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Design and Practical lnvestigation of the Vertical Axis Wind Turbine in the Climatic Region of Zabol

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Abstract: The upcoming study investigates the design and use of vertical-axis wind turbines for power extraction in Chahnimeha, Zabol. In Sistan and Baluchestan provinces, due to the vastness and climatic barriers, the use of renewable energy can greatly contribute to the well-being of people. Using the meteorological data of this province, the average wind speed in the Chahnime region is estimated at 6.4 m/s. At first, 4 airfoils with the highest lift-to-drag coefficient have been selected and studied for wind turbine design. By choosing the best airfoil among the four examined ones, a wind turbine with 3 different blade sizes and rotor radius was designed. The wind turbine, which is designed with a blade length of 3 meters and a rotor radius of 1.5 m, has the best performance. The vertical axis wind turbine has been investigated in 4 models with 3, 5, 7, and 9 blades. The power factor of the 3-bladed turbine is equal to 0.30, and of the 7-bladed wind turbine is equal to 0.45. Among the examined wind turbines, the best wind turbine with 7 blades was chosen. The reduction of wind speed before the blades is influenced by the solidity of the wind turbine. The study of wind turbine exergy was used to investigate the environmental effects such as humidity and temperature on the performance of wind turbines in the climatic region of Zabol. The exergy efficiency of the designed 3-blade and 7-blade wind turbine is equal to 45 and 75%, which shows the effect of temperature and relative humidity on the wind turbine efficiency in a climate region. The results of this study clearly show that it is possible to use a 7-blade vertical axis wind turbine to provide electricity to areas far from the grid and to produce scattered.

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1. Introduction

Today, environmental pollution has increased the temperature of the earth's surface. According to the climate change data of the Government Climate Change Forum, the emission of carbon dioxide gas must be reduced by 2050; otherwise, it will increase the temperature of the earth by 4.5 to 5 degrees Celsius [1]. In Iran, the use of fossil fuels and diesel fuel in country's power plants has caused an excessive increase in greenhouse gases. 99% of gas pollutants in Iran are related to gas production in carbon dioxide. In Iran, the highest energy consumption is in the domestic sector, which is equal to 22.38% of the total energy. The agricultural sector has the lowest consumption of 2.65%. In the field of energy carriers, natural gas with 66.18% and oil products with 33% play a role in Iran's energy supply[2]. In Sistan and Baluchestan province, due to the high air temperature and also the climatic conditions of this province, it is difficult to access and supply energy, especially electricity and gas. Considering the nature of the province and its extent and the urgent need for energy in the coming years, the use of renewable energy can be expanded in this province. Using renewable energy is one of the best ways to protect the environment. Due to the presence of wind channels and different wind speeds in this province, the use of wind turbines can be considered as one of the energy sources of the province. Wind energy is a clean and renewable energy source; renewable energy can be used as one of the most attractive alternatives to fossil fuels that have high carbon and pollute the environment [3].Vertical-axis wind turbines can be used in areas with lower wind speeds. The vertical axis wind turbine does not depend on the wind direction and is used in geographical areas that have many natural and urban obstacles. Vertical-axis wind turbines have been developed in many areas due to their easy construction. From wind energy, it is possible to develop scattered energy production in any area that has a suitable wind speed. In the design of wind turbines, the aerodynamic analysis of blades is very important. If the blade is designed properly, the wind turbine can be efficient [4].Santi Kumarmadasamy et al. dealt in 2022 with the design and development of a 1 kW horizontal axis wind turbine by examining aerodynamic, exergy, and energy issues. They used CFD method to solve aerodynamic problems and predicted wind turbine design problems. They optimized the wind turbine using Naca 63215 airfoil. They increased the initial weight of the wind turbine from 5.6 kg to 1.1 kg [4]. In 2019, Ranjbar et al. conducted a study on the practical disc for the experimental and numerical investigation of the wind turbine. They used pragmatic discs to reduce the cost of their laboratory tests. They proposed some semi-empirical equations for the strength range of 0.2 and 0.6 to select suitable practical discs [5]. In 2021, Tarighi et al. studied and analyzed the wind flow of the cross-axis wind turbine in AnsysFluent software and compared it with the vertical-axis wind turbine. In this research, the wind turbine was designed in Solid Works software and, then, analyzed in AnsysFluent software. For this purpose, they first designed Naca 0018 and Naca 4412 airfoils in solid works software. To analyze the wind flow, they needed a wind tunnel, and for this purpose, the wind tunnel was designed in solid works software. In the AnsysFluent software, boundary conditions should be solved; all the screens of the wind tunnel, cylinders, and turbine were named, and after naming, the meshing of the design parts has been done. In the AnsysFluent simulation part, they choose the flow model, boundary conditions, solution method, and equation discretization method. The results of their work obtained a production power of 12.415 (kW) [6]. In 2020, A. Antar and M. L. Khoury studied the issue of optimizing the cover of a Savonius wind turbine. To increase the performance of a Savonius vertical axis wind turbine, they carried out a size optimization using the Computational Fluid Dynamics (CFD) technique. The result of their research shows that the turbine with optimized casing has better performance compared to the turbine without casing, especially in low tip speed ratios (TSR) [7]. In 2017, Koka et al. investigated the airflow phenomena on the NACA 4412 wind turbine airfoil with low Reynolds numbers and the role of the laminar separation bubble in the flow evolution. The purpose of their study was to investigate the force produced by the NACA 4412 airfoil at different attack angles and Reynolds numbers. They used smoke to visualize the pattern of airflow around the airfoil [8]. Rogowski et al. studied the aerodynamic characteristics of the NACA 0018 airfoil using the SST model at a low Reynolds number in 2021. Their aim was to analyze the NACA 0018 airfoil at a Reynolds number of 160,000 and at an angle of attack of 6 to 11 degrees[9].

This study is divided into several parts. In section 2-1, the geographical area of Zabol Chahnimeha in Sistan and Baluchestan province is investigated. In sections 2-2, the research methodology is presented; in sections 2-3, the mathematical discussions of wind turbines, energy, and exergy of wind turbines are written according to the weather information of Zabol Chahnimeha. In part 3, the results of the investigation and study are written. In part 4, the issues related to energy and exergy of the wind turbine are examined based on the weather information of Zabol, and part 5 is related to the conclusion.

In this study, an attempt has been made to use the wind speed of Chahnimeha, Zabol, and exploit it through a wind turbine to make an impression on the supply of electric energy in the area. Due to its hot and dry nature, this area needs to generate electricity for the cooling system in hot seasons. Among the innovations of this study, in addition to the design of a vertical axis wind turbine with a Naca 4412 airfoil for the climate of the Zabol well area, it is possible to examine simultaneously several wind turbine models using q-blade and AnsysFluent software to verify the output of wind turbine data. The extraction of exergy of wind turbines in this area in order to investigate the effects of atmospheric water parameters on wind turbine performance can be mentioned as another innovation of this study. One of the novelties of this study is also the design of a wind turbine with an airfoil Naca 4412 for the first time, which is used in Chahnimeha area, Zabol.

2. Materials and Methods

The geographical area of Zabol wells in Sistan and Baluchestan province has been considered as a pilot area for wind turbine design. Chahnime is near the city of Zabol, and Hirmand river pours its water into this well. Chahnimha consists of four artificial lakes that were built around the mouth of Gholaman, in the eastern region of Zabl. They are known as Chahnimha in the local term. Chahnime 1, 2, and 3 are natural wells that draw water from the Hirmand River. Chahnime number 4 was built in the recent years [10].Figure 1 shows the position of the Chahnime of Zabol (Sistan and Baluchestan), and Chahnime number 4 is the largest.

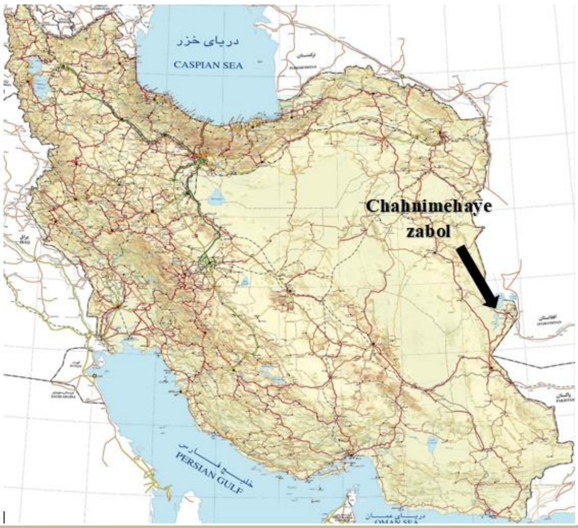

Fig. 1: Showing the location of the Chahnime (zabol) in Sistan and Baluchestan

2.1. ResearchMethodology

This study calculates the mean wind speed, air temperature, and relative humidity of the environment using weather information. Using the studies done by other researchers, the best airfoil that is effective at higher wind speed and low Reynolds number is chosen for the design and analysis of the vertical axis wind turbine. It is choosing the right airfoil and checking and calculating the production power of the wind turbine under study. First, it was done by using Q-BLADE software. To further investigate the wind turbine and perform validation and assurance of the software data, the investigation and analysis of the wind turbine was also carried out using Ansys Fluent software. To investigate environmental effects such as humidity and temperature on wind turbine performance, a wind turbine exergy study was used to compare the efficiency of designed turbines in environmental conditions. In general, the steps and methods of investigation in this research are presented in the chart of Figure No. 2.

