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Analyzing andInvestigating the Application of the Aerodynamic Airfoil for Use in Small Wind Turbines with Q-blade Software and Simulation with Ansys Fluent software.

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ABSTRACT

According to the review, the extraction of electricity using wind turbines can be done in remote regions with good wind speed. Wind speed Firozkouh as a pilot region to investigate the airfoil NREL's 835 with wind speed 5.6m/s with wind density 145W/m^2 is intended. By analyzing Q-blade and Ansys Fluent software on the above airfoil and with regional wind speed, the values of Cl and Cd were obtained equal to 0.595 and 0.213, respectively. Using the mentioned software, a blade with a length of 1.3m has been designed. According to the designed blade, the rotational output power of the turbine was analyzed, and the maximum power produced by the wind turbine at a speed of 20m/s, the output power is equal to 110W. This type of airfoil is suitable for regions with high wind speed15m/s and b length of at least 2m. Extract that for a small wind turbine is a very good production capacity that can be used in designs related to the construction of turbines and even the creation of small-scale power plants.

1. Introduction

Humans need electricity to live comfortably. Today, with the advancement of technology, hybrid cars have been built using electric energy, which consume less fossil fuel than previous generations, and as a result, emit less greenhouse gases than in the past. But with the increase in the number of cars compared to the past, the total production of greenhouse gases has not decreased. People's use of electrical appliances has caused a surge in electricity production. In power plants, fossil fuels, coal, etc. need to be burned, which produces greenhouse gases from the stage of extraction to the stage of combustion. In recent years, the increase in population in the world has caused an increase in electricity consumption. According to the report of the United Nations, about 1.4 billion people, who constitute almost 20% of the earth's population, do not have access to electricity (Ismail & Batalha, 2015). The variety of electrical appliances requires the production of more electricity. Electricity consumption is directly related to air pollution. Greenhouse gases such as carbon dioxide and methane cause global warming. Global warming causes floods, droughts, sudden rains, melting of polar ice, loss of plant species, etc. The use of renewable energy is inevitable to deal with the world's climate change. For example, Australia had planned to provide twenty percent of its energy from renewable energy by 2020 (R. Sharma & Patel, 2015). Renewable energies can be called solar energy, wind energy, geothermal energy, etc. The advantages of solar energy and wind energy are that they can be installed and used in areas that are far from the power grid. Wind energy is one of the energies that can generate wealth in areas with suitable wind speed. By using wind turbines, while preserving the environment, it is possible to produce agricultural products and create jobs by building a greenhouse the first windmill was discovered near the border of Iran and Afghanistan, which dates back to 200 BC. The Dutch used wind energy for irrigation and drainage in the fields between 1300 and 1875 (Chowdhury, Mustary, Loganathan, & Alam, 2015). Today, wind turbines are usually used to generate electricity, increasing the rotor efficiency in wind turbines has been considered to maximize the extraction of electricity from wind energy. The maximum efficiency of wind turbines is 59.3%, which is known as the Betz limit (Gulve & Barve, 2014). Studying and investigating airfoils and wind turbine

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blades to increase the efficiency of wind energy is on the agenda of researchers. The rapid evolution of Computational Fluid Dynamics (CFD) has been made due to the need for faster and more accurate methods for calculating flow fields around objects under technical investigation. CFD is used to design many components of air and space, automobiles, industries, and processes in which the flow of liquids and gases plays the main role(Ravi et al., 2013). Timmer in 2010 studied the airfoil with a high angle of attack. They tested a turbine with an airfoil that had an angle of attack centered on the maximum drag coefficient and lift ratio inside the wind tunnel. In addition to the effect of the high airfoil angle, they have studied the aspect ratio and rotation and fin in the high airfoil stretch ratio (Timmer & Bak, 2023). In 2010, Kim et al. conducted a study on the optimization and design of small wind turbine airfoils to reduce turbine noise. To conclude the new optimized airfoil has a 2.9 dB reduction in sound pressure level (SPL) and a higher aerodynamic performance is achieved (Kim et al., 2010). In 2013, Ravi HC and colleagues conducted a numerical study of flow transfer on the Naca 4412 airfoil. They have investigated the desired airfoil at the angle of attack from 0 to 18 degrees (Ravi et al., 2013). In 2015, Sharma and Patel designed and simulated the Darius vertical axis wind turbine using Q-blade software (Ismail & Batalha, 2015). In 2016, Hassanzadeh et al. studied the aerodynamics of a small turbine blade to optimize the chord distribution and pitch angle of the wind turbine blade. They are to produce the maximum annual energy (AEP) of the wind turbine blade, after examining and testing the turbine, they managed to obtain AEP values of 36413 and 39510 kilowatt hours per year for the distribution of wind speed in Ahar city (Hassanzadeh et al., 2016). In 2017, Ozganon and Sili Yart studied the effects of wind on a vertical axis wind turbine with high solidity by CFD method, and the results of their study show that modeling by CFD in evaluating the transient performance of the VAWT system, including the effects of inertia is the rotor (Onol & Yesilyurt, 2017). In 2019, Jian Hu Zhou and colleagues studied the design and optimization of a multi-MW wind turbine with NPU-MWA model airfoil and were able to reduce the weight of the 5 MW NPU-MWA series blade by 9% (Xu et al., 2019).

One of the innovations of this article is the investigation of the use of Nrel's 835 airfoils in the Firouzkoh climate region for the first time, which has been expressed nearly.

