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NUMERICAL INVESTIGATION OF THE EFFECT OF WINGLET CONFIGURATIONS ON THE BLADE PERFORMANCE FOR HORIZONTAL AXIS WIND TURBINE

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ABSTRACT

Numerical investigation of the effect of winglets on the blade performance for wind turbine is performed. Winglets with parameters of their height and 90º angle facing upstream (UW configuration) and downstream (DW configuration) direction from blade tip are proposed. Furthermore, the winglet tip thickness is varied to 100%, 85% and 70% of tip blade thickness to investigate its effect. Numerical simulation with RANS equations in combination with k-ω SST turbulence model was performed. Grid convergence index was applied to ensure the grid independence of the solution. Moving reference frame method was used to perform the blade rotating motion. Numerical results for the blades with and without winglet are compared to examine the effect on the blade performance at different flow conditions. Generated torque and thrust are used to evaluate the blade performances. The present numerical results for blades without winglet were found in well agreement with experimental data from NREL phase VI of a horizontal wind turbine. The UW configuration showed improvement on the blade torque, and reducing winglet thickness tends to increase the torque. Also, UW configuration showed it is able to improve the blade tip wake characteristic compare to the normal configuration. While winglet with DW configuration indicated lower blade torque and worse performance compared to the normal configuration.

KEY WORDS: CFD, Horizontal axis wind turbine, Turbine blade, Winglet, Tip vortices, Blade performance

1. INTRODUCTION

Wind turbine is a device that utilizes kinetic energy from wind flow to generate electricity. Wind turbine performance is greatly affected by its blade geometry. Wind turbine with additional winglet on its blade is known to have better performance compared to wind turbine without winglet. Winglet affects the blade performance by shifting blade tip vortices from blade tip to winglet tip and prevents spanwise flow from pressure side into suction side. This prevention keeps blade suction side pressure low. Winglet parameters such as cant angle, height, sweep angle, and toe angle [1] are known have significant effect to blade performance. According to Mourad et al. [2], winglet with height as 0.8% rotor radius R and toe angle 20º provided the best power increment. While Johansen and Sørensen [3] performed a numerical analysis for winglet with multiple parameters such height, curvature radius, sweep angle and twist angle, and showed that winglet with height 4% radius R, 12.5% curvature radius, 0º sweep angle and 4º twist angle had the best increment. Also, Garcia-Riberio et al. [4] have performed a parametric CFD analysis for the blade chord to winglet root chord ratio and the blade

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chord to winglet tip taper ratio. Winglet with root chord ratio 40% has the best performance in their analysis meanwhile winglet with tip taper ratio 10% has the best performance.

In this study, a CFD analysis for winglet configurations facing upstream (UW configuration) and facing downstream (DW configuration) with 90º was performed. This research aimed to understand the difference in flow field that leads to different blade performance. Winglets with height 1.5% R, 3% R, and 5% R are simulated for each configuration. Furthermore, winglet with height 3% R has its thickness with 100%, 85% and 70% of tip blade thickness, t_t was tested to investigate the effect on the blade performance.

2. NUMERICAL METHOD

2.1 Winglet Configuration and Computational Domain

Blade shape and operational condition is based on the Reference [5] and winglet is attached at the tip of the blade. Computational domain of 2R upstream, 5R downstream, 3R surrounding the blade is established. Grid number of about 3 million are built. y+ ≈ 1 is set to calculate viscous boundary layer. Turbulence model with k-ω SST is applied to RANS equations.

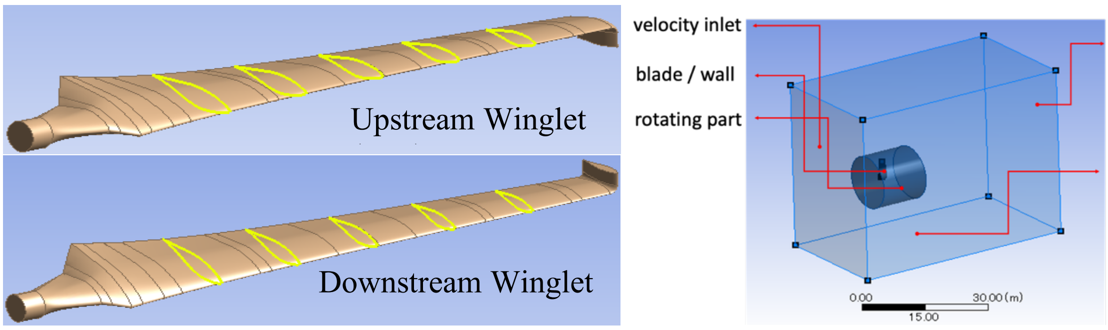

Fig. 1 Winglet configuration and computational domain.

