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INVESTIGATION OF THE PERFORMANCE OF A 2D H-DARRIEUS WIND TURBINE WITH DIFFERENT INLET GUIDE VANE CONFIGURATIONS

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ABSTRACT

Vertical axis wind turbines are practical solutions for the wind turbine applications. One of the great advantages of a vertical axis wind turbine is that they can work in any wind direction without a guidance mechanism. Therefore by increasing the efficiency of a vertical axis wind turbine without making the system more complicated, they can practically be used in many small scale wind energy projects. In this study, different configurations of an inlet guide vane system for a Darrieus wind turbine was investigated in a 2D numerical model. By changing the number of airfoils, which are the main elements of the system, and the angles of these airfoils, a proper configuration was found. According to the results that were acquired from the 2D numerical models, an eight airfoil inlet guide vane system which has 45^0 *angle airfoils is the best choice among the configurations that were investigated.* C_P *value of the vaneless model increased from 0.16 to 0.20 after the implementation of 8 airfoils guide vane with* 45^0.

INTRODUCTION

Satisfying the hunger of energy without harming the environment is one of the greatest challenges for civilizations. Many sources are investigated and investments were made on the technology for renewable and sustainable energy sources. Among these energy sources, wind energy is one of those renewable energy sources which occupy an important area in the renewable energy investments.

In order to harvest the energy of the wind, horizontal axis wind turbines (HAWT) are the dominant designs of wind energy sector compared to the vertical axis wind turbines (VAWT). Although HAWTs have higher efficiencies compared to the VAWTs [Mohamed et al., 2015; Parra et al., 2015 and Gosselin et al., 2013], issues like the need for high towers and guidance mechanisms make these turbines complicated solutions for different types of topographies. With an increase in efficiencies, VAWTs can be good and simple solutions for the small scale and modular wind turbine concept. Since these turbines do not need guidance mechanisms, they can work with winds from every direction, which make them a simpler technology compared to the HAWTs. Also since they work on the ground and the

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generator part is generally located at the bottom of the turbine, the maintenance of these turbines is much safer and simpler.

In order to increase VAWTs power output, many techniques were used [Wong et. al., 2017] like locating the turbine in a duct [de Santoli L. et. al., 2014 and Furukawa et. al., 2012], using a cowling device [Ali A. et. al., 2012] or placing a nozzle in front of the turbine [Nakashima et al., 2016]. A very simple method to increase the efficiency is to use guide vanes, which adjusts the inlet angle of the stream. Tabatabaeikia et. al. [2016], Poh et. al. [2014] and Chong et. al. [2014] used a row of inlet guide vanes to recover the energy in the exhaust of a cooling tower by using a Darrieus Wind Turbine. In these two studies the direction of the exhaust stream is fixed, therefore the wind direction independency, which is one of the greatest advantages of a VAWT, is ignored for these studies. In their work Takao et. al. [2009] used a row of inlet guide vanes, which position themselves according to the wind direction. Since this technique requires additional moving parts, a simpler method was used for the adjustment of the stream direction. This way is to use stator around the VAWT rotor, such as the omni-direction-guide-vane [Lim et al., 2013; Shahizare et. al., 2016a; Shahizare et. al., 2016b; Chong et. al., 2012; Chong et. al., 2013a and Wong et. al., 2014] or the vertical stator [Chen and Chen, 2015].

Another type of augmented VAWT is studied by [Nobile et. al., 2014], which was based on the model developed by [Mewburn-Crook, 1990]. In this study, CFD simulations of a Darrieus Wind Turbine surrounded by an array of airfoils were investigated. Such designs were also investigated on Savonius [Korprasertsak and Leephakpreeda, 2015] and Sistan [Chong et. al., 2013b] types of wind turbines.

In this study, the performance of an augmented VAWT, which is using a Darrieus wind turbine with different inlet guide vane configurations similar to the study of [Nobile et. al., 2014], was investigated by using 2D CFD analysis tools. The manuscript is composed of four parts, which are the introduction, methodology, results, and discussion and conclusion. Methodology part identifies the problem and the parameters that were used in the study. Results part shows the validation results and the comparison of the parameters that were done in the study. Finally, the conclusion and the discussion parts give the brief explanation of the results and the best configuration that was found.

METHOD

In this study, different configurations for the inlet guide vane additions applied to a H-type Darrieus wind turbine were investigated by using 2D CFD analysis tools.

In the first step of this study, validation of the 2D model of the three bladed H-type Darrieus turbine was made to get the correct methodology and mesh structure to solve the problem. Two different validations were made. The first validation process was made to check the mesh independency of the problem. Results were compared by changing the mesh number of the domain. The second validation was made to check the consistency of the results with the experimental value. In order to validate the results, a plain H-type Darrieus turbine experimental model was selected from the literature [Takao et. al., 2009] and the numerical results that were found in this study were compared with this study. The specifications of the Darrieus wind turbine used in this study are given in Table 1.

