Experimental study: Evaluation of the a Vane-Type Vortex Generator in Vertical Axis Wind Turbine Under Different Pitch Angles

Majid Kamandi [1] , Esmail Mahmoodi [2] , Ali HajiAhmad [1] , Mortaza Aghbashlo[1]

[1,]University of Tehran, Iran,Tehran

[2] : Shahrood University of Technology, Iran, Shahrood

Abstract

Today, wind energy has become one of the largest sources of energy in the world. This has led researchers to optimize this energy. The wind turbine is the largest converter of wind energy. One of the optimization methods in lift based wind turbines is to control the flow on the blade's airfoil section. One of the ways is to install vortex generators to stall delay. In this study, a Vane_type vortex generator is installed on low-pressure side of a lift-based vertical axis wind turbine blade and is evaluated at two different pitch angles and various wind speeds. In this case, two pitch angles of 0 and 8.5 degrees are investigated at a wind speed range from 3.2 m/s to 5.4 m/s. The results exhibit that not only installing a vortex generator on the low pressure side of a wind turbine airfoil increases the power production,but also increasing pitch angle of vertical blades up to 8.5 degrees increases the power production significantly. As far as the results of the turbine with a vortex generator on the high-pressure side of the airfoil, the wind turbine blade with a pitch angle of 8.5 degrees had more power and torque than the case without a vortex generator and a pitch angle of 0 degrees.

Keywords: Vortex generator, wind turbine, flow control, airfoil

1. Introduction

According to gwec information, in 2021, the total installed capacity of the global wind energy market is 837 GW, and wind energy has become the third largest energy in the world[1]. The importance of this issue led researchers to wind energy optimization. One of the ways to optimize the changes was on the turbine blade and its airfoil. One of the problems of this part was the stall in the airfoil. The stall caused the aerodynamic coefficients of the airfoil to decrease and ultimately caused the power loss in the wind turbine. Many methods were used such as vortex generator (vg), plasma operator, synthetic jets, which had a better efficiency than other methods[2]. The vortex generator is an aerodynamic device that is connected to the surface of the airfoil (or blade) and delays the separation point of the flow from the airfoil surface. Of course, the vortex generator may also be connected to the surface of cars. The principle underlying VGs' control of flow separation is that when a fluid flows over VGs, a concentrated vorticity is generated. Le investigated the effect of height (vg) due to boundary flow control in an airfoil with two theoretical and experimental methods and came to the conclusion that The maximum lift–drag ratio of the airfoil with VGs is lower than that of the airfoil without VGs, so the VGs do not affect the maximum lift-drag ratio of the airfoil. However, a VG does increase the angle of attack of the best lift-drag ratio[2]. Baldacchino studied the effects of vortex generation on a 30% thick airfoil and Baldacchino noticed The use of the VG mounting strip was detrimental to the airfoil's performance, highlighting the aerodynamic cost of the commonly used mounting technique. Time-averaged pressure distributions and the lift standard deviation revealed that the presence of VGs increases load fluctuations in the stalling regime, compared with the uncontrolled case[3]. Zhu studied the combined effect of passive vortex generators and leading edge roughness on the dynamic stall of a wind turbine airfoil and found that Dynamic stall is therefore significantly delayed by VGs with higher maximum lift, and aerodynamic hysteresis is also greatly reduced with the flow reattachment accelerated. Interestingly, serious LER may cause strong vortical disturbances and change the dynamic stall behaviors from light stall into deep stall. Double-row VGs are also found better than single-row VGs in improving the aerodynamic performance of roughened airfoil. These findings imply that VGs effectively control dynamic stall and diminish the adverse LER effect. Tavernier studied the dynamic stall control using a vortex generator and using the results found out:As soon as the VG's effectiveness vanishes, the configurations with VGs show a severe loss in normal coefficient, larger than in the case of the clear airfoil. However, the flow reattaches quicker and the airfoil recovers easier from the deep-stall conditions. The experimental results demonstrate that the use of VGs significantly changes the unsteady aerodynamic loads[4]. A Experimental Study of Airfoil Performance with Vortex Generators It was done by Bragg and the result was that This highly optimized laminar flow section had good clean airfoil performance, but suffered severe lift and drag penalties with early boundary-layer transition. These performance penalties resulted from a midchord boundary-layer separation. An experimental program was conducted to document this problem and then to design and test vortex generators in order to improve the tripped airfoil performance while having the least effect on the clean airfoil. A set of properly designed vortex generators were found to increase the lift and reduce the drag of the contaminated airfoil. A brief study documented a significant drag rise due to a rough surface in the turbulent boundary-layer region[5].

