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The Experimental Study of the Lens Wind Turbine Performance with Vortex Generator

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Abstract

Wind energy potential is available in several regions in Indonesia with wind ranges reaching 5 m/s. Wind turbine research continues to develop to produce optimal power. The aim of this research is to determine the performance of wind turbines equipped with diffusers or lens that put triangle fin vortex generator on lens's surface. The turbine blade used Clark-Y that has a winglet angle of 45-degrees. There are three variations of lens wind turbine that were tested: without vortex generator, z/h=4.5, z/h=2.5, z/h=0.5. The research was carried out experimentally with fifth wind velocity 3 m/s, 3.5 m/s, 4 m/s, 4.5 m/s, and 5 m/s. The results analyzed to determine turbine performance are turbine rotation, the power produced due to wind direction. Based on the results of the experiments that have been carried out, the results were obtained a straight comparison between TSR and wind turbine rotation (rpm), and straight comparison between Cp and TRS. The Cp is largest in a lens wind turbine with a vortex generator z/h=0.5, which is 0.59 and has the highest power output of 473 watt.

Keywords: Diffuser, Energy, Wind, Performance, Power.

1. Introduction

The need for electricity continues to increase, this can be met by implementing new renewable energy, one of which is wind potential. Several studies on wind turbines have been conducted. This aims to produce wind turbines that can produce optimal power. Several innovations have been made, including modifying the shape of the turbine blade [1]–[4] and modifying the arrangement of the turbine blades [5]–[7]. In this study, the turbine will be modified by adding a diffuser as the outer casing of the turbine, then a vortex generator is added to the outer surface of the diffuser, the blade used in the study has a 45-degree bending angle. The research was conducted experimentally by setting the wind velocity between 3-4 m/s. Several studies on the performance of diffuser turbines have been conducted and show that there is an increase in performance with the addition of a diffuser to the turbine. Research shows that placing a shroud around the rotor improves the aerodynamic performance by more than two times compared to a plain turbine. Experimental results show that the Cp obtained from the shrouded Wind Turbine increases by about 66.4% when compared to the conventional turbine based on CFD results, while according to experimental data, the Cp increases by 69.3% [8].

Other research explains that a new type of diffuser can accelerate the wind approaching the turbine before the wind velocity reaches the set velocity, the presence of the diffuser can also reduce wind resistance on the diffuser when the wind velocity exceeds the set velocity [9]. Other research results stated that the diffuser dimension is a key parameter to increase the velocity inside the shroud throat, where the length and low convergence angle of the diffuser can entrain more air inside the shroud, which in some cases reaches more than double the upward wind velocity. The study also stated that the diffuser is effective in various types of designs. The results showed that a very long diffuser with a length ratio

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of 2.9 LD to throat diameter D is optimal with a divergence angle of 7.6˚, accompanied by a nozzle with a ratio of 1.2 LN/D and a convergence angle of 12.6˚ and a flange length ratio of 0.6 LF/D. This optimal design increases the velocity ratio by almost 2.5 times [10].

Simulation studies were also conducted to determine the flow characteristics when passing through the wind turbine diffuser. The simulation results showed that the model with a grooved surface flange type caused an increase in wind velocity when approaching the wind turbine blades. The turbine produced about 5-7% higher output power compared to conventional turbines. Other results showed that the maximum velocity occurred at 5 cm after the entrance of the casing. This study provides suggestions for wind turbines to be installed at that location inside the casing, to obtain optimal energy harvesting [11].

