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Research Article

FLUID DYNAMICS MODEL FOR EFFECT OF WIND FLOW ON WIND TURBINE BLADES TO OPTIMIZE DESIGN OF BLADES

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ABSTRACT
In this study, the blade's form to optimize the flow regime at the back of wind turbine via numerical method has been examined. Kuhin, a city in the capital of Kuhin District, in Qazvin County, is a region under study, that its information has been mentioned in the article. This study aims to determine wind turbine class based on the obtained information and select the most suitable wind turbine for settlement at region. It can examine wind flow regime before and after encounter with wind turbine blades via software Fluent. Results indicate that the more we get far from turbine, size of minimum and maximum speed decreases, yet rate of uniformity of speed at the back of turbine undergoes decline. Further, three areas with axial speed under other areas at the middle radius of blades have been witnessed.

Keywords: *Wind Turbine, Optimization, Blade, Fluent, Flow Regime*

INTRODUCTION
Currently, return in wind turbines has widely reached to existing theory of wind turbine, under which it can assume industry of wind turbine as a prevalent industry with low growth. Yet, recent research has transformed old presumptions. According to the existing research, how to arrange wind turbines at a wind turbine farm can increase the total return for electricity generation to a large extent. Previously, it was believed in increasing size of turbine, using turbine at coasts, putting the governments under pressure to increase the share for wind energy at energy market as the most important barriers in development of electricity generation (Jones and Bouamane, 2011). In 1891, a person from Denmark, designed the first wind system via aerodynamic blades and used the best tower windmill. Higher speed at the movement of blades caused generation of more electricity (Dhanju *et al.*, 2005). In 1931, wind turbines 'Darrieus' well known with 'egg beate' were invented by a French engineer. The biggest wind turbine with the capacity of 1.25 MW was installed in Vermont. This turbine has been made from horizontal axis with 2 blades with a diameter of 175 feet across the wind. This turbine's rotor is made of stainless steel with the weight of 16 tons that its control system was set to 28 rpm. In 1945, one of the blades was destroyed after a few hundred hours of continuous work, due to metal abrasion and corrosion. In 1996, Ramsay and Gregorek examined effect of fine dusts and the volatility from their impacts on a particular airfoil shape (Ramsay *et al.*, 1996). Phillips *et al.*, (1999) examined effect of a diffuser around the blades of wind turbine. Vortec 7 is the first practical sample of diffuser for wind turbine. Vendan1 et al examined overview of NACA Profile 63 (Vendan *et al.*, 2010). This study has been conducted aiming at design of wind turbine for wind at low speed at urban areas, which the main focus on this research is to design the blade under high conditions. NACA Profile 63 has been selected for design of wind turbine, due to proper characteristics for the wind at lower speed. NACA 63-415 airfoil profile has been selected for analysis, which such profile has been made via a file in Java foil. Meshing flow around airfoil has been fulfilled via software ANSYS and analysis of CFD has been fulfilled via STAR-CMM+ at different attack angel ranging from 0° to 6°. Lift and drag coefficients have been calculated at low Reynolds number airfoils and low Reynolds number airfoils. In 2001, PAREZANOVIC et al fulfilled a practical experiment and theoretical analysis in an article entitled "DESIGN OF AIRFOILS FOR WIND TURBINE BLADES" (Parezanovic *et al.*, 2001). Design of an airfoil to increase the return at wind turbine is the most important point. Any aerodynamic surface must be set under a practical experiment at wind turbine so as to specify the rate of return and efficiency. In this research, it has been indicated that we can reduce the costs at practical experiment via modern technology and design method. This research has put a huge emphasis on

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computer simulation of plant sites to arrange wind turbines via professional wind software. Clausen *et al.*, (2004) examined a 5 Kw turbine in a study entitled "Advanced Blades for Small Wind Turbines" (Clausen *et al.*, 2004). In this research, design and construction of a 2.5 meter blade made from fiberglass for a 5 KW wind turbine have been considered. This blade has been made of fiberglass and tested under fatigue, found with a desirable shape with improvement of blade shape. Notably, this blade was modeled via software 'Solid Works' and meshed via software ANSYS. Bernhard (Stoevesand *et al.*, 2005) considering a wind turbine examined effect of turbulence in a high-pressure shock on wind turbine blades, in which they acquired critical states for blades and analyzed the results obtained from these empirical data via a variety of diagrams. Marcus *et al.*, (2005) examined wind turbulent flow based on Reynolds model and represented a numerical simulation to determine the loads due to wind flow on blades and discussed on turbulent flow at the results of simulation. Sofian Mohd, Abas Ab Wahab examined behavior of a wind turbine at high-pressure wind force (Mohd and Wahab, 2006). In this research, Finite Element Analysis (FEA) has been used to achieve an accurate design for rotor in wind turbine to the diameter of 10 meter under maximum pressure at wind force at speed of 36 m/s. finally, an optimal and secure design for rotor of turbine for working at the pressure and force obtained from wind speed via fluid dynamics under static and dynamic conditions. Vianna *et al.*, (2008) considered aerodynamic optimization of wind turbine blade. In this research, optimization operations for design of a blade in wind turbine at two stages of aerodynamic design and body design have been fulfilled. They deduced that the optimized rotor via method QEA has more power than method Schmitz. Pathike *et al.*, (2009) examined optimization of airfoil for wind turbine at small horizontal axis. They believed that small turbines to generate energy at low range do not exist, that setting them at urban areas without sufficient space and low wind speed will have the best return.

Kathryn *et al.*, (2009) examined control over wind farm and representation of mutual aerodynamic effect of turbines on each other. In this research, mutual effect of turbines on each other at wind farm has been considered, stating, a return named "Aη" is defined in a wind farm. They believe that it can reduce the cost of energy and increase return without use of sensor to control effects of turbines on each other and observance of distance and length and width of farm. The best transverse distance for two 4.6 MW turbines has been mentioned 300 meters and the best longitudinal distance for a 2.7 and 4.6 MW turbines has been mentioned 300 meter via software MATLAB. Further, they have deduced that it can reach to the best function at wind farm regarding wind speed under control of angle of attack and λ. Mansour and Yahyazade (2011) examined effects of turbulence model in computational fluid dynamics of horizontal axis wind turbine aerodynamic in three turbulence models. Results of turbulence modeling enjoy a high confidence degree. The blades been have set at angle of twist(12˚), that the results have been recorded for different turbulence states regarding standards RNG K-ε and SPALART-ALLMARAS, and compared with empirical data at National Renewable Energy Laboratory (NREL)for two different speeds. This research indicates that CFD calculations for Horizontal-Axis Wind Turbine based on RNG K- ε at low speed has more adjustment with empirical data and model SPALART-ALLMARAS at high speed has more adjustment with empirical data.