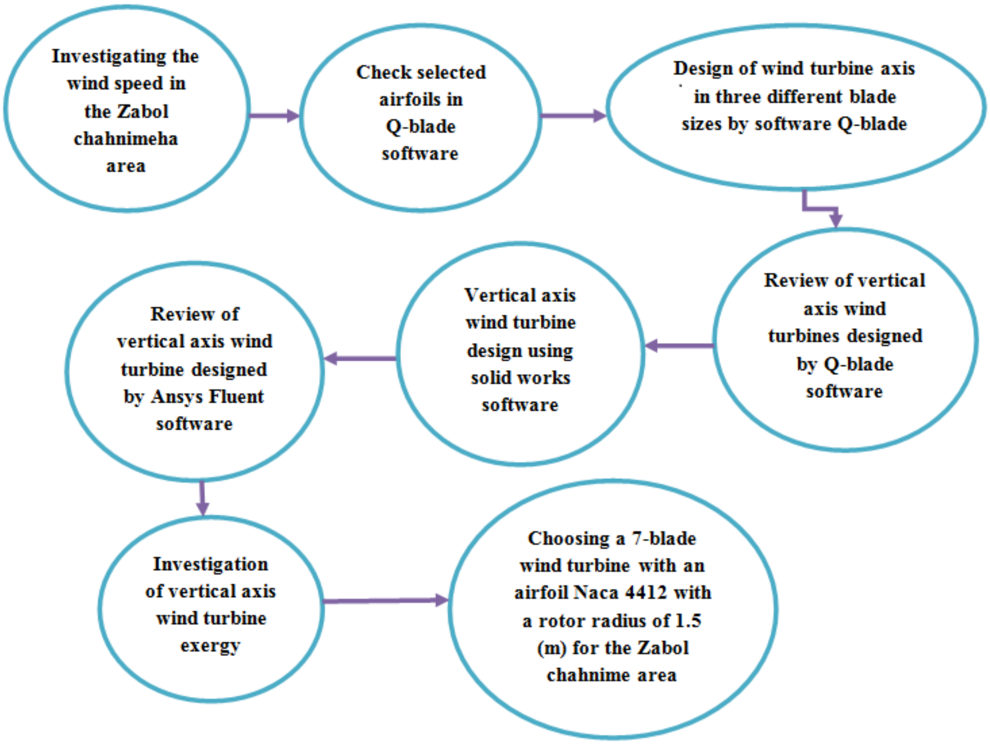

Fig. 2: Flowchart of research stages in the research

By using Q-blade software, it became possible to choose a suitable airfoil for checking and designing a wind turbine with the desired climate zone. Naca 0012, 0015, 0018, and 4412 airfoils were examined using Q-blade software to select and use the best airfoil for wind turbine design for the Chahnime, Zabol. The reason for choosing these four airfoils was their proper performance in low wind speeds and Reynolds's low number [11]. After selecting the airfoil from the Q-blade software data shown in Table 3, a wind turbine was designed with a blade length of 3m and a rotor radius of 1.5m.By using the changes in the blade length and the radius of the rotor arms, a suitable wind turbine was designed and its output power was calculated by the mentioned software. To investigate the environmental effects such as humidity and temperature on the operation of the wind turbine, a study on the exergy of the wind turbine was used.

To calculate the amount of exergy and its efficiency, the kinetic energy and the speed of the wind output from the wind turbine were needed. Ansys Fluent software was used to calculate the amount of changes in the output speed of the wind turbine. To analyze the vertical axis wind turbine in Ansys Fluent software, first, the wind turbine was designed by Solid Works software. The output power of the vertical axis wind turbine and the amount of energy, and the exergy of this wind turbine were investigated with the wind speed of the region. Using the weather information related to the region of Chahnimeha, presented in Table 1, it became possible to design a wind turbine that could be used in this region as a distributed production. The weather information is listed in Table 1, from May to October; the average wind speed is 4.6 m/s, and the highest wind speed is 9.8 m/s, which is the maximum electricity production by wind turbine. In the discussion of exergy and wind turbine energy used in these areas, the measured temperature, humidity, and relative pressure are also important.

Table 1: Climatic information of the Chahnnimeha of Sistan and Baluchestan[9]

Month	air temperature C^0	Relative humidity (%)	atmospheric pressure (Kpa)	wind speed (m/s)
January	8.1	48.5	96	3.9
February	11	43.6	95.8	4.7
March	16.9	37.6	95.5	4.6
April	24	29.1	95.2	5.8
May	29.4	22	94.9	6.4
June	33.1	17.7	94.3	8.6
July	34.5	16.9	94	9.8
August	32.6	16.7	94.3	7.9
September	27.8	18	94.9	8.2
October	21.9	24.6	95.6	6.2
November	15.6	34.5	95.9	4.5
December	9.8	44.8	96.1	4.1
yearly	22	29.4	95.2	6.4

2.2. Mathematical Discussions of Wind Turbine, Energy and Exergy and the Mathematical Topics of Wind Turbine

In the investigation of wind turbine use, the difference in wind speed in front and behind the wind turbine rotor indicates the absorption of wind energy by the wind turbine rotor blades. Wind turbine power according to the wind speed of the study area can be extracted from equation number 1 [12]:

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

According to Betz's theory, the maximum CP can be 2.59. The CP of the wind turbine can be obtained by using the wind speed entering the wind turbine and the wind speed exiting the wind turbine according to Equation 2[13]:

$$C_P = \frac{(V_{in} + V_{out})((V_{in})^2 - (V_{out})^2)}{(2V_{in})^3} \tag{2}$$

In the design of the vertical axis wind turbine, equation 3 can be used to calculate the radius of the turbine rotor[14].

$$R = \frac{P}{\rho V^3 C_P L} \tag{3}$$

In the above relationship, L is the blade length.

In the beauty of the landscape related to the design of the wind turbine, the radius of the rotor is considered to be half the length of the blade. One of the important parameters that can increase wind turbine efficiency is improving the airfoil lift-to-drag coefficient. By extracting the value of wind density and speed of the studied area, the value of the lift and drag coefficient (Cl and Cd) of the wind turbine can be obtained from the following relations [15]

$$CL = \frac{L}{\frac{1}{2}\rho V^2 AC} \quad (4)$$

$$Cd = \frac{D}{\frac{1}{2}\rho V^2 AC} \quad (5)$$

A high CL value of a wind turbine indicates better efficiency and more production power. The drag coefficient is the ratio of the force applied to the body to the dynamic force in the fluid. The coefficient changes linearly with the angle of attack, the slope of which is 2 radians, which can be obtained from equation 6.

$$CL = 2\pi\alpha \quad (6)$$

The solidity of the wind turbine can be checked by checking the number of installed wind turbine blades. The solidity of the wind turbine is derived from equation 7, which is very important in wind turbine laboratory tests. The solidity of the wind turbine indicates the ratio of the number and the area of the blades to the sweep surface of the wind turbine [16].

$$S = \frac{Nb}{A}C \quad (7)$$

In the software analysis and in the calculation of the efficiency of wind turbine airfoils and blades in different wind speeds, it is necessary to calculate the Reynolds number of the wind in the area, which is used from the following equation [17].

$$\mathrm{Re} = \frac{\rho VC}{\mu} \quad (8)$$

2.3. Mathematical Issues of Wind Turbine Energy and Exergy

In the analysis of wind turbine exergy, the characteristics of the free space environment in which the wind turbine starts working, including temperature, pressure, and chemical characteristics of the environment, are considered. In the discussion of wind turbine exergy, it is generally possible to calculate the kinetic energy of the air, the effects of air humidity as well as the power produced by the generator. By examining the amount of destroyed exergy, it is possible to point out the general weakness of the power generation system, including the design of the wind turbine. Equation number 9 is used to investigate and study the exergy of the wind turbine system according to the second law of thermodynamics [13]:

$$Ex_{k,in} - Ex_{k.out} - E_{gen} - E_{des} = 0 \quad (9)$$

The kinetic exergy of a turbine depends on the speed of the air entering and exiting the blades of the wind turbine. Kinetic exergy can be calculated from relations 10 [18]:

$$Ex_{k,in} = \frac{1}{2}mV^2$$

$$Ex_{k.out} = \frac{1}{18}mV^2 \quad (10)$$

The amount of exergy of air flow can be obtained from equation number 11.