Vortex generators (VGs), small devices typically consisting of small fins or bumps on the surface of an airfoil, have demonstrated significant potential for enhancing the aerodynamic performance of wind turbine blades. By strategically placing VGs on the blade surface, it is possible to manipulate the airflow and delay or even suppress the onset of dynamic stall, a phenomenon where the airflow separates from the blade surface at high angles of attack, leading to a sudden loss of lift and increased drag. Dynamic stall is a critical issue for wind turbines operating in turbulent or gusty conditions, as it can significantly reduce their efficiency and even cause structural damage. VGs work by inducing small vortices in the boundary layer of the airflow, which can re-energize the flow and delay separation. This can lead to several benefits for wind turbine operation. Firstly, by delaying stall, VGs can extend the operating range of the turbine, allowing it to extract more energy from the wind even under challenging conditions. Secondly, they can improve the overall aerodynamic efficiency of the blade, leading to increased power output and reduced energy losses. Furthermore, VGs can help to mitigate the effects of unsteady loads on the turbine blades, such as those caused by wind gusts or turbulence. By stabilizing the airflow and reducing the severity of stall, VGs can help to reduce fatigue loads on the blade structure, thereby increasing its lifespan and reducing maintenance costs. The optimal placement and configuration of VGs on a wind turbine blade require careful consideration. Factors such as the size, shape, and spacing of the VGs, as well as their location on the blade surface, can significantly impact their effectiveness. Computational fluid dynamics (CFD) simulations and experimental testing are often used to optimize the design and placement of VGs for specific wind turbine applications. In conclusion, the incorporation of VGs into wind turbine blade design represents a promising avenue for improving their performance and reliability. By effectively controlling the airflow and mitigating the effects of dynamic stall, VGs can contribute to the development of more efficient and robust wind turbines, which are crucial for the continued growth of wind energy as a sustainable source of power.

The study revealed that the use of vortex generators (VGs) has proven its ability to manipulate dynamic stall behavior. By adjusting the height and mounting position of the VG, it is possible to control the stall onset and reduce the hysteresis loop. The optimal VG configuration will result in improved overall aerodynamic performance [12]. This research carried out experimental testing by adding a lens to the outside of the turbine and several vortex generators on the outer surface of the lens with the aim of breaking up the air flow that passes through the outside of the lens. The shape of the vortex generator and the z/h ratio use research references that have been carried out previously, namely using triangular fins as can be seen in Figure 1(a), while the z/h that uses takes the lower difference and the difference in the optimal value where the optimal z/h value that has been carried out by the research is 2.5 [13]. Experimental testing was carried out with three velocity variations. The turbine performance that will be analyzed includes other power produced by the turbine, turbine rotation, tip velocity ratio and performance coefficient.

1.1 Wind Turbine Performance Theory

1.1.1 Wind Turbine Power

The Wind Turbine Power is a quantity that indicates how much electrical energy a wind turbine can produce from kinetic energy. Mathematically ,it can be expressed as:

$$P = V \times I \tag{1}$$

with:

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V : Voltage (V)
I : Current (A)

1.1.2 Tip Velocity Ratio (TSR)

The Tip Velocity Ratio (TSR) is a critical parameter in the design and operation of wind turbines. It is defined as the ratio of the tangential velocity of the tip of a turbine blade to the actual wind velocity. Mathematically, it can be expressed as:

$$TSR = \frac{2\pi rN}{60.v} \quad (2)$$

with:

N : rotation of the wheel axis every minute(rpm)
v : wind velocity (m/s)
r : wheel radius (m)

1.1.3 Coefficient Poer (Cp)

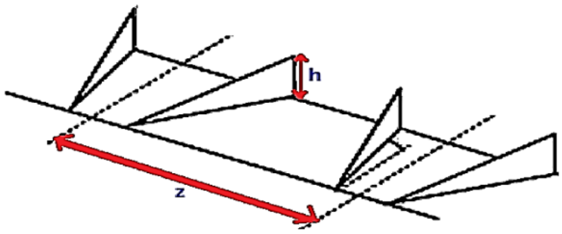
The power coefficient is dimensionless numbers indicating comparison of the power produced by the turbine (P_{out}) with power provided by the wind (P_{in}). So that Cp can be formulated:

$$Cp = \frac{P_{out}}{P_{in}}\ x\ 100\% \quad (3)$$

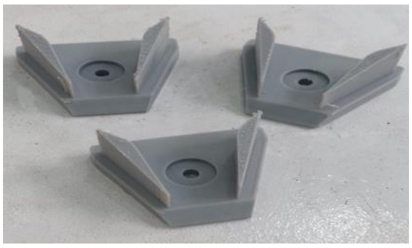
with:
Cp : power coefficient, %
P_{in} : wind power (watt)
P_{out} : the power produced by the turbine(watt)