Yu-Ting (2012) in a study on Atmospheric Turbulence Effects on Wind-Turbine Wakes presented a numerical study of atmospheric turbulence effects on wind-turbine wakes. In their study, large-eddy simulations of neutrally-stratified atmospheric boundary layer flows through stand-alone wind turbines were performed over homogeneous flat surfaces with four different aerodynamic roughness lengths. Emphasis is placed on the structure and characteristics of turbine wakes in the cases where the incident flows to the turbine have the same mean velocity at the hub height but different mean wind shears and turbulence intensity levels. The simulation results show that the different turbulence intensity levels of the incoming flow lead to considerable influence on the spatial distribution of the mean velocity deficit, turbulence intensity, and turbulent shear stress in the wake region. In particular, when the turbulence intensity level of the incoming flow is higher, the turbine-induced wake (velocity deficit) recovers faster, and the locations of the maximum turbulence intensity and turbulent stress are closer to the turbine. A detailed analysis of the turbulence kinetic energy budget in the wakes reveals also an important effect of

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the incoming flow turbulence level on the magnitude and spatial distribution of the shear production and transport terms (Wu and Port´e-Agel, 2012). Arvind singh Rathore in a study entitled "Aerodynamic Analyses of Horizontal Axis Wind Turbine by Different Blade Airfoil Using Computer Program", an aerodynamic analysis tool for analysis of horizontal axis wind turbine blades is developed by using both Blade Element Momentum (BEM) Theory and Computer Program. The method is used to optimize blade geometry to give the maximum power for a given wind speed, a constant rotational speed, a number of blades and a blade radius. The airfoil profiles and their aerodynamic data are taken from an existing airfoil database for which experimental lift and drag coefficient data are available. The goal of this study was to analyze the effects of different airfoil profiles blade on the overall wind turbine performance. In their research, a program written via language C-SHARP has been used. With regard to overview on research at the area of wind turbine and energy generated from wind force for over 25 years, it can clearly come to an end in this way that the most leading issues in wind turbines lies on increasing the return at wind turbine, for which the researchers have made an attempt to design and optimize optimum shape of airfoil for small horizontal-axis wind turbine so as to achieve a higher return by selection of a suitable shape for airfoil for the wind turbine blade (Rathore and Ahmed, 2012). In present research, the fluid dynamic model for effect of wind flow on wind turbine blades to optimize design of blades has been considered based on overview of various issues during years. In this regards, the main purpose is to determine the wind class at region based on the obtained information and select the most suitable wind turbine to settle it at the region.

Problem Statement

Selection of a Wind Turbine at Windy Sites

Characteristics of Wind Turbine

Wind turbines are grouped into different classes based on their tolerance and ability against wind conditions corresponding to standard IEC 61400- 1 Rev2 . These classes are grouped based on extent of mean of wind flow during 10 minutes with the probability for occurrence of stronger wind for once per 50 years and mean of wind speed per year at the height of turbine.

Table 1: Turbines classes based on standard IEC

WT classes	**I**	**II**	**III**	**IV**
V_{ref} [m/s]	50.0	42.5	37.5	30.0
V_{ave} [m/s]	10.0	8.5	7.5	6.0
A_{I15}	0.18	0.18	0.18	0.18
B_{I15}	0.16	0.16	0.16	0.16

The numbers shown in table represent maximum value pertaining to each wind class. Where Vref, Vave, A, B and L15 represent 50 years mean for hurricane wind during 10 minutes, annual mean for wind speed at hub height, subgroup for characteristics of hurricane and severe turbulence, subgroup for characteristics of hurricane and poor turbulence, amount of turbulence at speed of 15 m/s. To select type of wind turbine, Vave and Vref are calculated at first stage, yet a certain arrangement at wind farm is considered to calculate severity of turbulence that encompasses the turbulence due to function of turbines on each other.

Hurricane Wind

With regard to standard IEC, the reversible period has been organized during 50 years. Speed of basic wind (Vref) represent mean of wind speed per 10 minutes during 50 years. Parameter (Vref) is determined based on the anemometer operations at site by means of software wind. To specify the value of Vref at hub height of wind turbines, the equation below is used based on standard EC 61400-1.

$$v_{ref\_hub}(z) = 1.4 v_{ref} (z / z_{hub})^{0.11} \quad (1)$$

Annual Mean for Speed of Wind

The value obtained for annual mean of wind speed has been deduced based on anemometer operations at Kuhin site, obtained equal to 8.4 m/s at hub height of turbine. The value for mean of wind speed per year at more hub heights via power law is deduced based on equation below:

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$$v(z) = v_{hub}(z/z_{hub})^{\alpha} \quad (2)$$

α represents a coefficient which is determined based on table 2 at each region.

Table 2: Coarseness of different regions with different coverings

Characteristics of land	Coarseness z_0 (m)
Flat	0.0001-0.0005
Snowy	0.003
Flat grass	0.008
Grassland	0.01
Plowed field	0.03
Farmland	0.05
Little tree	0.1
Large trees , bushes and small buildings	0.25
Forest	0.5
countryside	1.5
Tall buildings	3.0

Determination of Wind Class at Kuhin Station

With regard to the contents above, it can obtained 50 years mean for speed of hurricane wind during 10 minutes (Vref).
There will be for Kuhin station: Vref=2.37 m/s
There will be Vave=3.8 m/s based on table above.
With regard to information above and table 1, the wind class at Kuhin region will represent II.
Determination of Wind Turbine corresponding to Wind Class at Region
As the wind class represents class II at Kuhin station, wind turbine V47–660 kW was selected.
Solution Method
Turbine blade was modeled in software catia. A turbine blade has been developed from different sections with a different profile shape that the three-dimensional pattern of blade is developed at software catia. The rest of turbine components were modeled in software solid work. Figure 1 represent three-dimensional model of turbine blade at software CATIA.