Table 1: Experimental features of H-Darrieus wind turbine

Number of Blades [-]	3
Airfoil Type [-]	NACA 4518
Length of Blade (L) [m]	0.7
Blade chord (c) [m]	0.1
Rotor Radius (R) [m]	0.3
Rotational speed (n) [r/min]	100-625
Velocity of wind (V_∞) [m/s]	6-18
Tip Speed Ratio (λ) [-]	0.3 – 2.3

The model was solved by using ANSYS Fluent CFD code. The model and boundary conditions were determined according to the studies of Lanzafame et al.[2014] and Balduzzi et al. [2015]. The boundary conditions, domains and the mesh structure were given in Figures 1 and 2, respectively. Since the turbine is a rotating machine a time dependent solution was made with a time step of 10^{-4} second.

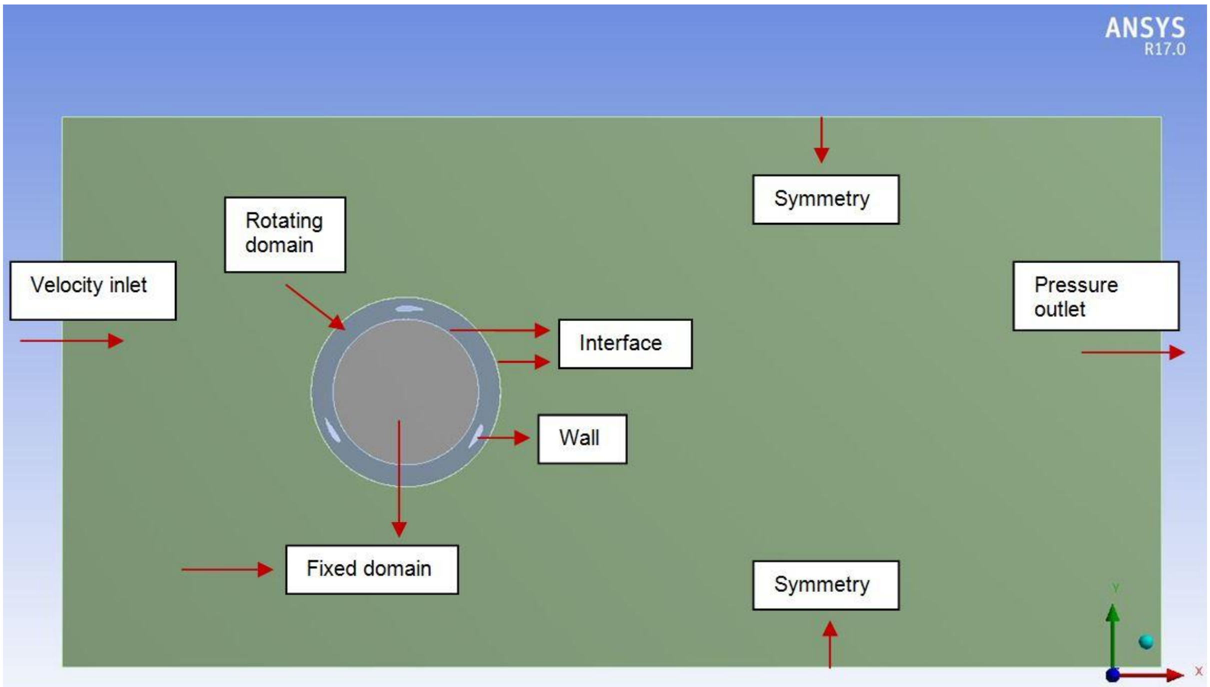

Figure 1: Boundary conditions and computational domain

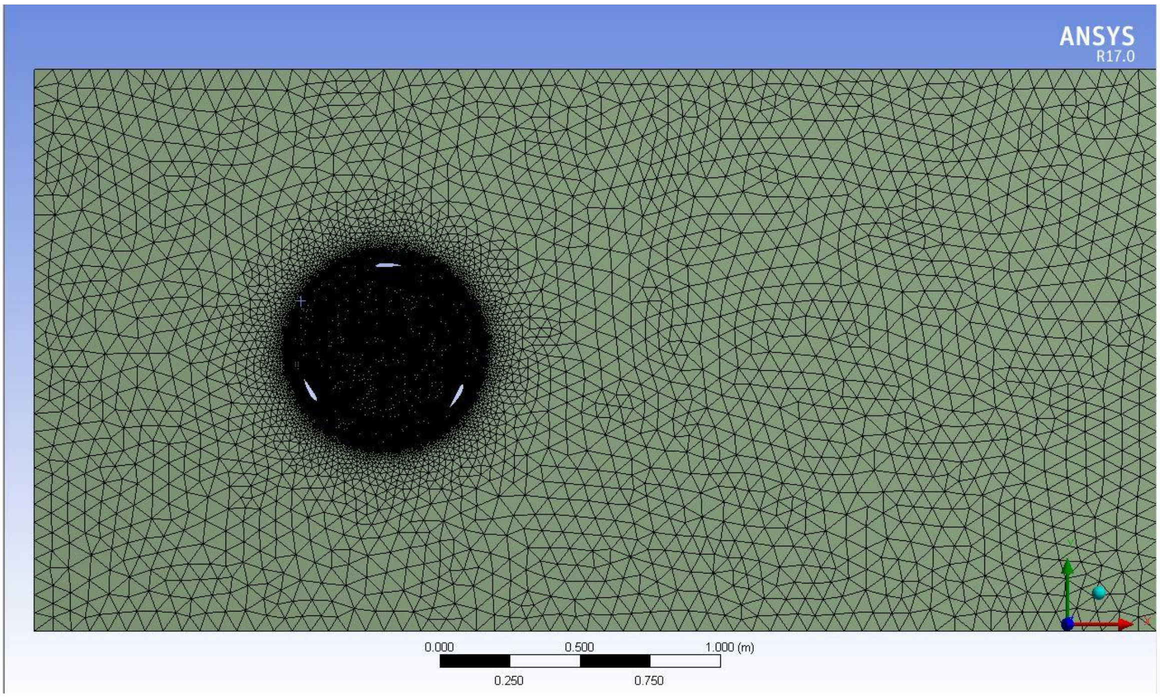

Figure 2: Mesh used in the model

As a validation parameter, power coefficients that were acquired from the selected tip speed ratio were compared. The tip speed ratio (λ) is defined as;

$$\lambda = \frac{Tip\ Speed\ of\ Turbine}{Free\ Stream\ Velocity} = \frac{\omega R}{V_\infty} \tag{1}$$

Where ω is the angular velocity, R is the radius of the turbine and V_∞ is the free stream velocity. Also the power coefficient is defined as the ratio of the power generated by the turbine to the power carried by the stream, which is given as;

$$C_P = \frac{P}{\frac{1}{2}\rho A V_\infty^3} = \left(\frac{T}{\frac{1}{2}\rho A V_\infty^2 R}\right)\left(\frac{R\omega}{V_\infty}\right) = C_T \lambda \tag{2}$$

Where T is the torque acquired from the shaft, ρ is the density of the air, A is the cross-section area of the turbine and C_T is the torque coefficient.

After the validation the results for the plain H-type Darrieus wind turbine, NACA 0012 airfoils were located around the turbine at a radius of 0.4 m to guide the stream and for this step 4, 6 and 8 airfoils were located with equal angles around the same turbine design given in the validation process at a constant angle of 30^0 (Figure 3). By comparing the power coefficients of these configurations, the best number for the airfoils was selected.