All the collected researches install a vortex generator on the low pressure side of the airfoil. In this research, we intend to install a vortex generator on the high pressure side of the airfoil. In this research, the behavior of the vortex generator will be investigated on different pitch angles..For this research, a vortex generator is installed on the high pressure side of a small scale vertical axis turbine and the results are evaluated. We are trying to increase the efficiency of airfoil and turbine with this method.

In (Figure 1) and (Figure 2) the types of vortex generators and the types of generator blades are known[6].

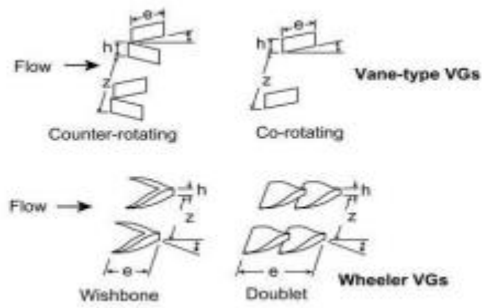


Figure 1. Types of vortex generators

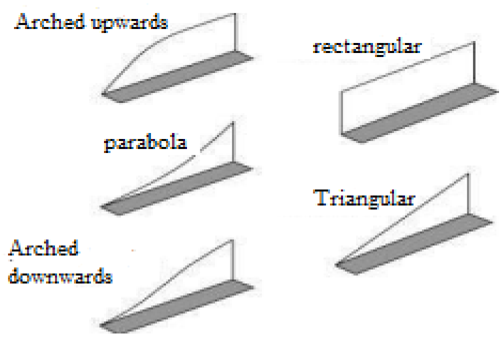


Figure 2. Types of blades of vortex generators

According to the said information, we must have a design and construction method, then with the help of it, we can build a vortex generator and install it on the turbine. There are several conditions for the design of a vortex generator:

A: Sufficient strength

B: Ease of installation

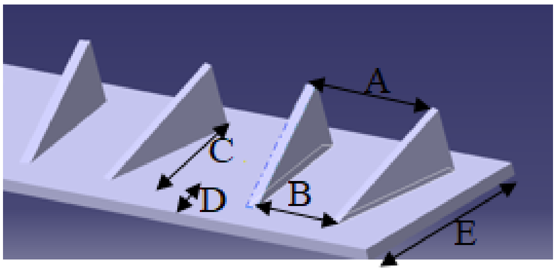
C: Different parts not having corners

D: Material suitable for wind turbine blades

2. Material and method

2.1. Design and construction of vortex generator

At the first step, vortex generators (VGs) are designed. They choosed to be designed according to the scales given by Velte et. al. [7]. The scales and dimentions are illustrated in (Figure.3). All the VGs are placed on a belt for easy installation on the turbine blades (Figure.3). To fit the VGs on the available VAWT baldes, the final design is then manufacutured by a 3D printer in six 20 cm pieces of belts because of limitation of the printer table (Figure.4). All VG belts are then installed on the low pressure side and at the 28% of the chord line form the tip of the airfoil before final tests.



A	B	C	D	E
30	20	20	5	30

Figure 3. Scales and dimentions of the vortex generators modeled in catia software.

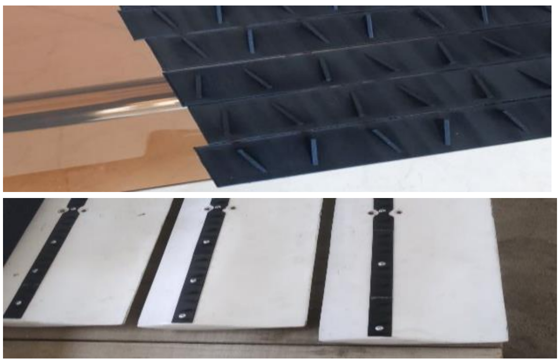


Figure 4. Top: Designed VG belt. Mid: Vortex generating pieces made by 3D printer. Down: Installation of the VGs the blades.