2. Method

2.1. Methodology

In this study, the wind speed of the Firuzkoh area has been extracted using meteorological data. In extracting the wind speed of the area, the wind density of the area was extracted using Weibull. By using airfoil 835, it has been investigated and the use of airfoil in this area has been studied. Finally, after studying the behavior of the wind on the 835 airfoil, a wind turbine has been designed with q-blade software to calculate the power output. Calculations governing the extraction of wind speed, aerodynamic behavior of airfoil, blade, and governing methods

A- Calculation of turbine power and wind speed of the study region:

To use a wind turbine, it is necessary to study the wind density of the desired region then, according to the wind density and wind speed, the right turbine can be selected and installed. The use and design of a wind turbine also have different parameters that can be designed and used by studying and checking these parameters to design and use a suitable turbine for the wind in the desired region. It is possible to obtain the power of the turbine using Eq. 1 (Ayodele et al., 2016).

$$p = \frac{1}{2}\rho A C_p \ V^3 \tag{1}$$

In the above relationship, ρ is the air density, A is the swept surface of the turbine, C_p is the aerodynamic efficiency (which is called the power factor) and V is the free flow speed of the wind (Shahbazi et al., 2019).

With precision, in Eq. 1, the power of the turbine has a direct relationship with the sweep level of the turbine, which needs to be studied and investigated to increase the available power of the turbine. The sweep level also depends on the length of the turbine blade to increase the sweeping surface, the length of the blade can be increased. Of course, increasing the length of the blade has limitations such as the installation space, the height of the turbine tower, and the construction cost. To increase the efficiency of the turbine and its efficiency, a suitable airfoil should be studied. In this research, the region of Firozkouh in Tehran province has been investigated. To obtain the wind speed and wind density of the studied area, the wind speed information recorded by the Iranian Meteorological Organization is used. This method uses separate data in wind speed intervals or classes that occur. One set of N wind speed observations is assumed. The data is divided into N_B of the speed class with width W_j, which is the middle point of m_j and the number of events in each class is f_j, which is expressed as real Eq. 2:

$$N = \sum_{j=1}^{N_B} fj \tag{2}$$

The wind speed of the studied region is obtained from Eq. 3:

$$\bar{V} = \frac{1}{N}\sum_{J=1}^{N_B} mjfj \tag{3}$$

Eq. 4 is used to calculate the average production power (Montoya et al., 2019) :

$$\overline{P_w} = \frac{1}{N}\sum_{J=1}^{N_B} P_w(mj)fj \tag{4}$$

The amount of energy is obtained from Eq. 5:

$$E_w = \sum_{j=1}^{N_B} P_w\left(mj\right)fj\,\Delta t \tag{5}$$

Discrete wind data have been replaced by the Weibull continuous distribution function. The probability distribution function is the most used for statistical analysis and calculations of wind in a place. The Weibull function is defined as follows (Li et al., 2018):

$$\mathrm{P}\left(\mathrm{V}\right) = \frac{\mathrm{k}}{\mathrm{c}} \times \left[\frac{\mathrm{V}}{\mathrm{c}}\right]^{\mathrm{k}-1} \times \exp\left(\left[\frac{\mathrm{V}}{\mathrm{c}}\right]^{\mathrm{k}}\right) \tag{6}$$

In this relation, V, wind speed, k, and c are respectively a dimensionless parameter called “shape factor” and a parameter called scale factor, which is calculated in meters per second. Various methods have been presented to obtain the parameters of the shape and scale of the Weibull function. One of the most widely used methods is the “least square fitting” method, which is obtained with the help of the cumulative probability function. By using the regression Eq., it is possible to obtain a linear relationship between the values of wind speed and the probability of their occurrence for this reason, it is necessary to obtain the frequency of the data obtained from the meteorological organization of the country first. Then Vi, which is the middle of the wind speed classes, and P(V), which is the probability of the cumulative frequency of each speed class, is obtained, and finally, X and Y values are calculated using these values and Eq. 7 and 8.

$$X = Ln\,Vi \tag{7}$$

$$Y = Ln\,(-Ln\,(1 - P(V)) \tag{8}$$

Using the obtained values, the linear relationship between the wind speed values and the probability of their occurrence can be determined by Eq. 9 (Shahbazi et al., 2019):

$$Y = AX + B \tag{9}$$

The values of A and B can be calculated by drawing the graph above in Excel where A is the angle coefficient and B is the width of the point of intersection of the line with the Y axis. The relation between A and B in this Eq. with parameters C and K is the Weibull function in the form of Eq. 10:

$$C = \exp\left(\frac{-B}{A}\right), \quad K = A \tag{10}$$

From the Weibull probability density function, many data can be estimated as described. Get the nominal wind speed that the maximum electrical energy can be produced by the turbine with Eq. 11 (Sharma & Bhatti, 2010):

$$V_{MaxE} = C\left(1 + \frac{2}{K}\right)^{1/K} \tag{11}$$

Also, the most probable wind speed is determined by Eq. 12:

$$V_{MP} = C\left(1 + \frac{K-1}{K}\right)^{1/K} \tag{12}$$

From Eq. 13, the average wind speed can be determined:

$$V = C\Gamma\left(\frac{K+1}{K}\right) \tag{13}$$

The gamma function, which is needed to extract the wind density, can be obtained from Eq. 14 (Li et al., 2018):

$$\Gamma(t) = \int_0^\infty x^{t-1}e^{-x}dx \tag{14}$$

Based on the Weibull probability density function, the average density of wind energy in a geographical location is determined by Eq. 15 (Shahbazi et al., 2019):

$$\frac{P}{A} = \frac{1}{2}\rho C^3\Gamma\left(\frac{K+3}{K}\right) \tag{15}$$

Here the famous gamma function is shown.