$$\dot{E}_X = \dot{m}\psi_\alpha \quad (11)$$

Equation No. 12 is used to obtain the specific exergy of humid air, which is indicated by ψ_α 12 [19, 20]

$$\psi_\alpha = (C_{Pa} + \omega C_{Pv})T_0[\frac{T}{T_0} - 1 - Ln(\frac{T}{T_0}) + (1+1.6078\omega)RT_0 Ln(\frac{p}{p_0}) + RT_0 \{(1+1.6078\omega) Ln[\frac{1+1.6078\omega_0}{1+1.6078\omega}] + (1+1.6078\omega)Ln\frac{\omega_0}{\omega}\} \quad (12)$$

To derive the humidity rate indicated by ω, the average humidity and the average monthly temperature of the studied area are used. They were obtained from equation number 13 [21].

$$\omega = \frac{\dot{m}_w}{\dot{m}} \quad (13)$$

The value of $\dot{m}$required to extract exergy is obtained from equation number 14.

$$\dot{m} = \frac{2}{3}\rho AV_{in} \quad (14)$$

The air density of Zabol region is calculated by examining the difference in the area's height compared to the sea level. It can be extracted from equation number 15[13]

$$\rho = P_0 e^{-(\frac{0.297H}{3048})} \quad (15)$$

The value of p, the secondary pressure behind the turbine blades, is obtained from equation number 16.

$$P = P_0 + \frac{V_{in}}{2} \quad (16)$$

The amount of destroyed exergy is calculated from the following equation.

$$Ex_{dex} = \dot{m}\psi_\alpha + (\frac{1}{2}mV^2 - \frac{1}{18}mV^2) - P \quad (17)$$

The exergy efficiency of the wind turbine can be obtained from equation 18 [18]:

$$ExergyEfficiency = \frac{P}{\frac{8}{27}\rho A V_{in}^{3}} \tag{18}$$

By comparing the production power of the wind turbine in theoretical and practical mode with its exergy value and exergy efficiency, the efficiency of the wind turbine can be understood. In case of its inefficiency, he took action to improve the components of the wind turbine to increase the efficiency of the turbine.

2.4. Review and Analysis with Software Q-blade Software

Q-blade is an advanced software designed in the field of wind turbine due to its comprehensive development, its hydro elasticity, prototyping, simulation and certification of wind turbines. This powerful simulation tool enables accurate wind turbine design. The mathematical formulas used in the Q-blade software are based on the Blade Element Momentum (BEM) method. In this research, four airfoil models named naca0012, naca0015, naca0018 and naca4412 were investigated using the mentioned software. In the Figure NO.3, the investigated sub airfoils are shown by the Q-blade software.

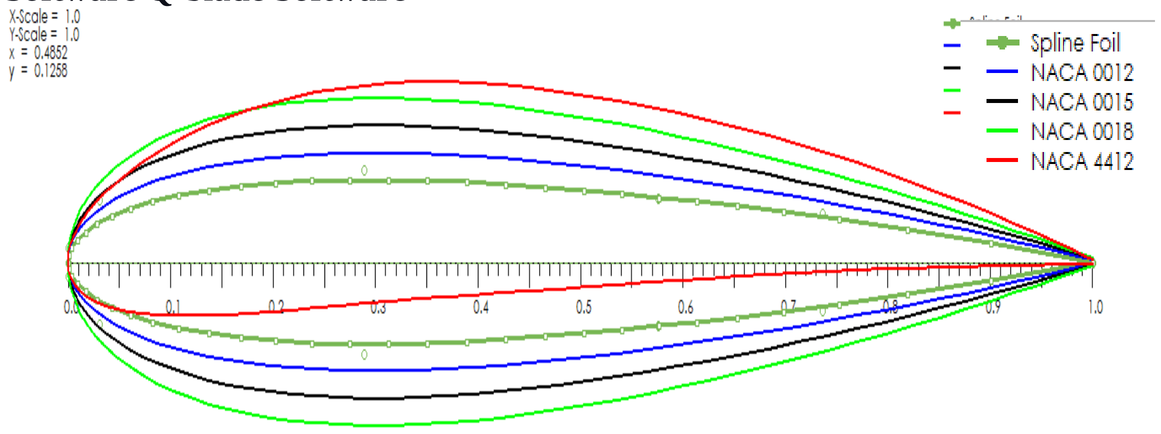

Fig. 3: Studied airfoils in the workspace of Q-blade software

Airfoil behavior, the dependence of airfoil coefficients on the angle of attack, the designed airfoil, and the Reynolds number, all depend on the behavior of the air boundary layer on the airfoil and the way the airflow is separated from the airfoil surface. If the separation of the flow from the airfoil starts instantaneously and quickly and increases with an increase in the angle of attack, the airfoil suffocation is mild and occurs slowly. If the separation of the airflow is done near the leading edge of the airfoil, the air boundary layer on the entire surface of the airfoil is separated suddenly and in an instant, which causes the drag force, drops suddenly. The drag force loss depends on the shape of the airfoil geometry. Thinner and sharp airfoils usually have a very fast suffocation and, finally, the drag force drops drastically. However, thicker airfoils have a milder choke stage and the drag force decreases at a slower rate. The smaller the drag coefficient, the better the airfoil. Of course, in vertical-axis wind turbines, the high drag force has a positive effect on the rotation of the wind turbine. Using Q-blade software and using Naca 4412 airfoil, a wind turbine has been designed. By examining the speed of wind output from wind turbines with different numbers of blades, it can be seen that with an increase in the number of blades, the wake created along the horizontal axis increases. In general, a wind turbine with fewer blades creates a smaller wake length. The following figure shows the wake created in different turbines. In Figure number 4, the maximum length of the created wake is related to the nine-bladed wind turbine, and its size is 40 m. The length of the wake of the seven- and five-bladed wind turbines are 39.2 and 31.42 m, respectively. The smallest wake turbine is related 3 blades with a length of 24.9 m. According to Figure 4, it can be seen that increasing the number of blades causes air disturbances behind the turbine. Also, increasing the number of blades is effective by creating a longer wake.