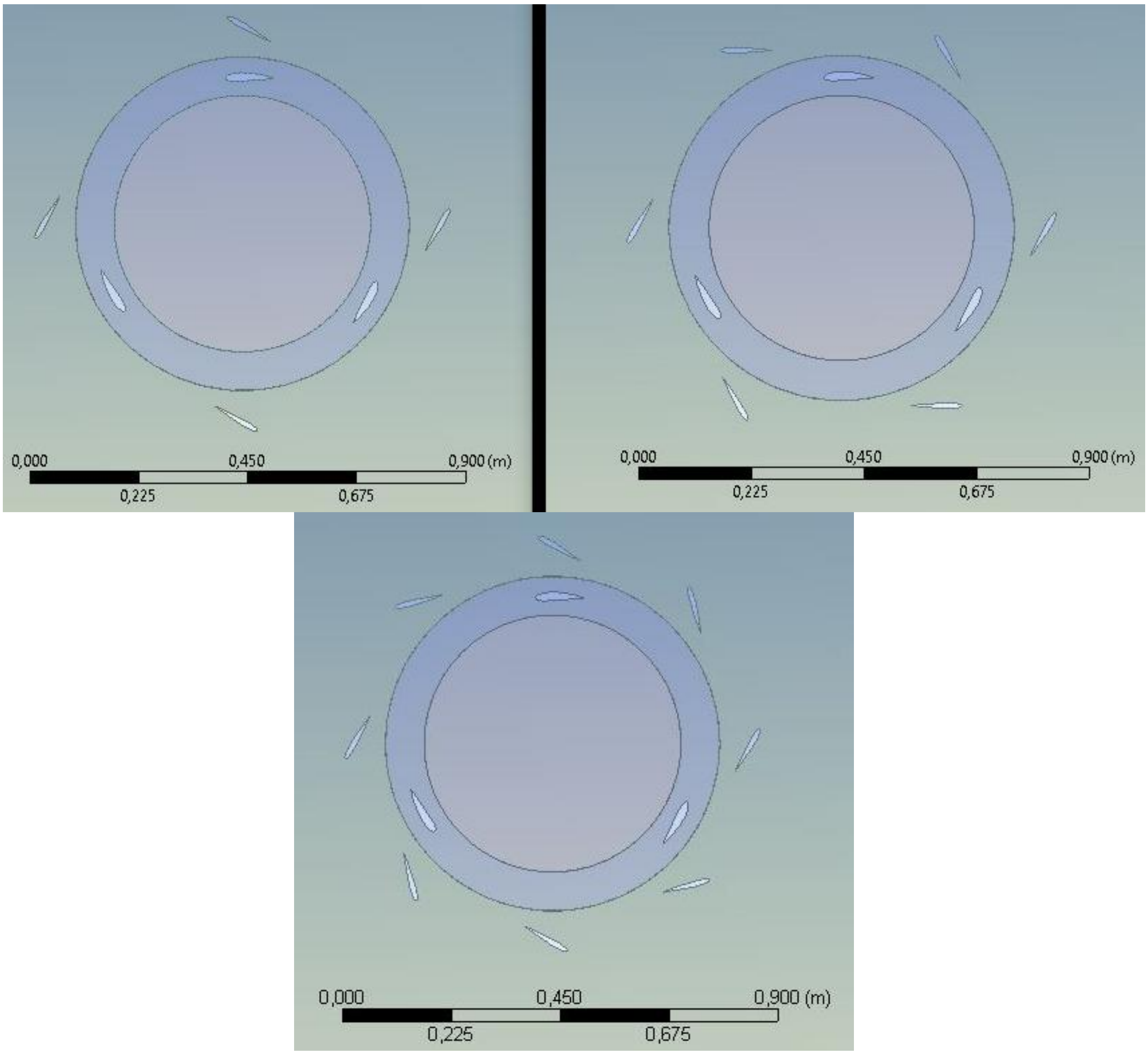

Figure 3: Darrieus turbine with 4, 6 and 8 airfoils guide vane at 30^0 angles

In the third step, by changing the angle of the airfoil (α), best configuration among the investigated cases was found. The angle of the stator mentioned in this study is the angle between the chord line of the airfoil and the line tangent to the outer circle, which the stators are located. In this study, 30^0, 45^0 and 60^0 angles were selected for the comparison.

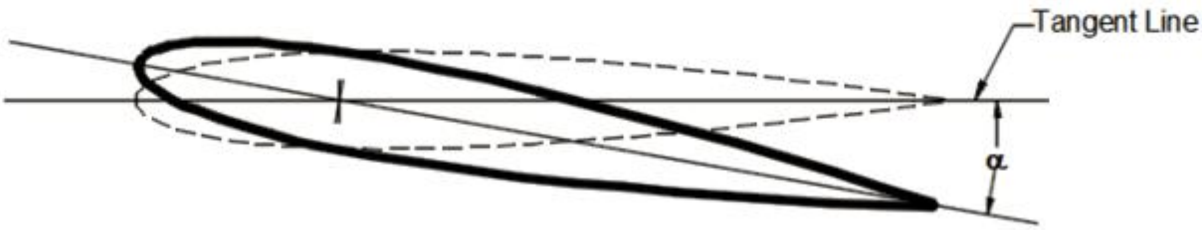

Figure 4: Angle of the inlet guide vane (α)

RESULTS

In order to validate the methods, in the first step, a 2D model of straight bladed Darrieus wind turbine was constructed, solved for different mesh densities and the results obtained from the optimum mesh structure were compared with the experimental results found by [Takao et al. 2009; Lanzafame et al. [2014].