2.2. Airfoil and Blade Design

The first step to using an airfoil and blade design is to check the aerodynamic forces.

2.2.1. Airfoil Aerodynamic Forces

Checking the amount of airfoil drag and lift is the first step to making a suitable blade and finally to designing a turbine.

The amount of C_L and C_d, in theory, can be obtained from Eq. 16 and 17 (Timmer & Bak, 2023):

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 cA} \tag{16}$$

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 cA} \tag{17}$$

In Eq. 17 and 18, the fluid flow density is at infinity and C is the length of the airfoil chord. L and D are the force acting on the airfoil chord length, respectively. The coefficient of C_L and C_d is the ratio of the force applied to the object to the dynamic force in the fluid in the distance. The coefficient changes linearly with the angle of attack, the slope of which can be obtained from Eq. 19.

$$Cl = 2\pi\alpha \tag{18}$$

Airfoil behavior and airfoil coefficients depend on the angle of attack and Reynolds number. Also, it all depends on the behavior of the boundary layer on the airfoil and how the flow is separated from the airfoil.

If the separation of the flow from the airfoil starts in a volatile manner and increases with the increase of the angle of attack, the airfoil choke condition is mild and occurs slowly. If the flow separation occurs near the leading edge, the boundary layer on the entire surface of the airfoil suddenly and at the same time causes the drag force to drop suddenly. The behavior of the boundary layer is complex and depends on surface curvature, surface roughness, Reynolds number, angle of attack, and high flows with high Mach number speed. In an airfoil, the proportional relationship between and the angle continues until this coefficient reaches a maximum value. The loss depends on the shape of the airfoil geometry. Thinner and pointed airfoils usually have a very fast choke and finally the drag force drops sharply. But thicker airfoils have a milder choke stage and the drag force decreases at a slower rate. One of the ways to check and diagnose the suitable airfoil for an area is to check the amount of Cl/Cd with the angle of attack.

2.2.2. Aerodynamic Forces on the Blade

When the wind starts to blow, aerodynamic forces appear on each fin (FL) and drag (FD). The forward (FL) and rear (FD) aerodynamic forces can be calculated using the following relations (Hassanzadeh et al., 2016).

$$FL = 0.5\rho C_L v_r^2 C\Delta h \tag{19}$$

$$FD = 0.5\rho C_D v_r^2 C\Delta h \tag{20}$$

2.2.3. The Lower and Upper Surfaces of the Airfoil

When the airfoil has a positive angle of attack, the pressure on the lower surface of the airfoil is high, and this part is called the pressure surface. In this situation, the pressure on the upper surface is small, and this part is called the suction surface. The lift force is a force whose direction is considered from the pressure side to the suction side of the airfoil, which is shown in Fig. 9.

2.2.4. Airfoil Pressure Center

The center of pressure is a point along the chord line which is assumed to be the result of all aerodynamic forces at that point. The pressure on the airfoil surface is variable. Therefore, in various problems, need to define a point where the sum of the pressure distribution is applied at that point. The location of this point can be calculated using the following integral relationship.

$$CP = \frac{\int xp(x)dx}{p(x)dx} \tag{21}$$

When the angle of attack on an airfoil changes, the thrust forces also shift and their magnitudes change in different locations, so the location of the center of pressure shifts as the angle of attack changes.

2.3. Airfoil Math Topics

The mathematical topics of an airfoil are expressed as follows (Hinze. J.):

$$\begin{aligned} \frac{\partial}{\partial xi}(pvi) = 0, \frac{\partial}{\partial xi}(pvivj) \\ = -\frac{\partial p}{\partial x} + \frac{\partial Tij}{\partial xj} + pgi + fi \\ \tau ji = \left[\mu\left(\frac{\partial vi}{\partial xj} + \frac{\partial vj}{\partial xi}\right)\right] - \frac{2}{3}\mu\frac{\partial vi}{\partial xi}\delta ij \end{aligned} \tag{22}$$

In the above Eq., vi is the speed of airflow in the desired direction i and j due to external forces.

2.4. Calculation of Reynolds Number

For software simulation and analysis, it is necessary to extract the Reynolds number.

Table 1. Statistical measurements of wind speed at the station of Firozkouh region in the statistical period of 2015-2016

Firozkouh			
Weibull (Pw)	Abundance (Fi)	Medium speed (Vi (m/s))	Speed Categories (V(m/s))
0.088724096	1064	1	.5-1.5
0.112774592	986	2	1.5-2.5
0.119407072	1581	3	2.5-3.5
0.115664434	1661	4	3.5-4.5
0.105739755	1452	5	4.5-5.5
0.092586998	1408	6	5.5-6.5
0.078303017	1118	7	6.5-7.5
0.06430531	935	8	7.5-8.5
0.051470292	718	9	8.5-9.5
0.040260274	719	10	9.5-10.5
0.030838827	341	11	10.5-11.5
0.023169787	453	12	11.5-12.5
0.017096917	222	13	12.5-13.5
0.01240383	218	14	13.5-14.5
0.008855904	175	15	14.5-15.5
0.006227143	114	16	15.5-16.5
0.004315374	71	17	16.5-17.5
0.002949037	79	18	17.5-18.5
0.001988397	27	19	18.5-19.5
0.001323402	53	20	19.5-20.5
0.000869823	14	21	20.5-21.5
0.000564789	20	22	21.5-22.5
0.000362419	5	23	22.5-23.5
0.000229902	22	24	23.5-24.5
0.000144216	16	25	24.5-25.5

The Reynolds number indicates the ratio of inertial forces to viscous forces and it arises due to fluid movement.