2.2. Experimental Setup

A small-scale vertical axis wind turbine (VAWT) is installed in front of an open loop wind tunnel in the Energy Laboratory of Shahrood University of Technology. The wind tunnel is equipped with an external diffuser for a better wind velocity distribution in out-section tests of small wind turbines (Figure.5). The airfoil section of the turbine blades are of the Riso type and the length of the blade is 130 cm [8]. The wind turbine is located at a distance of 2 meters in front of the diffuser where the wind speed profile measurement are available before installation of the turbine. A workshop dynamometer including a frictional brake and a S-type loadcell is used for measuring an rotational torque of the turbine rotor shaft. The brake has a manual controller located near the turbine for exerting load. A load cell connects the brake jaws to the turbine tower structure. The force from the manual brake multiplied by radial distance of the loadcell from the turbine axis is resulting the rotational torque of the wind turbine (Figure.6). A laser tachometer is used to measure the speed of the rotor.

Figure 5. Wind tunnel equipped with a out-section diffuser available in the Energy Laboratory of Shahrood University of Technology

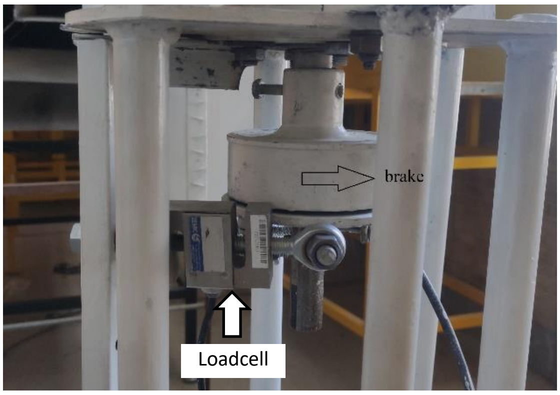


Figure 6. The workshop dynamometer including a frictional brake and a S-type loadcell measuring the rotational torque.

2.3. Turbine tests without VGs

In the initial setup, the power production of the VAWT is measured before installation of the VGs on the blades. The wind turbine is tested in six steps of wind speeds in the range of 3.2 to 5.4 m/s. The blades are set in two different pitch angles (0 and 8.5 degrees) in the whole experiment for a better inspection of the turbine performance. The measurement setup is illustrated in (Figure.7). These data are assumed to be a refernce of comparison in the discussion section.

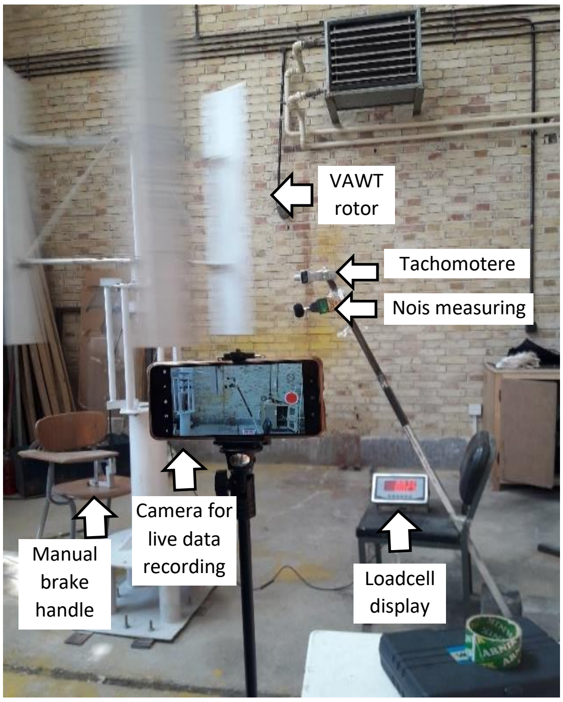


Figure 7. Measuring setup. A mobile phone camera is simply used to record live data from the loadcell display, tachometer and other sensors of the experiment.

