Pages: 135-145/ Vol. 15/ Issue 2 / Summer- Fall 2022

Journal of Aerospace Science and Technology

www:jast.ias.ir

Scientific-Research Article

Localization and aerodynamic improvement of an urban-scale vertical axis wind turbine With respect to the climate of Sistan

Sam Saham [1], **Saeed KarimianAliabadi** [2*]

1-2- Mechanical Engineering Faculty, Tarbiat Modares University ,Tehran, Iran

ABSTRACT

***Keywords**:Wind energy potential, Vertical axis wind turbine, Power coefficient, Air ventilation*

The use of wind turbines on the urban and rural scale with the desired ventilation while producing power will be of great appeal. This study has attempted to assess the potential of wind energy in Zahedan and then evaluate the performance of a V-rotor turbine. For this purpose, using the 3D semi-analytical method is based on the Double Multiple Stream tube Method (DMST). Using this method, the performance of the turbine has been evaluated in terms of power and ventilation and the effect of the conical angle on power and ventilation has been studied parametrically. According to the results of this study, it can be seen that increasing the conical angle by up to 20 degrees, while reducing the power of the turbine, will not have a significant effect on the power coefficient. It is also observed that at 10 degrees conical angle and the turbine working point, the 30 KW output power and 10,000 m^3/h ventilation discharge will be obtained. Therefore, the 10-degree conical angle can be determined as a suitable angle for producing power and acceptable ventilation in the city's climatic conditions.

Introduction

Consumption of fossil fuels causes environmental problems such as air pollution, the production of greenhouse gases, and water and soil pollution [1]. On the other hand, as time passes, oil and gas reserves are decreasing while the expansion of industries and factories increases the need for energy. Therefore, many countries are trying to reduce their dependence on fossil fuels and obtain the energy they need through renewable energies such as wind and solar energy. This type of energy, also known as the green energy, provides more than 20% of the world's energy demand [2]. Since wind energy is free and often available, it is considered one of the suitable methods of energy supply. The use of wind energy requires the use of wind turbines so that with the help of these turbines wind energy can be converted into mechanical energy and finally with the help of generators into electrical energy. Turbines are divided into two categories: horizontal axis and vertical axis turbines. Generally, horizontal axis wind turbines produce more power than the vertical axis type, but they require spending more money and allocating an area called a wind farm. For this reason, the use of vertical axis wind turbines with lower power, smaller dimensions, more insensitivity to wind direction, and lower

1 Msc.

2. Assistant Professor (Corresponding Author) **Email:** * Karimian@modares.ac.ir

DOI: 10.22034/jast.2022.315321.1106

Submit: 15.11.2021 / Accepted: 29.05. 2022

Print ISSN:2345-3648 Online ISSN: 1735-2134 Publish by Iranian Aerospace Society

construction and service costs is one of the suitable options to benefit from places such as house roofs, workshop roofs, and other similar places where it is practically impossible to use horizontal axis wind turbines or it is not economical.
Since Iran is geographically located in a low-pressure area, some of its parts are affected by strong summer and winter flows. These flows include winter and summer winds that blow from the Atlantic Ocean, the Mediterranean Sea, and the Indian Ocean. Also, a study at Sharif University shows that the potential of 26 points in the country is around 6500 MW [3,15]. The major parts of southeastern Iran are generally considered to be windy, which can be a good place to install wind turbines. Iran's first experience in installing wind turbines for electricity production dates back to 1994. At that time, two wind turbine farms with a capacity of 500 kW were built in Manjil and Rudbar in Gilan province located in the north of Iran, whose annual energy reached more than 1.8 million kW.h [15]. The second experiment was carried out in 1999 with the construction of 27 wind turbines in Manjil, Rudbar, and Herzeville [5,15]. Other parts of Iran that use wind turbines include Binaloud in Khorasan and Lotak in Sistan and Baluchistan.

On the other hand, wind catchers have always been defined as a traditional structure for room ventilation, which can be seen all over the Middle East from Pakistan to North Africa with different names and shapes. Wind catchers have been built in different places in the past and their structure and design have many variations. Despite the different structures of the wind catchers, all of them have a single function of transferring the prevailing and favorable winds into the residential spaces. Apart from Iran, the wind turbines exist in the countries of Egypt, Pakistan, Afghanistan, Iraq, and the United Arab Emirates. A small number of wind turbines can also be seen above the buildings of Mediterranean regions such as Syria, Lebanon, Palestine, and Turkey. Regarding the origin of wind catchers, archaeologists' research has not led anywhere. Because in their findings, except for the lower walls and foundations of buildings, little, or no information was obtained about the upper parts of the building.

Ghorashi and Rahimi investigated the details of renewable and non-renewable energy, as well as energy waste in some industries, and offered suggestions to improve this problem [17]. Alamdari et al. investigated wind energy potential in Iran. They compared the wind velocity in 2007 at heights of 10, 30, and 40 m from the ground. In their research, they estimated the average wind speed, wind velocity distribution function, and average wind density according to 68 weather information centers in Iran [18]. Mostafaeipour investigated the feasibility of using wind energy in the Yazd region of Iran. He evaluated the wind speed monthly and annually at different heights between 1992 and 2005 in 11 meteorological stations [19]. Also, in another research, he made an economic evaluation of the use of small wind turbines in the city of Kerman. In this research, three small turbines were investigated and it was shown that this city has the potential to use wind energy for small wind turbines [20]. Mousavi et al. compared the existing methods of electricity generation with wind turbines in Iran and stated that power plants based on wind energy can be one of the competitive power plants in the industry. Also, the issue of subsidies can affect the development of Iran's wind industry in the future [21]. Also, considering the importance of wind energy and its benefits, many researchers investigated the potential of wind energy in different regions of Iran and the world, which can be seen in cities such as Yazd [1], Tehran [4], Semnan [10], and Manjil [16] in Iran, and the countries of Turkey [1, 6, and 7], Greece [8, 9], Germany [10], Ethiopia [11], Bahrain [12], Saudi Arabia [13], and Pakistan [14].