For the mesh independency, model was solved for the 25000, 50000, 100000, 150000, 200000 and 250000 elements. According to results acquired (Figure 5) 200000 elements are enough for the solution of the model.

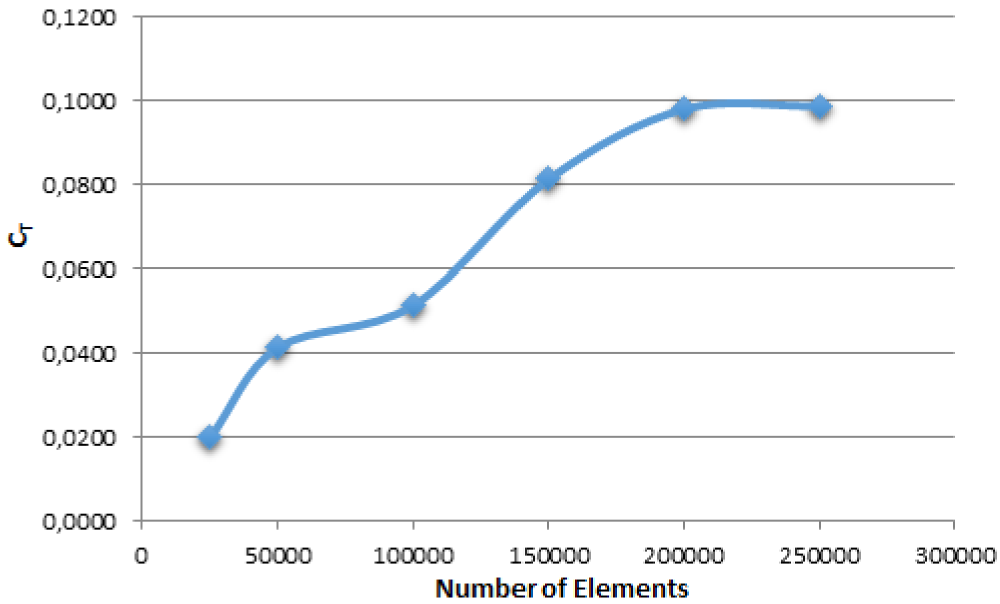

Figure 5: Mesh independency method (for λ = 1.6 and V_∞ = 8 m/s)

Also, for the 200000 elements, model was checked for the tip speed ratios of 0.4, 1.0, 1.6 and 2.2, which is given in Figure 6 and Table 2. According to results by the mesh size, boundary conditions and inflation rates are enough for a good result, which is also found in the literature [Lanzafame et. al., 2014] By using the same configuration, inlet guide vane additions were made.