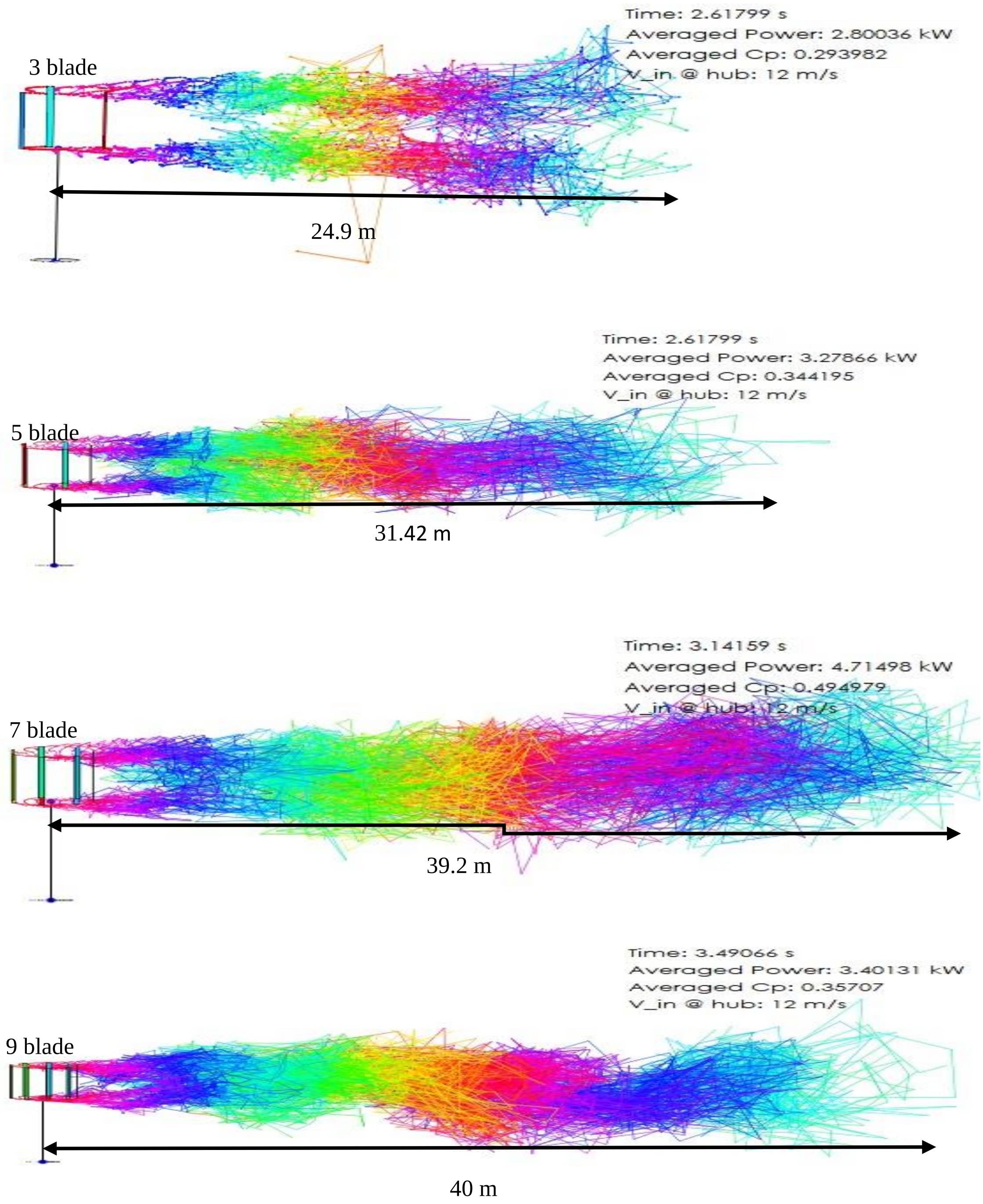

Fig. 4: Wake display of wind turbines with different number of blades

2.5. Review and Analysis with CFD Method

In this paper, computational fluid dynamics (CFD) is used to predict the aerodynamic efficiency of vertical axis wind turbine blades. Using CFD method, it is possible to observe the effects of wind speed and wind turbine behavior against different wind speeds at a lower cost. AnsysFluent software was used in the study of the designed wind turbine with a blade length of 3 meters, and a rotor radius of 1.5 m with a Naca 4412 airfoil to study the value of the wind speed exiting at the back of the turbine. In this study, two types of wind turbines with 3 and 7 blades were performed by the software. The designed 3-bladed wind turbine is shown in Figure 5. The purpose of the investigation by AnsysFluent software is to observe the output wind speed of the wind turbine so that the production power and the amount of exergy and energy of the wind turbine can be obtained in the studied climate area.

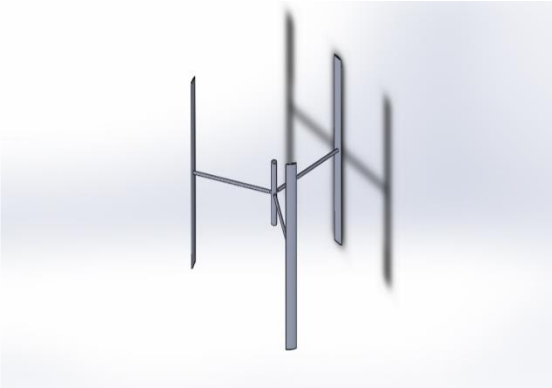

Fig. 5: Display of blades designed by solidworks software

Figure 6 shows the boundary conditions applied in AnasysFluent software to analyze the wind turbines of this study.

2.5.1. Boundary Conditions in AnsysFluent Software

The airflow around the wind turbine blades is incompressible. Incompressible flow in fluids is called a flow in which the fluid density is constant. In other words, it can be said that incompressible flow, even if the pressure changes, its density remains unchanged or is infinitely small. For the study of the turbine in the ANSYS Fluent software, a constant volume can be defined with the flow inlet and flow outlet items. The speed of the incoming air is considered equal to 6.4 m/s. The temperature of the free flow (ambient) air is 300 K, and its pressure is one atmosphere. Considering that the airflow around the wind turbine is incompressible, the inlet part of the wind flow is considered as the boundary condition with an inlet, and the outlet part of the wind flow is considered as an outlet; as shown in Figure 6, in the center of the marked boundary of the wind turbine is located.

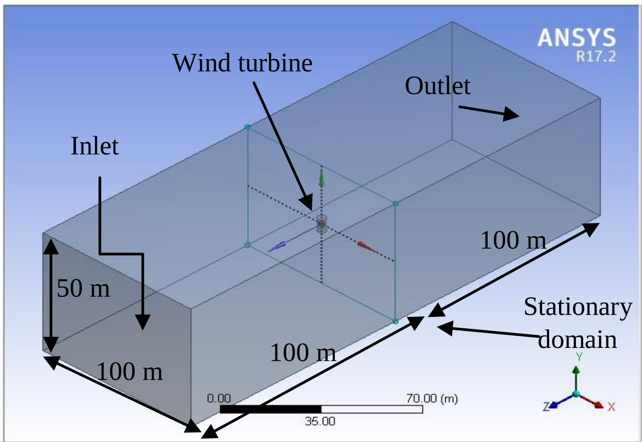

Fig. 6: Simulation domain

In table number 2, the boundary conditions of the AnsysFluent environment are written. The designed wind turbine blades are analyzed and checked by the AnsysFluent software environment.

Table 2: AnsysFluent environment boundary conditions information

Solution method	$k-\varepsilon$,Realizade
ρ	1.22
rotational wind Turbine3 blade	122 Rpm
rotational wind Turbine7 blade	101 Rpm

2.5.2. Investigating the Independence of the Grid in AnasysFluent Software Analysis

Considering the possibility that the numerical solution results in AnsysFluent software may be dependent on the created network. To be sure of the results of software data, the independence of the results from the network is checked first. In this study, it has been used to analyze wind turbines made of five mesh sizes. Number of grids are 73000, 90000,115000, 125000, and 192000. According to the same production power of the wind turbine in the number of meshes 115000, 1250000, and 197000 which is equal to 623 watts, it can be seen that the output data of the software is independent of the mesh. The number of meshes in this survey is 197,000. Figure 7 shows the meshing of the wind turbine by Ansys Fluent software. In Table 3, a summary of the independence of AnsysFluent software grid is written.

Table 3: Independence of the grid in AnasysFluent software analysis

Quality grid	Grid number	Power (W)	independence of the grid
Large	73000	990	no
Middle	90000	623	yes
	115000	623	yes
Small	125000	623	yes
	192000	623	yes

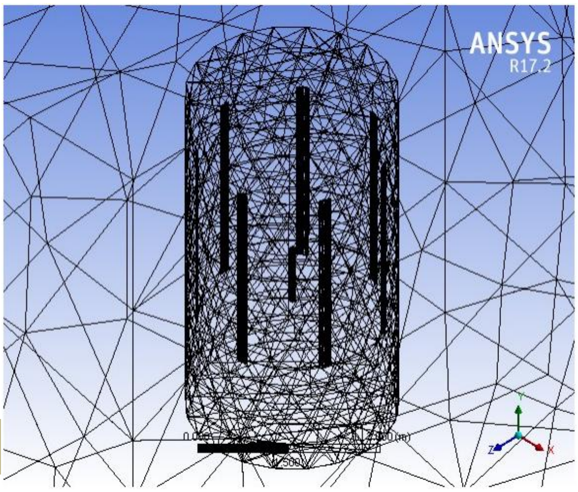

Fig. 7: Display of wind turbine meshing

2.5.3. Model Validation

2.5.3.1. Validation of Q-blade software

In this section, the article by Louis Angelo Danao et al. on the topic of Design Analysis of a Horizontal Axis Tidal Turbine was used to validate the Q-blade software. In part of their study, they investigated the lift coefficient of the Naca 4412 airfoil at an angle of attack of -20 to 20 degrees [22].Considering the comparison of the output and the lift coefficient curve at the angle of attack, as the article by Louis Angelo Danao et al., with the lift coefficient output at the angle of attack of -20 to 20, drawn in Figure 9, one can trust the accuracy of the output results of the q-blade software in this study. In Figure 8, the lift efficiency curve of the airfoil 4412 was examined, as drawn in the article by Luis Angelo Dana et al, along with the lift coefficient curve of the airfoil 4412, examined in this article.

2.5.3.2. Validation of AnsysFluentSoftware

In this study, one of the reasons for using two kinds of software, Q-Blade and AnsysFluent, is to validate the data of Ansys software. By comparing the power generation results of three-and seven-blade wind turbines in Q-Blade software, shown in Table 5, and the power results produced in Ansys Fluent software, shown in Table 6, it is possible to validate the Ansys software. According to Tables 5 and 6, the calculation error of two types of software in producing the power of wind turbines with 3 and 7 blades is 6 and 9% respectively. Considering the small error difference between the data related to the power of three- and seven-blade wind turbines in the mentioned software, the data output of Ansys Fluent software can be assured.