Regarding wind catchers, research was done by Liu and Mak in 2007, in which they investigated the two factors of wind speed and wind direction. They found that the wind speed entering the wind catchers was about the wind speed in the free environment, which makes the conditions suitable for the ventilation of the place in question. On the other hand, they found that with the increase in wind speed, the flow rate passing through the wind catchers increased. But a slight wind angle of about 15 degrees increases the flow rate at higher wind speeds. On the other hand, by increasing this angle too much, the amount of flow passing through the wind catchers decreases. They also observed that with increasing wind speed or increasing wind blowing angle, the uniformity of the flow entering the wind catchers decreases [22]. Also, in 2017, Chang et al. introduced a design called a cross-axis wind turbine, in which three vertical axis blades and six horizontal axis blades were used perpendicular to each other. They used a series of flow guides to deflect the flow and introduce it to the rotor plate of the horizontal axis turbine. Finally, in addition to using the vertical-axis turbine blades, the torque created by the horizontal-axis turbine blades is used [23].

From the economic point of view, the simultaneous achievement of the two goals of power generation and local ventilation, can be considered an important advantage of this plan. Because in some areas with a hot and dry climate, such as Zahedan, Zabul, Yazd, etc., the use of wind catchers is common. So, replacing this type of turbine instead of a wind catcher can produce power while benefiting from the advantages of wind catchers. This design does not require water and electricity consumption and is therefore preferable to water and coolers. On the other hand, air conditioning and refrigeration systems, including coolers and fans, require different equipment and in some cases require complex ducting and piping. Also, the issue of repair, maintenance, and service of such equipment increases their costs. While the mentioned plan does not need these items and since it has a simpler structure and less equipment, it will have lower maintenance costs. Therefore, it can be concluded that the considered plan is economical in the same capacity as other air conditioning and cooling equipment, especially in areas with hot and dry climates.

Therefore, according to the mentioned statistics, it is clear that the use of small vertical axis wind turbine (VAWT) can have better efficiency in the country. On the other hand, by using angled blades in the vertical axis wind turbine, it is possible to achieve the deviation of the output flow from the turbine, and by directing this flow through simple channels (similar to what happens in wind catchers), ventilation can be achieved. Therefore, in this research, after evaluating the potential of wind energy in Zahedan city, a VAWT with specific dimensions and geometry was used and by creating a conical angle (the angle between the extension of the blade and the axis of the turbine) it becomes a V-shaped turbine. It should be capable of diverting the flow in the direction of the turbine axis. Then, the amount of diverted flow and the influence of the cone angle on the power and ventilation coefficient were evaluated. This process makes it possible to ventilate the desired location by using this type of turbine and by taking advantage of the performance of the wind catchers while producing power.

VAWT components and performance

As stated in the previous section, wind turbines receive the kinetic energy of the wind with the help of blades. And with the rotation of the rotor, this energy is converted into mechanical energy and transferred to the shaft holding the blades. The other end of this shaft is located in the gearbox, where the rotation speed of the shaft increases and finally enters the generator. This brief explanation is the basis of wind turbines. But the way the blades receive wind energy is different according to the type of turbine. Some turbines, such as the Savonius type, operate based on drag force, and some operate based on lift force. But in Darrius turbines (similar to the turbine used in this research) the blades are designed similarly to Fig.1. So that the amount of drag against the flow is low. The lift force which is caused by the pressure difference between the high-pressure and low-pressure surfaces of the blade, is usually several times the drag force, and causes the torque around the turbine axis and rotates the rotor.

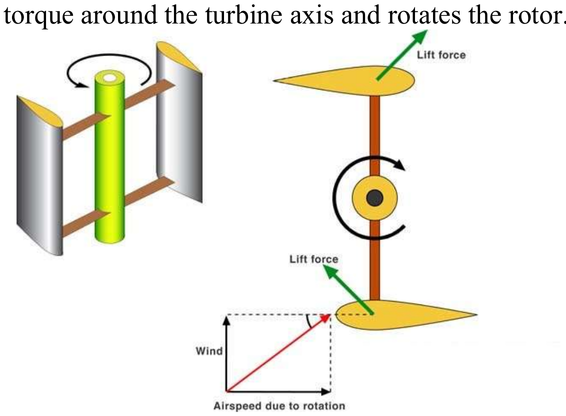

Figure 1. The VAWT performance (Lift base) [24].

The main components of VAWT can be divided into the following parts:

• **Turbine tower:** The tower or turbine base is the fixed part of the wind turbine and is responsible for carrying the static weight of the turbine as well as the dynamic load on it. In this type of turbine, unlike the horizontal axis type, the generator and gearbox are usually installed at the bottom of the tower (near the ground).

• **Turbine blades**: Turbine blades mediate the conversion of wind energy into mechanical energy, since the production of the output energy is relatively highly dependent on turbine blades. So, it is considered one of the main and important parts from an aerodynamic point of view. This part needs accurate and appropriate design because it in direct equation with power generation.

• **Gearbox and generator:** The gearbox increases the rotational speed of the output shaft of the gearbox, which makes the relatively low speed of the rotor reach the suitable speed for the generator. Finally, the output shaft from the gearbox is connected to the generator and mechanical energy is converted into electrical energy by the generator.