2.4 Turbine tests with VGs

The same range of wind speeds from 3.2 to 5.4 m/s at two different pitch angles of 0 and 8.5 degree are tested again in the wind tunnel for evaluation the effect of the VGs on the production performance of the wind turbine comparing to the reference data.

2.5. Installing a vortex generator on the low pressure side of the wind turbine blade airfoil

After the mentioned steps, the vortex generator must be installed in the place where the stall occurs. Stalls generally occur on the low pressure side of the airfoil, and for this reason, the vortex generator was installed on this side of the wind turbine blade. Due to the empty space behind this On the blade side of the wind turbine, it was not possible to install it using screws. Therefore, a vortex generator was installed using glue.

3. Results And Discussion

The pure maximum power production of wind turbine without VGs are shown in Figure.8. Each point represents maximum power production at the full range of the load application by the manual brake handle at a specific wind speed. It is found that the torque and subsequently the power production increased as the pitch angle increases from 0 to 8.5 degrees.

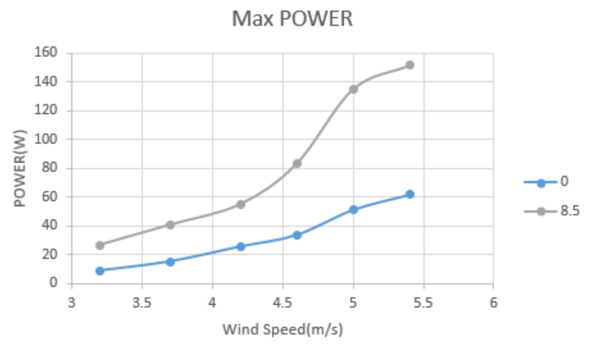


Figure 8. Maximum power production versus wind speed in the state without vortex generator at two pitch angles of 0 and 8.5 degrees

As seen, the pitch angle of 8.5 degrees is a more suitable option than 0 degrees (the power production is increased by about 154% at the wind speed of 5 m/s for example). As seen, as the wind speed increases, the difference between the output power of the two pitch angles increases. So, the bigger pitch angle has a greater effect at higher wind speeds.

The next step is to test the wind turbine with the vortex generator. This was done and the vertical axis wind turbine was evaluated at different wind speeds and two pitch angles of 0 and 8.5 degrees. Torque and power were obtained in different modes.

After installation of the VGs, the behavior is the same compared to the no VGs mode when the pitch angle is changing from 0 to 8.5 degrees. In Figure.9 the maximum power is displayed against different wind speeds at two pitch angles of 0 and 8.5 degrees in the case of VGs installed on the low pressure side. And again it's found that the pitch angle of 8.5 degrees is a more suitable option compared to the 0 degree.

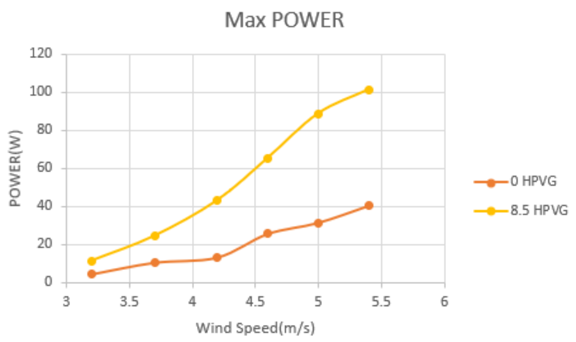


Figure 9. Maximum power versus wind speed at two pitch angles of 0 and 8.5 degrees, in the case of VGs installed on the high pressure sideof the blade.

As shown, the power production behavior at different wind speeds, at two different pitch angles of 0 and 8.5 degrees, and in both cases of with and without VGs are illustrated in Figure.10. As seen, the higher the wind speed, the more power at the bigger pitch angle (8.5 degrees), as well as the higher power at the VG installed mode.

At the end, after installing the vortex generator on the low pressure side of the airfoil of the wind turbine blade, the highest amount of power was obtained. In (Figure 10), the power value of the vertical axis wind turbine can be seen at two pitch angles of 0 and 8.5 degrees.