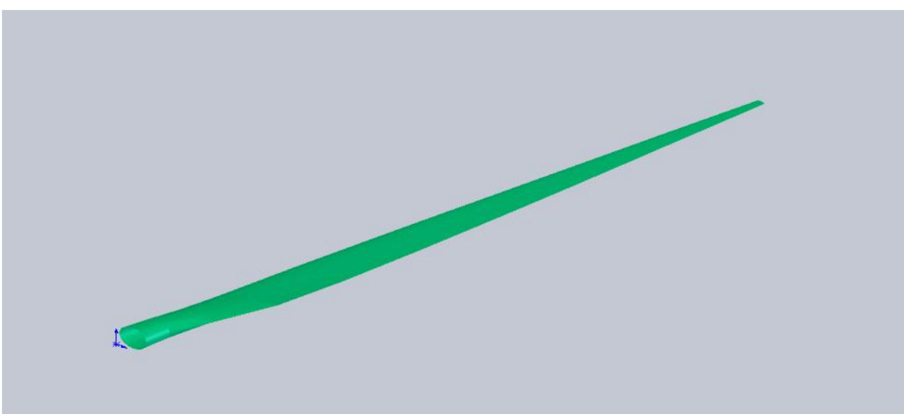

Figure 1: Three-dimensional model for turbine blade at software CATIA

The thorough Three-dimensional Model of Wind Turbine V47–660 kW
Analysis of wind flow behavior before encounter with wind turbine blade and after encounter to wind turbine has been made via software Fluent. Figure 2 represents three-dimensional model for wind turbine V47–660 kW.

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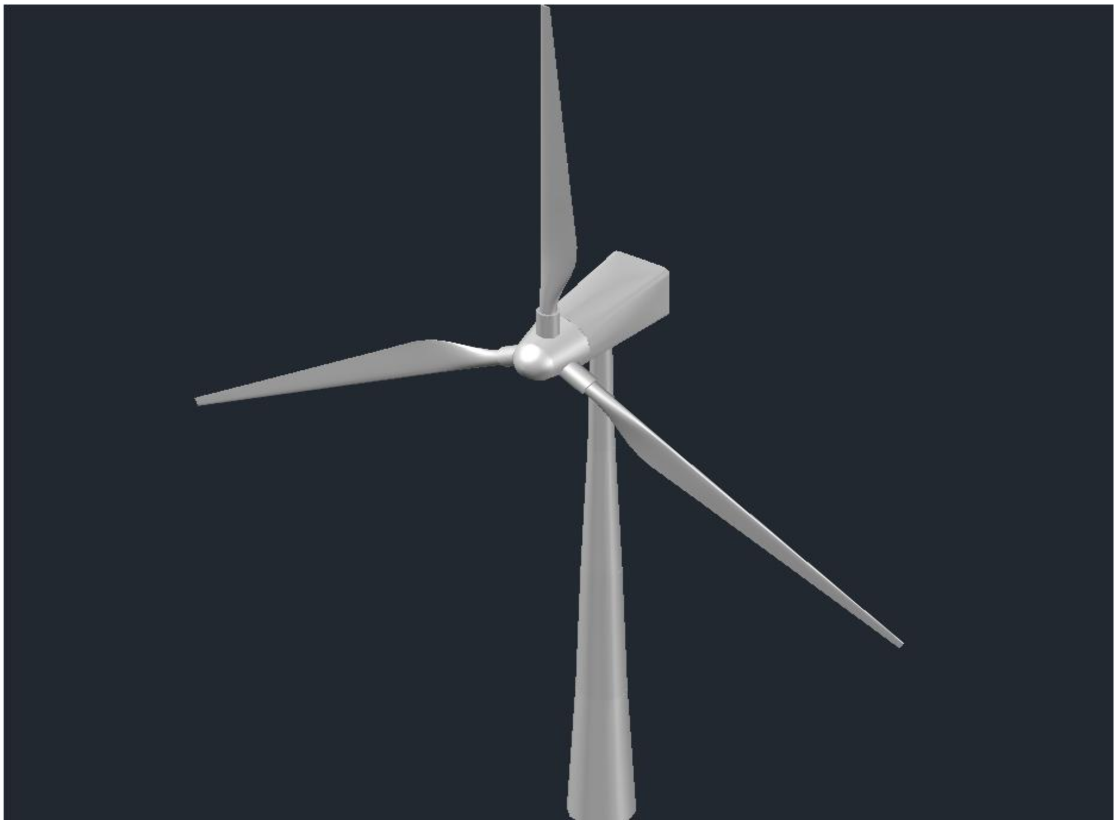

Figure 2: Three-dimensional model of wind turbine V47–660 kW

The Method for Flow Solution
Here, the solution for equations governing fluid movement is represented via software finite element method. Displacement attacks at momentum equation appear in discrete form via second-order upstream method and modification of pressure and speeds appear via simple method. Flow turbulence has appeared via model SST K- ω which is one of turbulence models at engineering applications, that has more power in estimation of key aspects of rotational flows than other models (Jones and Bouamane, 2011). It should be noted that standard wall function has been used to define the behavior close to wall. This function must be used in elements with maximum limit +y equal to 300 in order to have suitable accuracy. Dynamic density and viscosity of air has been considered equal to 1.225 kg/m^3 and 1.79 m/s. speed of wind flow equals to 13 m/s and the angular velocity of turbine equals to 5/28 rpm. It should be noted that the Convergence criteria has been determined equal to 10^{-4}. In this section, the flow has been assumed permanently, in which the spinning reference technique has been used. In this method, a simple method to resolve problems includes moving boundary, under which it is assumed that the coordinates system has set on blades and rotated with it. Hence, new sentences such as Coriolis effect are added to the left side of momentum equation.

Control of Program
It should be noted that independence of responses must be examined via the points existing in the network, that ultimately a suitable network must be selected. To examine independence of the results form numerical solution from network, five types of network via different number of cells have been generated via a networking model. The networking on surface of blades at each of networks has been indicated in figure 3. Numbers of cells, generation power and maximum parameter Y+ on surface of blade at each network have been compared with each other in table. In table 3, different networks have been compared with each other. As shown in table 3, networks 1 and 2 have not been seen with sufficient accuracy for modeling, not predicting the generation power in a proper way.