To obtain the Reynolds number in the wind speed, Eq. 23 is used (Villalpando et al., 2011):

$$Re=\frac{\rho V\ C}{\mu} \tag{23}$$

which can be expressed: ρ equals volume ratio Kg/m^3, V equals wind speed m/s, C equals airfoil chord length m, μ equals viscosity Kg/m.s.

To calculate the Reynolds number of the studied area, the density of air in standard conditions and a temperature of 25 degrees Celsius should be considered equal to 1.169. Air viscosity in standard conditions is equal to 0.00001789.

3. Result and Discussion

3.1. Calculation Results of Wind Speed in the Firozkouh Region

Using meteorological information extracted during 2010-2015 and statistical calculations, the wind speed and density of the studied area can be obtained. In Table 1, the frequency value, Weibull distribution of intermediate speeds, and speed categories of the Firozkouh region in Tehran province are calculated and written.

The values of x and y are calculated from Eq.s 7 and 8, respectively, and are drawn and displayed in Fig.1.

According to the obtained results, it can be understood that the data follow the Weibull probability density function.

Wind energy density in the Firozkouh region is based on the data of the mentioned years written in Table 1.

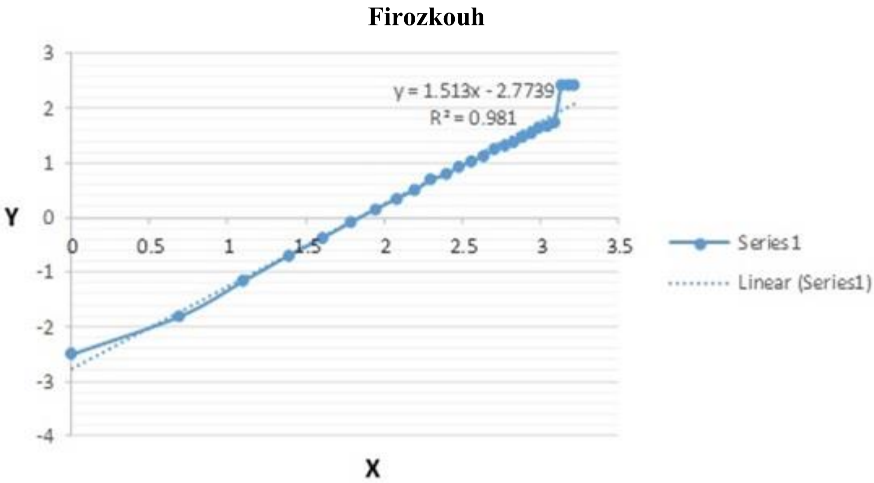

Fig. 1. Y=AX+B function diagram for calculating the metrometers of Firozkouh station

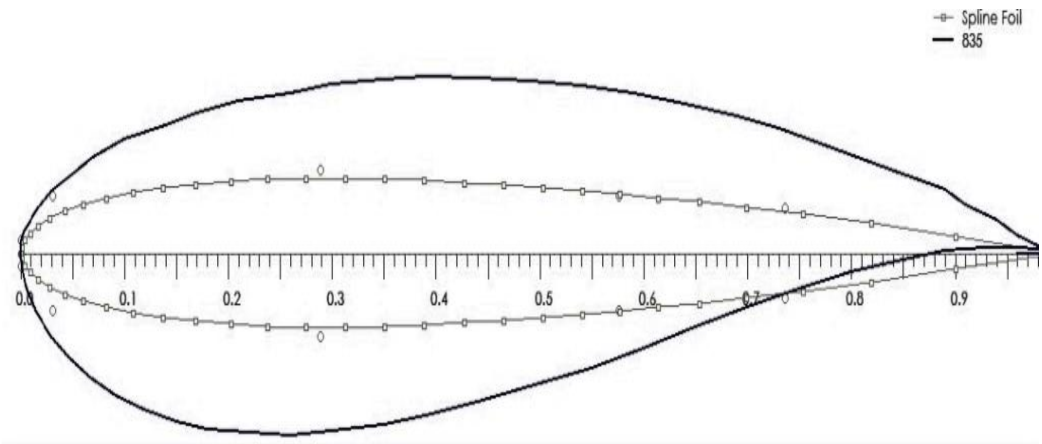

Fig. 2. Nrel's 835 airfoils drawn by Q-blade software

In the Firozkouh region, the wind density of the region is equal to 142.551W/m^2. The components obtained from the analysis of wind speed in the Firozkouh region of the mountain are written separately in Table 2.

Table 2. Wind components at a station in Firozkouh regions at a height of 10 m from the ground in the statistical period of 2015-2016

Name region	Firozkouh
$\frac{P}{A}(w/m^2)$	142.5
$V_{MP}(m/s)$	3.06
$V_{MaxE}(m/s)$	10.9
$V(m/s)$	5.64
C	6.25
K	1.513
Γ	0.9

3.2. Investigating the Effects of Wind Speed in the Firozkouh Region on the Blade Designed with Nerli 835 Airfoil in Q-blade Software

At the beginning of the analysis using the software, according to the Eq. 23 and with the length of the airfoil which is 20 cm, the Reynolds number of the Firozkouh region should be obtained, which is equal to 73000. According to the obtained Reynolds number, it is possible to analyze and check the mentioned airfoil with Q-Blade software for use in wind turbines. In this study, the attack angle of 0 to 20 degrees is considered for the airfoil. Fig. 2 shows the airfoil nerli835 drawn by Q-blade software.

According to the nerli 835 airfoil, a blade can be designed in the Q-blade software so that it can be examined and suggested for the construction of a wind turbine for use in the region of Firozkouh.

