Improvement of the design of plane blades in wind turbine with 3-blades horizontal axis by use of designing and construction of a physical model

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Abstract

Since Iran due to proximity with the sea and also existence of Alborz and Zagros plateaus is considered a windward country, it is not surprising that in the near future the use of wind energy technology in the country grows considerably. Based on preliminary studies the capacity of wind energy of Iran is 6500 Mw. Regarding the fact that wind energy is one of the renewable energies and compared with other renewable energies it has been used and exploited in greater dimensions, it is necessary to consider ways to increase the production power of the low-blades wind turbines with plane blades. The goals that are attended to in this study are: determining the optimal angle of the blade, the optimum of the level of the conical ratio of the blade, determining the optimum level of place of maximum arc from the length of the tendon, which by determination of the effective positioning of these levels we can reach to improvement of production power of low-blade wind turbines. In the experiment of the 3-blade wind turbine model, each blade was built with 20% thickness from the length of the tendon and camber in 6% of the length of the tendon. This model was placed in front of the wind producing mechanism system. All data of the experiment were analyzed by the Mstat-C, Excel, SPSS and Duncan software and it was found that the difference between the gained powers in the experiment in different wind speeds, angles, place of maximum arc and conical ratio of blade have significant difference. By use of the results of Duncan test, it was found that among the 5 levels of attack angles of blade, the 15 degree angle with mean power of 0.8612 w, among the 3 levels of conical ratio of blade, the 100% level with mean power of 1.17 w, among the 3 level of maximum place of arc, the 30% level with mean power of 0.8139 and among the 3 levels of wind speed, the 12m.s level with 1.078 w mean power, had the most producing power. Also, it was found that the mutual effect between the variables (the attack angle of the blade, conical ratio, place of maximum arc and sped) are significant and the model that its attack angle is 15 degrees, conical ratio is 100%, maximum arc is 30% and speed of wind is 12m.s, was introduced as the optimal model for producing more power.

Key words: wind turbine, attack angle, conical ratio of blade, speed of wind, power and plane blades

Introduction

Based on preliminary studies the capacity of wind energy in Iran is 6500 MW. If vaster examinations and studies take place, it will be clear that the potential capacity of this energy is much more than this number in our country. (1). Regarding the fact that wind energy is one of the renewable energies and due to vastness and being economic, compared with other renewable energies, it has been used in greater dimensions, it has practically a particular position which can be mentioned as certain necessities of doing research.(2).

The goals which are hidden in this study are: determining the optimal angle of the blade, the optimum of the level of the conical ratio of the blade, determining the optimum level of place of maximum arc from the length of the tendon, which by determination of the effective positioning of these levels we can reach to improvement of production power in low-blade wind turbines with plane blades.

In a research, 3-blade horizontal axis wind turbines were made. This turbine produced 3Kw electricity in a wind with 8m.s speed. With such a turbine, in an area with average wind, one could easily provide the electricity need of one or several rural families. (4). A project titled examination and designing optimal wind turbine for water pumping in windy areas of Iran has been done. In this study a wind mill with a vertical axis and 3-blades with airfoil symmetric level was built by use of NACA0012 specifications, in which the blades were placed by 6 arms (3 above and 3 below the blades) two by two under 120 degrees around the main axis. (7).

A project was done under the title of calculation, designing and testing of the 10 Kw wind turbine. In this study after determining the horizontal axis wind turbine as the optimal turbine, precise aerodynamic designing of the blades of the 10 Kw turbine took place. First, the aerodynamics of the turbines of the horizontal axis were studied comprehensively and then the vortexes of the current behind the rotor and geometric specifications in different points of the blades were studied. (2).

A project was done under the title of technical examination and preliminary designing of a wind powerhouse for various regions in Iran. In this project, first, the necessity of using new energies instead of fossil energies and generally renewable energies instead of non-renewable energies was discussed and then it was mentioned that wind energy, as a renewable energy should be paid attention, in order to be used properly as a God-given force. (1).

Aerodynamic section

Airfoil is a certain section that by transit of air from its around, by producing pressure difference, an aerodynamic force is produced. This section is generally like a spindle and its thicker part places in front. When the air passes from above and below the airfoil, above the airfoil the air density will decrease, speed will increase and the pressure will decrease. At the lower part, the density increases, speed decreases and pressure increases. Therefore, airfoil produces pressure difference. We can obtain integral from tees pressures and change them into a force, which is called an aerodynamic force. Thus, it is necessary to explain and examine the most important sections of designing the blades.

Attack edge: the first point from the vertical section that confronts air before any other part. The shape of the attack edge depending on the airfoil being used for high or average speeds, is different.

