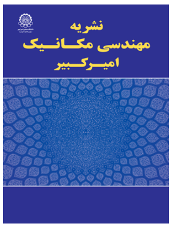

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(5) (2021) 655-660
DOI: 10.22060/mej.2021.17491.6647

a Numerical Investigation on the Effect of Blade Tip Shapes on Power Generation of a Horizontal Axis Wind Turbine

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ABSTRACT: A way to increase the generated power of an available wind turbine blade without changing its base shape is to add proper add-on to the blade tip. In this paper, seven tip add-ons are added to the blade tip of the NREL Phase VI wind turbine, and their effect on generated power is studied using computational fluid dynamics. Reynolds averaged Navier-Stokes equations are used with k-ω SST turbulence model to simulate the flow over the blade. Results show that the tapered tip add-on does not have a notable effect on generated power, while the shark-tip add-on increases the output power by about 4%, which is a minor increase comparing to the other add-ons. The suction surface and pressure surface winglets (without sweepback) increase the power generated by 5.23% and 9.6% respectively, which shows the superiority of pressure surface winglet over suction counterpart. Afterwards, sweepback is added to winglets, showing 11.87% and 13.25% power increase for suction surface and pressure surface winglets respectively, which shows the positive effect of sweepback angle in generated power increase. This is obtained by only a 28 cm add-on to the base blade with a radius of 553 cm.

Review History:

Received: Jan. 08, 2020
Revised: Apr. 21, 2020
Accepted: Jun. 21, 2020
Available Online: Feb. 17, 2021

Keywords:

Blade tip geometry
Computational fluid dynamics
Wind turbine
NREL Phase VI blade

1. Introduction

Considering the growing demand for wind energy, there is a growing interest in improving the aerodynamic efficiency of wind turbines in recent years, and the NREL Phase VI wind turbine is an important case study, thanks to available experimental data [1, 2].

There are several studies suggesting efficiency of steady Reynolds Averaged Navier-Stokes (RANS) method for simulation of this turbine [3, 4]. There have been previous studies to improve the aerodynamic efficiency, including wind turbine airfoil optimization by Yilei He et al. [5], and blade twist and taper ratio optimization by Kaya et al. [6], which consider fundamental change in design and cannot be applied to improve the efficiency of currently manufactured wind turbines.

A novel way to improve aerodynamic efficiency of available wind turbine blades, is to add a tip add-on on the current blade. There are some studies on wind turbine winglets, including the work of Elfarra et al. [7] Tobin et al. [8], and Johansen et al. [9], but these studies lack information on the effect of sweepback angle on winglet efficiency, the difference between the pressure side and suction side winglets, and other tip shapes including Sharktip and tapered tip.

To address these subjects, current research is presented. Simulated wind speed is set to be 10m/s, as the average wind speed of wind turbine sites in Iran [10]. In the following chapters, a brief explanation of methodology and validation is presented, and afterwards, the results are discussed.

2. Methodology and Validation

RANS equations are used with k-ω SST turbulence model, utilizing Moving Reference Frame (MRF) method.

In order to decrease computational cost, a periodic boundary condition was used. Inlet flow was set with 10m/s velocity and 1% turbulence intensity, and outlet was set as pressure outlet with zero gauge pressure. Boundary conditions are shown in Fig. 1.

After domain study and grid study, a domain was selected as a half-cylinder with 50m radius and 40m upstream distance and 100m downstream distance with 6.5 million nodes.

Total generated power is validated with experimental data [2,4]. The experimental result described output power as 9800W with ±800W tolerance. Comparison of the simulation output power of 9320W with the experimental value, shows less than 5% difference, which is in the range of described experimental tolerance. Afterwards, pressure coefficients in different sections were validated with experimental data, which is shown in Fig. 2. As seen in the figure, the results show an acceptable accuracy.

Eight geometries including base blade and seven tip add-ons were generated. Geometries are described and shown in Table 1 and Fig. 3. Fig. 4 shows parameters of winglet geometries.