Table 2: Results for the numerical model for different tip speed ratios

λ [–]	Radius [m]	A [m^2]	ω [rad/s]	V_∞ [m/s]	C_T	T [N.m]	C_P
0.40	0.30	0.60	10.67	8.00	0.0382	0.27	0.02
1.00			26.67		0.0723	0.51	0.07
1.60			42.67		0.0979	0.69	0.16
2.20			58.67		0.0467	0.33	0.10

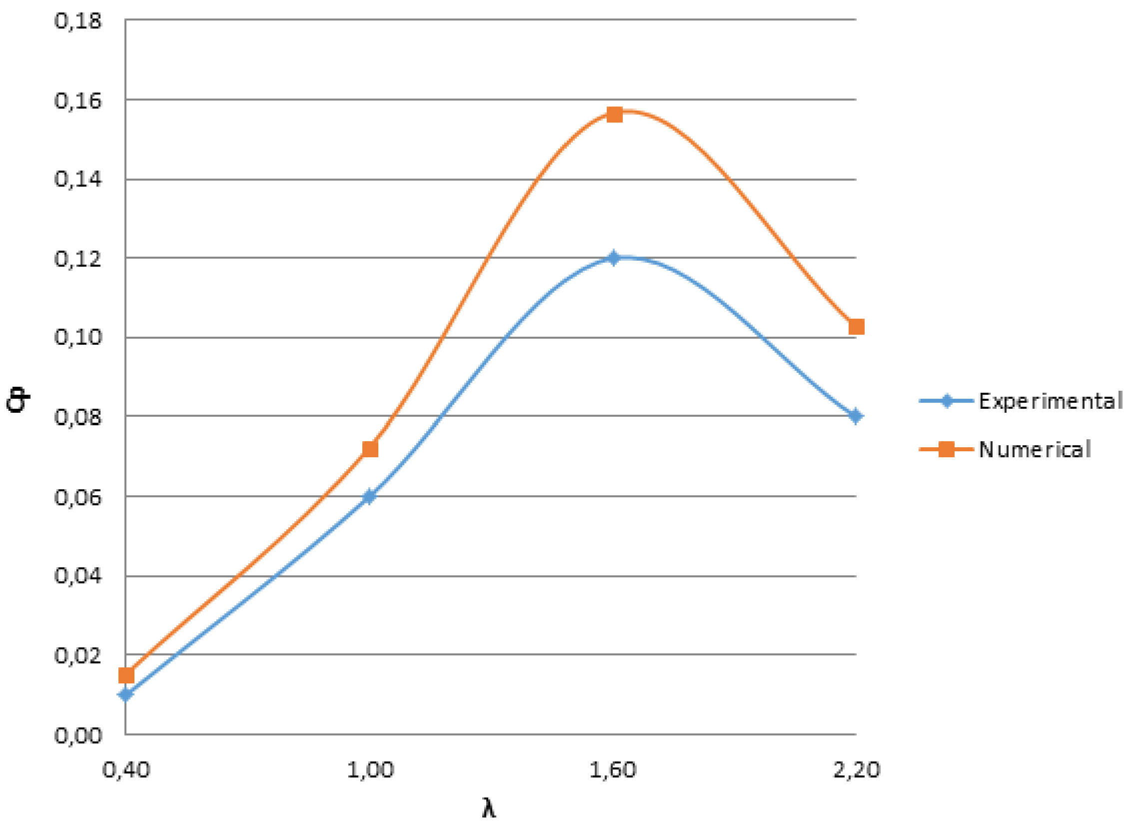

Figure 6: C_P vs λ with no guide vane configuration

In the second step of this study, performance of different number of airfoils that surrounds the turbine was investigated. For this purpose, four, six and eight airfoils were selected and placed around the turbine at a 30^0. For a tip speed ratio of 1.6 (Table 3), it is found that eight airfoil configuration is the best choice among the cases that were studied.

Final step is the determination of the best angle of the airfoil for the eight airfoil vane system. For this step, 30^0, 45^0 and 60^0 airfoil angles were selected and tested as it is given in Table 3. According to this table, it can be said that 45^0 is the best choice for the eight airfoil inlet guide vane system.

Table 3: C_P and C_T values for all configurations at $\lambda = 1.6$

Guide vanes	λ	C_T	C_P
Experimental	1.6	0.0750	0.12
No guide vane		0.0979	0.16
4 airfoils with 30^0		0.0985	0.16
6 airfoils with 30^0		0.1049	0.17
8 airfoils with 30^0		0.1146	0.18
8 airfoils with 45^0		0.1288	0.20
8 airfoils with 60^0		0.1174	0.19

Figure 7, 8, 9 and 10 show the pressure contours and velocity streamlines of vane-less Darrieus turbine and the eight airfoil inlet guide vane system. According to these figures, the inlet guide vanes directs the stream into the area, where the turbine runs and this increases the power that was acquired from the system.

