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Improving The Efficiency Of The Small Wind Turbine

A. Maamoun[1], O. E. abdelatif[2], M. A. Moawad[2], H. A. Refaey[2] and I. Shaheen[2]

[1]Egyptian Electricity Transmission Company

[2]Mechanical Engineering department, Faculty of Engineering at Shoubra, Benha University

1. Abstract

The present paper presents the effect of inlet wind speed on the rotor power and efficiency of the horizontal axis wind turbine (HAWT). A proto type wind-cube is constructed, and it consists of two parts; the upper part is a steel sheet nozzle and the down part is a base which used to carry the upper-frame and the generator chair. The cone shape nozzle is used to increase the input air velocity. Four different rotors with different number of blades three, four, five and six have been tested. The main aim of this study is to get the most efficient number of blades for the wind turbine used for this system. Also, the study is aimed to investigate the minimum wind speed at which the wind turbine start to rotate and generate energy for the system. The results showed that the rotor with six blades produced the maximum power compared to the other rotors. Moreover, the results showed that, the minimum air velocity to start the rotation is 0.7 m/s and the power was equal to 0.14, 0.17 and 0.39 W for the rotor with 4, 5 and 6 blades, respectively.

Keywords: Small wind turbine; Betz limit; wind-cube; renewable energy.

Nomenclature:

A	The area
A_1	The area of the nozzle inlet
A2	The area of the nozzle outlet, swept area by the rotating blades
$\dot{m}$	The mass flow rate of air
P_{avail}	The available power in the air
$P_i)_{BL}$	The maximum power can be extracted from the air which limited by Betz limit
$P_o)_{BL}$	The maximum power output from generator which limited by Betz limit
U	The air velocity
U_1	The air velocity at the nozzle inlet (air stream)
U_2	The air velocity at the nozzle outlet
η_{Gen}	Generator efficiency
ρ	The air density

2. Introduction

The European Commission evaluated the socio-economic effect of a wide range of power generation technologies for fossil, nuclear and renewable fuel cycles on socio-environmental damages due to electricity and transport. They found that the wind technologies are very environmental friendly with regard to emissions of "classical" pollutants (SO_2, NO_X, dust particles) and regarding greenhouse gas emissions [1].

At end of 2015, the estimated non-renewable energy share of global electricity production is about 76.3% and renewable energy share of about 23.7% out of which is 16.6% from hydropower, 3.7% from wind, 2% from bio-power, 1.2% from solar PV and 0.4% from geothermal, concentrated solar power and ocean.

2.1. Renewable Energy

Renewable energy is a kind of energy which exists freely in nature and exists infinitely. Renewable energies such as water, wind, sun and biomass (vegetation) are all available naturally and were not formed. They don't get out pollution this is why some people call it "***Green Energy***".

The world is going to spread out the use of renewable energies. There are many types of renewable energy sources such as: wind energy, solar energy, biomass energy, tidal energy, wave energy, geothermal energy and hydroelectricity energy.

2.1.1. Wind power:

The terms "wind energy" or "wind power" refer to the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or converted directly into electricity by using a generator.

Wind energy has plentiful benefits in helping to provide a source of clean and sustainable electricity for countries all over the world. The wind energy has many of advantages such as: Wind energy is both renewable and sustainable. It is one of the most environmentally friendly energy sources existing today. It doesn't produce any greenhouse gases comparable to power plants that depend on combustion of fossil fuels. Wind energy is completely free. It has a moderately small land footprint. So, the area around the base of a wind turbine can often be used for other activity such as agriculture. It can play a main role in helping to bring power to remote sites. Since the first ever electricity-generating wind turbine invented, wind turbines have improved considerably and at the present time the technology is become inexpensive, making it much more affordable. Wind energy is affordable, as Land-based utility-scale wind is one of the lowest-priced energy sources available nowadays.

Wind turbines are considered relatively low maintenance. Running costs are considered to be low and the only cost associated with wind energy projects is for the maintenance of wind turbines, which is considered costly low. It has huge potential. Using wind energy to generate electricity helps to reduce the dependency on fossil fuel alternatives such as coal, oil and natural gas.

2.1.1.2. HAWT Disadvantages

There are many disadvantages for the horizontal axis wind turbines such as: Wind energy has a similar problem of solar energy in that it is not a continuous and it doesn't always blow at time of needing electricity. Sites which have a suitable level of air blow are often found far from sites where the electricity is needed. Although costs are reduced by time, the installation of a wind turbine is still considered expensive. It's widely stated that wind turbines projects pose a risk to wildlife, principally birds and bats. Massive tower construction is required to support the heavy blades, gearbox, and generator. Taller masts and blades are more difficult to transport and install. Transportation and installation cost 20% of equipment costs. Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) are being lifted into position. Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.

In addition to, downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow. Reflections from tall HAWTs may affect side lobes of radar installations creating signal clutter, although filtering can suppress it.

Very low rotating speed for the blades (10 – 22 rpm) leads to very complex gearbox to speed up the rotate velocity and big generator and consequently high expensive.