Equations and modeling

The turbine analysis in this research is based on the DMST method and with the help of MATLAB software. This method is based on the momentum model, in which the turbine rotor is divided into two parts: upwind and downwind. Then the flow momentum equations are applied separately for each part. As it is clear from Fig. 2, the turbine rotor is divided into sections along the flow path, which is proportional to the division of the azimuth angle ($\Delta\theta$). The free flow velocity (V_∞) loses some of its energy by hitting the upwind blades. Similarly, the speed V_e is decreased by passing through the downwind blades. Finally, the speed of the flow exiting the rotor reaches its lowest value (V_w). The speed of the flow at the place of passing between the blades of the upwind and downwind is affected by the induction coefficients of the upwind (V_{au}) and downwind (V_{ad}). These coefficients which show the effect of the vane on the flow passing through the rotor are obtained by trial-and-error and with the help of momentum equations in two actuator disks.

$$V_\infty > V_{au} > V_e > V_{ad} > V_w \tag{1}$$

$$\begin{gathered} aV_u = a_u V_\infty \\ V_e = V_\infty(2a_u - 1) \\ V_d = a_d V_e \end{gathered} \tag{2}$$

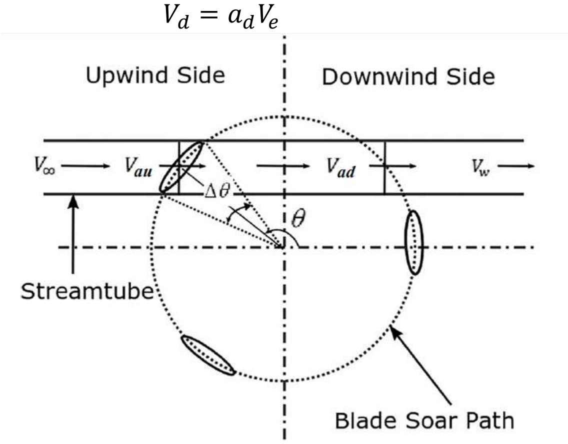

Figure 2. Flow stream in double actuator disk (DMST method) [25].

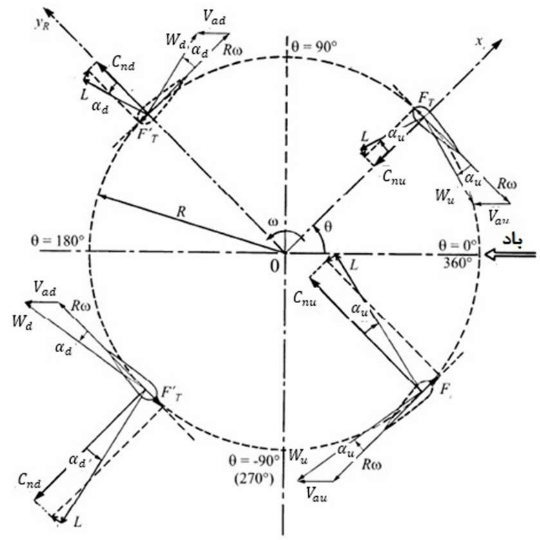

Figure 3. Force reaction on rotor plane [26].

With the initial assumption of the induction coefficient, the flow velocity can be calculated in the desired section and then the flow velocity perpendicular and tangential to the blade can be calculated by equations 3, 4, and 5. Aerodynamic calculations to achieve lift and drag forces are based on relative velocity. So, the relative velocity of the flow is obtained by equation 6 and then, the apparent angle of attack can be calculated similarly to equation 7. Fig. 3 also shows the position of the blade at four different moments. As can be seen, the relative velocity of the flow and angle of attack can be obtained. Also, the lift and drag forces can be converted to tangential and perpendicular forces by changing the coordinate system.

Since the turbine blades have a limited length, some of the flow at the tip of the blade is diverted from the high-pressure surface of the blade to the low-pressure surface of the blade, which is called tip vortices. These tip vortices cause the downwash flow and decrease the angle of attack. This phenomenon results in the reduction of the aerodynamic performance of the tip of the blade. Therefore, to improve the DMST method, the effective angle of attack is obtained according to Eq. (8). In this equation, α_{eff} is an effective angle of attack, α is the geometric angle of attack, and α_i is the induced angle of attack. The induced angle of attack is caused by the flow drop from the tip of the blade, which is obtained through Prandtl equations [27].

$$V_n = V_a \cos\theta \cos\delta \tag{3}$$

$$V_t = r\omega - V_a \sin\theta \tag{4}$$

$$V_s = V_a \cos\theta \sin\delta \quad (5)$$

$$W = \sqrt{(V_n)^2 + (V_t)^2 + (V_s)^2} \quad (6)$$

$$\alpha = \sin^{-1}(V_n/W) \quad (7)$$

$$\alpha_{eff} = \alpha - \alpha_i \quad (8)$$

In the next step, the lift and drag force coefficients can be obtained. Then, by changing the coordinate system the vertical and tangential force coefficients on the blade can be calculated similarly to Eq. (9) and Eq. (10). After obtaining the force coefficients, the amount of force at each section of the blade can be calculated according to Eq. (11) and Eq. (12). In these equations, C_n and C_t are the normal and tangential force coefficients proportional to lift and drag coefficients, respectively.

$$C_n = C_L \cos\alpha + C_D \sin\alpha \quad (9)$$

$$C_t = C_L \sin\alpha - C_D \cos\alpha \quad (10)$$

$$F_N(\theta) = \left(\frac{1}{2} C_n . \rho . c . \Delta h . W^2\right) \quad (11)$$

$$F_T(\theta) = \left(\frac{1}{2} C_t . \rho . c . \Delta h . W^2\right) \quad (12)$$

By calculating the normal and tangential force coefficients and use of Eq. (13) and Eq. (14), the value of the new induction coefficient can be obtained. The convergence rate of the model is considered to be 0.0001. By calculating the new induction coefficient, the relative velocity of the flow, the angle of attack, and the coefficients of the tangential and normal forces are obtained. This loop is repeated for each element and each azimuth angle for upwind and downwind until it reaches a suitable convergence. Finally, obtaining the value of tangential forces on the blade and perpendicular to the blade can calculate the forces applied to the entire turbine. One of these forces is in the direction of the turbine axis (the z direction of the coordinate axis), which is obtained by equation 15. By momentum equations it is possible to calculate the speed of the flow in this direction and the amount of flow rate output from the rotor.