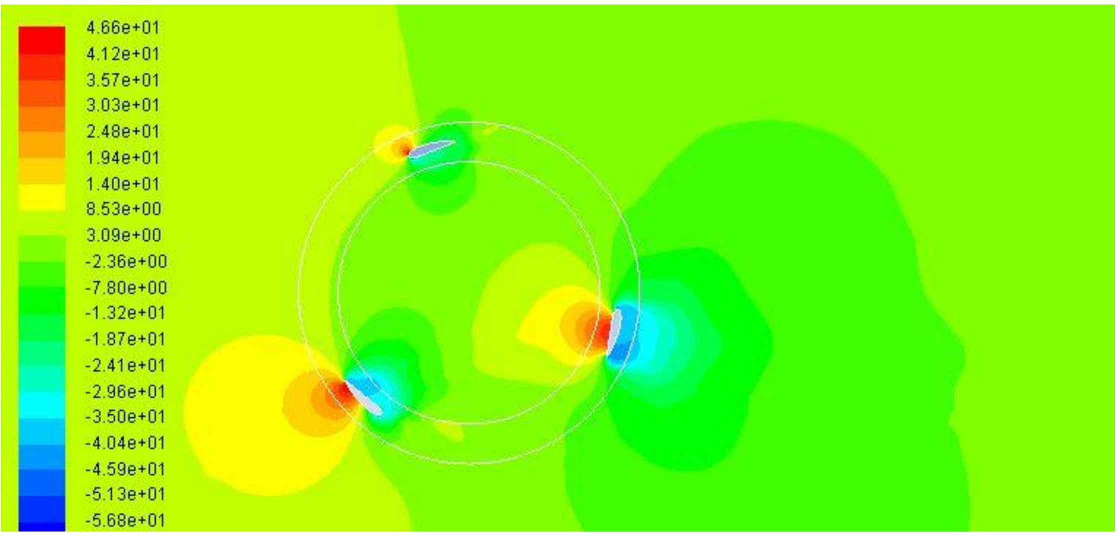

Figure 7: Pressure contours of vane-less model

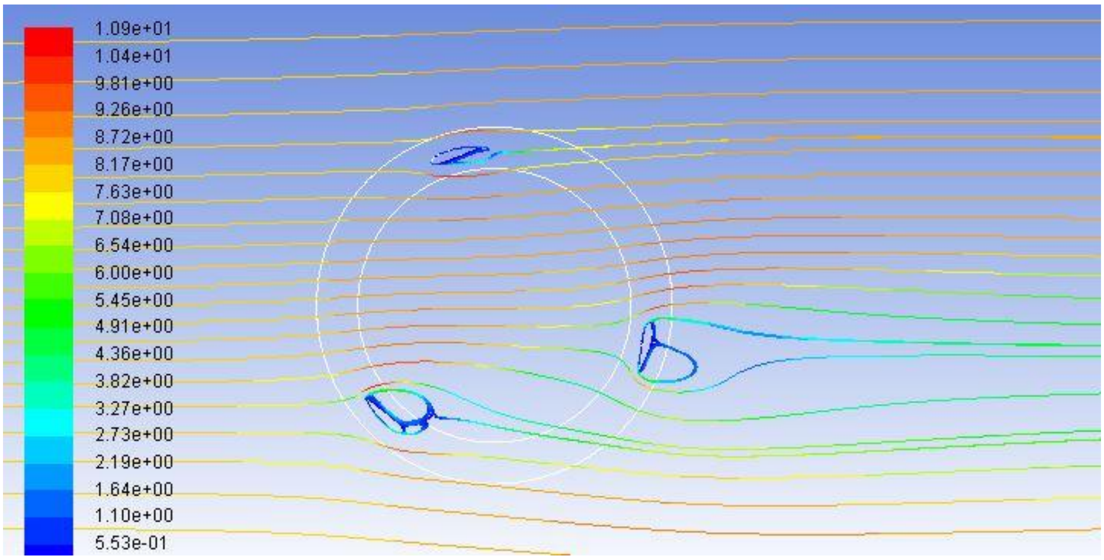

Figure 8: Velocity streamlines of vane-less model

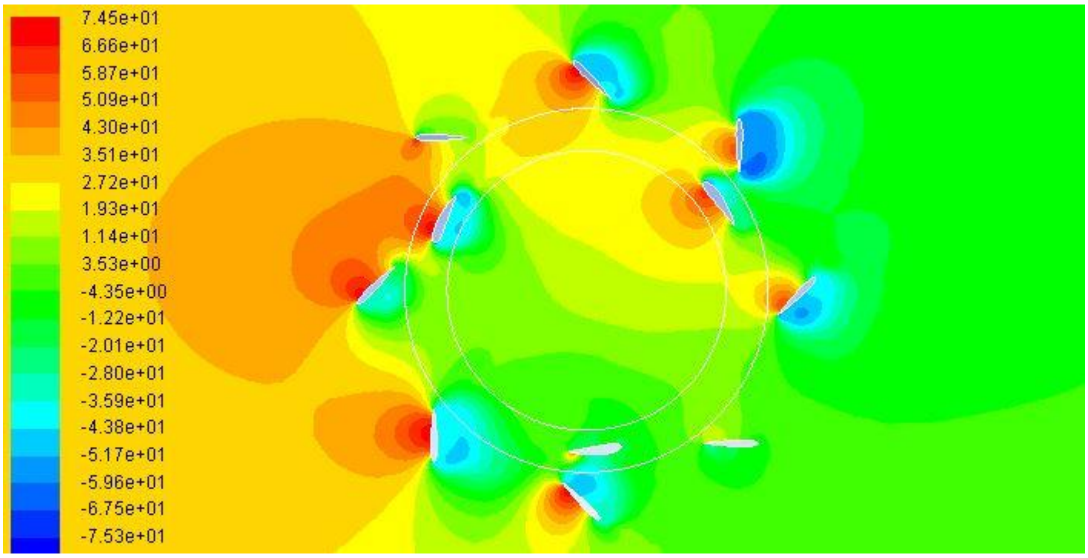

Figure 9: Pressure contours of 8 airfoil guide vane for 45^0

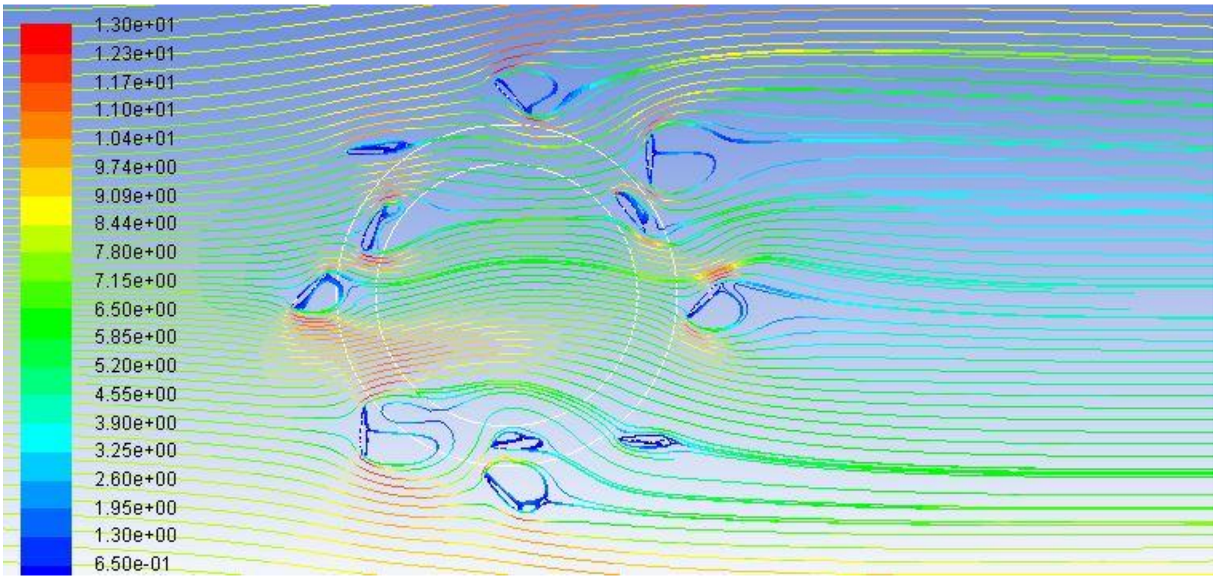

Figure 10: Velocity streamlines of 8 airfoil guide vane for 45^0

DISCUSSION and CONCLUSION

In this study, 2D CFD model of H-Darrieus vertical axis wind turbine was build in ANSYS Fluent software and compared with the experimental data which are collected from wind tunnel tests. Suitable conditions for flow and mesh structure was chosen to validate the results. After validation process, different configurations of guide vane systems were positioned around the turbine. It was shown that, the best performance increase observed with 8 airfoil guide vane system with $45^{\mathbf{0}}$ angles. The most important parameter that was used to assess the efficiency is the power coefficient. According to results it was found that the plain H-type Darrieus