2.1.2. Producing electricity from wind energy

By the end of 2017, the worldwide wind capacity reached 539 291 MW out of which 52 552 MW was added in 2017. This represents a growth rate of 10.8 %. All wind turbines installed worldwide by the end of 2017 can generate more than 5 % of the world's electricity demand [2].

Small-scale turbines are used for a variety of applications, including defense, rural electrification, water pumping, battery charging and telecommunications, and they are deployed increasingly to displace diesel in remote locations [3].

The small wind turbines usually used where the power is required, often within a built environment rather than where the wind is most promising. In such location the wind is normally weak, turbulent and unstable in terms of direction and speed due to the presence of buildings and other obstructions. To produce a reasonable power output from a small-scale wind turbine located in this turbulent environment, and to justify such an installation economically, the turbines have to improve their energy capture, particularly at low wind speeds and be flexible to the changes of wind direction.

In addition to the instability of wind condition and the weak of the air, there is another problem facing the small wind turbines, it has small aerodynamic starting torque due to its small blade radius. A. K. Wright et al. [4] (2004) have measured the starting performance of a three bladed, 2 m diameter horizontal axis wind turbine in field tests. They found that small wind turbines ordinarily start rotating at about 4.6 m/s. So, many studies had been done to increase the power efficiency of the wind turbine and hence the power output of a turbine to overcome the obstacles in order to work at cost-effective production condition.

The power in wind is proportional to the cubic power of wind velocity, so any small amount of acceleration of wind velocity gives a large increase in the energy output; many researches have attempted to exploit this relationship. The mechanisms of increasing the air velocity could be achieved by either throttling the air at the entrance or by making diffuser augmented at the exit of the wind turbine or by using the two mechanisms.

Wei Tong, deduced that Albert Betz concluded that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor [5]. This limit has nothing to do with inefficiencies in the generator, but in the very nature of wind turbines themselves.

The theoretical maximum **power efficiency** of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). Once you also factor in the engineering requirements of a wind turbine - strength and durability in particular - the real world limit is well below the *Betz Limit* with values of 0.35-0.45 common even in the best designed wind turbines. By taking into account other inefficiencies in a complete wind turbine system - e.g. the generator, bearings, power transmission and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity [6].

K. Abe et al. [7] did experimental and numerical investigations for flow fields of a small wind turbine with a flanged diffuser which gave a power coefficient higher than the Betz limit due to the effect of the flanged diffuser.

They estimated the flow fields and compared it with those for a simple wind turbine. They indicated that the wind turbine with a flanged diffuser was seen a significant difference in the destruction process of the tip vortex if compared with the simple wind turbine. Furthermore, the power coefficient of the diffuser-shrouded wind turbine was about four times as high as that of the simple wind turbine. The results showed that both simple and diffuser-shrouded wind turbines returned nearly the same peak performance when the performance was regularized by the local mean velocity just behind the turbine blades.

Sung et al. [8] investigated the aerodynamic performance expectation of a unique 30 kW counter-rotating (C/R) wind turbine system, which consists of the main rotor and the auxiliary rotor. The momentum theory combined with the experimental wake model was used. Concerning the relative dimension of the two rotors, the size of the auxiliary rotor should be smaller than one-half of the main rotor diameter. The results revealed that the interval between the two rotors affects the power output, and the greatest performance achieved when the interval remained at around one-half of the auxiliary rotor diameter.

Seungmin et al. [9] did an aerodynamic analysis of the counter-rotating wind turbine – due to the gearbox was set between the two rotors a front rotor and a rear rotor - by using a free-wake vortex lattice method. The power coefficient and the wake geometry of the counter-rotating wind turbine with a single rotor turbine have been compared. The results showed that the tip vortex trajectories of the single rotor was less expanded radially than those of both the front and rear rotors. Furthermore, the convection velocity of the tip vortex from the front rotor became higher than that of the single rotor however that of the tip vortex from the rear rotor was much lower than that of the single rotor.

Izumi Ushiyama et al. [10] proposed two kinds of two staged wind turbines consist of the co-axial type and the counter-rotating type. The co-axial-type was used to improve the torque (starting) characteristics and the counter-rotating type was used to increase the relative rotational speed of the generator.

The power characteristics of the trial machine were measured and they deduced that the higher the setting wind speed, the larger become the output of the machine. The maximum output correspond to each wind speed were 2.6W for 6m/s, 19.8W for 8m/s, and 38.9W for 10m/s respectively.

The design angle of attack is generally at the point of maximum lift to drag ratio. Twisted blade for wind turbine has proved to be superior to the untwisted one due to its full utilization of blade area to produce lift at low drag while providing a good starting ability. The power output of a wind turbine depends both on lift and lift to drag ratio, so the optimal angle of attack might be somewhere between the point of maximum lift to drag ratio and the point of maximum lift.

The blade element theory indicates that wind turbine power depends strongly on lift and relatively weakly on lift to drag ratio as is shown in the following analysis:

A. Varol et al. [11] decided that they can increase the rotational speed of the wind blades by 32% by adding fixed steering airfoils surrounding the blades at an optimum distance. The results showed that the position of the airfoils is very important and if it is not achieved the airfoils will affect the system negatively.