2.2 Numerical Validation

Experimental data [5] are used as comparison to validate present numerical solution. As an example, Fig. 2 shows that present results represented by CFD are in a good agreement with experimental data of pressure distribution for blade with normal tip.

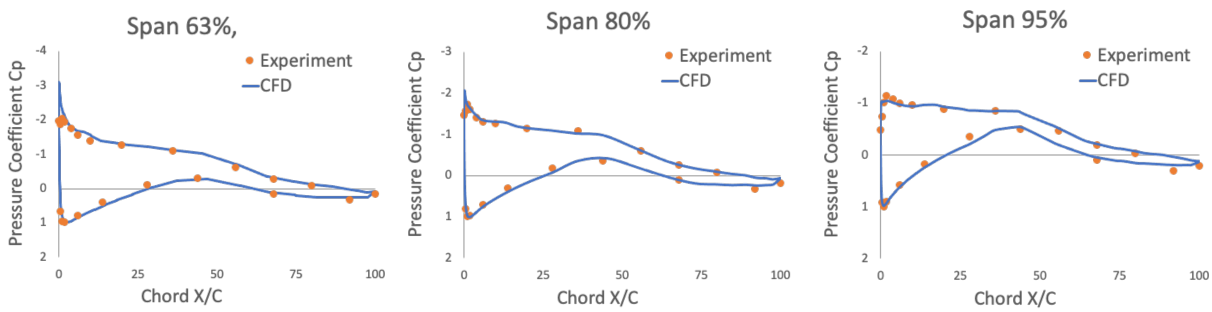

Fig. 2 Pressure distributions of blade without winglet at v = 7 m/s.

3. NUMERICAL RESULTS AND DISCUSSION

3.1 Winglet Effect on Power Performance

Table 1 shows a power coefficient (Cp) and thrust coefficient (Ct) increments compared to the blade normal tip at several winglet heights and velocities. From the data, it was known that UW configuration can increase the blade performance in Cp. Meanwhile DW configuration mostly decrease the blade performance. DW configuration also increase Ct when Cp decrease. Overall UW configuration with height 3% R has the best performance compared to the other configuration.

Table 1 Performance of winglet with different configuration vs velocities

Velocity	Upstream configuration (UW)						Downstream configuration (DW)					
	1.5% R		3% R		5% R		1.5% R		3% R		5% R	
	Cp (%)	Ct (%)	Cp (%)	Ct (%)	Cp (%)	Ct (%)	Cp (%)	Ct (%)	Cp (%)	Ct (%)	Cp (%)	Ct (%)
8	-0.55	0.56	1.34	2.91	0.05	2.91	0.93	2.89	-5.14	0.85	-2.57	4.19
9	1.09	0.48	1.14	0.96	0.80	1.74	0.02	0.99	-2.76	0.71	-1.00	2.35
10	1.12	0.98	2.21	2.02	2.88	2.41	-0.96	1.32	-3.89	-0.17	0.31	3.45

3.2 Blade Flow Characteristics

Flow characteristics of winglets with H 3% and 100% t_t at wind velocity 8 m/s are displayed in Fig. 3. It shows that blade with normal tip can't prevent the spanwise flow near the tip because of tip vortices. UW configuration able to block spanwise flow on the pressure surface so the flow didn't jump directly to blade suction surface. DW configuration blocks spanwise flow on the suction side, so that the spanwise flow from pressure side is entering to the suction side. From the pressure distributions on suction surface in Fig. 4, UW configuration has the biggest area of low pressure around the blade tip.