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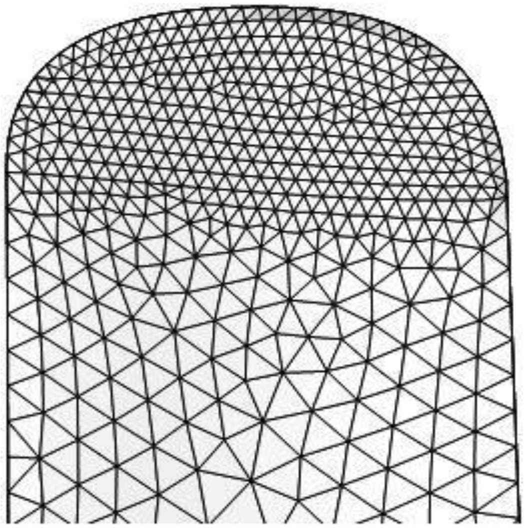
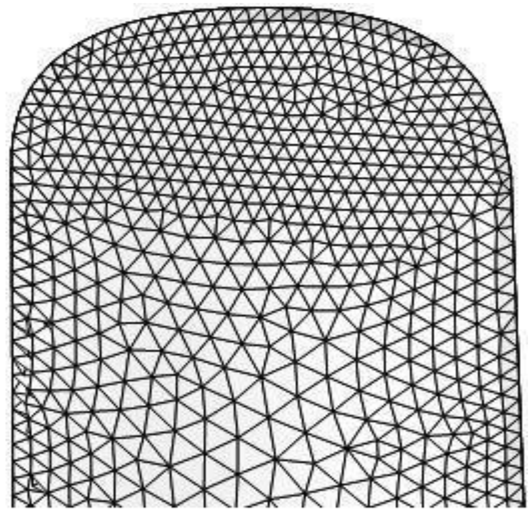
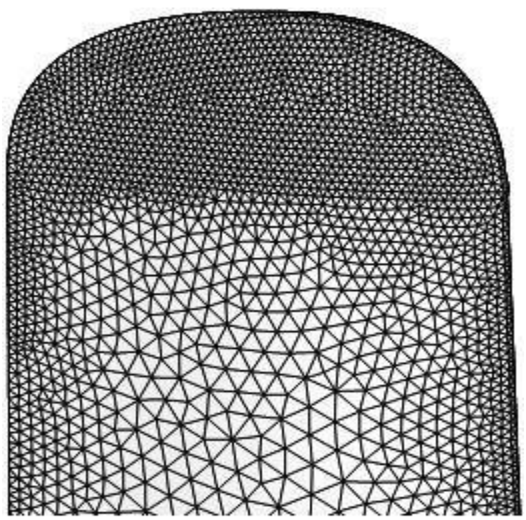


Network 1

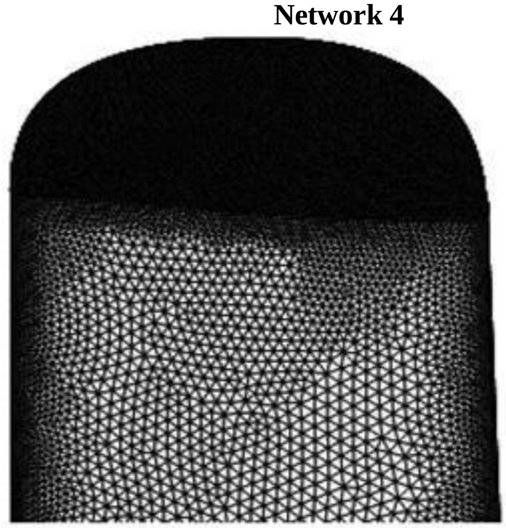


Network 2



Network 3

Network 4

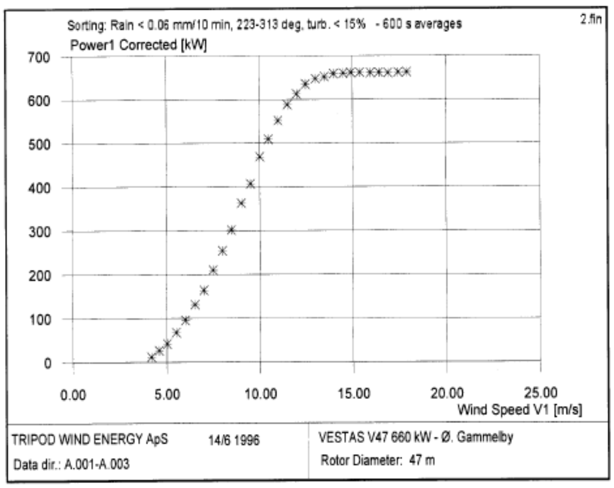


Network 5

Figure 3: Networking on surface of blades at different networks

Table 3: Comparison of different networks

Network	Number of cells	Power generation(KW)	Maximum Y+
1	0/67	955	2200
2	1/25	752	1700
3	3/9	592	1445
4	4/1	650	772
5	5/3	700	290
6	5/4	720	250



The measured power curve is corrected to the standard air density of 1.225kg/m^3.

TRIPOD WIND ENERGY : 14/6-1997 14:59 (2.fin)

Object of bin-analysis : Sorting: Rain < 0.06 mm/10 min, 223-313 deg turb. < 15%
: VESTAS V47 660 kW - Ø. Gammelby
: Rotor diameter: 47 m
Data directories : \A.001 - \A.003
Basic averaging time : 60.00 secs
Final averaging time : 600.00 secs

X-axis (bins) : Wind speed V1 [m/s]
Y-axis (binned) : Power1 Corrected [kW]

X-bin	# data	mean(Y)	rms(Y)	min(Y)	max(Y)
4.17	4	11.75	1.58	9.41	13.31
4.58	36	26.46	7.22	11.77	42.61
5.02	90	41.79	8.35	25.42	57.86
5.50	97	67.86	12.85	43.90	121.74
6.00	119	95.69	14.21	65.51	165.56
6.51	133	131.45	18.04	95.44	230.63
6.99	142	164.31	17.77	119.24	205.93
7.49	128	209.85	20.23	174.14	268.28
7.99	83	253.80	22.68	193.43	318.20
8.47	69	301.19	22.79	262.51	360.79
9.02	68	362.48	27.29	308.11	423.27
9.51	60	406.70	31.41	322.22	482.98
10.01	67	468.74	38.10	378.42	548.99
10.47	70	508.55	36.66	393.63	614.14
10.99	86	551.26	26.27	476.08	602.81
11.50	59	587.82	27.41	498.62	649.74
11.99	48	612.36	16.74	577.32	647.15
12.48	41	634.38	15.86	592.10	657.99
13.01	33	646.79	12.15	609.59	661.80
13.49	25	651.40	10.01	626.58	660.70
13.99	24	658.40	4.63	645.43	662.67
14.50	32	659.46	3.61	645.79	662.79
14.91	13	661.11	1.85	656.63	662.91
15.39	11	661.16	1.54	658.73	662.91
15.96	7	660.87	1.04	659.71	662.91
16.42	8	661.22	1.27	659.83	662.79
16.91	6	660.49	0.99	659.71	662.67
17.45	4	661.47	1.16	660.08	662.79
17.91	1	662.42	0.00	662.42	662.42
Total	1564				

Figure 4: Empirical information of turbine

To examine accuracy at results, it can compare the obtained data with the values reported from actual measurements. As shown in figure 4, the reported value for turbine power equals to 658 KW. This is in a way that the calculated value equals to 720 KW which equals to 10% error. The contributing factors in error include:

-the reported power in catalog is the electricity power generated via turbine, yet the calculated power via software is the mechanical power of rotor. It is obvious that the mechanical power of rotor and electrical power of generator differ from each other due to return in power transmission system.

