambered plate airfoil.

2. METHOD

The wind turbine is positioned in front of a fan in an open space to serve as a wind energy source, and the turbine rotor is rotated during the experiments. Data is collected through various instruments, including a tachometer to measure the turbine's rotation, a spring balance to measure loading force, and an anemometer to measure wind speed. The testing setup is illustrated in Figure 1.

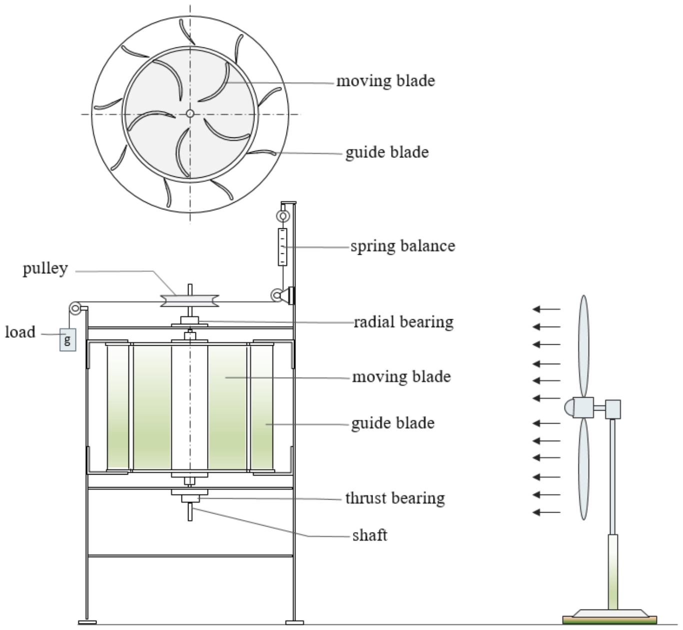

Fig. 1. VAWT experimental setup

The rotor diameter and height of a vertical axis wind turbine can be determined using the following equation based on the desired power output, wind speed, and turbine power coefficient:

$$P_T = 0.5\, CP\, \rho_a\, A_T\, v_a^3 \quad (1)$$

where: P_T = Power (W), CP = Power coefficient, ρ_a = Air density (kg/m^3), A_T = Wind sweep area (m^2), v_a = Wind velocity (m/s).

Tip Speed Ratio (TSR) is a dimensionless parameter used to characterize a wind turbine's performance. It is defined as the ratio of the speed of the tip of the rotor blade to the speed of the wind. Mathematically, it is given by:

$$TSR = (Tip\ Speed)/(Wind\ Speed) \quad (2)$$

The rotor moving blades and stator guide blades of the vertical axis wind turbine are designed using cambered plate airfoils, which are easy to fabricate or manufacture. The cross-section of the cp-100-050-gn model (shown in Figure 2) is modeled using various parameters. For instance, the pipe wall thickness is set to 8% of the radius, the leading edge (LE) is semicircular, the camber is based on the top surface (outer radius of the pipe), the trailing edge (TE) is sharp and cut at the bottom of the airfoil until it meets the bottom surface of the tangent, and the top surface is used as a datum and passes through the points (0,0) and (1,0). Although it needs to be correctly normalized, marking the shape on the pipe surface is more practical.

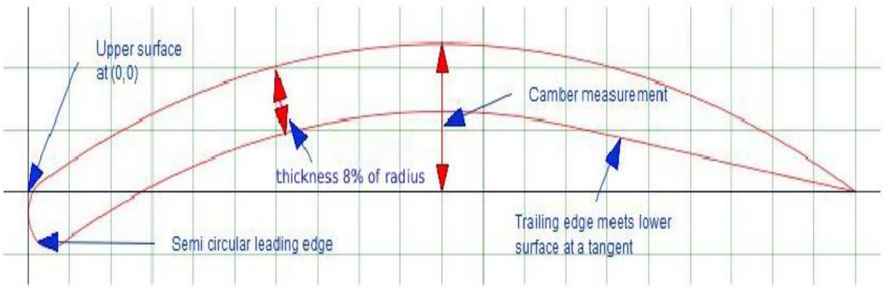

Fig. 2. Curved plate airfoil profile

The stator height is set equal to the rotor height, which is 0.352 mm with an inner and outer diameter of 0.340 m and 0.460 m, respectively. The moving blade and the stator guide blade have curved airfoil profiles modified cp 160-050-gn data as presented in Table 1. The tests involved varying the number of stator (guide) blades from 0, 6, and 12 at a wind speed of 4 m/s.

