USE OF CIRCULAR WIND REGULATOR ON VERTICAL AXIS WIND TURBINE

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ABSTRACT

In this study, energy performance and aerodynamic forces of NACA0015 airfoil type on a vertical axis Darrieus wind turbine have been investigated numerically at different tip speed ratio. To improve performance of vertical wind turbine, circular wind regulator has been placed front of the turbine. So, negative torque zones have been reduced. Numerical calculations have been conducted with the Fluent CFD code, using the k-ε Realizable model. Wind seep at these calculations has been chosen. Tip speed ratio and influence of the wind regulation for NACA0015 airfoil type have been determined.

Keywords:
VAWT, circular wind regulator, tip speed ratio

1. INTRODUCTION

Wind is the air flow that formed from the high pressure to low pressure. The wind energy is the movement (kinetic) energy which the air flow creates. Firstly, Greek engineer, Heron was defined the usage and description of wind energy at the beginning of the first century. Power of the wind are used for thousands of year for farming or to move some contractions such as mills in the in rural areas, water pumps etc. Especially after both decrease amount of the fossil fuels consequently increase in the cost of them caused more research on new, efficient and nontoxic energy sources and productions. To benefit from this renewable energy source lots of the mechanism or system were developed and increasing step by step.

Various techniques are widely applied to generate the electricity and lots of scientists, engineers and designers try to gather more efficient body or shape. Wind turbines are widely used in order to produce electricity. Nowadays, mostly horizontal axis wind turbines are chosen to creating electricity. However, this type of turbines cannot start its initial movement at low wind speed. Because of the adversely effect of this phenome, vertical axis wind turbines are selected to cope with this problem instead of horizontal system for low power production.

In order to examine the vertical axis wind turbines, Rainbird et al. [1] have experimentally investigated on the influence of virtual camber effect on airfoil polars for use in simulations of Darrieus wind turbines. They concluded that when modeling a Darrieus rotor using blade element momentum methods, applying experimental data for the profile used in the turbine will yield inaccurate results if the c/R ratio is high, in such cases it is necessary to select a profile based on the virtual shape of the blades.

One of the principle of harvesting high efficiency is that right location of wind blades according to fast variable wind angle of attack. Although vertical axis wind turbine is dominant in the future study, it is investigated in different areas. Croskey [2] examined that the dynamic wind forces acting on the vibrated aircraft blades.

Necessity to reach the renewable wind energy source caused turbine application that established the best by wind direction. Borg and Collu [3] had studied in this area. In order to increase the forces at high wind speed numerical flow model was carried out by Svendsen and Merz [4].

Strong interaction between aerodynamic loads and location for variable wind conditions were stated by Borg and Collu [3]. They showed that platform of the aerodynamic model did not affect to movement but lower than 0.4 rad/s wind speed frequency caused bigger amplitude with bigger blades. For big blades at that frequency high level aerodynamic

status were achieved and more torque were obtained at high speed.
Vertical and horizontal axis wind turbine were compared at the atmospheric condition and stated that vertical axis model was more efficient by Sutherland et al. [5]. They have expressed that H and Y connection type can be change according to cost. Allet and Paraschivoiu [6] identified that the performance of the horizontal axis wind turbine was decreased at low wind speed but on the other hand for vertical axis turbine model this performance were increased and they studied on this type problem.
Vertical axis turbine with small dimensions were investigated by McLAren et al. [7]. Also, they simulated for high aerodynamic using computational fluid dynamic. Hydrodynamic performance of helical vertical axis turbine which designed and located under water analyzed by Cahay et al. [8]. In study of Ross and Altman [9] vertical axis wind turbine was used to observe the blockage occurred in the wind tunnel. They had indicated that the wind channel will absolutely clogged.
Nabavi [10] carried out the tidal current turbine with 3 blades for hydrodynamic performance study which common investigation area. In this work, he used a vertical axis wind turbine and tried to increase performance of the turbine through the upstream. Howell et al. [11] used a vertical axis wind turbine with small dimensions for wind tunnel and study f numerical analsys. They formed 3 blades wind turbine and simulated in their experiment. After that their findings were compared with the values that they obtained and same results were observed.
Islam et al. [12] designed the vertical axis wind turbines with flat blade in order to apply to different areas such as electricity production, water pumping systems, water treatments, hot water usage and heating and cooling operation with high pressure pump. Vertical axis wind turbines which can be located to the roof at possible atmospheric condition were designed and analyzed. They tried to economically benefit with this experiment at the end of their study.
Brusca et al. [13] performed vital experiment on blade of vertical axis wind turbine to maximize system’s aerodynamics performance. Castelli et al. [14] examined the influence of the number of blades to turbine efficiency how affected by geometrical changes.
Dagdevir [15] produced 1/10 scale 8 different Darrieus vertical axis wind turbine model and determined appropriate blade profile. Different blade profiles of vertical axis wind turbine’s change in the torque coefficient according to blade position were investigated by Akansu et al. [16].
Difficulty of initial movement and low efficiency at high wind speed can be observed in the vertical axis Daireus turbines. In this study, a cylindrical geometry was used to maximize the efficiency of the Daireus turbine at different wind speed conditions.