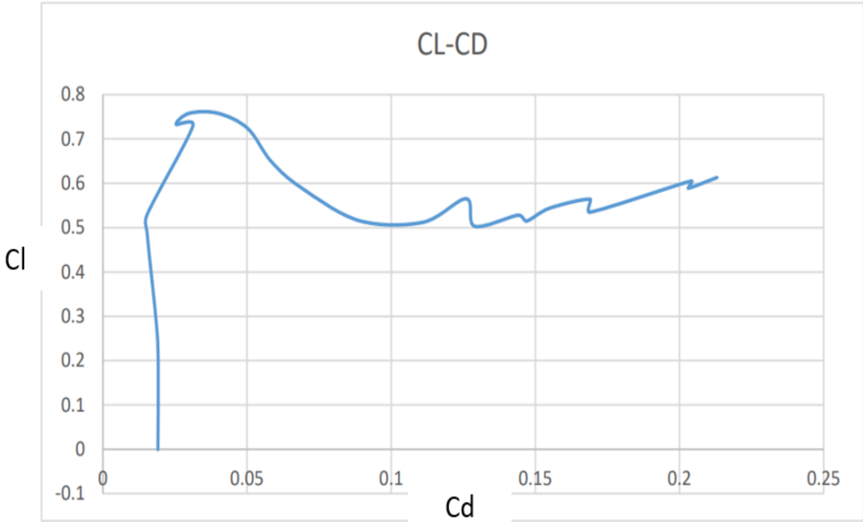

Fig. 3. Lift and drag diagram of Nrel's 835 airfoil

Table 3. Information obtained from the airfoil analysis studied with the program Q-blade

Airfoil	Reynolds	Cl	Cd	Cm	L/D
NREL's 835	73000	0.595	0.213	-0.07	2.797

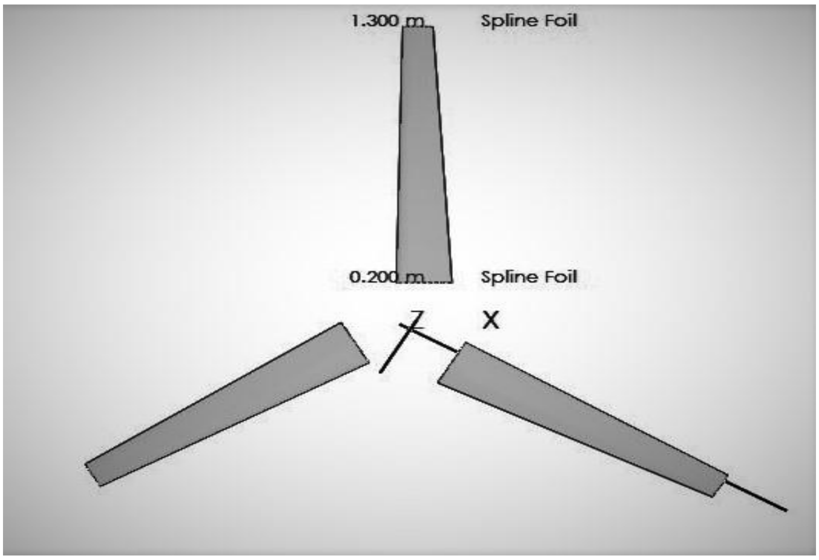

Fig. 4. Horizontal three-blade turbine designed using Nrel's 835 airfoils by Q-blade software

As seen in Fig. 3, it shows the change curve of the drag coefficient to the drag coefficient (C_l-C_d) for the airfoil under investigation, which was done by the software. This curve is the most important curve of an airfoil.

Table 3 shows the processing output of the nerli835 airfoil with a fin length of 1.3m with Q-blade software. Cl and Cd coefficients show 0.595 and 0.213 respectively.

According to the nerli835 airfoil, to investigate the effects of air and power generation, using Q-blade software, a blade with a length of 1.3m has been designed in the form of three blades, so that the rotational power of the turbine can be calculated by the wind speed of the studied region. It is shown in Fig. 4.

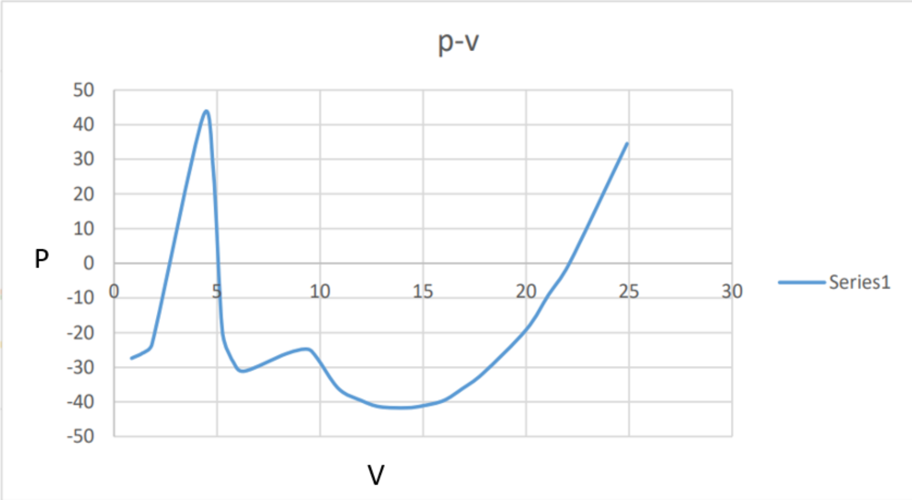

Fig. 5. Power curve produced by a 3-blade turbine with a length of 1.3 (m) at different wind speeds with Q-blade

For the analysis of the blades and turbine created by the three fins software, the wind speed is considered to be min 3m/s and max 25m/s.