Table 1: Blade parameters

Parameter	Moving blade	Stator blade
Outer radius (m)	0.100	0.100
Chord length (m)	0.120	0.060
Thickness of blade (m)	0.008	0.008
Number of blades	5	0, 6, 12
Blade orientation (^{O})	15	15

3. RESULTS AND DISCUSSION

The test results obtained for turbines with a wind velocity of 4 m/s are presented in Table 2 - 4 for the number of stator (guide) blades of 0, 6 and 12, respectively.

Table 2: Wind turbine testing with number of stator blades of 0

No.	Rotation (rpm)	Load (kg)	Torque (Nm)	*TSR*	P_T (W)	*CP*
1	108	0	0,000	0,1838	0,0000	0,0000
2	85	0,022	0,0071	0,1446	0,0635	0,0147
3	55	0,043	0,0104	0,0936	0,0598	0,0138
4	33	0,065	0,0143	0,0562	0,0493	0,0114
5	0	0,086	0,0194	0,0000	0,0000	0,0000

Table 3: Wind turbine testing with number of stator blades of 6

No.	Rotation (rpm)	Load (kg)	Torque (Nm)	*TSR*	P_T (W)	*CP*
1	124	0	0,0000	0,2110	0,0000	0,000
2	90	0,022	0,0097	0,1532	0,0918	0,021
3	75	0,043	0,0123	0,1276	0,0968	0,022
4	56	0,065	0,0162	0,0953	0,0951	0,022
5	36	0,086	0,0188	0,0613	0,0709	0,016
6	0	0,108	0,0259	0,000	0,0000	0,000

Table 4: Wind turbine testing with number of stator blades of 12

No.	Rotation (rpm)	Load (kg)	Torque (Nm)	*TSR*	P_T (W)	*CP*
1	142	0	0,0000	0,2416	0,0000	0,0000
2	121	0,022	0,0078	0,2059	0,0987	0,0228
3	104	0,043	0,0130	0,1770	0,1413	0,0327
4	83	0,065	0,0175	0,1412	0,1522	0,0352
5	48	0,086	0,0227	0,0817	0,1141	0,0264
6	0	0,108	0,0311	0,0000	0,0000	0,0000

The effect of the number of stator blades (nsb) on the torque and turbine rotation presented in Figure 3 shows that as the number of stator blades increased from 0 to 12, the torque and rotation speed also increased; this can be attributed to the fact that the stator blades help to guide the incoming wind to the rotor blades more effectively, increasing the amount of torque generated.

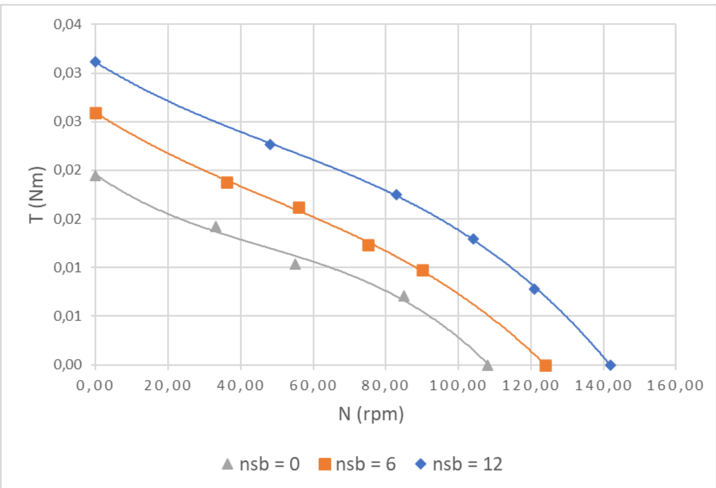

Fig. 3. Effect of the number of stator blades (nsb) on the torque at various speeds