Table 1. Program costs and avoided costs in assessing the savings of promoting cogeneration.

TSR	**Bare case**	**With wind Regulator**	**Percentage change**
1.44	0.598402	0.749644	+25
2.33	2.311698	2.474052	+7
2.64	3.330109	2.727829	-17
3.30	2.691375	1.674065	-37

2. EXPERIMENTAL FACILITY

2.1. Setup
Computational Fluid Dynamics (CFD) programs have been used to investigate and analyze some problems such as flow around any type of body, combustion in the engines, in cooling tower even electronical devices by applying mathematical model codes. The purpose of this study is to examine the influence of the wind regulator that located at the certain location of the vertical axis wind turbine VAWT. After two different 2D model was constructed in GAMBIT programme, some kinematic and dynamic characteristics were investigated of the system using continuity and momentum equations. Designed mode was transferred to ANSYS Fluent programme in order to analyze determining conditions that we desired.

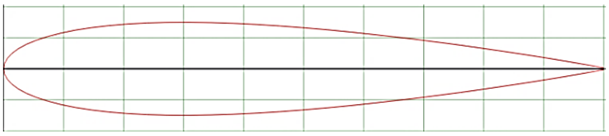

Fig. 1. An air foil NACA0015 model used in the experiment.

The NACA0015 coordinates of the airfoil model geometry that taken from the airfoil tool was used in this numerical investigation as shown in figure 1. 3 blades were placed at an angle of 120 degrees. A rectangular outer zone (100000 mm x 80000 mm), specifying the overall calculation domain, with a circular body which is called wind regulator tangential positioned on the turbine x axis, which was identified in figure 2. Also, wind inlet and outlet boundaries were determined of the experiment zone and the experiment was based on the k-ε and wall treatment as turbulence model.

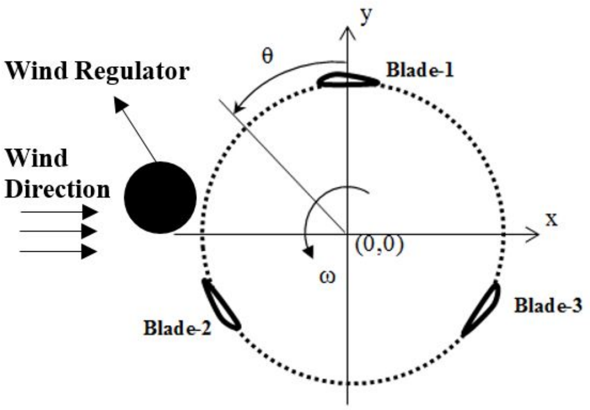

Fig. 2. Schematic representation of numerical system.

2.2. Numerical Scheme

Dimensionless the power coefficient, C_p and Tip-Speed-Ratio, *TSR* were determined in order to obtain aerodynamic parameters for wind turbines as shown below:

Where; ω is angular velocity of rotor,
R is radius of the rotor,
U is free stream velocity,

$$TSR = \frac{\omega R}{U}$$
(1)

and

where; P is power that obtained from wind,
A = 2RL is the frontal rotor area,
ρ is air density,

$$C_p = \frac{P}{\frac{1}{2}\rho A U^3}$$
(2)

Radius of the rotor, *R*= 0.515 m, free stream wind velocity, *U*=9 m/s were determined and ω values were calculated as 25.16505, 40.71845, 46.13592, 57.6699 for *TSR*, λ, 1.44, 2.33, 2.64 and 3.3 respectively for mentioned two model.