2. Experimental Method

This research uses experimental methods, a wind turbine with a diameter of 1.35 m with a 45-degree winglet blade with Clark-Y airfoil, an outer lens diameter of 1.4 m, and an inner lens diameter of 1.5 m. The blade material and diffuser (lens) are made from composite. There are five variations of wind velocity that tested 3 m/s, 3.5 m/s, 4 m/s, 4.5 m/s, and 5 m/s. The aim of the variation wind velocity is to obtain optimal results to determine the best vortex generator ratio variation. There are three variations used in this research, including: z/h= 4.5, z/h= 2.5, and z/h= 0.5 where h is the height of the vortex generator and z is the distance between the innermost sides of the vortex generator. Table 1 shows the Lens Wind Turbine design presented in top view and side view. Meanwhile, Figure 1 shows the design of the vortex generator and the vortex generator that has been created.



(a)



(b)

Figure 1. a) Vortex Generator Design, b) Vortex Generator

The working principle of a lens wind turbine is that the wind with a velocity of 3.5 m/s rotates the turbine blade and rotates the generator shaft. The generator produces DC current electrical energy which is then converted by the inverter into AC current. The energy stored in the battery is passed on to light the light bulb. Figure 2 shows the entire circuit. system in this research. The wind turbine lens in this research consists of a series of components to produce electrical energy, including inverter, battery, as shown in Figure 3 for the three variations of the wind turbine lens that have been made and are being tested.

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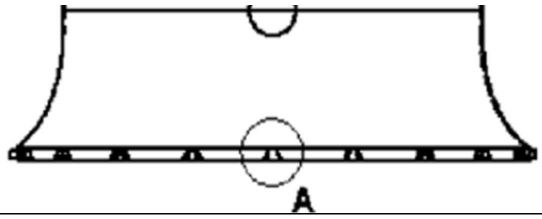
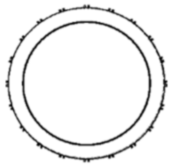
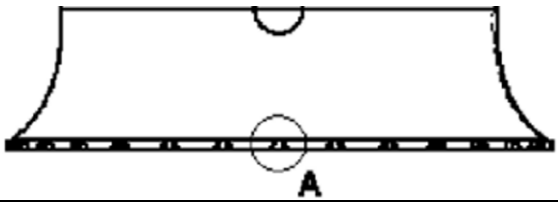
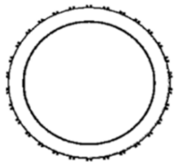
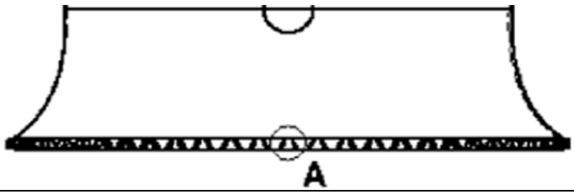
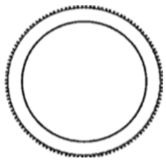
Table 1. Lens Wind Turbine Design

Variation	Side View	Top View
z/h = 4.5		
z/h = 2.5		
z/h = 0.5		

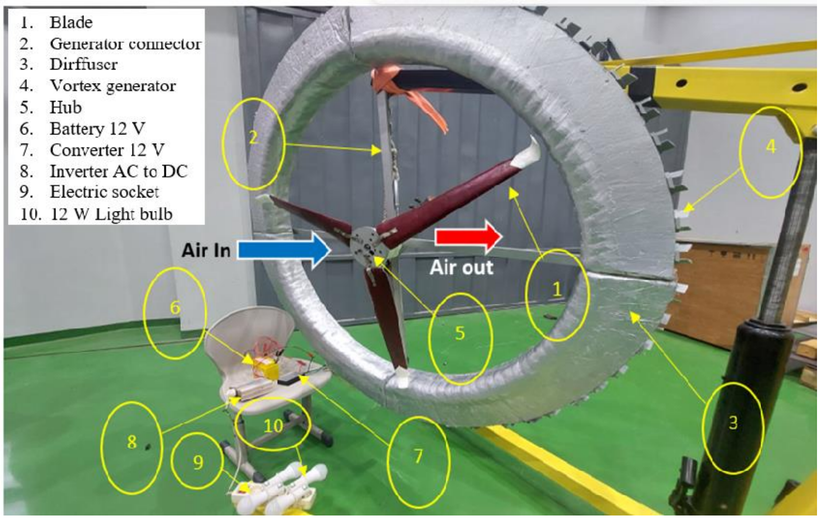
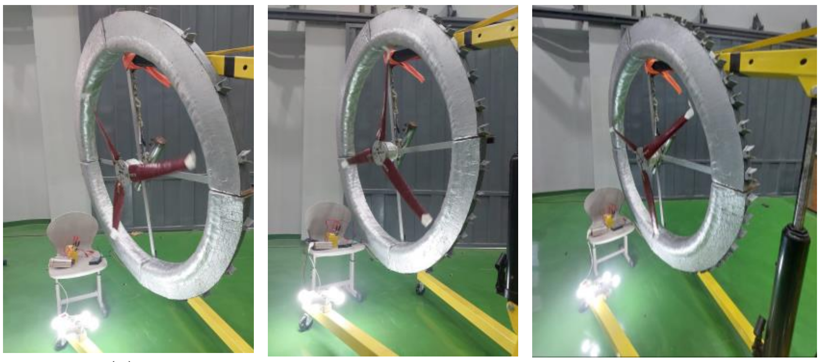