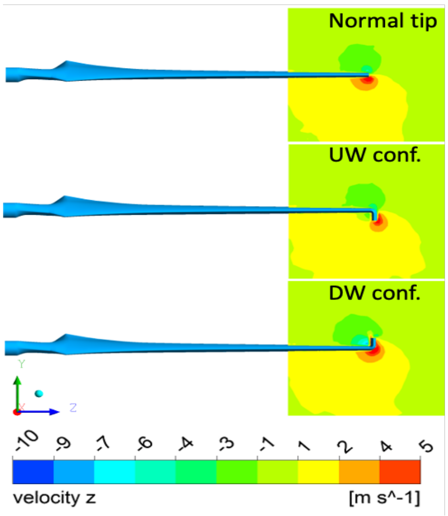

Fig. 3 Spanwise velocity contour

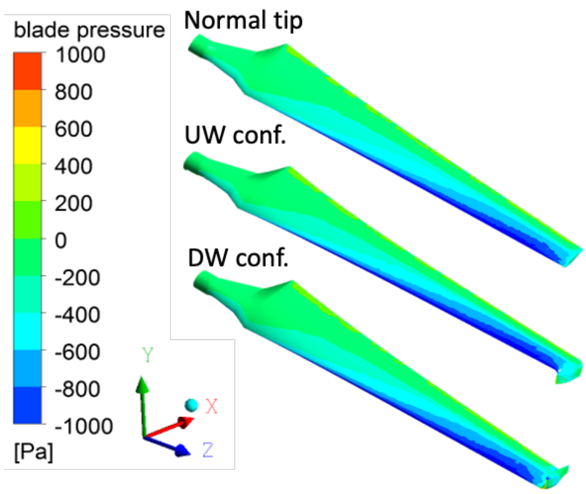

Fig. 4 Pressure on the suction surface of blade.

3.2 Surfaces Pressure Distribution

Surface pressure distribution at span location 98% of blade with flow velocity 8 m/s are shown in Fig. 5. UW configuration has the best distribution compared to the other configuration. This configuration mostly improve the distribution in leading edge area up to around 50% of chord. Meanwhile DW configuration improve pressure distribution at trailing edge area by decrease the pressure at suction side of blade.

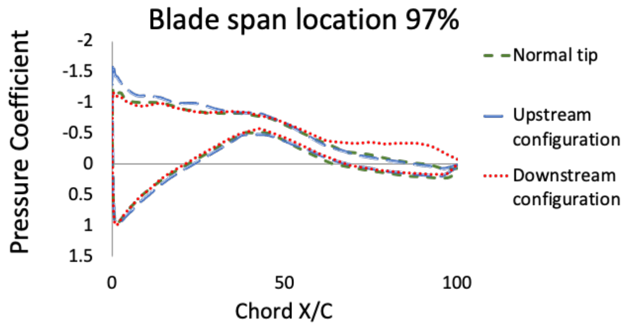

Fig. 5 Surface pressure distribution at span 97% and V=8 m/s.

3.3 Wake and Winglet Thickness

Decreasing the winglet thickness, for example, from 100% to 70% t_t is effective to reduce intensity of wake behind the blade as seen in Fig. 6.

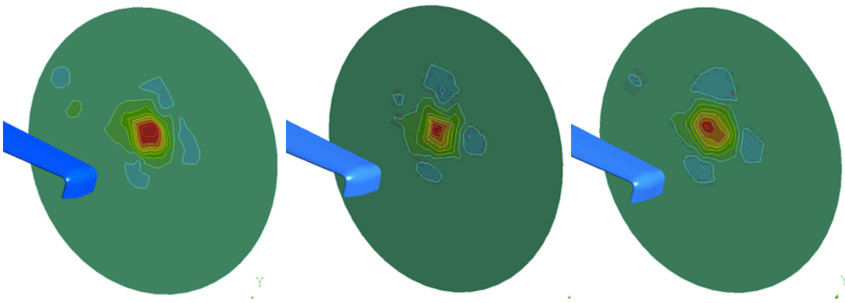

Fig. 6 Wake formation behind UW winglet with thickness 100%, 85% and 70% t_t from the left at V=8m/s.

4. CONSLUSIONS

Numerical simulation are performed for multiple winglet configurations. UW configuration with height 3% rotor R showed the best increment of blade performance. The power increment also followed with increment of thrust coefficient. Reducing winglet thickness improves the wake characteristic of blade. DW configuration decrease the blade performance.

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