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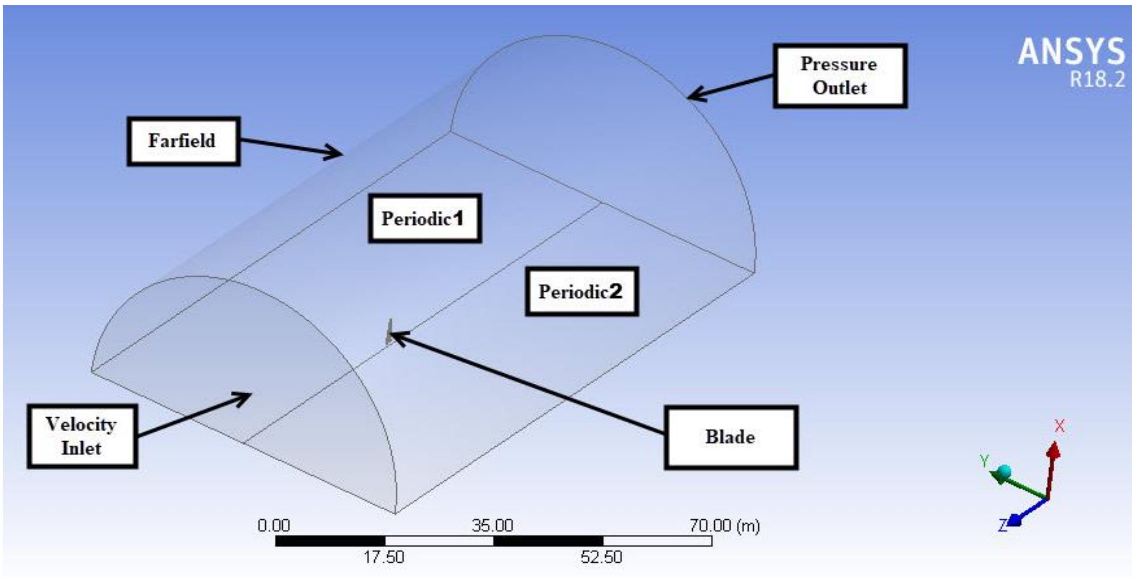