Figure 2. Lens Wind Turbine System



(a) (b) (c)

Figure 3. Lens Wind Turbine: a) z/h = 4.5, b) z/h = 2.5, and c) z/h = 0.5

This research uses several measuring instruments, including anemometer, tachometer, voltmeter, ampere meter, avometer with the specifications of each measuring instrument shown in Table 2 that taken from the name plate printed on the measuring instrument.

Table 2. Measuring Instrument Specification

No.	Measuring Instrument	Brand	Specification
1	Anemometer	HT-81	Range: 59~5900ft/min; 0.3~30.00m/s; 1.1~108.0km/h; 1.1~108.0km/h; 1.1~108.0km/h
2	Tachometer	CEM AT-8	Contact test range: 2 to 20,000 RPM Non-contact test range: 2 to 99,999 RPM Tot test range: 1 to 99,999 RPM Accuracy: ± (0.05% + 1digit) Resolution: 0.1RPM (2 to 9999.9 RPM) Sampling time: 0.5 sec. (over 120 RPM) Detecting distance: 50 mm to 500 mm Time base: Quartz crystal Quartz crystal: Approx. 45mA Battery: 9V
3	Avometer	SANWA CD 800a	DCV Measuring range 400m/4/40/400/600V ACV Measuring range 4/40/400/600V DCA Measuring range 40m/400mA
4	Amper meter	SANWA CD 800a	DCV Measuring range 400m/4/40/400/600V ACV Measuring range 4/40/400/600V DCA Measuring range 40m/400mA
5	Voltmeter	SANWA CD 800a	DCV Measuring range 400m/4/40/400/600V ACV Measuring range 4/40/400/600V DCA Measuring range 40m/400mA
6	Battery	GSL 12 VDC	12 VDC 7 Ah
7	Inverter	POWER	Input 12 VDC Output 220 VAC Power 500 Watt Modified Sine Wave

The steps taken in this research is as follows: (1) The Turbine Shaft is connected to the Generator Shaft, (2) Install the blade/blades on the Turbine Shaft, (3) Install the Diffuser and Vortex Generator on the support pole, (4) Installing the Electrical System, (5) Install the blower/fan set for first wind velocity 3 m/s in front of the turbine. (6) When ready, the blower is turned on to spin the turbine, (7) First experiment without using a vortex generator, (8) The second experiment used 3 variation Vortex Generators (20 pcs, 30 pcs, 60 pcs), (9) Measuring the loading on the turbine and generator using a millimeter, (10) Measure wind velocity using an anemometer, turbine rotation velocity using a tachometer, voltage and electric current using a multimeter, (11) Observe for a predetermined time, and (12) Experiment with other wind velocity by repeating step (a) to step (k).