$$f = \frac{Bc}{8\pi r} \int_{-\pi/2}^{\pi/2} \left(C_n \frac{\cos\theta}{|\cos\theta|} - C_t \frac{\sin\theta}{|\cos\theta| \cos\delta}\right) \left(\frac{W}{V_a}\right)^2 d\theta \quad (13)$$

$$a_{new} = \pi/(f + \pi) \quad (14)$$

$$F_z = \left(F_N \sin\delta\right) \cos\theta \quad (15)$$

In the next step, by use of the tangential force on the blade, the torque is created and finally, the production power of the turbine is obtained by equations 16 to 19. In these equations Q is blade torque proportional to each azimuth angle $\bar{Q}$ is the rotor mean torque, λ is the tip speed ratio, and A is swept areas by the turbine rotor.

$$Q(\theta) = r . F_T(\theta) \quad (16)$$

$$\bar{Q} = \frac{N}{2\pi} \int Q \, d\theta \quad (17)$$

$$C_{\bar{Q}} = \frac{\bar{Q}}{1/2 . \rho . A . R . U_\infty^2} \quad (18)$$

$$C_P = \lambda . C_{\bar{Q}} \quad (19)$$

Fig. 4 shows the DMST algorithm method that is based on upwind and downwind. At first, the input variables such as blade length, rotor diameter, blade chord, airfoil type, rotational speed, and desired free flow speed are defined. Then, the elementalization of the blade and division of azimuth angles is done. After calculating the tip speed ratio for the blade elements can calculate the upwind specifications part of the turbine. In this step, first, the induction coefficient. For this purpose, by using the trial-and-error method and applying a default induction coefficient and performing the repetition loop, the appropriate induction factor is obtained. Then, it is possible to calculate the key parameters of the aerodynamic solution, i.e., the relative speed and the effective angle of attack.

By calculating the relative speed and angle of attack, as well as the data of the lift and drag coefficient of the desired airfoil, the perpendicular and tangential force on the blade is calculated. Then, the forces applied to the blade can be obtained, which include three forces in the direction of the wind speed, perpendicular to the wind, and in the direction of the turbine axis. The torque applied to the blade is also obtained. In the next step, similar to the process that was done for the upwind part of the turbine, it is repeated for the downwind part. The only difference is the change in the speed of the incoming flow to downwind. Finally, by obtaining the force in the direction of the axis, the speed in this direction and its flow rate is calculated, as well as the torque and power input in the two parts of the rotor are also obtained.

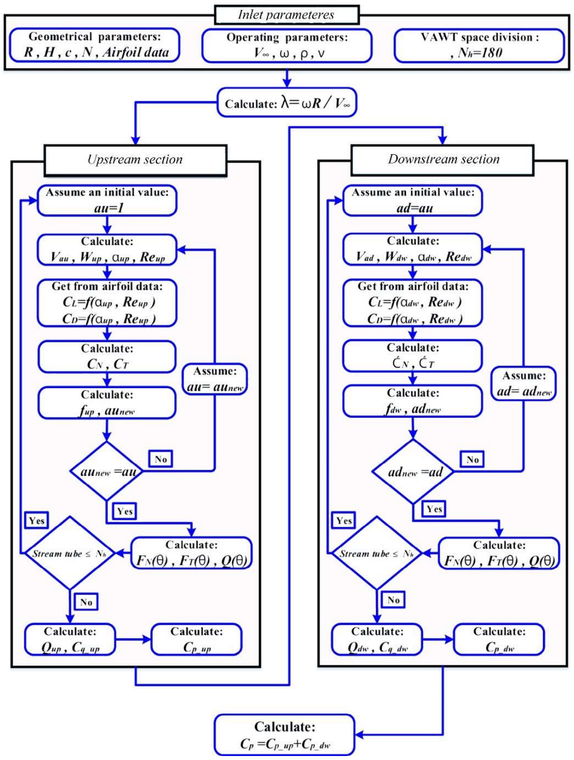

Figure 4. DMST algorithm [28].

Base turbine and validation of the methodology

To validate the method an H-shaped turbine is used, as shown in Fig. (5) with geometric specifications with respect to table 1. The result of the power coefficient was compared with the experimental data obtained from Sandia Laboratories in Fig. 6. In this figure, the horizontal axis represents the blade tip speed ratio and the vertical axis represents the turbine power coefficient. According to this figure, it can be seen that the DMST method used in this research was able to estimate the power factor of the turbine with an error value of about 17%. The difference between the analysis performed and the experimental data can be attributed to factors such as flow sequence, flow expansion, and dynamic stall.

Table 1. Base turbine geometry

Airfoil type	**NACA 0015**
Blade number	2
Blade chord	0.61 m
Blade length	16.7 m
Rotor diameter	17 m
Rotational speed	42.2 rpm

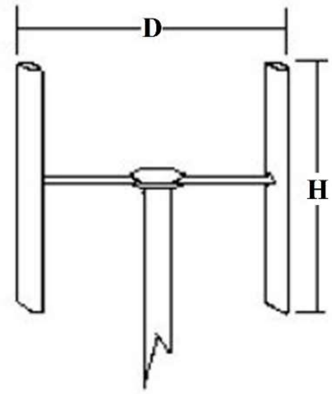

Figure 5. H-type Darrius turbine.

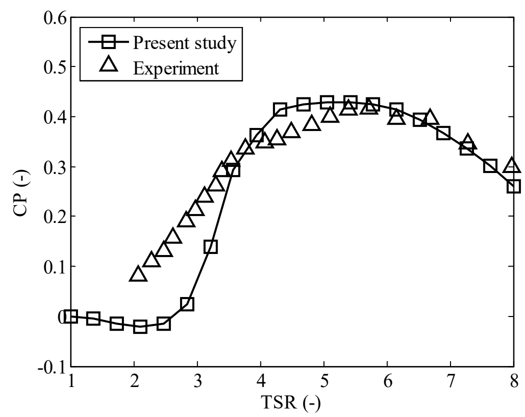

Figure 6. DMST validation with experimental data.