Escape edge: the last point from the vertical section of the airfoil that confronts the air, or in other words, a point at which air leaves the airfoil.

Tendon: a direct line that connects the attack edge to the escape edge. The extent of this is very important and all the main measures of the vertical section are stated as a percentage of the tendon length. (5).

Mean line of the section: the geometric place of points that are placed in the middle of the distance of the upper and lower curve. In case the mean airfoil line becomes a straight line, it is called symmetric and otherwise, its asymmetric.

Attack angle: an acute angle that is created between the extension of the tendon and relative wind. Changes in the extent of it make a substantial difference in the extent of the production power of a wind turbine. (figure 1).

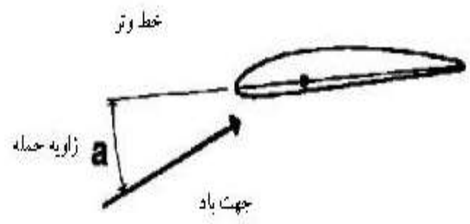

Figure 1: attack angle of the blade

Conical ratio: the ratio of the tendon length at point to the tendon length at the root of blade is called conical ratio and is between 0 and 1. The more it decreases the weight of the blade decreases, thus, less constructive issues are attended to and it can play a role as a substantial parameter in the extent of the production power.

Maximum thickness; maximum vertical distance between upper and lower curvature of the profile. This, depending on the airfoil design for blades of the wind turbine is in the 20% to 30% distance of the tendon length, and causes the resistance and firmness of the blade.

Arc: the most arc that the tendon line makes with the mean section line is called arc. (6).

The collection of blades and the plug in the middle of them are called rotor. A horizontal axis wind turbine is composed of a number of blades that are placed as radius around an axis that is parallel to the direction of wind, and thus, form a rotor that rotates vertical to the wind direction. (7). Usually the rotor is placed by a tower in a proper height toward the ground and also required predictions are done to make it same direction with the extension of the axis with different directions of the wind, and also for controlling the speed, and the absorbed power by tis rotor is transited directly or by a mechanical system to a machine that is supposed to be driven. Blades might be composed of a frame that is covered by a tiny layer. The number of blades might be between 2 to 12. (10). The tendon length might be fixed at all length of the blade or it might change gradually (conical ratio) and the blade might be plane or in the extension of the length axis or it might be complex. The specifications of an airfoil are shown in figure 2. (3)

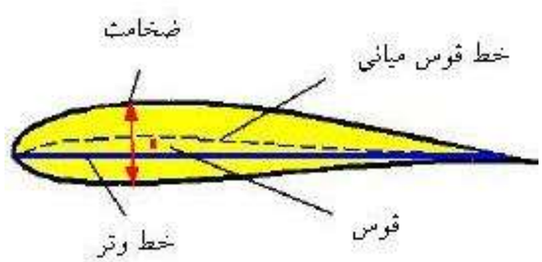

figure 2: specifications of an airfoil (9)

The working method of wind turbine

Generally when a generator of wind energy is moved by wind force, the power is transferred to outside by its rotor. The wind force creates two driving and inhibiting forces on the turbine. In fact, the air strands when confronting the lower edge of the wind turbine that is built in a certain way, while exiting at the upper point and in the lower area, change the path a bit and then join one another. Depending on the form, the air current that passes from above the blade passes a longer path, therefore it becomes thin and produces suction on the blade and on the contrary, the air current that passes from beneath the blade, passes a smaller path and thus it is thick and exerts pressure on the blade. The driving force causes the rotation of the blades of the turbine and produces power and the inhibiting force that is vertical to the circle surface of the rotation of blades is neutralized by keeping blades of the turbine. In designing of 3-blade turbines, it is tried to use less inhibiting force. Figure 3. (1).

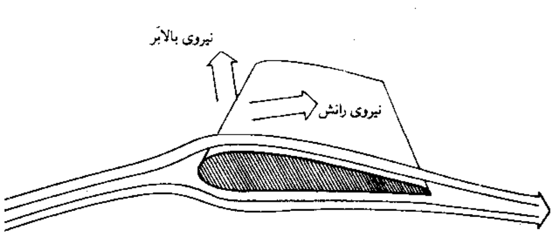

figure 3: forces that affect the blade of the wind turbine (3)