It is also observed that the maximum torque and rotation speed were obtained at 12 stator blades with a value of 0.0311 Nm and a maximum rotation speed of 142 rpm. The torque and rotation speed obtained at 6 stator blades were higher than those obtained at 0 stator blades, indicating that even a small number of stator blades can improve the performance of the wind turbine. The highest torque and rotation speed was obtained with 12 stator blades, suggesting the fact that the stator blades help to guide and direct the wind towards the rotor blades, increasing the amount of energy extracted from the wind. Additionally, using cambered plate airfoils for both the rotor and stator blades may also contribute to the increased performance of the VAWT, as these airfoils are designed to provide high lift and low drag.

The results of the analysis show that the number of stator blades has a significant impact on the power coefficient of the wind turbine (Figure 4). The power coefficient also increases as the number of stator blades increases from 0 to 12 because the stator blades help improve the turbine's efficiency by directing the flow of air toward the rotor blades.

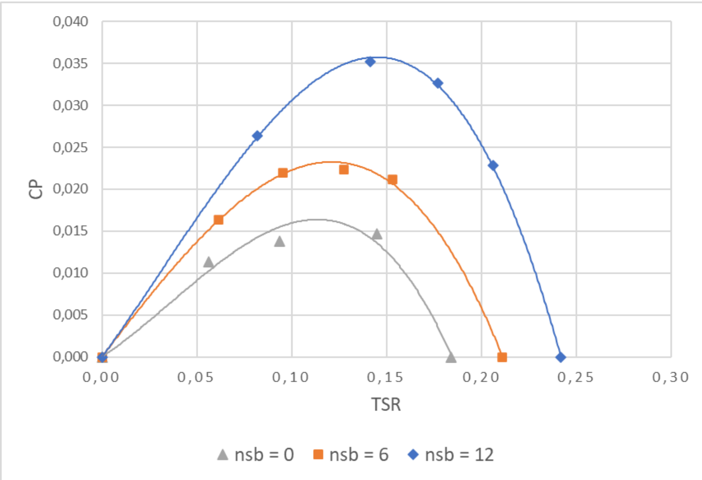

Fig. 4. Effect of the number of stator blades (nsb) on the power coefficient of the turbine at various tip speed ratios (*TSR*)

The highest power coefficient value is obtained at the number of stator blades 12, which indicates that this configuration is the most efficient among the tested variations. This result is consistent with the torque-speed curve, where the highest torque value was obtained at the same configuration. The results also show that the optimal Tip Speed Ratio (*TSR*) value, which corresponds to the maximum power coefficient, is around 0.14 for all stator blade configurations; this indicates that the rotor blades are operating at their most efficient point when the rotation speed is around 14% of the wind speed.

Figure 5 depicts the effect of several stator blades on the Tip Speed Ratio (*TSR*) and turbine power. At a wind speed of 4 m/s, the highest P_T value was obtained at the number of stator blades 12, which had a P_T value of 0.1522 W with a *TSR* value of 0.1412.

With a low TSR value, the rotor blades rotate slowly, and the turbine cannot harness enough energy from the wind. On the other hand, at high TSR values, the rotor blades rotate too fast, leading to aerodynamic inefficiencies and structural limitations. The turbine with 12 stator blades produces the highest power output compared to turbines with 6 or 0 stator blades because the stator blades guide the wind flow towards the rotor blades, and a higher number of stator blades leads to better wind flow guidance and improved power output. Tip Speed Ratio (TSR) and power are critical factors in the design of wind turbines. TSR is the ratio of the rotor blade tips' speed to the wind's speed. In other words, it is the ratio between the tangential velocity of the blade tips and the incoming wind velocity. A higher TSR means that the blade tips are moving faster than the wind, which can lead to higher efficiency and power production. However, if the *TSR* is too high, the blades may stall and produce less power.