-at any simulation, a certain rate of error on effect of error at model, a certain rate of error on effect of computational methods and a rate on effect of raising discrete range of solution are built that cannot be removed.

RESULTS AND DISCUSSION

Results

The convergence at numerical solution in periodic model has been displayed via display of the curve showing changes in residuals in figure 5 based on number of repetitions. According to this figure, after 500 repetitions, each of the residual curves has reached to a suitable rate, so that the highest residual rate

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equals to 10^{-4}. The convergence in numerical solution with display of the curve representing the force entered to each of blade surfaces based on time has been represented in figure 5. As shown, this parameter has reached to a certain rate.

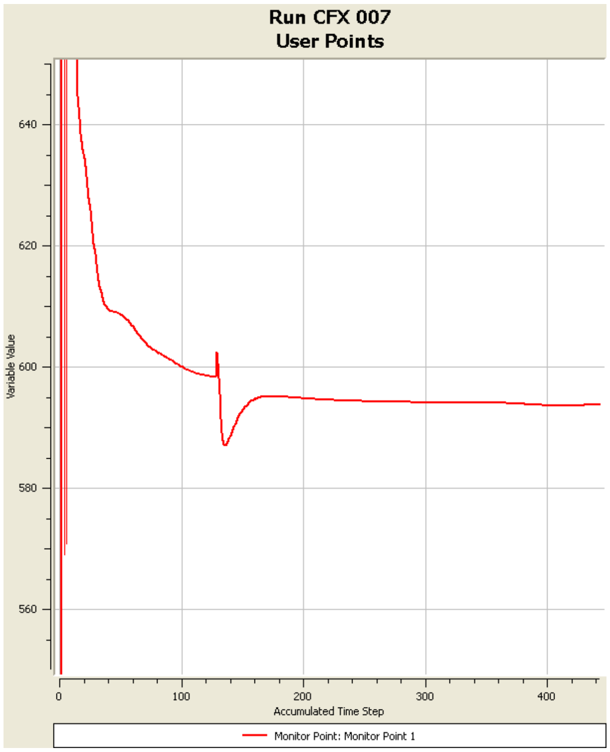


Figure 6: The curve representing the force entered to blade surfaces based on repetition

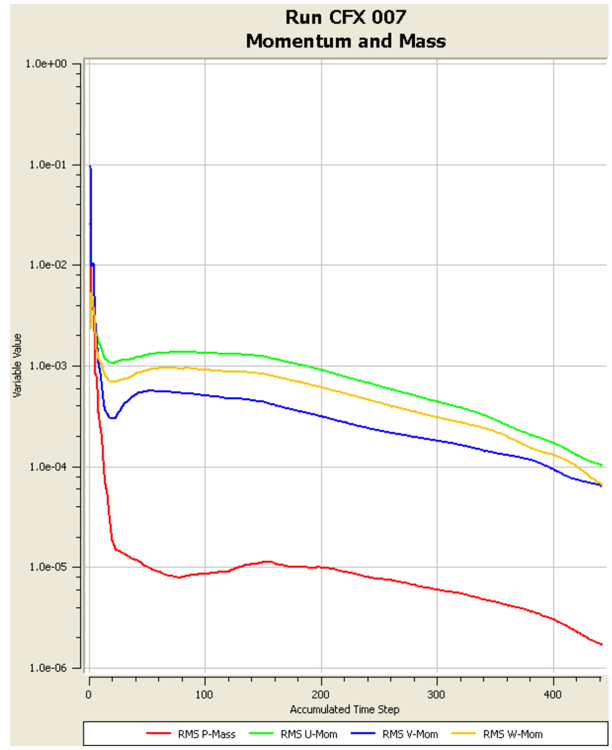
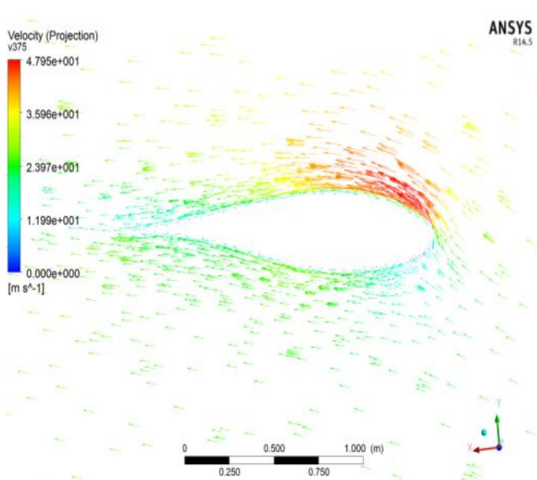
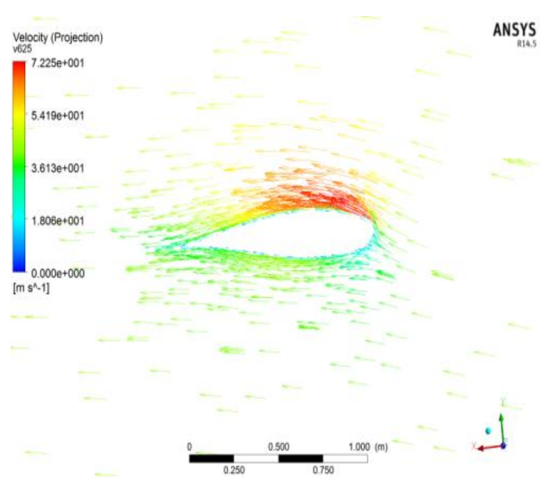


Figure 5: The curve for changes in residuals based on repetition in periodic model