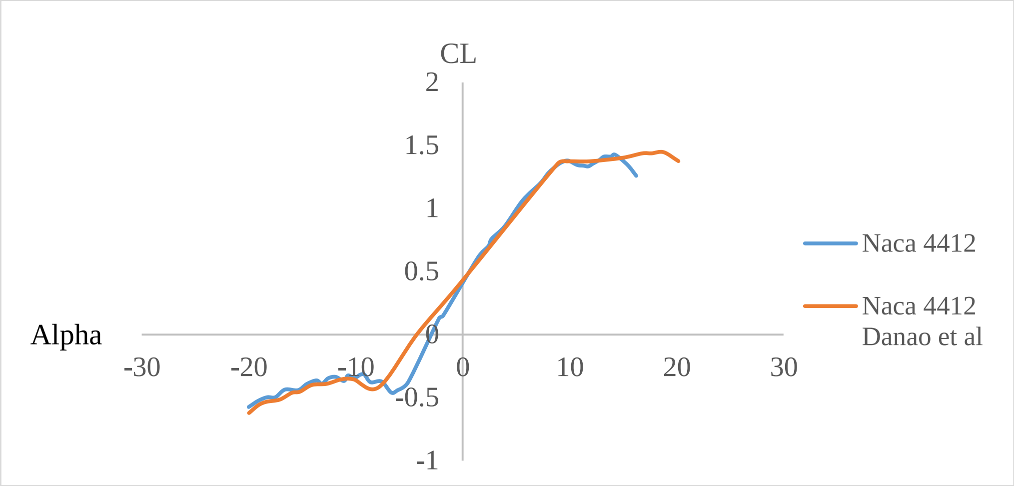

Fig. 8:Output curves for validation of Q-blade software[22]

3. Results

3.1. Results of Selecting the Appropriate Airfoil

One of the ways to check and identify the suitable airfoil for an area is to check the Cl/Cd ratio with the angle of attack. Using Q-blade software, the behaviors of 4 Naca series airfoils 0018, 0015, 0012and, 4412 were investigated. Figure 9 shows the CL/Cd curve of the investigated airfoils in Q-blade software. According to the curves of the airfoils, shown in Figure 9, the Naca 4412 airfoil has the highest Cl/Cd coefficient at an angle of attack of less than 10 degrees, which is better in performance than the other studied airfoils. The lift and drag values of the studied airfoils Naca 0012, 0015, 0018, and 4412 are illustrated in Table 4

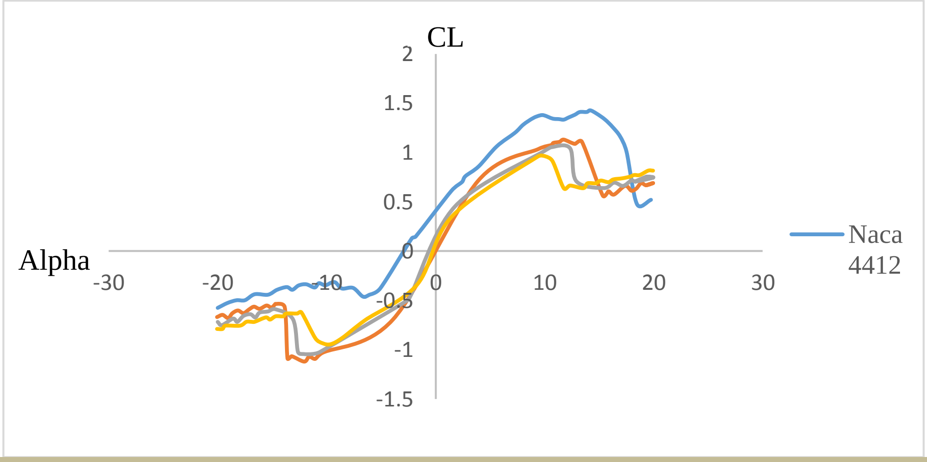

Fig. 9: Showing the curve related to cl/cd in the angle of attack of airfoils 0012, 0014, 0018, 4412

Table 4: Output data of airfoils examined by Q-blade software

Airfoil	Cl	Cd	L/D
Naca4412	0.514	0.12	4.29
Naca0012	0.798	0.275	3.11
Naca0015	0.73	0.243	3.006
Naca0018	0.67	0.234	2.866

According to the data in Table 4, the lift-to-drag value of the Naca 4412 airfoil, which is equal to 4.29, indicates that it has a higher lift than other airfoils and can receive more energy from the wind in the area. Airfoil 4412 has the best Cl/Cd at an angle of attack of less than 10 degrees, as shown in Figure 9. Figure 10 shows Naca 4412 airfoil drawn by Q-blade software.

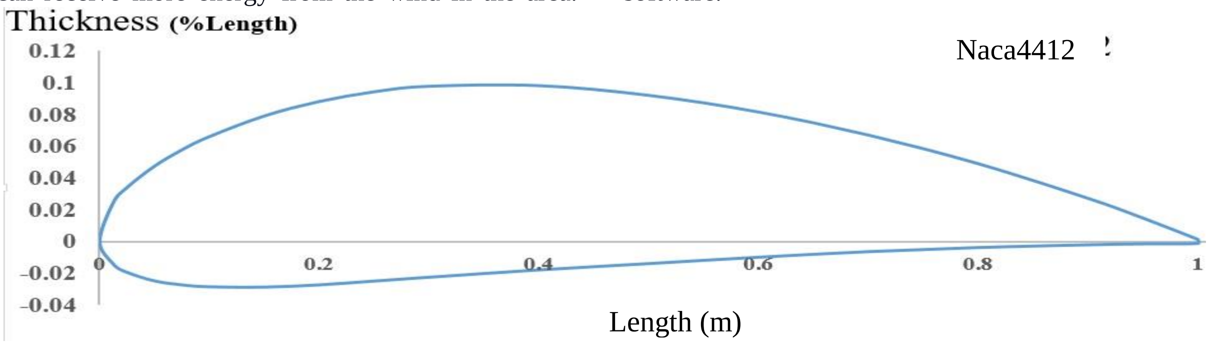

Fig. 10: Naca 4412 airfoil designed in Q-blade software

In Q-blade software and with Naca 4412 airfoil, a wind turbine was designed so that the amount of CP and production power can be measured by the wind speed of the area. The design of the turbine was undertaken in three different sizes. The designed turbines are considered with blade lengths of 3 m, 2.5 m, and 2 m and rotor radii of 1.5 m, 1.25 m, and 1 m, respectively. The length of the airfoil in this design is 0.2 m. In the design of the turbine and its analysis, the parameters (wind speed, airfoil length, air density, and TSR) of the wind turbine are considered constant. The results of wind turbine analysis designed with different blade lengths and rotor radii by q-blade software are written in Table No. 5. In this study, the TSR of wind turbine with 3blades is considered. According to Table 5, the Cp of a wind turbine with a blade length of 3 m and a radius of 1.5 m can produce the most wind power in the region. Its solidity and impact on the turbine power were investigated to examine further the production power of a wind turbine with a blade length of 3 m and a rotor radius of 1.5 m. By increasing the number of blades, different solidities can be obtained. In addition to the 3-bladed wind turbine, wind turbines with 5, 7, and 9 blades were investigated in this research. To check more accurately the production power of the wind turbine for using in the Zabol Chahnimeha area, the wind speed was considered to be 2, 4, 6.4, 8, 10, and 12. Table 5shows the production power curve of wind turbines with different solidities.

Table 5: Q-blade software analysis results on 3 designed turbine models

V	6.4	6.4	6.4
TSR	0.3	0.3	0.3
blade length	3m	2.5m	2m
Rotor radius	1.5m	1.25m	1m
air density	1.22	1.22	1.22
CP	0.32	0.26	0.۲۹
POWER	473W	260W	123W
Energy produced with a generator factor of 0.85	402W	221W	140W

According to the curve of wind speed and production power, shown in Figure 11, the seven-bladed wind turbine has the highest production power compared to other studied wind turbines. The seven-bladed wind turbine has a production power of nearly 5 kW. One of the reasons that the nine-bladed wind turbine has less power than the seven-bladed wind turbine can be the weight of the rotor and its high solidity. According to relation 7, the solidity of seven- and nine-bladed wind turbines is 0.46 and 0.6, respectively. Increasing the number of blades and keeping the radius of the wind turbine rotor constant create a state of a windbreaker; this factor causes insufficient passage of wind through the rotor. It can lead to a decrease in power and rotational speed.