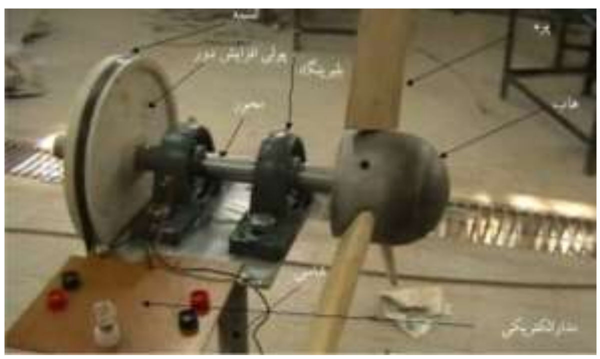

Figure 4: different components of the constructed model

Generally, the maximum power of wind in a wind turbine that might change to electricity is almost 59.3 percent of the moving energy of the wind, which is called the ratio of maximum power. In fact the practical power of a wind turbine is calculated by the following relation: (3)

$$P = \frac{1}{2}.e.\rho.A.v^3$$

e: feedback of the wind turbine

p: volume mass of air (kg.m^3)

A: swept surface by blades of turbine (m^2)

v: speed of wind or speed of mass of air (m.s)

P: real power of wind (w)

Materials and methods

Model construction

The sample of the made turbine is shown in figure 4. This includes blade, electric generator, hub, axis or rotor, plastic strap, ballbearing, chassis or tower, electric orbit, and cycle increase system. The anemometer used was digital butterfly model (ltron AM-4200) made by Taiwan with a range of 0.8 -30 meter per second measurement. The sensor in the handle of it was used for measuring the speed of wind. Figure 5 shows the anemometer.

Figure 5: butterfly digital anemometer

In this study, all blades had thickness of 20% of tendon length, maximum arc of 6% of tendon length, tendon length of 5.5 cm, and the length of blade was 30cm and was made of Russ wood. The reason of these numbers was easiness of making the blades. If smaller number were used, the error in making the blades would increase and the proper result would not be obtained. The specifications of blades are shown in figures 6 and 7. In figure 6 blade with conical ratios of 0%, 50% and 100% of tendon length and in figure 7, blades with place of maximum arc of 30%, 40% and 50% of tendon length which totally add to 9 different blades for a 3-blade wind turbine, the total number of blades is 27, with regards to the mentioned parameters were built. Considering that, the more the conical ratio lowers the blade weight lowers too, and the weight of construct decreases, it was attended to as a substantial parameter. In building blades, more surfaces can be used but due to increase of surfaces the experiment will be more complex and the examination of the mutual effects of the parameters would not be possible.

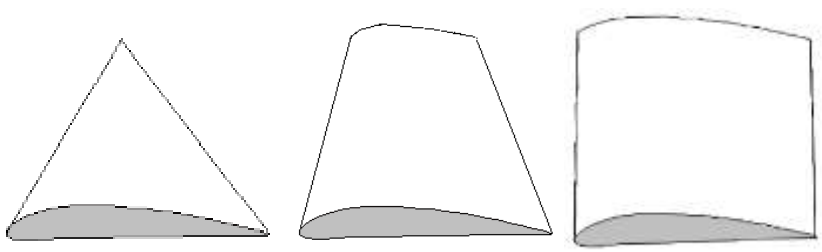

Figure 6: blade with conical ratio of 0, 50 and 100% of tendon length (respectively from right to left)

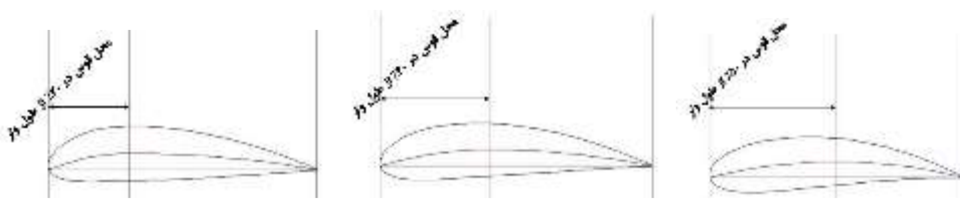

Figure 7: blade with place of maximum arc of 30, 40 and 50% of tendon length (respectively from right to left)

In this study, a generator of bicycle (mountain) of 6 volts was used. This system composed of two hubs with diagonal of 1cm and 15cm, one connected to the head of generator and second to the end of the rotor axis. Thus, the cycle of generator is increased 15 times. Considering that the efficiency of generator was low, we had to increase the cycles to lighten the 3-volt lamp in the electric orbit sufficiently. By building various hubs with various diagonals, 15cm was chosen which is shown in figures 4 and 9. The plug was made for wind turbine. Rotor was connected to the inside of the plug center by lateral screws. On the plug, there are places for placing the blade with 120 degree and the plug is made from aluminum by foundry. Considering that, aluminum is a light metal it is proper for working. First, the plug was made of Russ wood but because of opening and closing of blades on it, the blade got loose and the quality lowered. (figure 4) for obtaining the production power a simple orbit (figure 8) and its schematic shown in figure 4 were used. In this orbit, a 3-volt lamp was used as resistance and the place of ammeter and voltmeter that are respectively placed in the orbit in a parallel way is determined