To examine flow around the profiles at different sections of turbine and examine existence or lack of existence of phenomenon of separation at sections of turbine, the relative speed vector per different radius has been displayed in figure 8. As shown, separation has not existed in any separation sections, indicating that turbine works out under proper conditions. Axial velocity cantor at these sections can be observed in figure 8.



r/R=0.375a



r/R=0.625b

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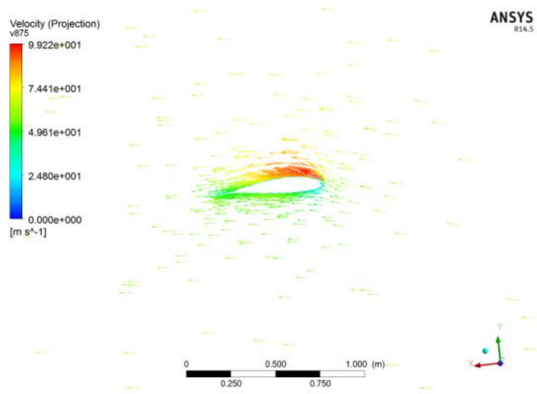
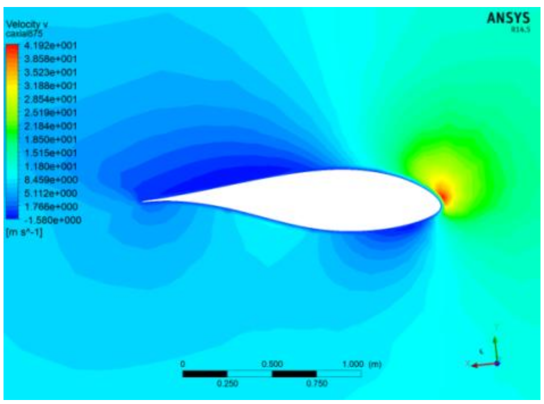
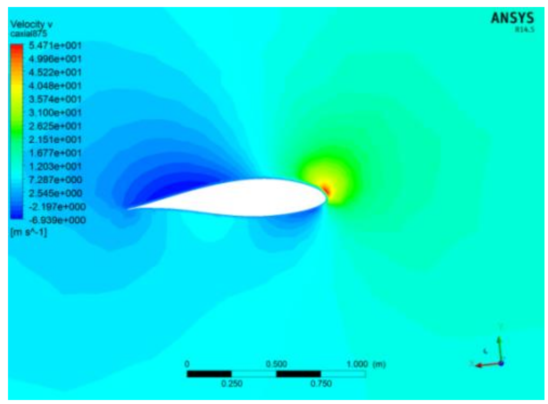


r/R=0.875c

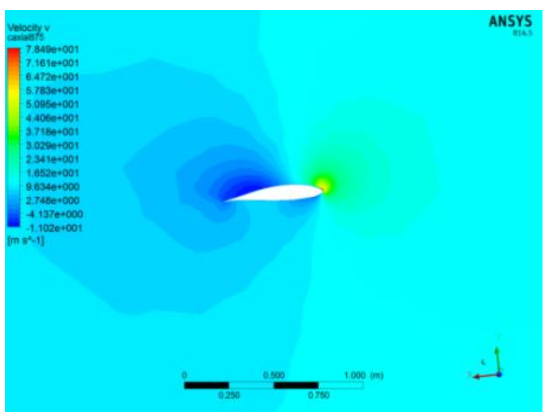
Figure 7: Relative speed vector at different sections of turbine blade



r/R=0.375a



r/R=0.625b



r/R=0.875c

Figure 8: Axial speed cantor (m/s) at different sections of turbine blade

Axial speed cantor at a plane which has passed through the middle of solution range(X=0) has been displayed in figure 9. A flow at the back of turbine in which the speed of flow is under the speed of wind flow is tangible. It should be noted that this range must remove and not to reach to system boundaries, because the boundary conditions will face problem under this situation. To examine the region and flow at the back of turbine, the axial speed cantors at different distances have been displayed from the middle of blades in figure 10. Comparison of rate of axial speed at different distances indicates that the more we get far from turbine, size of minimum and maximum speed decreases. Yet, as mentioned, rate of

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uniformity of speed at the back of turbine is so slow. Further, three regions with axial speed lower than other regions at any figures which have set at the middle radius of blades are tangible.