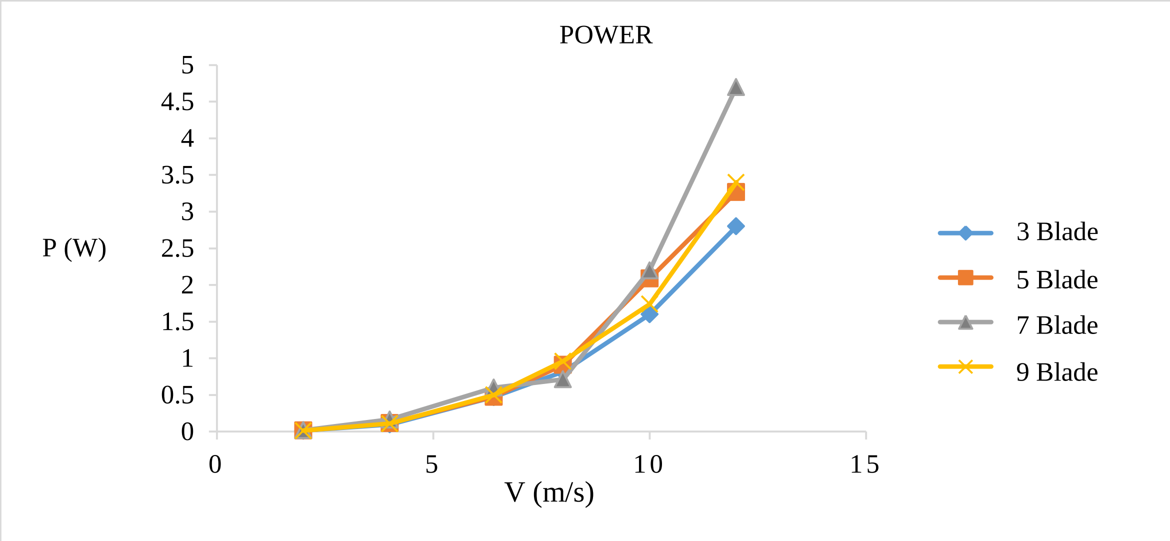

Fig. 11: Wind speed-power curve of wind turbines with different solidities

According to the Cp-Tsr curve of wind turbines, shown in Figure 12, the highest wind power factor is related to the seven-bladed wind turbine, which is close to 0.5, and the lowest power factor is related to the 3-blade wind turbine, which is 0.32. The power factors of five-bladed and nine-bladed wind turbines are 0.37 and 0.35, respectively. According to curve 7, it can be concluded that the best-designed wind turbine has 7 blades.

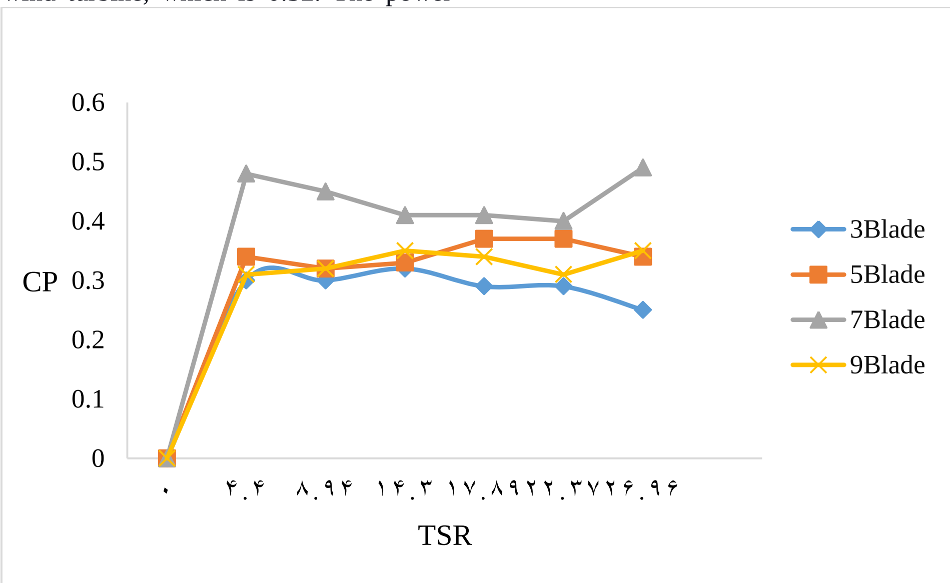

Fig. 12: Cp-TSR curve of studied wind turbines

3.2. The Results of Wind Turbine Designed Using AnsysFluent Software

Using the information in Tables 2, three- and seven-bladed wind turbines were investigated using AnsysFluent software. After that, the analysis was carried out by AnsysFluent, as shown in Figures 12,

Including the contours of wind speed, created in the blades of a 7-blade wind turbine. According to Figure 13, it should be noted that the reduction of the speed of the wind entering the blades before reaching the rotor is reduced due to the high density of air (point A), while the air pressure in this area increases. The results of the AnsysFluent software, as shown in Figures 9 and 10, show that according to the wind speed of 6.4 m/s, the test environment indicated by the letter (A), the wind speed at the previous point is the maximum wind speed on the blade (B) and is equal to 9.52 - 21.2 m/s. This speed increases the speed of the rotor. The wind speed after passing through the vane (C) and the wind speed at the distance away from the vane (point E) are 2.12 m/s and 3.17 m/s. With relation number 1 related to the production power of the wind turbine with changes in the input and output speed to the wind turbine, the output power of this turbine can be calculated. The production power and CP of the wind turbine designed by checking the AnsysFlent software can be completely seen in Table 6.

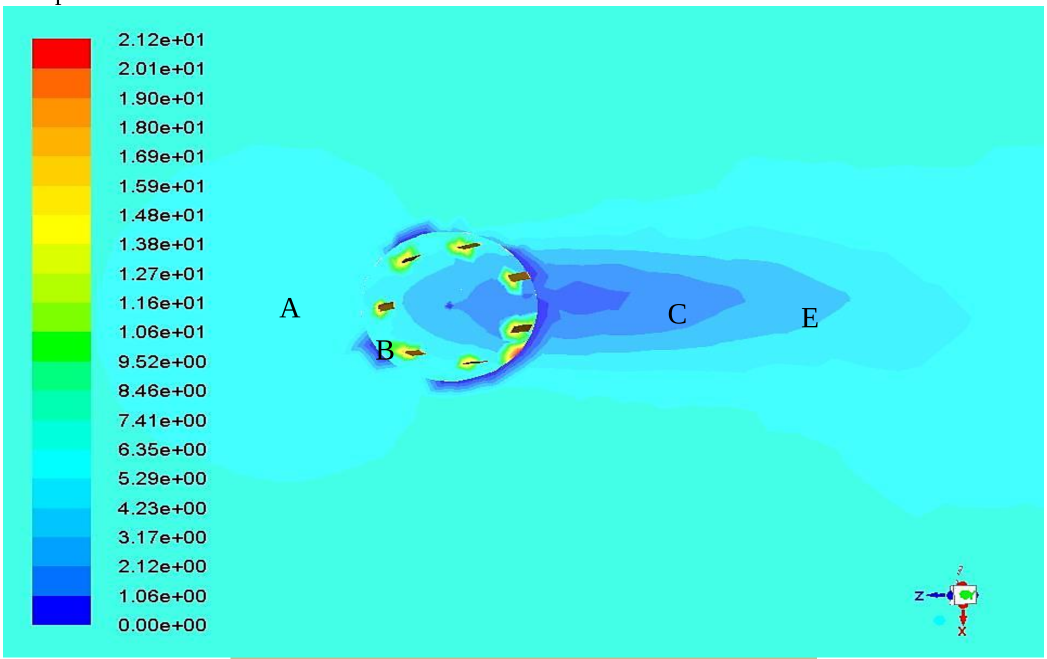

Fig. 13: Velocity contour display in Ansys fluent software

Table 6: Analysis results of AnsysFluent software on the turbine designed with Naca4412 airfoil

V	Wind turbine	moment	cm	Rad/s	landa	CP	POWER	Software error between Q-blade - AnsysFluent
6.4m/s	3 blade	82	0.24	5.23	1.22	0.30	448 W	6%
	7 blade	59	0.174916	10.5	2.47	0.43	623 W	9%

According to Table 5 and 6, which are related to the output of q-blade and AnsysFluent software, the amounts of calculation error in three- and seven-bladed wind turbines are 6 and 9% respectively. The reason for using two kinds of

software to simulate the performance of the vertical axis wind turbine is to validate the data and performance of the software and also to assure by considering this error percentage, the efficiency of the wind turbine and its output power. Figure14 is related to the flow of air passing through a seven-bladed vertical axis wind turbine. Due to the impact of the air on the wind turbine and its congestion in front of the wind turbine, the wind speed decreases before it reaches the wind turbine and collides with it.