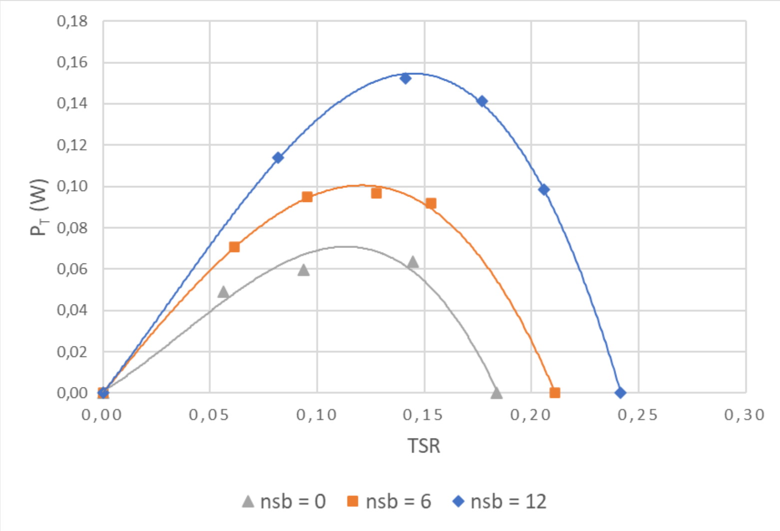

Fig. 5. Effect of the number of stator blades (nsb) on the turbine power output (P_T) at various tip speed ratios (*TSR*)

Figure 6 demonstrates the relationship between turbine power (P_T) and rotation at various stator blade numbers. The findings suggest that increasing the stator blades can boost the turbine's maximum power output and rotation. The turbine reached its maximum P_T of 0.1522 W at 83 rpm with 12 stator blades, and its maximum rotation value was 142 rpm. This result exceeds the maximum P_T values for the number of stator blades of 6 and 0; adding more can improve turbine performance. The turbine reached its maximum P_T of 0.0968 W at 75 rpm with a maximum rotation speed of 124 rpm at a stator blade count of 6. This result is lower than the maximum P_T value at 12 stator blades but higher than the maximum P_T value at 0 stator blades.

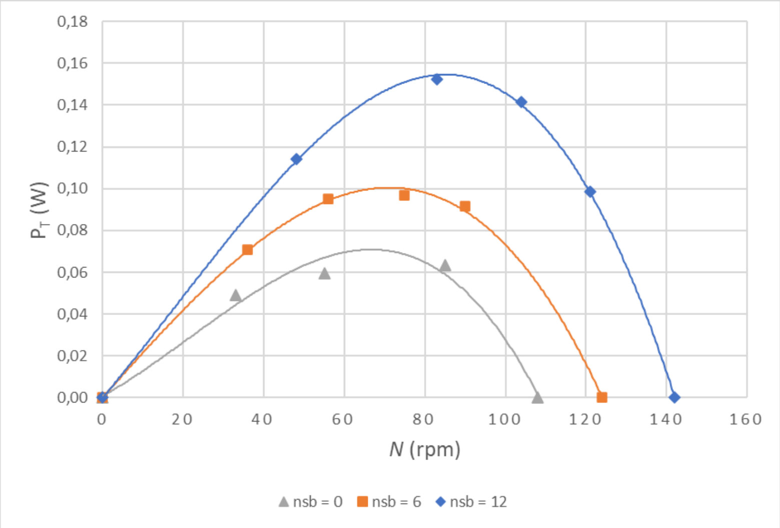

Fig. 6. Effect number of stator blades (NSB) on the turbine power (PT) and turbine rotation

Figure 7 shows the relationship between the number of stator blades and the starting characteristic of the turbine. It can be seen that with the number of stator blades 12, the turbine has a faster-starting characteristic compared to the other blade configurations; this may be due to the increased efficiency of the turbine at this configuration, allowing it to start up more quickly.