3. RESULT AND DISCUSSION

The vertical axis wind turbine that moved less initial wind speed and have more efficiency was observed using circular wind regulator with respect to bare case of the wind turbine. Negative torque region which created by the wind direction and rotation of the wind turbine was minimized as shown in table 1. C_p values were calculated from every torque result for each λ and these result were compared with normal case values.

Table 1. Numerical results of the tested model.

TSR	Bare case	With wind Regulator	Percentage change
1.44	0.598402	0.749644	+25
2.33	2.311698	2.474052	+7
2.64	3.330109	2.727829	-17
3.30	2.691375	1.674065	-37

As it can be seen from the table 1 calculated value of effective TSR number increased %25 for 1.44λ. This TSR values started to decrease since 2.64λ.

C_p values were calculated versus the TSR value for NACA0015 airfoil type. Bare case and with regulator wind turbine data were compared with the numerical and experimental values that taken from Castelli et al. [14]. According to value of TSR, it can be seen that efficiency of the designed vertical axis wind turbine was better at low angular speed of rotor. Also it increased until the 2.64 level of TSR then starts to decrease for our study. The maximum C_p value was obtained about 2.64 tip speed ratio. Frunzulica et al. [17] stated that obtained power from wind is less than high rational speeds at low TSR numbers. As stated by Ferreiara et al. [18], at low TSR number fluctuations cause fatigue on the body.

Fig. 3. Torque values as a function of rotor azimuthal position for NACA0015 for bare case.

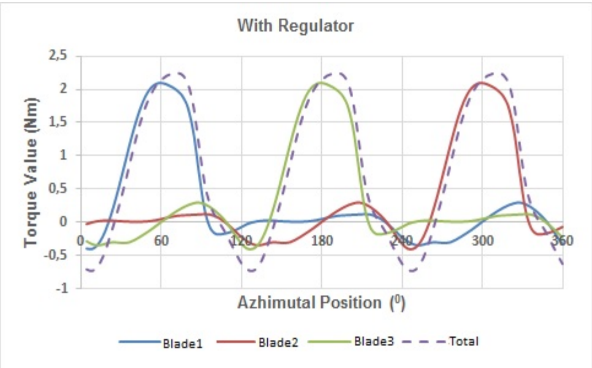

Fig. 4. Torque values as a function of rotor azimuthal position for NACA0015 for with regulator.

Figure 3 and 4 represents the torque values as a function of rotor azimuthal position of bare case and with regulator wind turbine for one cycle. It can be seen that change in the maximum torque values of with regulator were less than bare case. Also while high level values were obtained in negative torque region between angle of 60^0 and 120^0 for bare case, this issue was limited and minimized using the wind regulator.

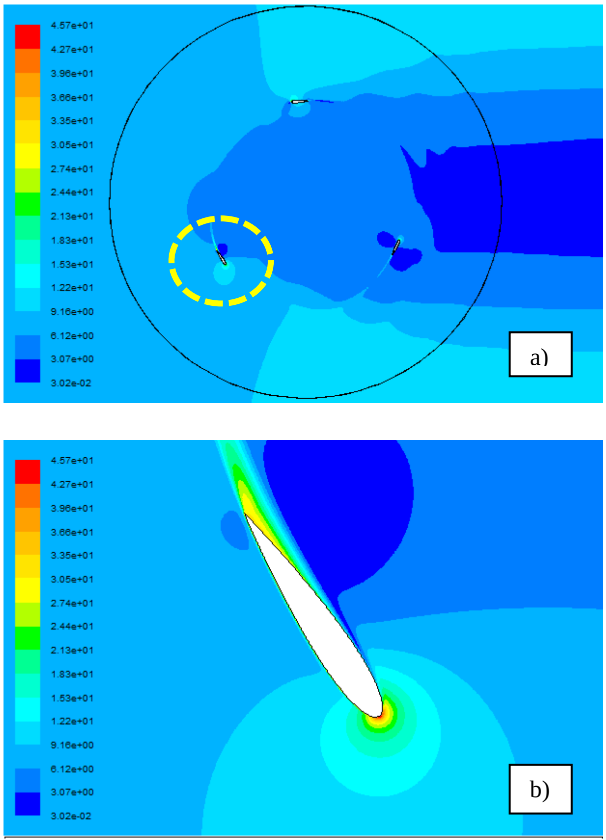

Fig. 5. Velocity contour magnitude of λ:3.3 for bare turbine.