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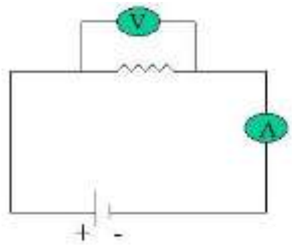

Figure 8: electric orbit used in the model

In this study for obtaining 3 speed winds of the experiment, the wind producing system was designed. Considering that the goal of this study was not making a mechanism system of producing wind and regarding the wind conditions in one area, it seems wise to design a wind source to include more farming conditions rather than laboratory conditions. This system consists of an electromotor with 1 stream horse, 220 volt, single-phase, blower fan with 75cm diagonal, evening network of wind current and the chassis for keeping the fan system and network. (figure 9).

Figure 9: wind production mechanism

With installing the network that evens and parallels the wind current it is tried to obtain the wind speed as equally in certain areas of the net. For determining the wind speed, the model was faced against wind in three various conditions. For measuring the speed, a tool named anemometer was used. At the distance of 68cm of the net, 12m.s speed, at 68cm of the net, 10m.s speed and at the 93cm of the net, 8m.s speed was observed.

Method

The independent variables of this study are:

-angle of the blade at 5 sections (5, 10, 15, 20 and 25 degrees)

-place of maximum arc at three sections (30, 40 and 50% of the tendon length)

-conical ratio at three sections (8, 10 and 12m.s)

For measuring the output power of model in different speeds of wind, first by the mentioned generator, the mechanical force was changed to electrical force and then by an electric orbit the receiving energy per time (which is power) was measured. By rotation of the rotor, a direct current of the exiting of generator was obtained. From two ends of the electricity generator, voltage was easily gained by voltmeter. However, voltage is not effective on its own and for measuring power, the current should be measured by ampere too, and by multiplication of current in voltage, the power obtained and the current are gained in case there is a consumer in the orbit. Thus, a 3-volt lamp was used as a consumer. Voltmeter and ampere-meter in various speeds were read and measured and by their multiplication, the producing power was gained.

Statistical method

Based on the gained information, the used statistical method is a 4-factor experiment in a frame of a completely random design with three repetitions. (2). The results of the mean powers were compared and analyzed by multiple range Duncan test at 99% level. At this study, the wind turbine model was placed in the wind producing mechanism system. This was done in three repetitions and the amounts of voltage and current were measured. By multiplying voltage into current, the producing power was measured with 4 digits decimal.

Results and discussion

All data of this experiment were analyzed by the Duncan test by use of Mstat, Excel and SPSS softwares and it was found that the difference between the gained powers at different speeds, angles, conical ratio of blades, and place of maximum arc are significant, and in table 1 of the variance analysis of the variables (angle of blade, place of maximum arc, conical ratio and wind speed) and their mutual effects are shown. As it is seen in the table the F value measured is considerably higher than the F of the table and shows that the treatments have a significant difference and this was not due to chance, but they really have been different significantly.

In the variance analysis table, A factor is angle of blade, B factor is place of maximum arc, C factor is conical ratio and D factor is wind speed. Also, AB is the mutual effect of the angle of blade and place of maximum arc, AC is mutual effect of angle of blade and conical ratio of blade, BC is mutual effect of the place of maximum arc and conical ratio, ABC is the mutual effect of the angle of blade, place of maximum arc and conical ratio, AD is mutual effect of angle of blade and wind speed, BD is mutual effect of place of maximum arc and wind speed, CD is mutual effect of conical ratio and wind speed, BCD is mutual effect of place of maximum arc, conical ratio and wind speed, and ABCD is mutual effect of angle of blade, place of maximum arc, conical ratio and wind speed. As said, the measured F is higher than the F in statistical tables and shows that treatments have significant difference and that is not due to chance. Therefore, it is necessary to compare the variables. For this, the multiple- range Duncan test was used. This test analyzes the trend of increase or decrease of the mean of variables or their mutual effects and determines that the changes of the mean of variables are effective on the producing power of the made physical model to what extent.

The effect of variable for the extent of producing power

By observing the results of Duncan test at 99% level, it was clear that the attack degree of 15 had the most output power equal to 0.8612 volts. (figure 10). The main reason of this is the separation phenomenon. In angles more than 15 degrees and less, the required air current doesn't exist for passing the path on the blade and is broken away from the blade, thus the coherence of current is gradually lost on the blade. This incoherence of current and difference of the movement of current in entering causes the exiting of blade. Thus, the main force on the blades caused by the difference in movement of air current on the blades, doesn't exist, therefore, the increase of angle of blade more than 15 degrees or less than that is in no way suggested.