Figure No. 5 of the diagram (Pw-V) shows the wind production power on the 130cm long blade created with the Nrel's 835 airfoil. In this diagram, the maximum power produced is between 3 and 5m/s, and at a speed of 4m/s, the generated power is more than 40 W. According to the diagram, after the wind speed is 5m/s, the wind production power becomes negative, or the so-called power is not produced.

3.3. Checking the Production Power by the Turbine Created in the Q-blade Software with Different Blade Lengths

According to the defined wind speed, the possible power produced by the Turbine made with an airfoil and the Cp created as the output of the Q-blade software were checked. In this research, according to the change in the length of the blades with the sizes of (0.7, 1.3, 2 and 3) meters, the wind speed from 3m/s until 25m/s, the rotational power of the rotor has been investigated so that an initial estimate can be made. Find out what length of blade can be suggested for Nrel's 835 airfoils of Firozkouh region.

Fig. 6 shows the image of the turbine created by Q-blade software to calculate the output power at different speeds and with different blade lengths. Using the Q-blade software, the power produced by the turbine with different blade lengths and different wind speeds is written in Tables 4 to 7.

According to tables 4 to 7 related to the rotational output of the turbine rotor, it can be seen at the wind speed corresponding to Firozkouh 5.6m/s, the wind turbine with a blade length of 70cm made of Nrel's 835 airfoil has a power of 60W, and the rest of the turbines produce power at a speed higher than the speed of Firozkouh. In a turbine with a blade length of 1.3m, the maxpower produced by rotation is created at a wind speed of 11m/s, which is equal to 1.8kW. In a turbine with a blade length of 2m, the maxi power is generated at a wind speed of 15m/s the production power is 12.8kW. In a turbine with a blade length of 3m, the production power is created at a wind speed of 20m/s, which is equal to 61kW.

3.4. Investigating the Behavior of the Wind Speed in the Firozkouh Region on the Blade Created with the Airfoil by Ansys Fluent Software

In this part, the numerical investigation of the turbulent and stable and incompressible flow around the blade designed by the Nrel's 835 airfoils in AnsysFluent software with a wind speed of 5.6m/s in Firozkouh region is discussed**.**

After drawing the blade in the design section of Ansys, meshing must be done for analysis in the software. The maximum mesh size is set to 0.003m.

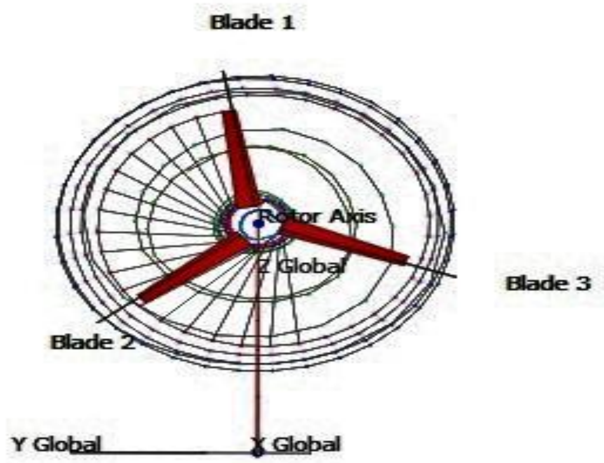

Fig. 6. Turbine image created to check rotational power in Q-blade software

Table 4. Power produced by a turbine with a blade length of 1.3m

V	3	5.6	10	11	15	20	25
Cp	-0.11	-0.33	0.39	0.42	-0.096	0.0043	0.017
P (kW)	-0.71	-0.19	1.2	1.8	-0.75	0.11	-0.88

Table 5. Power produced by a turbine with a blade length of 2m

V	3	5.6	10	11	15	20	25
Cp	-0.17	-0.24	0.34	0.4	0.49	-.073	-0.03
P(kW)	-3.6	-3.3	2.6	4.2	12.8	-4.53	-3.6

Table 6. Power produced by a turbine with a blade length of 3 m

V	3	5.6	10	11	15	20	25
Cp	-37	-2.4	0.0052	0.21	0.45	0.44	-0.065
P(kW)	-17.7	-7.36	0.09	4.8	26.46	61	-17.58

Table 7. Power produced by a turbine with a blade length of 0.7m

V	3	5.6	10	11	15	20	25
Cp	-1.6	-0.38	-0.093	-0.049	-0.026	-0.015	0.008
P(kW)	-0.04	0.06	-0.088	-0.061	-0.048	-0.117	-0.12

Fig. 7 shows the examined blade in the working space of Fluent, the length of the blade is 1.3m and the length of the airfoil of the blade is 0.2m. After blade meshing in Ansys Fluent software, analysis can be started. The path of air entry and exit from the blade is defined in the software. In this part, an air speed 5.6m/s is considered as input, air density is 1.225kg/m^3 and air viscosity is 0.000017894, which is shown in Fig. 7.