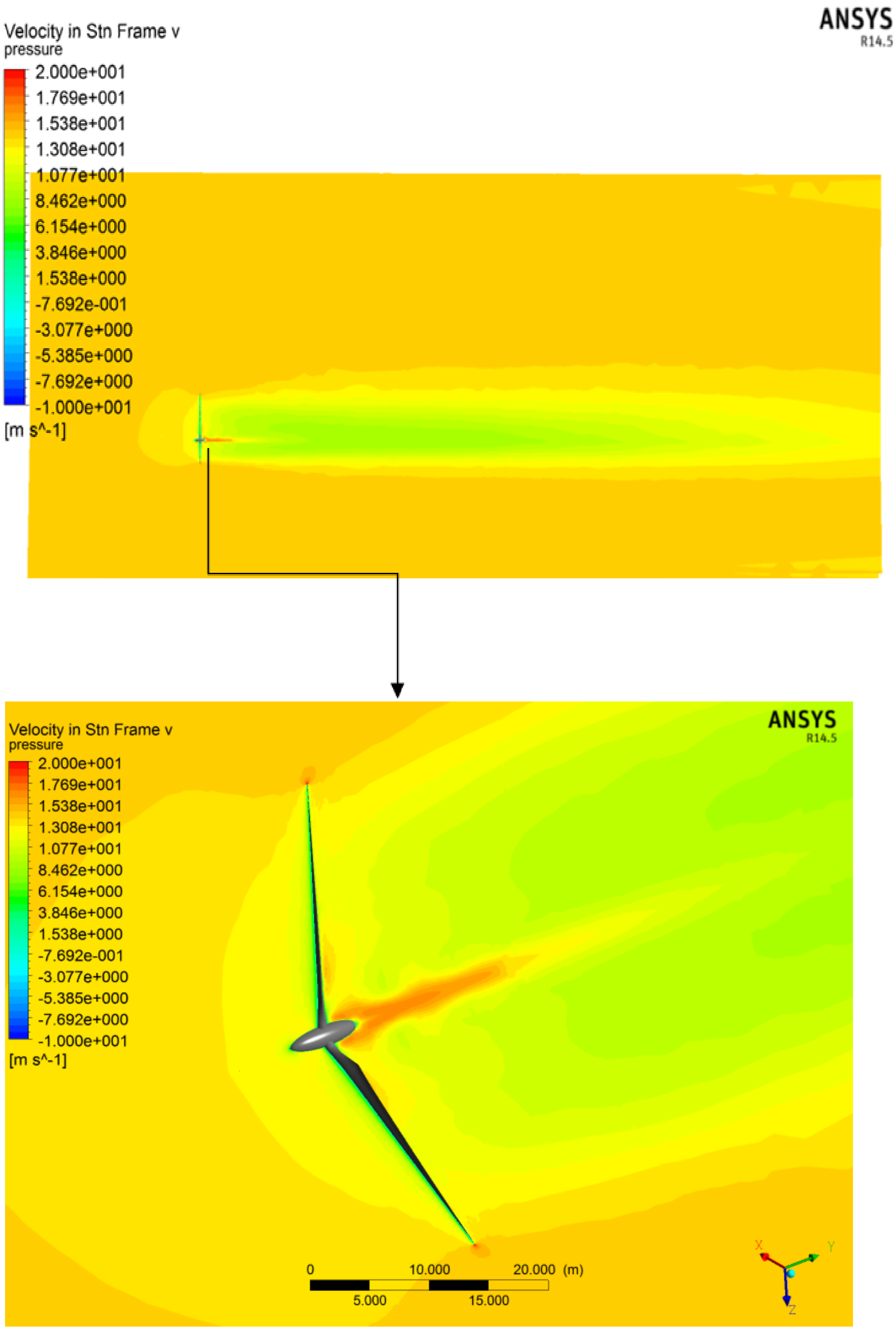

Figure 9: Axial speed cantor(m/s) at plane which has passed through at the middle of solution(X=0)

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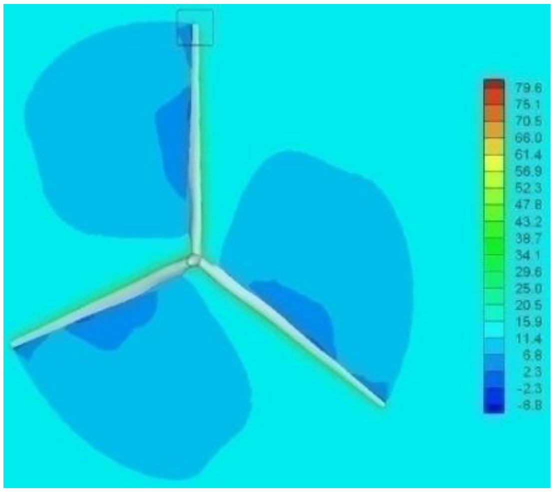
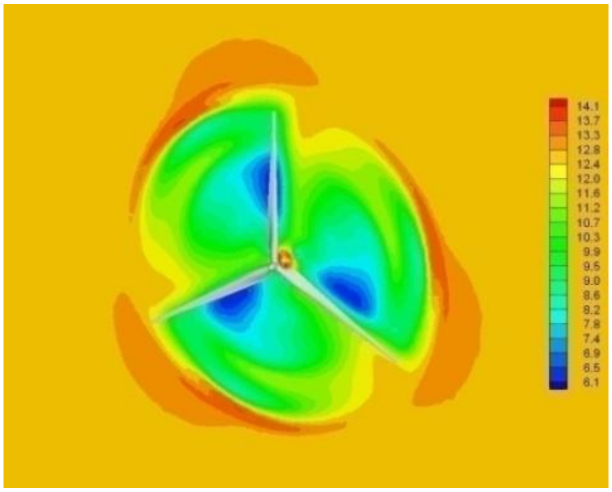
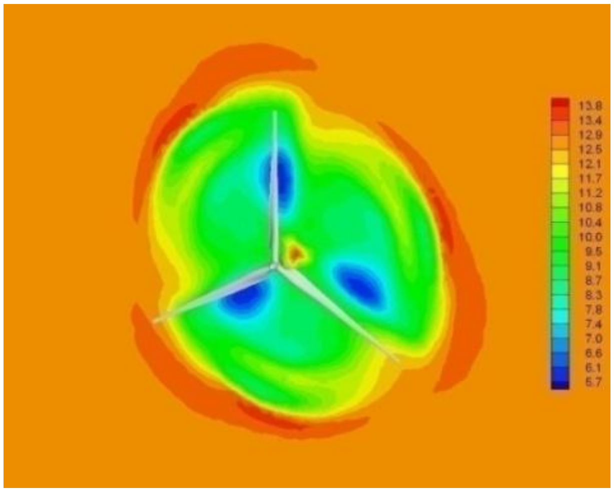