Table 1: variance analysis for 3-blade wind turbine

significance	F	Mean squares	Total squares	Degree of freedom	Source of changes

000.0	65.6817	0.022	0.045	2	repetition
000.0	3892.8236	1.319	5.277	4	A factor
		0.000	0.003	8	error
000.0	2867.9834	2.142	4.284	2	B factor
000.0	30.8667	0.023	0.184	8	AB
000.0	33506.0535	25.026	50.053	2	C factor
000.0	235.2693	0.176	1.406	8	AC
000.0	414.7168	0.310	1.239	4	BC
000.0	4.3107	0.003	0.052	16	ABC
000.0	22502.2141	16.807	33.615	2	D factor
000.0	160.0768	0.120	0.957	8	AD
000.0	160.8007	0.120	0.480	4	BD
0.0003	2.8338	0.002	0.034	16	ABD
000.0	3833.5605	2.863	11.453	4	CD
000.0	29.9241	0.022	0.358	16	ACD
000.0	42.1821	0.032	0.252	8	BCD
0.0550	1.4715	0.001	0.035	32	ABCD
		0.001	0.194	260	error
			109.920	404	total

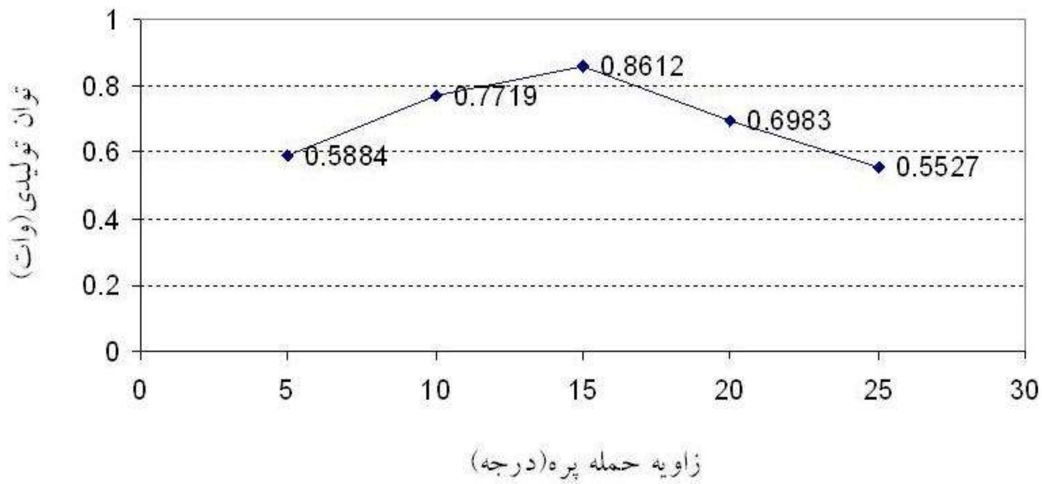

Figure 10: effect of angle of attack on output power

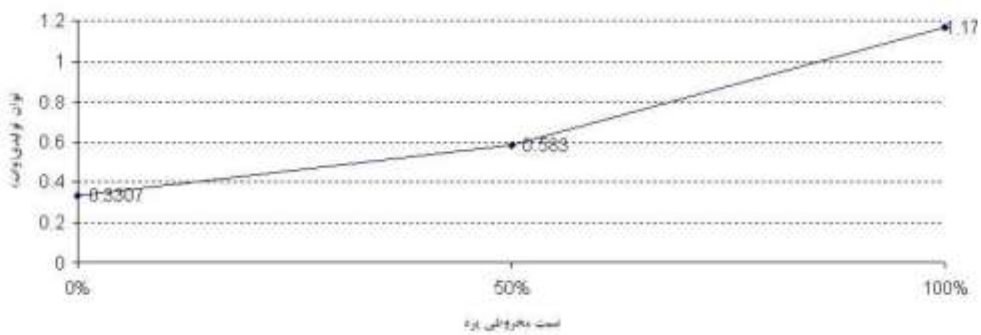

Figure 11: effect of conical ratio on output power

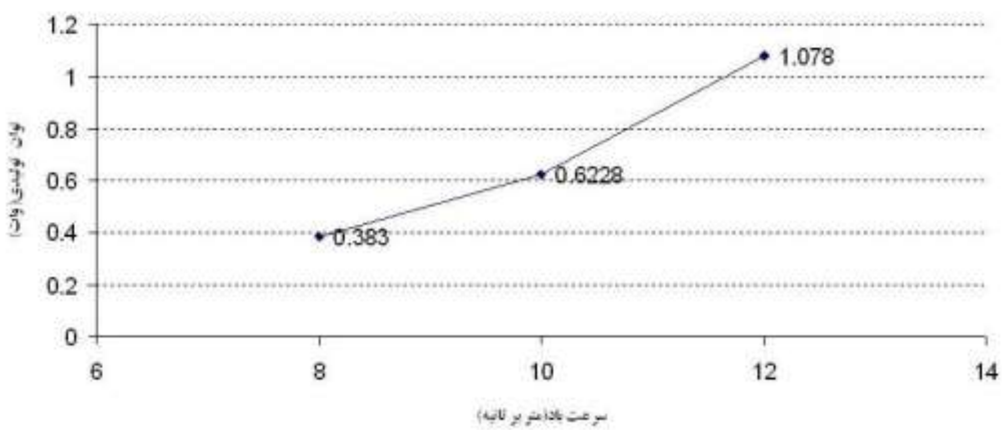

Figure 12: effect of wind speed on output power

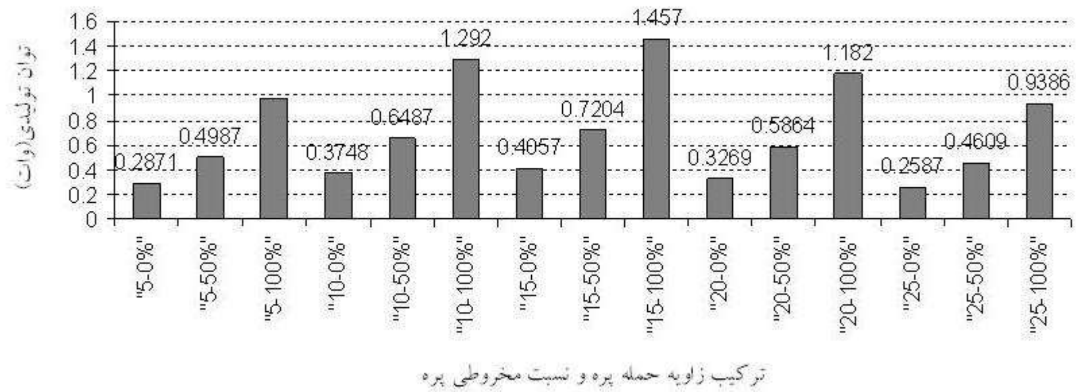

Figure 13: mutual effect of angle of attack of blade and conical ratio on output power