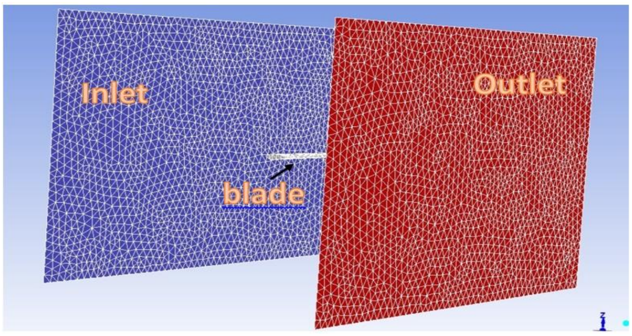

Fig. 7. Meshing of the inlet and outlet and the wall of the space designed in Ansys Fluent

After applying wind speed and data such as viscosity, and air density as input, the software starts to analyze the speed of air passage and the pressure exerted by the air on the blade. The software shows the speed on the surface of the blade and under the blade, respectively 7.4m/s and 2.6m/s, and this difference in speed is the cause of the pressure level and the suction level in the airfoil. The amount of drag and lift of the blade has been investigated, which is equal to 0.46 and 0.0018, respectively, as the output of the software, which is shown in Fig. 8. Using the outputs of the software, turbine design can be done using airfoils. Turbine design can be done using Nrel's 835 airfoils for the Firozkouh region using Q-blade and Ansys Fluent software data.

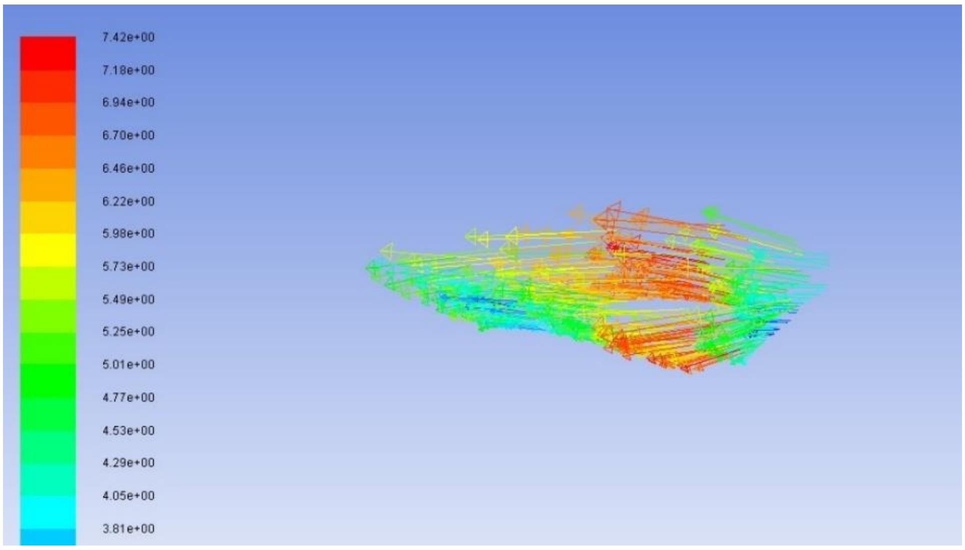

Fig. 8. Display of the speed of air passing through the blade (Ansys Fluent software)

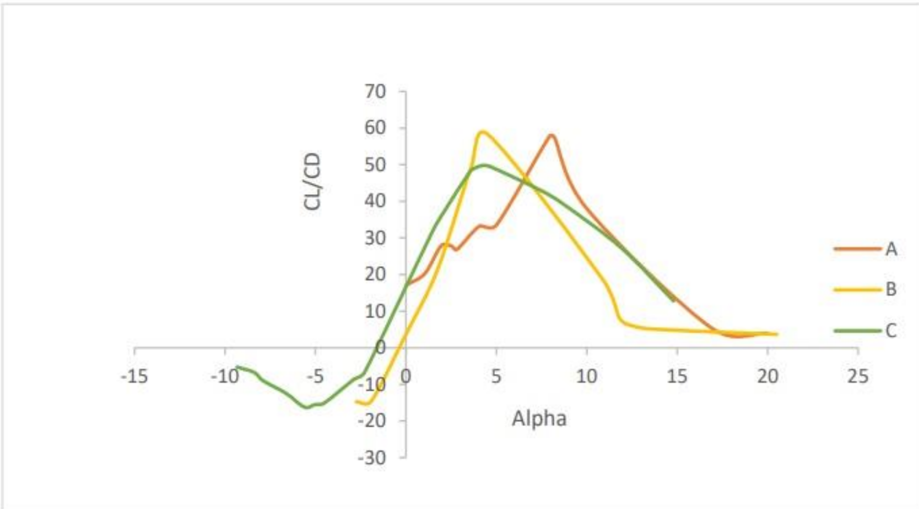

Fig. 9. Output curves for validation of Q-blade software(Altmimi et al., 2022; Airfoil Tools Site).

3.5. Validation of the Software Used in this Study

3.5.1. Validation of Q-blade Software

To verify the performance of the Q-blade software used in this study, the article of I. Altmimi et al., who studied the design and simulation of a horizontal axis wind turbine using Q-Blade, was used (Altmimi etal., 2022). The diagram of C_l/C_d at the angle of attack (Alpha) between -5 and 25 degrees with a Reynolds number of 100,000, which was carried out in the article by I. Altmimi et al., is shown in Fig. 10. Also, for more certainty, using the airfoil tools site, the C_l/C_d (SG-6041 airfoil) curve at the angle of attack (Alpha) was examined (Airfoil Tools Site), the result of which is shown in Fig. 9.

In Fig. 9, the A curve related to the C_l/C_d diagram at the angle of attack (Alpha) drawn by I. Altmimi et al., Curve C corresponds to the C_l/C_d diagram at the angle of attack (Alpha) related to the airfoil tools site. Curve B is the result of SG-6041 airfoil analysis to verify the effectiveness of Q-blade software for this study. According to the curve in Fig. 9, the highest C_l/C_d in the angle of attack (Alpha) in the diagram of curve A in the angle of attack of 7 degrees is equal to 55. The highest C_l/C_d in the angle of attack (Alpha) in the graph of curve C at the angle of attack of 5 degrees is equal to 50. Also, the highest C_l/C_d in the angle of attack (Alpha) in the graph of curve B at the angle of attack of 5 degrees is equal to 55. According to curves A, B, and C in Fig. 9, less difference in C_l/C_d value and angle of attack is observed, which shows the accuracy of Q-blade software for use in this study.