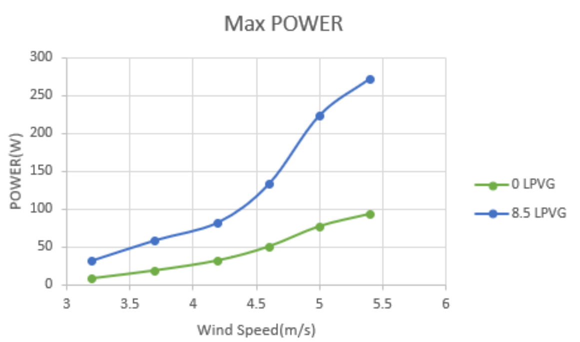


Figure 10. Maximum power versus wind speed at two pitch angles of 0 and 8.5 degrees, in the case of VGs installed on the low pressure sideof the blade.

As shown, in this mode, more power was produced than in the previous modes, and again, more power was produced at the pitch angle of 8.5 degrees than at the pitch angle of 0 degrees. As the wind speed increased, the power difference increased with respect to the pitch angle of 0 and 8.5 degrees. This graph was drawn according to the maximum power at each wind speed. According to this case, it can be predicted that higher powers will be produced at higher speeds

In (Figure 11) all the information related to different modes, different speeds and step angles of 8.5 and 0 degrees are given.

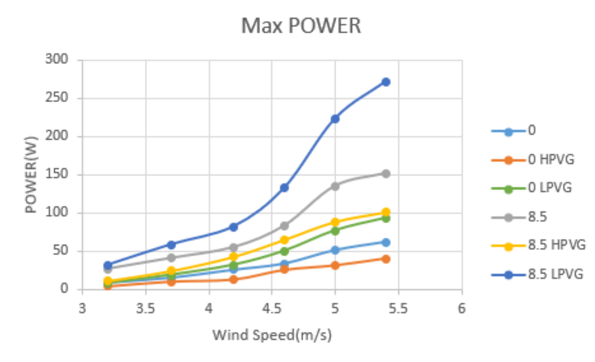


Figure 11. Maximum power at different speeds in the states without vortex generator, vortex generator on the high pressure side, vortex generator on the low pressure side

According to the graph, the maximum power is produced in the mode with the vortex generator on the low pressure side of the turbine. Also, the lowest power is produced in the 0 degree mode with a vortex generator on the high pressure side. According to the graph shown, an increase in the wind speed causes a better performance of the vortex generator. Also, choosing the right pitch angle increases the power of the turbine. The application of both of these cases has a great impact on the power of the wind turbine. The pitch angle is a very important element in increasing the power, so that the production power of different speeds in the 8.5 degree state with the vortex generator installed on the high pressure side of the airfoil is higher than the 8.5 degree state with the vortex generator installed on the low pressure side.

4. Conclusions

According to the obtained results, Increasing the pitch angle to 8.5 degrees was the right choice. This increased the power and torque in the vertical axis wind turbine. The choice of pitch angle was chosen according to the experience of the vertical axis wind turbine manufacturer, but other angles can also be tested it is not recommended to install the vortex generator on the high pressure side of the airfoil. But in comparison, the state with a vortex generator installed on the high pressure side of the airfoil with a pitch angle of 8.5 degrees has a higher power than the state without itwith a pitch angle of 0 degrees . Installing a vortex generator on the low pressure side of the vertical axis wind turbine blade airfoil was the right choice and increased the power of the wind turbine. In the field of making a vortex generator, although 3D printing was a good option, it is better to choose another method or a bigger printer for this work. Being a piece of the vortex generator makes it more difficult to install it on the blade and lowers its efficiency. In the design of the vortex generator, the best choice was made and it had the least loss for the work of the vortex generator and even had a good effect compared to other designs. About the setup, a good method was chosen to obtain power and torque But you can think of less difficult ways. Future researches can be in the field of new methods of making a vortex generator, Different pitch angle,moving the installation point of the vortex generator on the airfoil and new wind speeds.

5. References

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