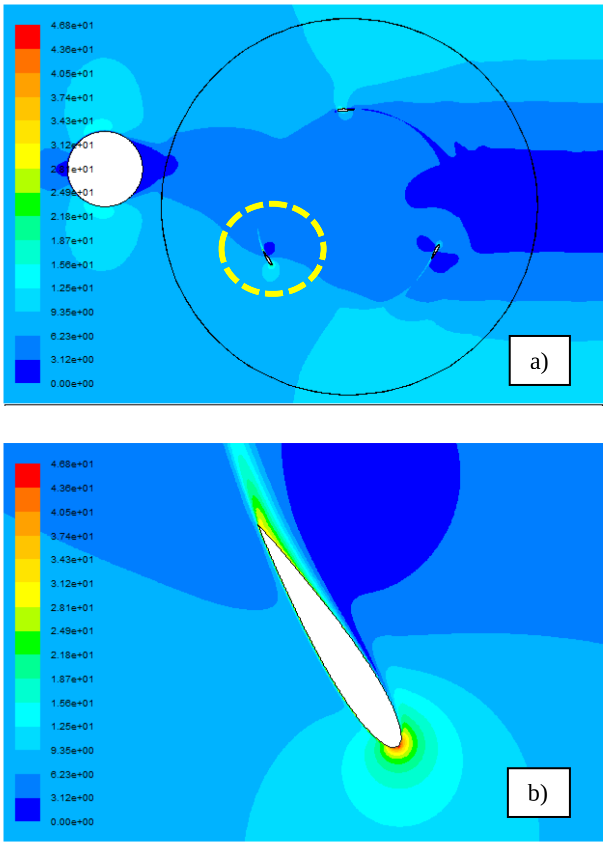

Fig. 6. Velocity contour magnitude of λ:3.3 with wind regulator.

Figure 5 and 6 illustrate numerical data of λ:3.3 both bare and with regulator case. Section that shown with yellow dashed line circle magnificated as represented in (b) for each two images. While the maximum velocity magnitude of bare case is 45.7 m/s at leading edge of the wing, on the other hand this value increased to 46.8 m/s. The wake flow region just behind the blade of the turbine was shifted from the surface of the blade with existing of the wind regulator as it can be seen from the (b) section of figure 5 and 6. Negative torque region which formed rear of the obstacle was restricted by the aid of the wind regulator.

4. CONCLUSIONS

In this experiment, NACA0015 airfoil type on a vertical axis Darrieus wind turbine have been investigated numerically using ANSYS Fluent CFD program.

As a result, some outcomes are listed below:

- When the air force was applied to the wings of the vertical axis wind turbine, maximum torque values of first blade were formed at angle of lower than 60^0 for bare case. In contrast, this angle was altered higher angles with regulator.
- Maximum torque region had been seen wide angle zone using regulator.
- Negative torque region which created by the wind direction and rotation of the wind turbine was minimized.
- Calculated value of effective TSR number increased %25 for 1.44λ. This TSR values started to decrease since 2.64λ.

Acknowledgements

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Nomenclature

A	rotor swept area (m^2)
C_P	power coefficient
D_{rotor}	rotor diameter (m)
L	rotor height (m)
k	turbulent kinetic energy
R_{rotor}	rotor radius (m)
N	number of blades
P	wind turbine power output (W)
U	free wind velocity (m/s)
TSR	tip speed ratio

Greek Letters

ε	turbulent dissipation
ω	rotor angular velocity (rad/s)
θ	rotor azimuthal position (°)
ρ	air density (kg/m3)

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