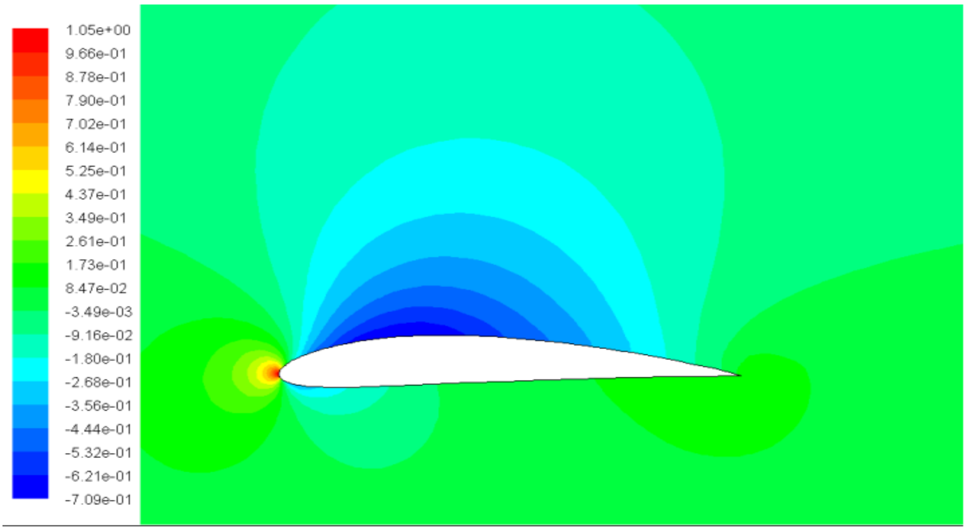

Fig. 10. Shows the maximum pressure in the Naca 4412 airfoil at a zero-degree angle for validation (Kevadiya, 2013)

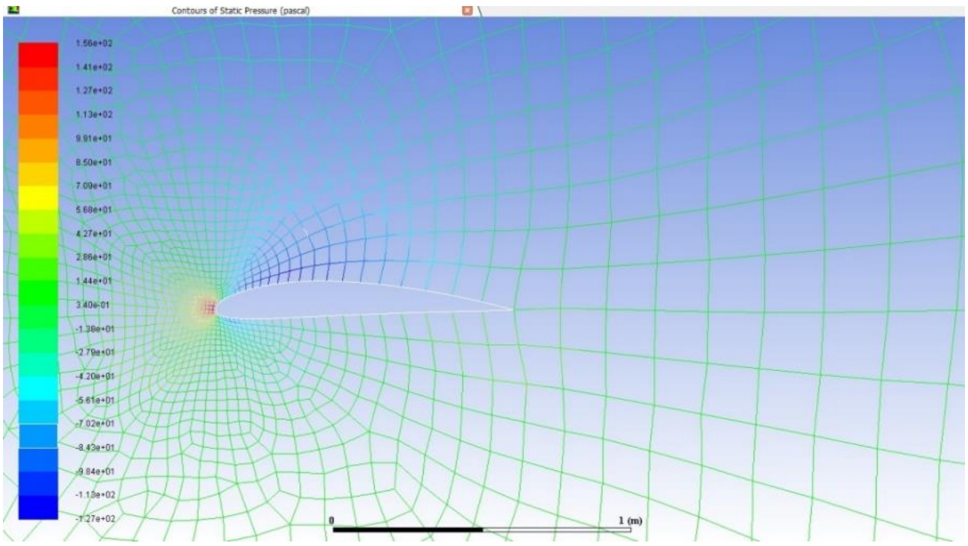

Fig. 11. Shows the maximum pressure in the Naca 4412 airfoil in this article for verification purposes

3.5.2. Validation of Ansys Fluent Software

To validate the performance of Ansys Fluent software for simulating the Naca 4412 airfoil, " Kevadiya " has done a CFD Analysis of the Pressure Coefficient for Naca 4412 in 2013. It has been analyzed with drawing software and at a wind speed of 18 meters per second (Kevedia, 2013). In the mentioned article, according to Fig. 11 of the Naca 4412 airfoil analysis, it can be seen that at the angle of attack of zero degrees, the highest air pressure is at the tip of the airfoil. In checking the Naca 4412 airfoil by Ansys Fluent software for verification, the result shows that the highest pressure was applied at the same point as shown in Fig. 10, which is shown in Fig. 11 and this shows the correct operation of the software.

4. Conclusions

According to this research, which used Q-blade and fluent Ansys Fluent software, significant results can be reached:

1) airfoil is suitable for wind speeds less than 11m/s and with blade lengths not less than 2m, which should be used for areas with wind speeds close to 11m/s.

2) The use of Nrel's 835 airfoil at a height of 10m in Firozkouh is not suitable, and it is possible to achieve more suitable results by increasing the height to more than 10m and with a blade length of more than 2m.

3) Nrel's 835 airfoil is more suitable in regions with wind speeds above 15m/s and with a blade length of 3m.

4) In the design of the airfoil and blade, it should not be expected to extract more power from the turbine at high wind speeds.

5) In the design and construction of the turbine, an appropriate airfoil should be used by the wind speed of the region.

6) In the airfoil design, special attention should be paid to the top surface and the bottom surface by changing the airfoil length to obtain a suitable top pressure and surface to increase the amount of C_l/C_d.

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