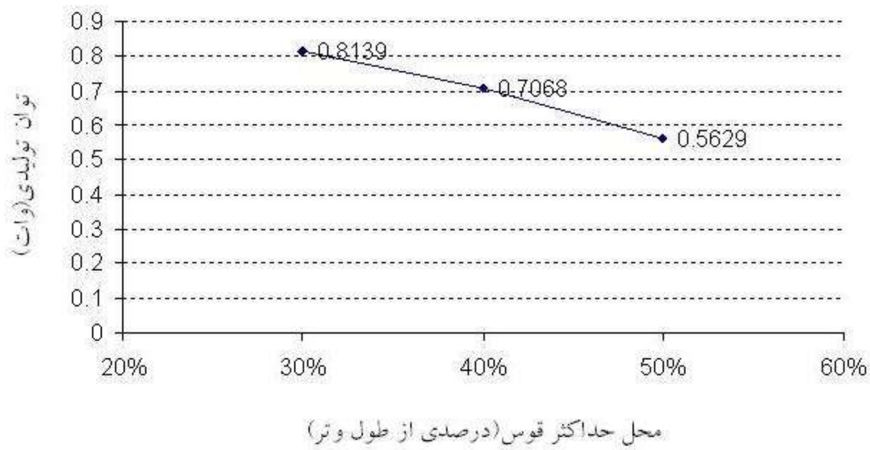

Figure 14: effect of place of maximum arc on output power

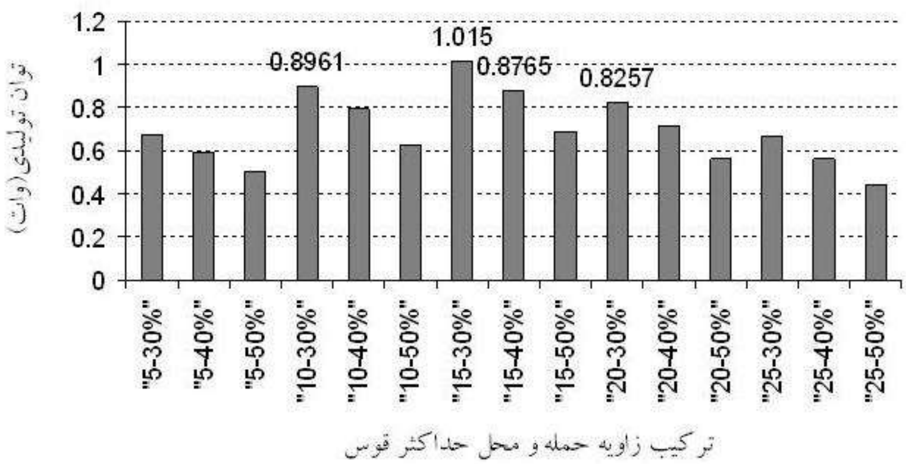

Figure 15: mutual effect of angle of attack of blade and place of maximum arc on output power

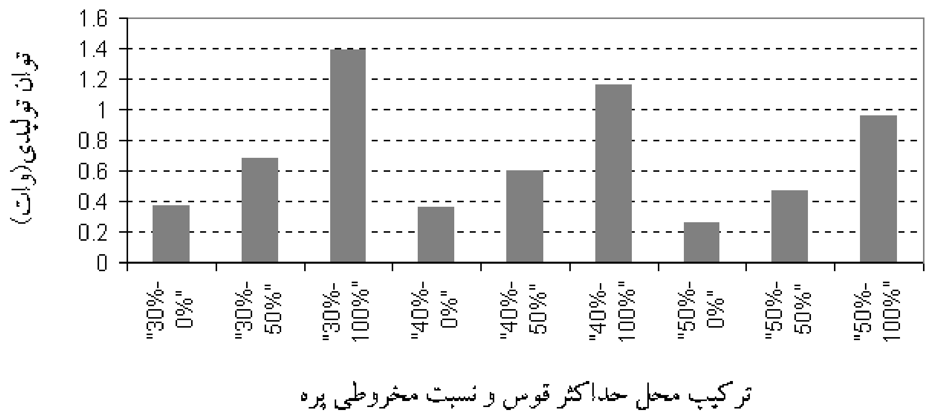

Figure 16: mutual effect of place of maximum arc and conical ratio on output power

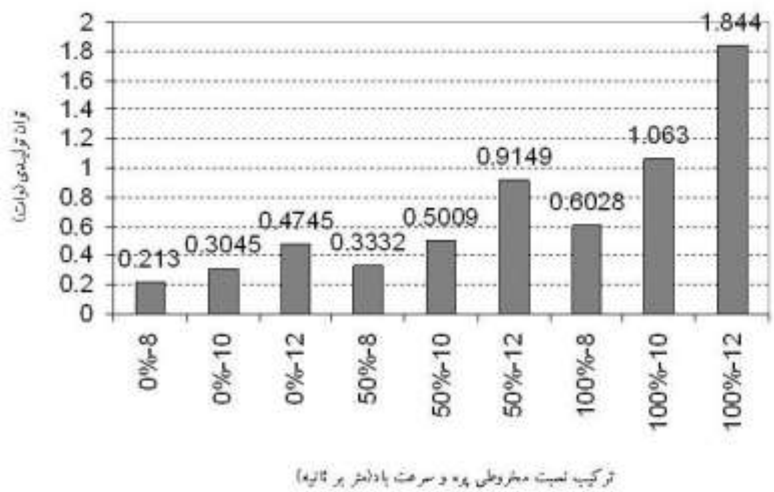

Figure 17: mutual effect of conical ratio of blade and wind speed on output power