By angling the H-shaped rotor blade, the desired geometry is achieved in this research. For this purpose, by keeping the diameter of the upper part of the H-shaped rotor constant and bringing the lower parts of the blade closer to each other, the geometry of the V-shaped rotor can be created. The angle between the blade lengths with the turbine axis is called the conical angle or delta angle. Three conical angles of 10, 20, and 30 degrees have been used for power and ventilation analysis. Fig. 7 shows how to achieve the V-shaped rotor geometry

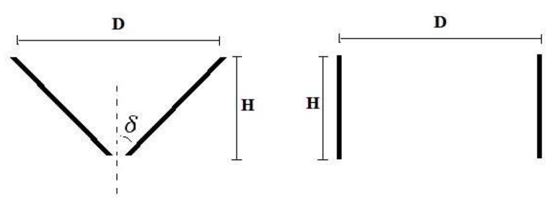

Figure 7. Side view of H-type and V-type turbine.

Wind energy potential in Zahedan

Zahedan city which is the capital of Sistan and Baluchistan province, is located in the southeast of Iran at an altitude of 1,385 meters above Mean Sea

Level (MSL). It has a population of about 600,000 people in an area of 78000 m^2. This city is located in a windy area that is exposed to strong seasonal winds in different directions throughout the year. The method of calculating the wind speed for each month (separately) is obtained by averaging the monthly wind speed in three consecutive years from 2018 to 2020 at a height of 10 meters above the ground. The wind speed profile for Zahedan city according to the mentioned method is shown in Fig. 8. Also, the data source which is used has been validated with reference [29], as is shown in Fig. 9. The wind speed profile of this city is the basis for evaluating the desired turbine. According to the profile in Fig. 8, it can be seen that the average speed during the year is equal to 3.77 m/s and the maximum and minimum average wind speed is about 4.87 m/s and 2.9 m/s, respectively. These speeds occur in the months of February and October. On the other hand, with the probability distribution of wind speed according to Fig. 10, it can be seen that the probability of occurrence of wind speed between 3 and 4 is the most likely, around 38% and 21%, respectively.

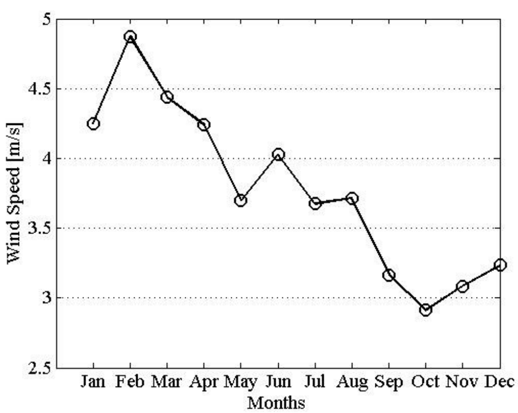

Figure 8. Average wind speed profile in Zahedan city.

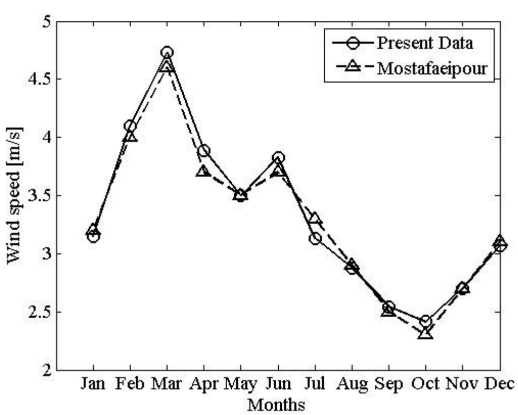

Figure 9. Average wind speed validation with [29].

Further, according to the Eq. (20) and Eq. (21) the power and energy density of the wind in this city can be estimated, respectively. The equations represent the wind speed in the desired probability distribution and the probability of occurrence of that speed. In Eq. (21) after calculating the wind power, it is possible to calculate the maximum wind energy of the region by equating one year to 8760 hours. Therefore, according to the distribution of Zahedan's wind speed and the equations, the annual wind power and energy of this city can be estimated at around 98 W/m^2, and 855 kW.h/m^2 .

$$P = \sum_{n=1}^{15} \frac{1}{2} \rho V_n^3 . p \qquad (20)$$

Fig. 12 shows the steps of the parametric study of the VAWT. Energy potential evaluation studies were presented in the previous section. Next, the effect of the cone angle (the angle of the blades with respect to the vertical axis) in creating a ventilation flow and turbine power have been investigated. So, the appropriate range of turbine operation in terms of power can be determined. The production and the ventilation are specified in Fig. 12.

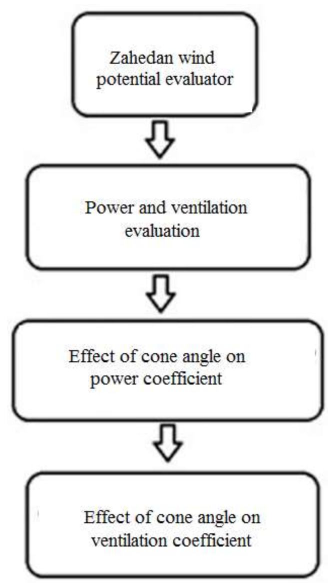

Figure 12. Design steps of a vertical axis wind turbine.

By applying a conical angle to the base turbine, in addition to benefiting from flow deviation and ventilation, the output power of the turbine is also affected. In Fig. 13, three conical angles of 10, 20, and 30 degrees are applied which caused a change in the output power of the turbine. As can be seen, with the increase of the cone angle, the geometry of the turbine changes in such a way that the effective area decreases (as in Fig. 14). This issue alone causes a reduction of a part of the produced power. But on the other hand, we note that applying the conical angle and then reducing the dimensions of the turbine makes it possible to install and use more turbines in the same space. In other words, part of the power loss is due to the reduction of turbine dimensions, and by adding more turbines this power loss can be reduced. For example, by a cone angle of 10 degrees, the effective area will be about 200 m^2, which is reduced by about 25% compared to the H-rotor case. Hence, this power loss is caused by the reduction of the effective area which is compensated by adding more turbines. Therefore, firstly, a part of the mentioned power loss is compensated. Secondly, according to the V-rotor performance curve, the operating range of the turbine has increased which makes it possible to produce power in a wider range of wind speeds. Thirdly, it is possible to achieve the issue of flow diversion and the benefit of flow ventilation. Also, the power loss at high wind speeds is reduced by increasing the cone angle. In the other words, the sensitivity of power to wind speed changes is reduced.