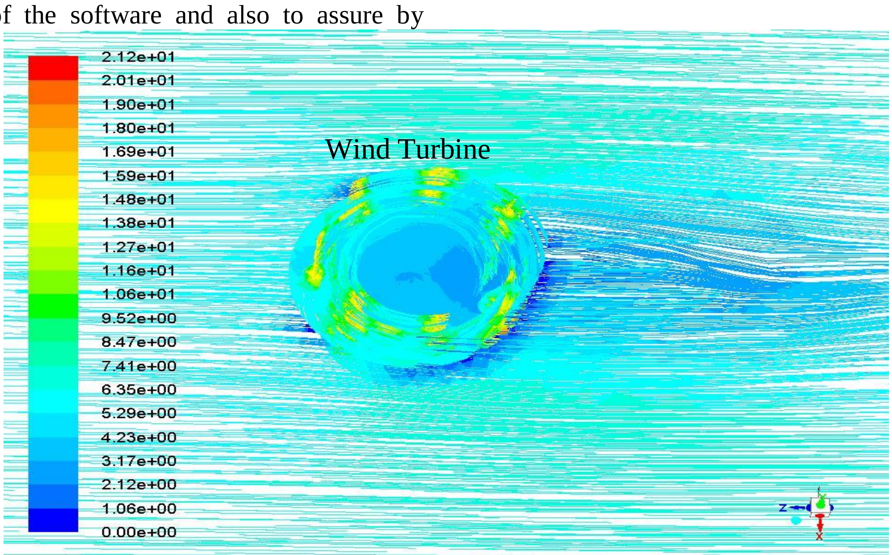

Fig. 14: Showing the flow of wind through the wind turbine (7 blade)

The curve of wind speed changes, effected by a seven-bladed wind turbine, is shown in Figure 15.According to the curve in Figure 15, it can be seen that the wind speed of 6.4 m/s in the seven-bladed wind turbine is reduced by 2.5 m/s. The wind speed is reduced to a distance of 6 m, after passing through the wind turbine. Afterwards, the wind speed increases again to reach the wind speed of the free environment. The wind speed reaches its initial speed in the free environment at a distance of 9 m after the wind turbine.

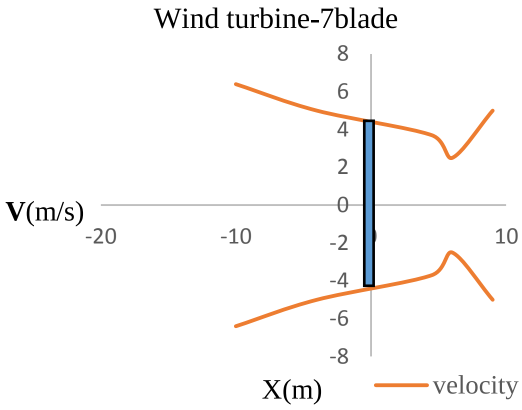

Fig. 15: Wind speed curve (6.4 meters per second) from a 7 blade wind turbine

4. Examining Exergy and Wind Turbine Energy

The reason for examining wind turbine exergy is to study external effects on wind turbine operation. By using exergy data, the best decision can be made to use a wind turbine in a region. To investigate the environmental effects such as humidity and temperature on the operation of the wind turbine, a study on the exergy of the wind turbine is used. To extract wind turbine exergy, it is necessary to calculate kinetic exergy, physical exergy, and chemical exergy. The kinetic exergy created by the wind flow, is relation number 10 related to this exergy. Physical and chemical exergy can be calculated from relations No. 11 to 16. By using air-water information in Table No. 1, the amount of energy, exergy, destroyed exergy, and exergy efficiency of 3-blade and 7-blade wind turbines are written in Tables 7 and 8, respectively. Exergy efficiency can be obtained by the ratio of wind turbine production power to wind flow exergy, which is calculated from Equation 18. By studying the production capacity and exergy efficiency, the effectiveness of the wind turbine design can be seen and, if necessary, the optimization of the wind turbine can be done. According to equation 1 and using the wind turbine production power information with the electric production coefficient using the generator, the efficiency of which is considered 0.85.

Table 7: Calculation results of energy, exergy, depleted exergy and flow exergy (3 blade wind turbine)

Month	Flow exergy	Degraded exergy	Exergy efficiency	Energy
January	1650.163	1285.431	0.51	97.38341
February	1983.469	1345.097	0.51	170.4452
March	1921.233	1322.747	0.51	159.7955
April	2438.173	1238.494	0.51	320.3134
May	2714.096	1094.693	0.51	432.3796
June	3614.87	296.025	0.51	1044.207
July	4117.505	1669.57	0.51	1545.145
August	4095.508	1516.21	0.51	1498.326
September	3469.853	79.67574	0.51	905.1753
October	2630.439	1165.04	0.51	391.2607
November	1907.905	1347.608	0.51	149.599
December	1737.979	1314.206	0.51	113.1469
yearly	2693.327	2187.022	0.51	430.3592
CFD	2692.86	2100.68	0.45	380

Table 8: Calculation results of energy, exergy, depleted exergy and flow exergy (7 blade wind turbine)

Month	Flow exergy	Degraded exergy	Exergy efficiency	Energy
January	1650.163	1248.273	0.82	128.9672
February	1983.469	1280.062	0.82	225.7247
March	1921.233	1261.776	0.82	211.6211
April	2438.173	1116.276	0.82	424.1989
May	2714.096	929.7155	0.82	572.6109
June	3614.87	-694.45	0.82	1382.868
July	4117.505	-2259.13	0.82	2046.274
August	4095.508	-2087.91	0.82	1984.27
September	3469.853	-265.701	0.82	1198.746
October	2630.439	1015.751	0.82	518.1561
November	1907.905	1290.528	0.82	198.1176
December	1737.979	1271.034	0.82	149.8432
yearly	2693.327	2022.815	0.82	569.9351
CFD	2692.86	2043.84	0.75	529

Using the data related to energy in Tables No. 7 and 8, the highest energy production is in July and the lowest is in January. In all months related to Zabol wind speed, 3-bladed and 7-bladed wind turbines, in theory, the exergy efficiency is equal to 51 and 82%. The exergy efficiency of the CFD method, which is close to the ambient conditions, in 3-bladed and 7-bladed wind turbines at a wind speed of 6.4 m/s is equal to 45 and 75 %. In theory, the amount of electricity produced in 3- and 7-blade wind turbines and considering the generator efficiency of 0.85 in the tested wind speed is equal to 430 and 569 watts, and the amount of electricity produced in the CFD method is equal to 380 and 529 watts. According to the results of exergy losses listed in Tables 5 and 6, it can be drwan that by making corrections on the number of blades and by increasing the radius of the rotor and other parameters, involved in increasing the destroyed exergy, the performance of the wind turbine improved. According to the power efficiency and exergy of the seven-bladed wind turbine compared to the three-bladed wind turbine, it is clear that in the climate region of Chahnimeha, the seven-bladedwind turbine, with the same rotor radius as the three-bladed wind turbine, has higher efficiency production, whilethree-bladedpower has more and better exergy efficiency. An increase in the turbine's solidity should be enough to pass the wind between the rotor blades. The nine-bladed turbine has a low efficiency compared to the seven-bladed wind turbine, due to its less porosity and less air passage. The production power of the three-bladed and of the seven-bladed vertical axis wind turbine generator, at a wind speed of 12 m/s,are equal to 2700 and 4800 (W). It seems that by increasing the number of blades, the efficiency of the turbine can be increased, but in this study, it was observed that an increase in the number of blades makes the wind turbine act like a wind breaker. By comparing the results of thee- and five-bladed wind turbines with seven-bladed wind turbines, it becomes clear that the small number of blades and an increase in the porosity level also decrease the efficiency of the wind turbine. When building wind turbines, it is necessary to act so that the change of the radius of the rotor can obtain a suitable solidity for the exploitation of the wind in the region. Increasing the number of blades can have the opposite effect on exergy efficiency. An increase in the number of blades, due to an increase in exergy loss of wind turbines, can be resulted in the decision that an improvement in the efficiency of individual blades can end up in the reduction of the number of blades of a rotor to reduce exergy loss. Reducing exergy losses makes it possible that a wind turbine can better convert the kinetic energy of the wind into power.