By observing the results of Duncan test and figure 1 at 99% level, it was found that at conical ratio of 100% of tendon length, the most output power is 1.17 w. the more the tendon length at point is greater to the length at root of blade, the weight of blade will increase and its rigidness will increase as well. Rigidness means the ratio of blades section to the swept section of the blades. (3). The increase of rigidness has a direct impact on the obtained power. In 3-blade horizontal axes turbines with plane blades the increase of rigidness will cause increase of the cycles of the blade or increase of the speed and also will be efficient. (3). Thus, the more the conical ratio the more will be the impact of wind on the blade and the speedy rotation of the blade. Thus, it is advised that in low-blade horizontal axis wind turbines with plane blades the greater conical ratio would increase the producing power. By observing the results of Duncan test and figure 14 at 99% level it was found that at the place of maximum arc of 30% level, model had the most output power equal to 0.8139w and this shows that the place of maximum arc more than 30% has never been optimal since by its increase more than 30% we observe decrease of producing power. It is probable that this place at less than 30% level produces more power, which requires making blade with qualities of place of maximum arc of less than 30%. Regarding the qualities of blade and aerodynamic features of airfoil of blade, the place of maximum arc at 30% had the most power and had been able to make a great change in the airfoil and has increased the driving force. By observing the results of Duncan test and figure 15 it was found that regarding the mutual effect of attack angle and place of maximum arc, model at 15 degrees and place of maximum arc of 30% had the most output power of 1.015 w. by observing the results of Duncan test and figure 12 at 99% level it was determined that wind speed of 12m.s had the most power of 1.078w. Regarding relation (1), the more the speed of wind, the more the power of wind turbine will be since the power of a turbine is related with the third power of wind speed. Thus, it is suggested that to increase the power, greater speed of wind be used. Of course the maximum speed of wind for turbines is 25m.s and at higher speeds turbine will get out of order due to security reasons. (6). By observing the results of Duncan test and figure 13 it was found that model at attack angle of 15 degrees and conical ratio of 100% level had the most output power equal to 1.457. The mixture of angle and conical ratio describes exactly the overlapping act without least mutual effect. Angle and conical ratio as two separate parameters and in mixture due to being separate the effects of each variable states that the separation phenomenon is adapted with the conical ratio. In figure 17 it was clear that model at conical ratio of 100% and wind speed of 12m.s had the most power of 1.844w. The increase of conical ratio cause the increase of rigidness. Thus, its increase in higher speeds of wind will have more powers. Thus, it is suggested to increase the power, the rigidness be increased and this is possible by increasing the conical ratio of the blade. By the results of the Duncen test it was found that in the model of turbine among the 5 attack angles of the blade, the 15 degrees angle with mean of 0.8612w power, among the 3 conical ratio levels, 100% level with mean of 1.17w, among the 3 speeds of wind, 12m.s level with mean of 1.078w power and among the 3 place of maximum arc levels, the 30% level with power of 0.8139w had the most producing powers. Also, it was found that the mutual effect of variables (attack angle of blade, place of maximum arc, conical ratio of blade and wind speed) are significant regarding the variance analysis table and the model with attack angle of 15 degrees, place of maximum arc of 30%, conical ratio of 100% and wind speed of 12m.s with power of 2.304 is the best model for producing the most power among the selected levels. Regarding the impact of attack angle on output power, the best is 15 degrees and if more levels (more than 5) were studied in the experiment, it wouldn't have any effect and still 15 degrees would be the best angle in increasing the power. This could be related to the aerodynamic driving and inhibiting forces of the blade too. Considering that the attack angle is an angle that tendon line makes with the wind direction, the aerodynamic force at a certain angle can make the most driving force and this happens at 15 degrees the reason of which is separation phenomenon. In addition, the impact of conical ratio on producing power showed that the ratio of 100% level had the most power and never ratios under 100% had been optimal. This might be because the more the ratio is smaller the blade would have smaller weight and can't receive the wind force well. Regarding the decrease of the rigidness of blades less lifting force is created. Thus, at different speeds of wind, turbine will have fewer rotations.

Mathematical model of the producing power of 3-blade wind turbine

By use of SPSS software and multiple regression the mathematical model for producing power of turbine was made and the ratios are shown in table 2. In relation (2), X is the attack angle of blade, Y is place of maximum arc of blade, Z is conical ratio of blade and W is wind speed.

Table 2: ratios of the model of wind turbine by SPSS software

Coefficients(a)

Model		**Unstandardized Coefficients**	**Standardized Coefficients**	**T**	**Sig.**

		B	Std. Error	Beta		
1	**(Constant)**	-545.0	.0106		-5.143	.000
	(Cod-Angle)X	-014.0	.0015	.-0039	.-0937	.0350
	(Cod-Camber)Y	-.0126	.0027	.-0197	-4.688	.0000
	(Cod-Taper)Z	.0420	.0027	.0658	15.674	.0000
	(Cod-Speed)W	.0347	.0027	.0545	12.977	.0000
a Dependent Variable: (Angle.Camber.Taper.Speed) *P*						

The standard error is very low and shows the significance of independent parameters in relation (2). Of course, computer has suggested the standardized ratios and fixed ratio is 0, the ratio of X is -0.039, the ratio of Y is -0.197, the ratio of Z is 0.658 and the ratio of W is 0.545. It is noteworthy that in relation (2), the ratio of W is positive and is 0.374. The positive number means that the more the speed of wind increases, the power increases as well. Also by increase of conical ratio, the power increase since it's positive. The reverse of this is about the place of maximum arc and attack angle, which the more thy increase regarding their negativity, the less the producing power will be.

(2)

$$P = -0.14X - 0.126Y + 0.42Z + 0.347W - 0.545$$

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