Based on previous data with the number of stator blades 12, the turbine achieved a maximum power output of 0.1522 W at 83 rpm, with a relatively fast and stable starting characteristic; this indicates that the use of 12 stator blades not only improves the overall power output of the turbine but also its starting characteristic, compelling it a more efficient and reliable option. In line with this, at the number of stator blades 6, the starting characteristic is slightly slower compared to the number of stator blades 12. However, the power output is still significantly higher than the number of stator blades 0.

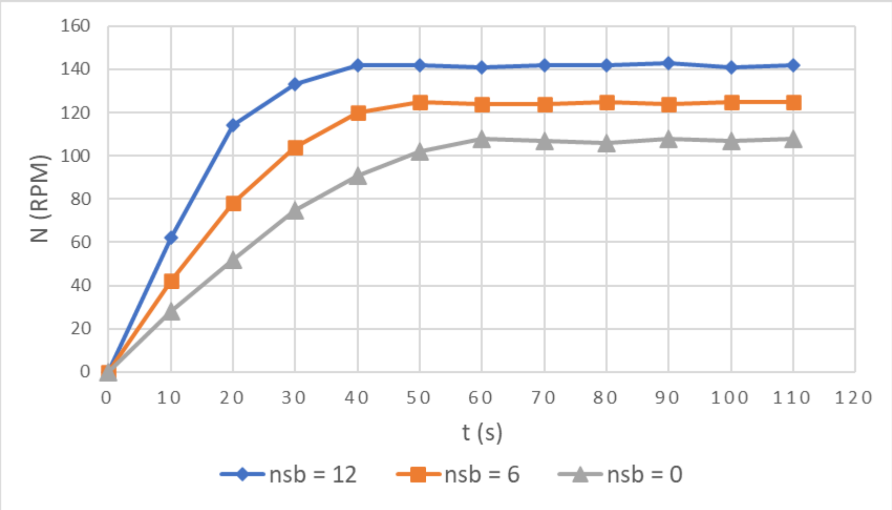

Fig. 7. Effect number of stator blades (nsb) on the starting characteristic of the turbine

Stator blades in wind turbines can improve the turbine's efficiency by redirecting the flow of wind toward the rotor blades, which allows for more efficient energy conversion. The stator blades can also help to reduce turbulence and increase the uniformity of the flow of wind, which can lead to a more stable operation of the turbine and higher power output. However, adding stator blades at a certain number can also affect the starting characteristic of the turbine; this is because more stator blades can create additional resistance to the incoming wind, making it more difficult for the turbine to start rotating. The starting characteristic of the turbine is important because it determines how quickly the turbine can begin producing power and how much wind speed is required for the turbine to start operating.

The design of wind turbines with stator blades involves a trade-off between increasing the turbine's efficiency and maintaining an acceptable starting characteristic. Wind turbines with more stator blades may have higher efficiency and power output but also have a slower starting characteristic [16]. Wind turbines with fewer stator blades may have faster starting characteristics but may sacrifice some efficiency and power output.

Overall, the results suggest that using stator blades in wind turbines can improve the turbine's efficiency and affect its starting characteristic; this is an important consideration in the design of wind turbines, as a faster-starting characteristic can be beneficial in areas with variable wind conditions.

4. CONCLUSION

After conducting tests on a vertical axis wind turbine with pre-swirl augmented in the variations number of stator blades (0, 6, and 12) at a wind speed of 4m/s, several conclusions can be drawn:

1. Using stator blades to design a vertical axis wind turbine as a pre-swirl augmented has been experimentally proven to increase efficiency. The efficiency of the vertical axis wind turbine with pre-swirl augmented using 12 and 6 stator blades increased by 58% and 52.3%, respectively.
2. The generated power of the turbine with 12 and 6 stator blades increased by 56.7% and 51.5%, respectively. The generated power is generally relatively small due to using a simple curved plate airfoil profile (pipe profile).
3. The starting characteristic of the turbine with pre-swirl augmented is also improved. Compared to other blade configurations, a turbine with 12 stator (guide) blades required a shorter time to reach its maximum speed in no-load conditions.

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