5. Conclusion

One of the novelties of this study is the design of a wind turbine with an airfoil Naca 4412 for the first time to be used in the Chahnimeha area, Zabol.By studying the wind speed in Zabol well area, the average wind speed is 6.4 (m/s). By examining 4 airfoils, named Naca 0012, 0015, 0018 and 4412 by Q-blade software, it was found that Naca 4412 airfoil has a lift-to-drag coefficient of 4.29 compared to other airfoils. According to the choice of airfoil 4412, the wind turbine was designed in three sizes: that with blade length of 3 m and with turbine radius 1.5 m; that with blade length of 2.5 m and with radius 1.25 m, and that with blade length of 2 m and with rotor radius of 1 m with Solidwork software. By examining these three designed wind turbine models, the obtained results showed that the wind turbine with a blade length of 3m has the highest production power equal to 437 watts and CP equal to 0.32. Two wind turbine models with the number of blades of 3 and 7 were designed using Naca 4412 airfoil to analyze the effect of changes in the number of blades of a turbine rotor on the wind changes in the Zabol, Chahnimeha area. With the analyses done on the wind turbines, designed by AnsysFluent software, it was determined that the highest TSR of the rotor of the seven-bladed turbine is equal to 26.96, which shows an efficiency of 0.46. In this research, it was shown that wind speed decreases before reaching the blades of the wind turbine. This situation depicts that an increase in the solidity of the wind turbine can play an important role in the efficiency of the wind turbine. With an increase in the number of blades of the wind turbine, the length of the wake also increases. The nine-bladed rotor has the maximum length of 40 m. To reduce costs, it is possible to use and apply changes to solids and exergy information of a turbine, which can be theoretically calculated. Exergy analysis method with Cp 0.30 and 0.46, obtained by Ansys software, was used to check how the wind turbine works in air temperature and other environmental factors on the designed three- and seven-bladed wind turbines. After examining the exergy of the turbine in the well environment, the amount of exergy losses in the 3-blade wind turbine is equal to 2187 and the 7-blade wind turbine is equal to 2022. The amounts of exergy loss, obtained in the CFD method, are 2100 in three-bladedturbine and 2043 in seven-bladedwind turbine. According to Tables 7 and 8, the amounts of exergy destruction of two wind turbines are not much different from those with 3 and 7 blades, but the production power of the seven-bladed turbine is high at the wind speed of 6.4 m/s. This small difference in exergy destruction regarding the amount of production power shows that the destructive effects of environmental parameters on the efficiency of seven-bladedwind turbines are more than those of three-bladedwind turbines. The exergy destruction results of the two turbines, studied in the exergy part, show that for an increase in exergy efficiency and a decrease in exergy destruction, more studies and research are needed to be done on the seven-bladedwind turbine. According to the exergy degradation results in Tables 7 and 8, if two three-bladedwind turbines are used, the efficiency is better than a seven-bladedturbine. This shows an increase in the number of blades should be alonga consideration of more production. Power and exergy destruction must also be considered. Along with wind turbine efficiency, exergy destruction, and exergy efficiency, economic issues are also involved in wind turbine construction. According to the results of the power production and related Tables as well as considering the economic the issues in this region, the construction and use of a seven-bladedwind turbine is suggested.

Nomenclature			
ρ	Volumetric mass of air (1.225 kg/m^3)	CP	Wind turbine coefficient
A	swept area of the turbine (m^2),	p	Power wind turbine
S	solidity	V	The wind speed of the .studied area is in (m/s)
Cd	Wind airfoil drag coefficient	C	Airfoil length
U_2	Average daily wind speed at a height of 2 meters above the water surface	CP	Wind turbine coefficient
R	turbine radius	CL	Airfoil lift coefficient
es – ed	Lack of steam pressure	Nb	Number of blades
D	drag	L	lift
CM	Momentary torque coefficients	vi	Air flow speed
Rpm	revolutions per minute	M	Momentum
λ	The rotor tip speed ratio is .(ω_sR/V)	ω_s	Turbine rotation speed (rad/s)
R	Reynolds	μ	0.00001647
ΔC	Blade area element	E	Evaporation from the free surface of water with unit (mm/day)
ed	Actual water vapor pressure (mmHg)	es	Saturated vapor pressure (mmHg)

Reference

[1] Abedi, S., Ebrahiminia, D.,"*Assessment of renewable energy potential in Sistan and Baluchistan province*", Solar, Wind, Geothermal, and Bioenergy Sources, Vol. 2, No. 4, pp. 353-367, 2023, http//doi.org/10.22059/ses.2024.373293.1064

[2] https://pep.moe.gov.ir/.

[3] Bourhis, M., Pereira, M., Ravelet, F.,"*Experimental investigation of the effects of the Reynolds number on the performance and near wake of a wind turbine*", Renewable Energy, Vol. 209, pp. 63-70, 2023, https://doi.org/10.1016/j.renene.2023.03.093.

[4] Madasamy, S.K., Rajab, V., Albonsrulah, H., Albaheayni, M.,"*Design, development and multi-disciplinary investigations of aerodynamic, structural, energy and exergy factors on 1 kW horizontal-axis wind turbin*", International Journal of Low-Carbon Technologies, Vol. 17, pp. 1292-1318, 2022, https://doi.org/10.1093/ijlct/ctac091.

[5] Ranjbar, M.H., Zanghanekiya, H., Nasrazadani, S,A., Gharali, K., Nathwani,J., "*Experimental and numerical investigations of actuator disks for wind turbines*", Energy Science&Engineering, Vol .8, pp. 2371-2386, 2020, http://dx.doi.org/10.1002/ese3.670.

[6] Tarighi, j., "*Analysis of wind flow of cross-axis wind turbine in Ansys Fluent software and its comparison with vertical axis wind turbine*", Jornal of Environmental Sciences Studies, Vol. 7, No. 4, pp. 5605-5614, 2022, https://doi.org/10.22034/jess.2022.342987.1789.

[7] Antar, E., Elkhoury, M.,"*Casing optimization of a savonius wind turbine*", Energy Reports, Vol. 6, pp. 184-189, 2020, https://doi.org/10.1016/j.egyr.2019.08.040.

[8] Koca, K., Genc, M., "*Identification of flow phenomena over NACA 4412 wind turbine airfoil at low Reynolds numbers and role of laminar separation bubble on flow evolution*", Energy, Vol. 144, pp. 750-764, 2018, https://doi.org/10.1016/j.energy.2017.12.045.

[9] Rogowski, K., Królak, G ., Bangga, G., "*Numerical study on the aerodynamic characteristics of the NACA 0018 airfoil at low Reynolds number for Darrieus wind turbines using the transition SST model*, Processes, Vol. 9, p. 477, 2021, https://doi.org/10.3390/pr9030477.

[10] Erfani, M., et al., "*Tourism positioning using decision support system (case study: Chahnime—Zabol, Iran)*", 040 Environmental Earth Sciences, Vol. 74, pp. 3135-3144, https://doi.org/10.1016/j.egyr.2019.08.040.

[11] Roslan, S.A.H., Rasid, Z.A., Ehsan, A.K.A.M., "*The aerodynamic performance of the small-scale wind turbine blade with NACA0012 airfoil*", CFD Letters., Vol. 14, pp. 87-98, 2022, https://doi.org/10.37934/cfdl.14.10.8798.

[12] Shahbazi, R., Kouravand, S., Hassan-Beygi, R., "*Analysis of wind turbine usage in greenhouses: wind resource assessment ,distributed generation of electricity and environmental protection*", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Vol. 45, pp. 1-2, 2019, http://dx.doi.org/10.1080/15567036.2019.1677810.

[13] Aghbashlo, M., Tabatabaei, M., Hosseini, S, S., Dashti, B.B., Soufiyan, M.M., "*Performance assessment of a wind power plant using standard exergy and extended exergy accounting (EEA) approaches*", Journal of Cleaner Production, Vol. 171, pp. 127-136, 2018, https://doi.org/10.1016/j.jclepro.2017.09.263.

[14] Brusca, S., Lanzafame, R., Messina, M., "*Design of a vertical-axis wind turbine: how the aspect ratio affects the turbine's performance*", International Journal of Energy and Environmental Engineering, Vol. 5, pp. 333-340, 2014,http://dx.doi.org/10.1007/s40095-014-0129-x.

[15] Nugroho, S., Diana, L., Ariyanti, D.P., "*Multistage Wind turbine capability to the rotor axial distance changes. International Electronics Symposium (IES)*", IEEE, 2019, http://dx.doi.org/10.1109/ELECSYM.2019.8901579

[16] https://civilica.com/doc/1275445.

[17] Mirafzali, S.M.B., A.H., "I*nvestigating the energy absorption quality of the porous Schwarz P structure made by 3D printing method*", Iranian Journal of Engineering, Vol. 9, No. 2, pp. 13-20 (in Persian), 2023, https://www.doi.org/10.22034/IJME.2023.383269.174.

[18] Asgari, E., Ehyaei, M., "*Exergy analysis and optimisation of a wind turbine using genetic and searching algorithms*", International Journal of Exergy, Vol. 16, No. 3, pp. 293-31, 2015, https://doi.org/10.1016/j.enconman.2019.01.

[19] Ozgener, O., Hepbasli, A., "*Experimental performance analysis of a solar assisted ground-source heat pump greenhouse heating system*", Energy and Buildings., Vol. 37(1), pp. 101-110, 2005, http://dx.doi.org/10.1016/j.enbuild.2004.06.003.

[20] Baskut, O., Ozgener, O., Ozgener, L.,"*Effects of meteorological variables on exergetic efficiency of wind turbine power plants*", Renewable and Sustainable Energy Reviews, Vol. 14. No. 9, pp. 3237-3241, 2010, https://doi.org/10.1016/j.energy.2011.01.047.

[21] Source: Zhang, Z., Pate, M. B., *ASHRAE Transactions*, Vol . 94 , Pt. 1, 1988.

[22]Dano, L.A., Angelo, L., Abuan, B., Howell, R., "*Design analysis of a horizontal axis tidal turbine*", Asian Wave and Tidal Conference, 2016, https://www.researchgate.net/publication/309731963_Design_Analysis_of_a_Horizontal_Axis_Tidal_Turbine.