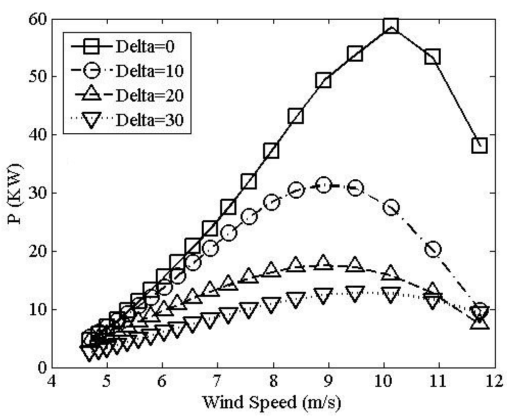

Figure 13. Effect of cone angle on the power curve.

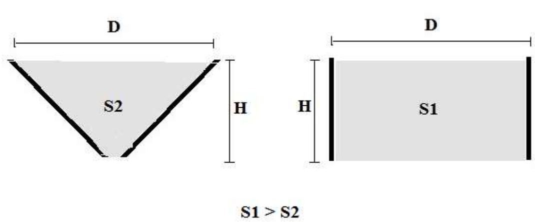

Figure 14. Compare between H-type and V-type swept area.

The performance of the turbine is assessed by comparing the desired climate with that of Yazd [19]. The results of this comparison show that the average annual wind speed in Yazd is about 2 m/s. Which is about 1.7 m/s less than Zahedan. Therefore, the maximum power produced by this turbine for the city of Yazd will be about 15 kW if the cone angle is 10 degrees. This amount of power is about half of the power produced by this turbine in Zahedan city. Therefore, using this turbine is more economic than Yazd.

By calculating the speed of the deflected flow for the upwind and downwind of the turbine, the sum of the flow rate of the deflected flow from both parts is added together and comes out as the deflected flow from the entire rotor. In other words, this flow is the diverted flow from the entire rotor to the desired location. Therefore, by using the momentum equation, the entire rotor's flow rate is obtained for cone angles of zero to 30 degrees, as shown in Fig. 15. Since the flow speed in the upwind is higher than the downwind, then the upwind is determined as the final direction of deviation. Therefore, the final direction of flow deviation according to this part is along the z-axis and for the same reason, the flow rates of this flow are in the negative range. On the other hand, according to this figure, it can be seen that in the wind speed range of 13 m/s, the flow deviation value for each of the cone angles reaches its minimum which is the starting point of the stall phenomenon. Also, at speeds higher than this value, the flow rate with slope irregular increases. The reason for this growth is due to the sudden increase in the drag coefficient and its irregularity due to the fluctuations of the drag coefficient in the post-stall area. At speeds, less than 13 m/s, when the turbine blade does not stall, the trend of the graph is more regular and no particular fluctuation is observed. The entire rotor's flow rate output is dependent on the speed difference between the diverting flow from the upwind and downwind of the rotor. This speed difference occurs at lower wind speeds, therefore, by decreasing the wind speed, the diverting flow increases.

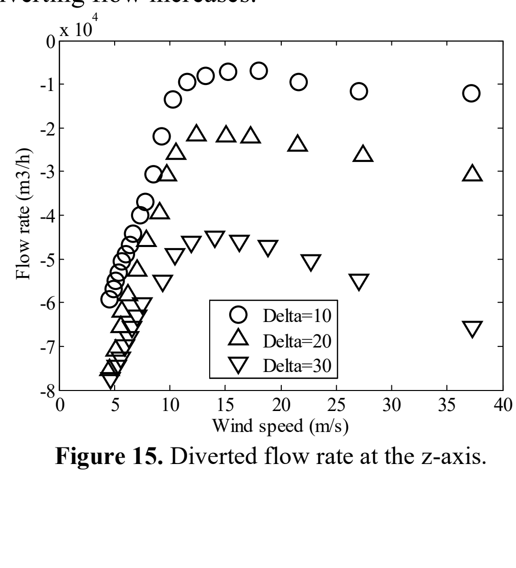

Figure 15. Diverted flow rate at the z-axis.

The flow deviation rate can be obtained by dimensioning the deflected flow in the direction of the turbine axis compared to the free flow entering the rotor. Since the purpose of this flow deviation is ventilation, this so quantity is called the ventilation coefficient. Now it is possible to draw the changes in the ventilation coefficient according to the tip speed ratio. These quantities have dimensionless values similar to Fig. 16 and for different cone angles. According to this figure, it can be seen that the ventilation coefficient is strongly increasing with the increase of the tip speed ratio. For example, at a tip speed ratio equal to 8 for cone angles of 10, 20, and 30 degrees, about 1.5, 2.3, and 2.8 percent of the flow entered into this turbine exits vertically from the end of the turbine, respectively. In other words, by keeping constant the turbine rotation speed constant, the ventilation coefficient increases with the decrease in wind velocity. This problem shows that the reduction of the wind velocity causes the relative volume of the deviation flow to increase. While the absolute value of the deviation flow also has a similar function in the points where the vane has not yet entered the stall area. Therefore, it can be concluded that the amount of ventilation flow rate and ventilation coefficient generally increases with increasing blade tip speed ratio (decreasing wind speed) until the occurrence of stall phenomenon.

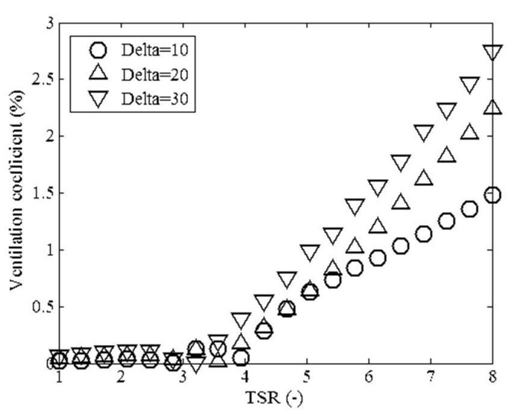

Figure 16. Diverted flow rate (ventilation coefficient).