wind turbine and the Darrieus wind turbine with eight bladed inlet guide vane system for $45^{\mathbf{0}}$ angle are 0.16 and 0.20 which means a 25% increase in power generation.

References

Ali, A. et. al. (2012*) Experimental and computational study of a micro vertical axis wind turbine*, Procedia Eng, 49, p:254–62.

Almohammadi, K.M., et al. (2013) *Computational Fluid Dynamics (CFD) Mesh Independency Techniques for a Straight Blade Vertical Axis Wind Turbine,* Energy, Vol. 58, p: 483-493, Jul 2013.

ANSYS, Inc. *ANSYS Fluent Theory Guide,* 2013

Balduzzi, F., et al. (2015) *Critical issues in the CFD simulation of Darrieus wind turbines,* Renewable Energy, Vol.85, p: 419-435, Jul 2015.

Castelli, M.R., et al. (2010) *Modeling strategy and numerical validation of Darieus Vertical Axis Micro-Wind Turbine,* International Mechanical Engineering Congress & Exposition, Nov 2010.

Chen, T.-Y., Chen, Y. –Y. (2015) *Developing a Vortical Stator Assembly to Improve The Performance of Drag-Type Vertical-Axis Wind Turbines*, Journal of Mechanics, Vol. 31, No. 6, p: 693-699.