3. Result and Discussion

The measuring instrument used has gone through a calibration stage before being used to produce accurate results, then experimental data collection was also carried out five times until the results obtained were in a stable condition. After experimental testing, the results were obtained in the form of turbine rotation (rpm), current (ampere), volts, output power (watts), wind power (watts). The experiment used five variations of air velocity, namely 3m/s, 3.5m/s, 4m/s, 5m/s, and 5.5 m/s. Wind velocity is adjusted to environmental conditions that have been previously measured. The results of the fifth variation of experimental testing are shown in Table 3. Based on Table 3, the magnitude of the turbine rotation in rpm will produce voltage and current which will also increase, or in other words these three values are directly proportional. Multiplication of voltage and current will produce output power,

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that is, the data produced by the wind turbine is maintained by the generator and this experiment uses a light bulb. Meanwhile, wind power is obtained from multiplying the properties of the air by the velocity and dimensions of the turbine. From the test results, calculations are then carried out to obtain the tip velocity ratio (TSR) and performance coefficient (Cp). Based on Table This research produced a TSR range of 2.05 to 4.9, while for Cp it was between 0.18 to 0.59. The research results show that the lens wind turbine with a vortex generator z/h=0.5 has the highest TSR and Cp among the other three variations, namely TSR=4.9 and Cp=0.59 which occurs at a wind velocity of 5 m/s. The results are like the tests carried out on the low-speed wind turbine namely that the greater the wind velocity, the TSR and Cp will also increase [14].

Table 3. Experimental Data Result

	Air Velocity (m/s)	RPM	V (Volt)	Current (Ampere)	P_{out} (Watt)	P_{Wind} (Watt)	TSR	Cp
No Vortex Generator	3.0	87	110.3	0.3	32.0	173.8	2.05	0.18
	3.5	137	141.9	0.5	69.5	276.0	2.77	0.25
	4.0	194	186.1	0.7	128.4	412.0	3.43	0.31
	4.5	235	217.5	1.0	215.3	586.7	3.69	0.37
	5.0	332	278.3	1.2	331.2	804.7	4.69	0.41
	Air Velocity (m/s)	RPM	V (Volt)	Current (Ampere)	P_{out} (Watt)	P_{Wind} (Watt)	TSR	Cp
Vortex Generator z/h=4.5	3.0	91	114	0.5	55.9	173.8	2.14	0.32
	3.5	141	145.6	0.7	100.5	276.0	2.84	0.36
	4.0	198	189.8	0.9	168.9	412.0	3.49	0.41
	4.5	239	221.2	1.2	263.2	586.7	3.75	0.45
	5.0	336	282	1.4	392.0	804.7	4.74	0.49
	Air Velocity (m/s)	RPM	V (Volt)	Current (Ampere)	P_{out} (Watt)	P_{Wind} (Watt)	TSR	Cp
Vortex Generator z/h=2.5	3.0	92	117.1	0.6	78.8	173.8	2.15	0.45
	3.5	142	148.7	0.8	132.8	276.0	2.86	0.48
	4.0	199	192.9	1.0	213.2	412.0	3.51	0.52
	4.5	240	224.3	1.3	318.2	586.7	3.76	0.54
	5.0	337	285.1	1.5	462.5	804.7	4.75	0.57
	Air Velocity (m/s)	RPM	V (Volt)	Current (Ampere)	P_{out} (Watt)	P_{Wind} (Watt)	TSR	Cp
Vortex Generator z/h=0.5	3.0	102	127.6	0.7	89.3	173.8	2.40	0.51
	3.5	152	159.2	0.9	143.3	276.0	3.07	0.52
	4.0	209	203.4	1.1	223.7	412.0	3.69	0.54
	4.5	250	234.8	1.4	328.7	586.7	3.93	0.56
	5.0	347	295.6	1.6	473.0	804.7	4.90	0.59

The comparison of rpm and TSR can be seen in Figure 4. TSR which is a parameter to show the efficiency of a wind turbine. The higher the value, the better the turbine efficiency is said to be. Based on Figure 4, the lowest TSR value is 2.05 at 87 rpm for a lens wind turbine without a vortex generator. Meanwhile, the highest TSR value is 4.9 at rpm which is owned by a turbine lens with a vortex generator z/h=0.5. In the graph, the greater the turbine rotation, the TSR will increase, this is because the power produced by the turbine will be greater if the turbine rotation is greater, which provides energy to produce electricity in the generator.