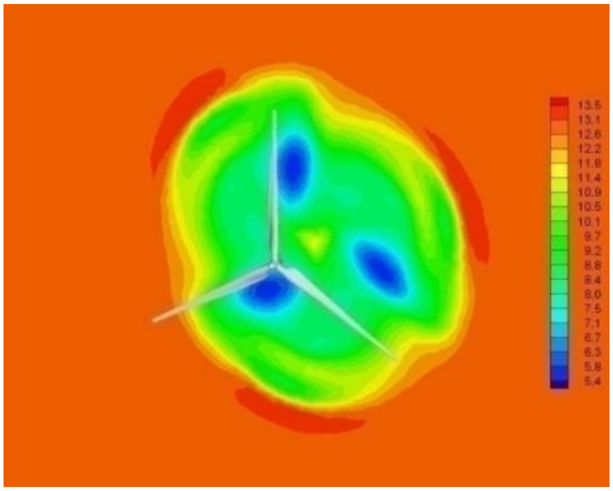
y/R=0



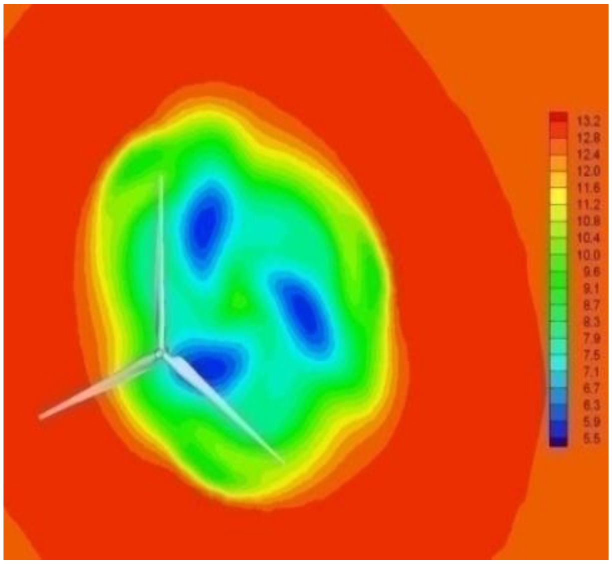
y/R=0.125



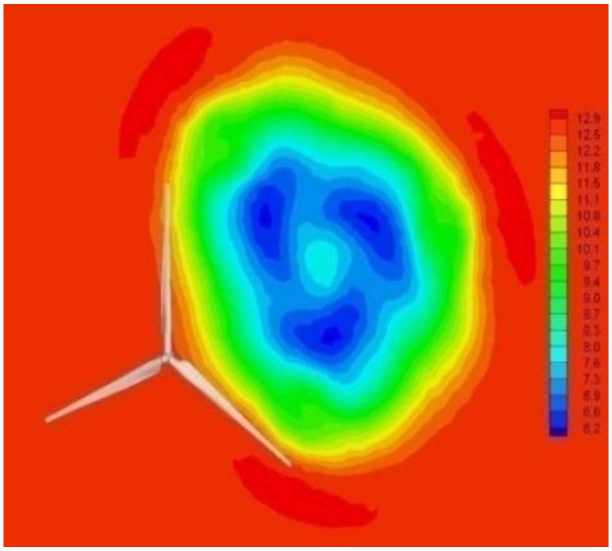
y/R=0.25



y/R=0.5



y/R=1



y/R=2

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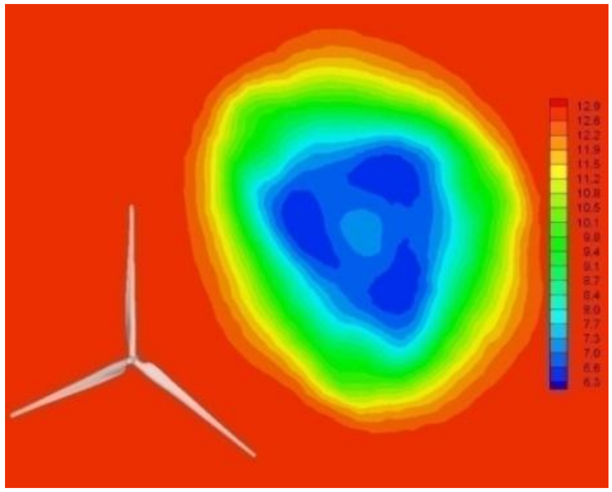

y/R=3

Figure 10: Axial speed cantor (m/s) at different distances from turbine

Conclusion

In this article, fluid dynamics model for effect of wind flow on Wind Turbine Blades to optimize design of blades has been examined. Kuhin, a city in the capital of Kuhin District, in Qazvin County, is a region under study, that its information has been mentioned in the article. It can examine wind flow regime before and after encounter with wind turbine blades via software Fluent. Results indicate that the more we get far from turbine, size of minimum and maximum speed decreases, yet rate of uniformity of speed at the back of turbine undergoes slowness. Further, three regions with axial speed under other points at the middle radius of blades have been witnessed.

REFERENCES

Amardeep Dhanju, Phillip Whitaker and Sandra Burton (2005). Assessment of Delaware Offshore Wind Power, College of Marine Studies University of Delaware 4-6.

Arvind Singh Rathore AND Siraj Ahmed (2012). Aerodynamic Analyses of Horizontal Axis Wind Turbine by Different Blade Airfoil Using Computer Program. *IOSR Journal of Engineering (IOSRJEN)* **2**(1) 118-123.

Bernhard Stoevesand, Andrei Shishkiny and Joachim Peinke *et al.*, (2006). Direct numerical simulation of the turbulent flow around an airfoil using spectral/hp method. *European Conference on Computational Fluid Dynamics ECCOMAS CFD.*

Clausen PD, Peterson P and Wilson SVR *et al.*, (2004). Advanced Blades for Small Wind Turbines. *Sciences & Technology.*

Dg Phillips BE *et al.*, (1999). Aerodynamic analysis and monitoring of the Vortec 7 diffuser-augmented wind turbine. *IPENZ Transactions* **26**(1) EMCh.

Geoffrey Jones and Loubna Bouamane (2011). Historical Trajectories and Corporate Competences in Wind Energy. *Harvard Business School* 11-19.

Júlio Xavier Vianna, Rodrigo Canestraro Quadros and Leandro dos Santos Coelho *et al.*, (2008). *Wind Turbine Blade Aerodynamic Design Through Quantum-inspired Evolutionary Algorithm* (Springer) Heidelberg, Germany.

Kamyar Mansour and Mohsen Yahyazade (2011). Effects of turbulence model in computational fluid dynamics of horizontal axis wind turbine aerodynamic. *Wseas Transactions on Applied and Theoretical Mechanics*, ISSN: 1991-8747 **6**(3).

Kathryn E Johnson and Naveen Thomas (2009). Wind farm control: addressing the aerodynamic interaction among wind turbines. *2009 American Control Conference Hyatt Regency Riverfront, St. Louis, MO, USA June 10-12.*

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Parezanovic V, Rasuo B and Adzic M (2001). Design of airfoils for wind turbine blades, *World Academy of Scince, Engineering and Technology.*

Pathike P, Katpradit T and Terdtoon P *et al.*, (2009). *Optimum Shape of Airfoil for Small Horizontal-Axis Wind Turbine*, Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Thailand 50200.

Reuss Ramsay R and Gregorek GM *et al.*, (1996). Effects of Grit Roughness and Pitch Oscillations on the S814 Airfoil, Airfoil Performance Report, Revised (12/99), The Ohio State University Columbus, Ohio 2-150.

Sofian Mohd and Abas Ab Wahab (2006). Static analysis of a 10m diameter wind turbine, Department of Plant and Automotive Engineering.

Vendan SP and Aravind Lovelin S *et al.*, (2000). Analysis of a Wind Wind Turbine Blade Profile for Tapping Wind Power at the Regions of Low Speed. *International Journal of Mechanical Engineering*, ISSN: 2277-7059 **2**(2).

Yu-Ting Wu and Fernando Port´e-Agel (2012). Atmospheric Turbulence Effects on Wind-Turbine Wakes: An LES Study. *Energies* **5** 5340-5362; doi:10.3390/en5125340.

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