Chong, W.T. et. al. (2012) *Vertical Axis Wind Turbine with Omni-Directional-Guide-Vane For Urban High-Rise Buildings*, Journal of Central South University of Technology, 19, p: 727-732.

Chong, W.T. et. al. (2014) *The Experimental Study on the Wind Turbine's Guide-Vanes and Diffuser of an Exhaust Air Energy Recovery System Integrated with the Cooling Tower*, Energy Conversion and Management, 87, p: 145-155.

Chong, W.T., et al. (2013a) *The Design, Simulation and Testing of an Urban Vertical Axis Wind Turbine with the Omni-Direction-Guide-Vane,* Applied Energy, Vol. 112, p: 601-609, Jan 2013.

Chong, W.T. et. al. (2013b) *Performance Investigation of a Power Augmented Vertical Axis Wind Turbine for Urban High-Rise Application*, Renewable Energy, 51, p: 388-397.

Daroczy, L., et al. (2015) *Comparative Analysis of Turbulence Models for the Aerodynamic Simulation of H-Darrieus Rotor,* Energy, Vol. 90, p: 680-690, Aug 2015.

De Santoli, L., et. al. (2014) A preliminary energy and environmental assessment of a micro wind turbine prototype in natural protected areas, Sustainable Energy Technologies and Assessments, 8, p:42–56.

Durrani, N., et al. (2011) *A Detailed Aerodynamic Design and Analysis of 2D Vertical Axis Wind Turbine Using Sliding Mesh in CFD,* AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Jan 2011.

Furukawa, A. et. al. (2012) *Research on Darrieus-Type Hydraulic Turbine for Extra-Low Head Hydropower Utilization. IOP Conference Series: Earth and Environmental Science,* Volume 15, Part 1

Gosselin, R., et al. (2013) *Parametric Study of H-Darrieus Vertical Axis Wind Turbines Using uRANS Simulations,* 21st Annual Conference of the CFD Society in Canada, May 2013.

Korprasertsak, N., Leephakpreeda, T. (2015) *CFD-Based Power Analysis on Low Speed Vertical Axis Wind Turbines with Wind Boosters. Energy Procedia,* 79, p: 963-968.

Lanzafame, R., et al. (2013) *2D CFD Modeling of H-Darrieus Wind Turbines Using Transition Turbulence Model,* Energy Procedia, Vol. 45, p: 131-140.

Lim, Y.C. et. al. (2013) *Performance Investigation and Optimization of a Vertical Axis Wind Turbine with the Omni-Direction-Guide-Vane,* Procedia Engineering, 67, p: 59-69.

Mewburn-Crook, A. (1990) *The Design And Development Of An Augmented Vertical Wind Turbine,* PhD. Thesis, Kingston Polytechnic.

Mohamed, M.H., et al. (2014) *CFD Analysis for H-Rotor Darrieus Turbine as a Low Speed Wind Energy Converter,* Engineering Science and Technology, an International Journal, Vol. 18, p: 1-13, 2015.

Nakashima, K. et. al. (2016) *Performance Prediction of Darrieus-Type Hydroturbine with Inlet Nozzle Operated in Open Water Channels,* IOP Conference Series: Earth and Environmental Science, Volume 49, Sustainable Hydropower.

Nobile, R. et. al. (2014) *Unsteady Flow Simulation of a Vertical Axis Augmented Wind Turbine: A Two-Dimensional Study,* Journal of Wind Engineering and Industrial Aerodynamics, 125, p: 168-179.

Parra, T., et al. (2015) *Design of H-Darrieus Vertical Axis Wind Turbine,* EPJ Web of Conferences, Vol. 92, 2015.

Poh, S.C. et. al. (2014) *Computational fluid dynamics simulation of the effect of guide-vane angles on the performance of the exhaust air energy recovery turbine generator,* Energy Procedia, 61, p: 1286-1289.

Shahizare, B. et. al. (2016a) *Investigation of the Optimal Omni-Direction-Guide-Vane Design for Vertical Axis Wind Turbines Based on Unsteady Flow CFD Simulation,* Energies, 9, 146, doi: 10.3390/en9030146.

Shahizare, B., et al.(2016) *Novel Investigation of the Different Omni-Direction-Guide-Vane Angles Effects on the Urban Vertical Axis Wind Turbine Output Power via Three-Dimensional Numerical Simulation,* Energy Conversion and Management, Vol. 117, p: 206-217, 2016.

Tabatabaeikia, S. et. al. (2016) *A Comparative Computational Fluid Dynamics Study on an Innovative Exhaust Air Energy Recovery Wind Turbine Generator,* Energies, 9, 346, doi:10.3390/en9050346

Takao, M., et al. (2009) *A Straight-Bladed Vertical Axis Wind Turbine with a Directed Guide Vane Row –Effect of Guide Vane Geometry On the Performance,* Journal of Thermal Science, Vol.18, p: 54-57, Jun 2009

Wong, K.H. et. al. (2014) *The Design and Flow Simulation of a Power-Augmented Shroud for Urban Wind Turbine System,* Energy Procedia, 61, p: 1275-1278.