Fig. 1. Boundary Conditions

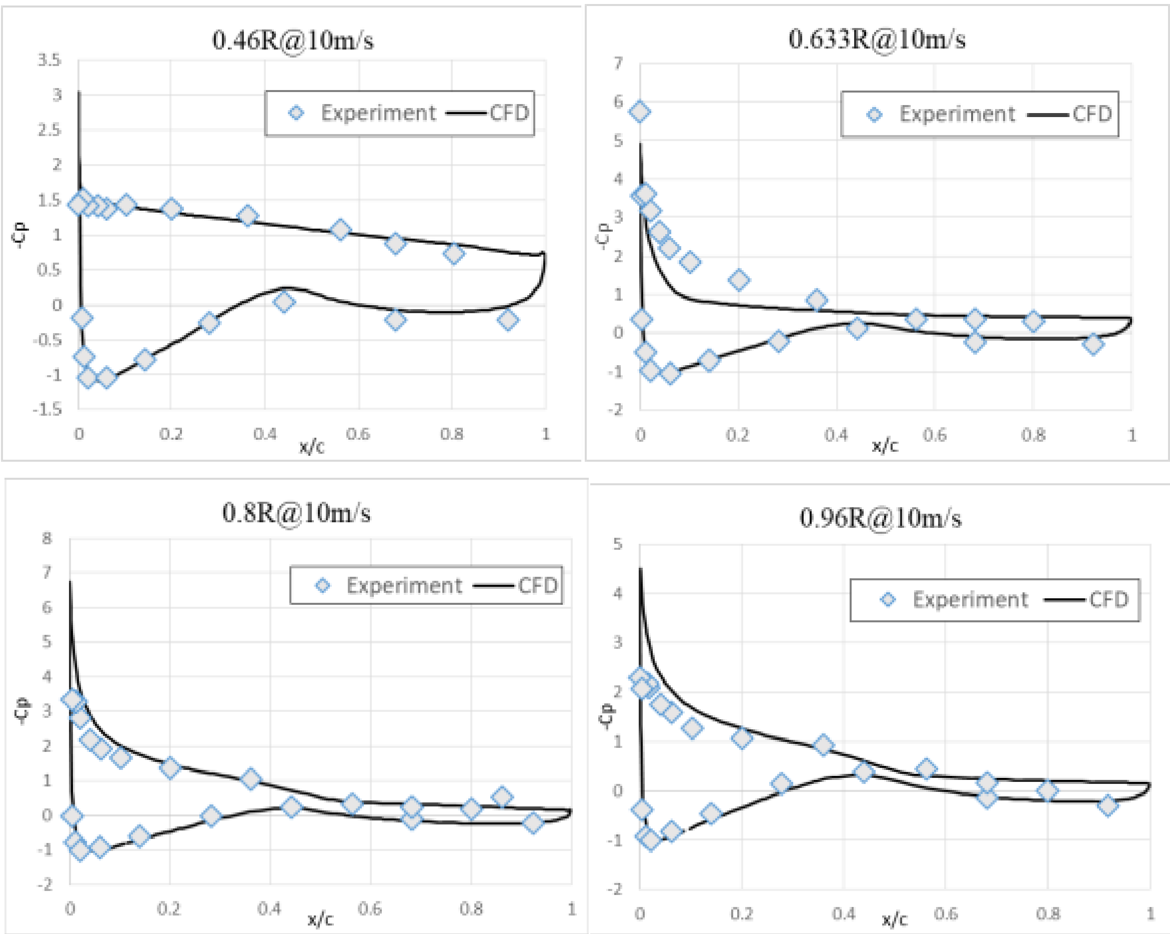

Fig. 2. Cp validation with experimental results at different blade sections

3. Results and Discussion

Table 2 presents torque and power results of the add-ons. Last column on the table presents power increase compared with the base blade with a clear tip.

Studying these 8 geometries, we can see that Tapered tip (geometry 2) does not present any notable increase in the generated power. Also, Sharktip add-on (geometry 3) shows the least increase in efficiency, while winglets show good results. Among the 4 investigated winglets, comparing geometry 4 with geometry 5, and 6 with 7, pressure surface winglets show better results than suction surface winglets. It can be concluded that, in order to achieve the best results, winglets should be designed on pressure surface, towards the upstream. Pressure surface winglets are also technically more feasible to build, as suction surface winglets have geometric limitations to avoid collision with wind turbine towers.

In order to study the effect of sweepback angle on generated power, geometries 4 and 6, and geometries 5 and 7 should be compared. As the results show, sweepback angle has a positive effect on aerodynamic efficiency and can further increase the generated power.

4. Conclusions

In this study, 7 different tip add-ons were simulated, and the results showed that among the studied geometries, pressure surface winglet tip add-on with sweepback angle can achieve the highest increase in the generated power. It also shows the positive effect of having the winglet on the pressure surface, and adding sweepback angle, on the generated output power. It is also notable that as shown, a proper add-on can increase the output power of the turbine by more than 13%, by adding a 28cm long Add-on to its 553m radius.

Table 1. Description of the Add-on geometries

Number	Title of add-ons	Geometry description	Total radius (m)
1	Base Blade	No Add-ons	5.532
2	Tapered Tip	0.2m length and taper ratio of 0.3	5.732
3	Sharktip	0.4m radius, 75 degrees circular sector, 0.02m sector extension	5.924
4	Suction surface winglet 1	0.02m initial length, 0.1m radius, 0.2m second length, 60 degrees slope	5.743
5	Pressure surface winglet 1	0.02m initial length, 0.1m radius, 0.2m second length, 60 degrees slope	5.743
6	Suction surface winglet 2 (swept)	0.05m initial length, 0.2m radius, 0.1m second length, 60 degrees slope, 0.35 tip sweepback offset from root	5.805
7	Pressure surface winglet 2 (swept)	0.05m initial length, 0.2m radius, 0.1m second length, 60 degrees slope, 0.35 tip sweepback offset from root	5.805
8	Extended Tip	Extension of main blade up to 0.273m	5.805