In Fig. 17, the maximum power coefficient of the turbine at different cone angles has been investigated. According to this figure, it can be seen that the maximum power coefficient increases with the increase of the cone angle up to 10 degrees and then decreases. This issue is related to the definition of the power factor equationship and in other words the act of making the power, dimensionless. As discussed before, since the effective area in the H-shaped turbine is rectangular, the same parameter in a V-shaped turbine with the same diameter is trapezoidal or triangular. Therefore, the effective area in the V-shaped turbine will be smaller than the H-shaped one (Fig 14). So, according to the equation of the power factor with the reduction of the effective area, wind power also decreases. This issue was also shown in Fig. 13. On the other hand, the value of the power coefficient for each of the desired cone angles is calculated at the wind speed corresponding to the maximum power. For example, the wind speed corresponding to the maximum power at the conical angle of 0 and 10 degrees is equal to 11 m/s and 9.5 m/s, respectively. Therefore, by calculating the power coefficient, in addition to changing the effective area the wind speed corresponding to the maximum power for different cone angles changes according to Fig. 18. According to this figure, it can be seen that at any given speed, the wind power has an inverse equation with the cone angle, and the wind speed corresponding to the maximum power reaches its lowest value in the range of 10 degrees (9.5 m / s). Therefore, in this area, the power coefficient reaches its maximum value.

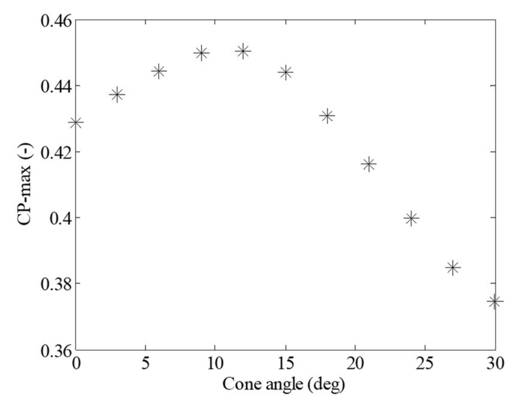

Figure 17. Variation of maximum power coefficient concerning the cone angle.

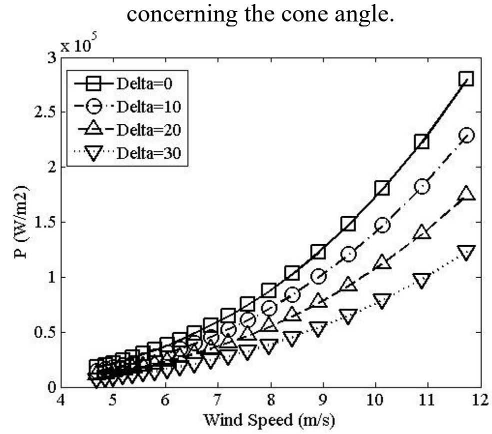

Figure 18. Wind power for various cone angle.

We can draw the curve for the ventilation coefficient in Fig. 19. According to this figure, it can be seen that the diagram of the ventilation coefficient has an almost linear behavior concerning the change of the cone angle. This value has a direct equation to the cone angle. In other words, increasing the cone angle increases the ventilation efficiency or the ventilation coefficient. Also, a summary and comparison of the desired turbine performance in different cone angles in terms of power and ventilation can refer to table 2. According to this table, it can be seen that with the increase of the conical angle, the annual energy produced by the turbine decreases and the average ventilation coefficient increases. Also, by examining the maximum power coefficient it is clear that the factor does not decrease until the conical angle of 20 degrees, but it decreases after that.

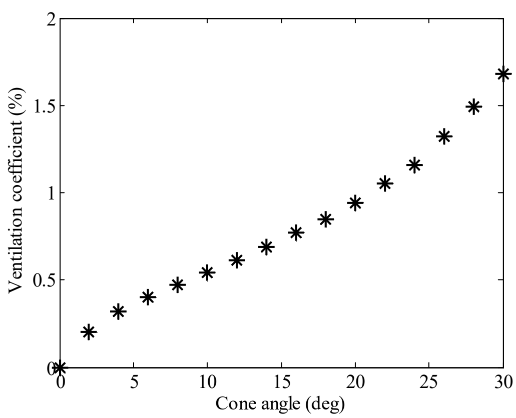

Figure 19. Average ventilation coefficient concerning the cone angle.

Table 2. Comparing power and ventilation indexes.

Cone angle (degrees)	Max power (KW)	AEP ($MW.h$)	Max power coefficient (%)	Max ventilation coefficient (%)
0	58	60	42	0
10	35	45	45	0.5
20	21	30	42	0.9
30	15	20	37	1.7

Conclusions

In this study, the statistical analysis of wind speed in the last three years (2018 to 2020) in the city of Zahedan was discussed. The assessment of wind speed distribution in this city showed that Zahedan has an average annual wind speed of 3.77 m/s and considering the possibility of occurrence of different wind speeds. The wind potential of this city is around 98 W/m^2, which is considered a low value compared to other windy areas of the world. But compared to other cities of this country (Iran) such as Yazd, it is relatively superior. Comparing the annual average speed of these two cities showed that the average wind speed of Zahedan is about 1.8 times the average wind speed in Yazd. Therefore, the use of wind turbines in this city will be more economic. The turbine which is considered in this research can produce energy equal to 60, 44, and 19 MW.h in the conical angles of 0 degrees, 10 degrees, and 30 degrees. These amounts of energy are respectively equivalent to 25%, 22%, and 18% of the total energy in the wind of this region.