The comparison of TSR and cp is shown in Figure 5, the comparison is straight between TSR and Cp, the greater Cp, the more TSR produced, Cp is one of the parameters to show the efficiency of the power produced by a wind turbine. Based on Figure 5 the lowest Cp value occurs in a lens wind turbine without a vortex generator 0.18 during TSR 2.05. While the highest Cp value occurs in a lens turbine with a vortex generator z/h=0.5, which is the same as 4.90 during TSR 0.59. The greater the TRS, the Cp will also increase. This is different from the results shown on wind turbine performance where the relationship between TSR and Cp is usually parabolic like tests that have been carried out to obtain the aerodynamic performance of turbines in urban areas [15].

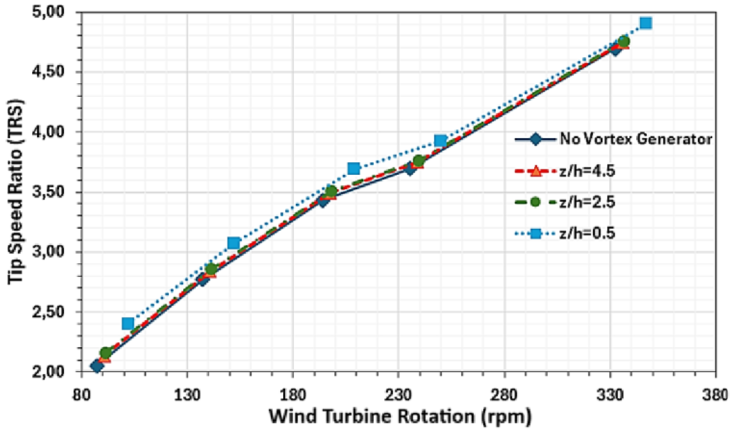

Figure 4. Relationship between Wind Turbine Rotation (rpm) and Tip Speed Ratio (TSR)

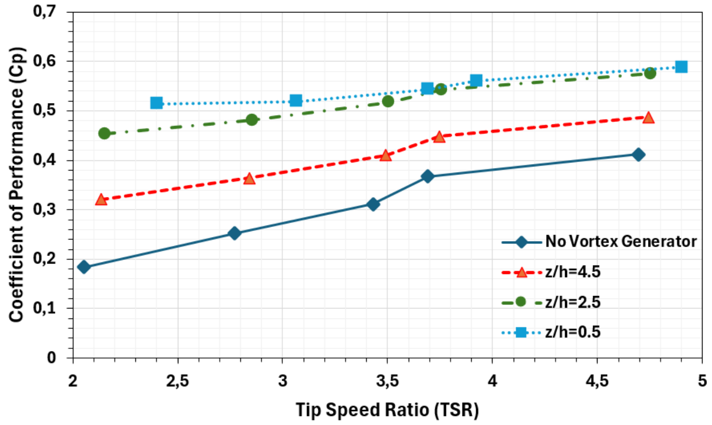

Figure 5. Relationship between Coefficient of Performance and Tip Velocity Ratio

The low aerodynamic performance due to the absence of a vortex generator causes turbulent air flow and initial flow separation along the blade surface, thereby reducing lift and rotational speed. Application of a vortex generator can overcome this problem by inducing controlled turbulence to maintain air flow, increase the lift-to-drag ratio, stabilize rotor rpm, and increase energy conversion efficiency, especially at low wind velocity. Research has shown that vortex generators can increase power output by 10-20%, making it important to optimize small-scale wind turbines by ensuring consistent and higher energy output across a wide range of wind conditions. The application of the vortex generator in Table 3. Presented significantly improves system performance by optimizing aerodynamic dynamics and energy conversion. Experimental data from variations of 20 pcs, 30 pcs, and 60 pcs show that increasing generator vortex variations correlate with increasing velocity, rpm, and converter efficiency. Overall, vortex generators are effective in improving system performance, with optimal variations possible between 10% to 30% to balance efficiency and power output.

4. Conclusion

There are several points to conclude this reseah, it is consist of:

- The largest turbine output occurs in a lens wind turbine with a vortex generator z/h=0.5.
- There is a straight comparison between the wind turbine rotation and the turbine TSR. The largest TSR is 4.90 on a lens wind turbine with a vortex generator z/h=0.5.
- There is a straight comparison between Cp and TRS where Cp is largest in a lens wind turbine with a vortex generator z/h=0.5, which is 0.59 has the highest power output of 473 watts.
- Further research is recommended to refine the design and improve long-term operational stability.

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