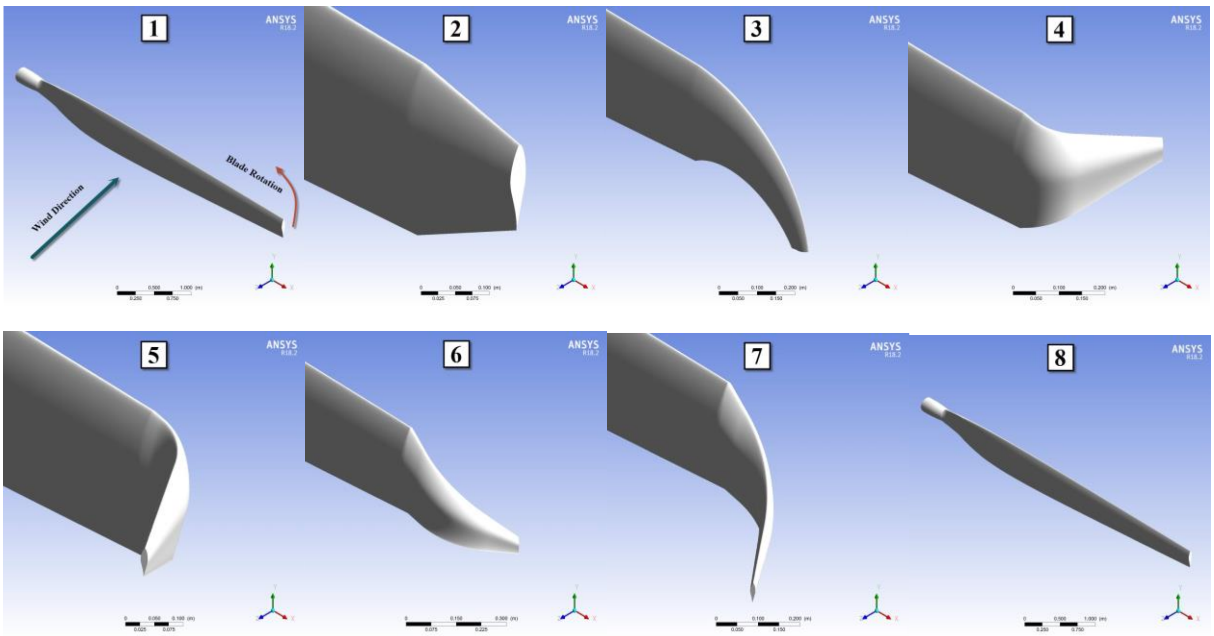

Fig. 3. Investigated geometries

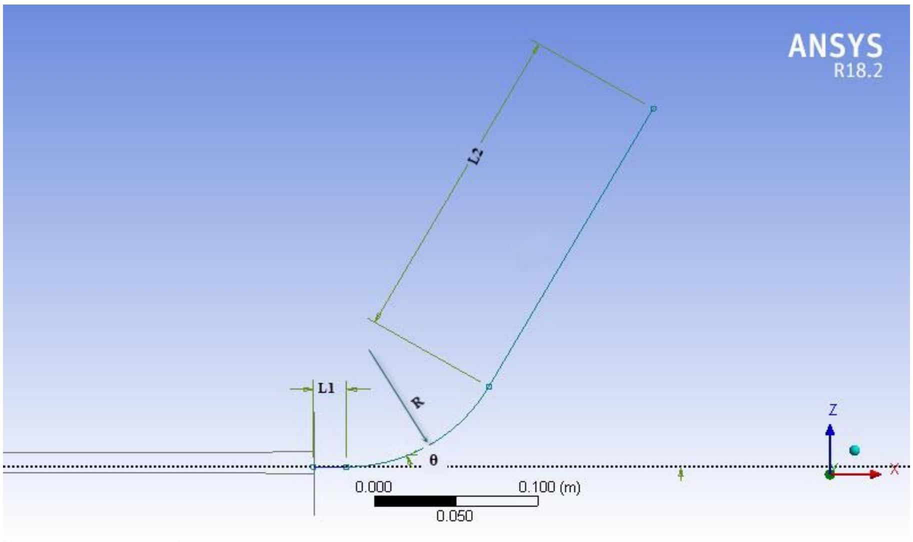

Fig. 4. Geometric parameters of the winglet

Table 2. Torque and power results

Number	Title of Add-ons	Total radius (m)	Total torque (N.m)	Total power (W)	Power increase
1	Base Blade	5.532	1235.7	9317	0%
2	Tapered Tip	5.732	1234	9304	-0.14%
3	Sharktip	5.924	1289	9719.1	4.32%
4	Suction surface winglet 1	5.743	1300.3	9804	5.23%
5	Pressure surface winglet1	5.743	1354.3	10211.3	9.60%
6	Suction surface winglet2 (swept)	5.805	1382.3	10422.5	11.87%
7	Pressure surface winglet2 (swept)	5.805	1399.4	10551.2	13.25%
8	Extended Tip	5.805	1349.1	10172.1	9.18%

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HOW TO CITE THIS ARTICLE

A. Rouhollahi, A. Jahangirian, M. Heidari Soreshjani, a Numerical Investigation on the Effect of Blade Tip Shapes on Power Generation of a Horizontal Axis Wind Turbine, Amirkabir J. Mech. Eng., 53(5) (2021): 655-660.

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