Also, the creation of a conical angle in the blades causes a flow deviation which can be used as a wind catcher by diverting this flow towards the desired location. So that the flow diverted from the turbine can be used for Air conditioning of the desired room. The value of the diverted flow rate in the working range of the turbine is around 9 m/s and for the cone angle of 10 degrees is 10000 m^3/h. This value is less than one percent of the ventilation coefficient. It was also observed that the power value decreases with the increase of the cone angle up to 20 degrees. But the power coefficient does not change significantly. Also, among other achievements of this research, the following can be mentioned:

- The power coefficient of the turbine has a maximum in the cone angle range of 10 degrees.
- Increasing the cone angle increases the operating range of the turbine and also reduces its power.
- The diverted flow rate as well as the ventilation coefficient increases with the increase of the cone angle.
- Before the blade stall, the diverted flow rate has an inverse relation with the wind speed. While they will have a direct relation after the stall area.

Finally, it can be stated that with the use of V-shaped turbines, especially on a small urban scale we can provide a part of the desired electric energy in a renewable way and cause the ventilation of the desired place. This issue is important, especially in areas with hot and humid climates.

References

[1] Eskin N, et al. (2008). Wind energy potential of Gökçeada Island in Turkey. *Renew Sustain Energy*. Rev. vol 12. pp 839–51.

[2] Kumar A, Prasad S. (2010). Examining wind quality and wind power prospectson Fiji Islands. *Renew Energy*. Vol 35. pp 536–40.

[3] Chaparzadeh, Feseqandis R. (1999). Feasibility of applying wind turbine for achieving sustainable development. *Proceedings of 2th national conference of energy*. vol 2.
[4] Keyhani A, et al. (2010). Anassessment of wind energy potential as a power generation source in the capital of Iran. *Energy.* vol 35. pp 188–201.
[5] Mostafaeipour A, et al. (2011). Wind energy feasibility study for city of Shahrbabak in Iran. *Renew Sustain Energy*. vol 15. pp 2545–56.
[6] Akdag SA, Guler O. (2010). Evaluation of wind energy investment interest and electricity generation cost analysis for Turkey. *Appl Energy*. vol 87.pp 2574–80.
[7] Ucar A, Balo F. (2009). Evaluation of wind energy potential and electricity generation at six locations in Turkey. *Appl Energy*. vol 86. pp 1864–72.
[8] Fyrippis I, et al. (2010) Wind energy potential assessment in Naxos Island, Greece. *Appl Energy*. vol 87. pp 577–86.
[9] Xydis G, et al. (2009). Exergy analysis in a wind speed prognostic model as a wind farm sitting selection tool: a case study in Southern Greece. *Appl Energy*. vol 86. pp 2411–20.
[10] Weigt H. Germany's wind energy: the potential for fossil capacity replacement and cost saving. Appl Energy. vol 86. pp 1857–63.
[11] Bekele G, Palm B. (2009). Wind energy potential assessment at four typical locations in Ethiopia. *Appl Energy*. vol 86. pp 388–96.
[12] Jowder FAL. (2009). Wind power analysis and site matching of wind turbine generators in Kingdom of Bahrain. *Appl Energy*. vol 86. pp 538–45.
[13] Elhadidy MA, Shaahid SM. (1999). Feasibility of hybrid (Wind | Solar) power systems for Diiahran, Saudi Arabia. *Renew Energy*. vol 16. pp 970–6.
[14] DaniloFeretić, et al. (1999). Feasibility analysis of wind-energy utilization in Croatia. *Energy*. vol 24. pp 239–46.
[15] Mirhosseini M, et al. (2011). Assessing the wind energy potential locations in province of Semnan in Iran. *Renew Sustain Energy*. vol 15. pp 449–59.
[16] Mostafaeipour A, A barghooei H. (2008). Harnessing wind energy at Manjil area located in north of Iran. *Renew Sustain Energy*. vol 12. pp 1758–66.
[17] Ghorashi AH, Rahimi A. (2011). Renewable and non-renewable energy status in Iran: art of know-how and technology gap. *Renew Sustain Energy.* vol 15(1). pp 729–36.
[18] Alamdari P, et al. (2012). Assessment of wind energy in Iran: a review. *Renew Sustain Energy*. vol 16(1). pp 836–60.
[19] Mostafaeipour A. (2010). Feasibility study of harnessing wind energy for turbine installation in province of Yazd in Iran. *Renewable and Sustainable Energy reviews*. vol 14 (1). pp 93–111.
[20] Mostafaeipour A. (2013). Economic evaluation of small wind turbine utilization in Kerman. *Energy Convers Manag*. vol 73. pp 214–25.
[21] Mousavi SM, et al. (2012). The competitiveness of wind power compared to existing methods of electricity generation in Iran. *Energy Policy*. vol 42. pp 651–6.
[22] Li L, Mak C.m. (2007). The assessment of the performance of a wind catcher system using computational fluid dynamics. Building and Environment. Vol 42. pp 1135-1141.
[23] Chong WT, et al. (2017). Cross axis wind turbine: Pushing the limit of wind turbine technology with complementary design. *Appl Energy*. vol, 207. pp, 78–95.
[24] E. A. D Kumara et al. (2017). Overview of the vertical axis wind turbines. Vol 4. No 8.
[25] Mohammed A, et al. (2019). Vertical axis wind turbine aerodynamics: Summary and review of momentum models. *Journal of Energy Resources Technology*. Vol 141.
[26] Paraschivoiu, I. (2002). *Wind turbine design: with emphasis on Darrieus concept*. Presses inter Polytechnique.
[27] John D. Anderson Jr. (2001). Fundamentals of Aerodynamics. Aeronautical and Aerospace Engineering. 3rd.
[28] Moghimi M, Motawej H. (2018). Developed DMST model for performance analysis and parametric evaluation of Gorlov vertical axis wind turbines. Sustainable *Energy Technologies and assessments*. vol 37.
[29] Mostafaeipour A, et al. (2014). An analysis of wind potential and economic evaluation in Zahedan, Iran. Renewable and sustainable energy reviews. pp 641-650.