Al-Bahadly et at. [12] represented an investigation for a ducted twin turbine wind power generator. The ducted turbine used variable inlet guide vanes (VIGVs) mounted in the air stream prior to the first stage turbine to control angle of attack maintaining optimum performance. The results showed that there was a theoretical power rating improved by factor of 17.

Wang et al. [13] developed a methodology using physical tests conducted in a boundary layer wind tunnel and computer modeling using commercial computational fluid dynamics (CFD) code to improve wind energy capture, under low wind speed conditions. The results indicated that the scoop improves the power output of the wind turbine of 2.2 times with the same swept area by accelerating the airflow in the cylindrical section by a factor of 1.5 times. Finally the measured data compared with the results of CFD and the validation of the results was verified with light discrepancy.

Since the power output of a wind generator is proportional to the cube of the wind speed; i.e. if the *wind speed* is doubled hence the power output will increase by a factor of eight.

Then the aim of the study is to concentrate the air via passing through a nozzle shape in order to; firstly increase the air velocity and consequently increase the generating energy from the poor wind speed sites. Secondly decrease the blades length and hence minimize the vibration and consequently the stress on the blades.

3. Experimental Setup

The proto type of wind-cube is consists of two parts; the upper part is the nozzle; the down part is the base which the nozzle and the generator chair are fixed on it.

The nozzle is in a cone shape which has an inlet in a square shape of dimension 2m×2m and an outlet in a circle shape with diameter 0.5 m, as can be seen in Fig. 1. The body of the nozzle is made of steel sheets with thickness of 1 mm and fixed by welding.

The base was designed to carry the upper-frame and the generator chair and also has the availability to be rotated manually according to the variation of the wind direction.

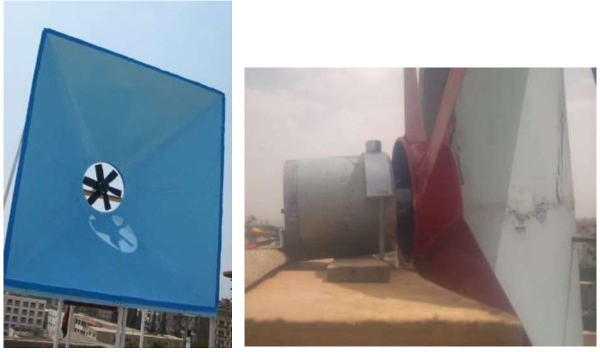

Fig. 1: Final assembly of the wind cube and the generator on its base.

K. L. Kumar stated that in subsonic flow, reduction in area results in increased velocity [14]. By applying the continuity equation on the nozzle:

$$\dot{m} = \rho * U * A = \text{constant} \quad (1)$$

Where: $\dot{m}$ is the mass flow rate in kg/s, ρ is the air density in kg/m^3, U is the air velocity in m/s and A is the area in m^2.

Therefore the ratio between inlet and exit velocity

$$U_2 = (A_1 / A_2) * U_1 \quad (2)$$

Where: U_1, U_2 are the air velocity at the inlet (air stream) in m/s and the outlet of the nozzle respectively, and A_1, A_2 are the area of the inlet and the outlet of the nozzle respectively in m^2. Hence the side length of the nozzle inlet (L_1) = 2 meter and the diameter of the nozzle outlet (D_2) = 0.5 meter.

Then the air velocity at outlet $U_2 \approx 20\ U_1$ (3)

I.e. the air velocity at the cube outlet is theoretically equal about twenty times the air velocity at inlet (stream air velocity).

The inlet and outlet velocities of the wind cub were measured by fixing the Kestrel 4500 at the inlet of the wind cube and the Kestrel 4200 at the outlet of the wind cube, as showed in fig. 2. The maximum three amplified outlet velocities recorded were 5, 5.8 and 6 times the inlet velocity.

Fig. 2: Fixing the Kestrel 4500 at the inlet of wind cube and Kestrel 4200 at the outlet of wind cube to measure the nozzle efficiency.

The rotor which used is made of iron sheet with thickness 0.8 mm, with outer diameter equal to 0.5 m and inner diameter equal to 0.135 m. The rotors which used were made of three, four, five and six blades, as seen in fig. 3.

Fig. 3: The different used rotors with three, four and five blades.

Since the power output is in theory proportional to the square of the radius of the rotor, i.e. as the power of the installed turbines increases the long of the blades increases, which leads to:

- High vibration.
- High stress on the blades.
- Needs for high technology for blades manufacturing and consequently needs for new materials to withstand the stresses.

4. Data Reduction and Procedures

The data collected by Kestrel device and PcLap2000SE device was analyzed in case of 3 blades, 4 blades, 5 blades and 6 blades rotor. Then the results compared and get the best number of blades for this kind of blade.

4.1 Analyzing the data for rotor with different number of blades:

The data is analyzed according to the next steps:

1- The data which collected by Kestrel device [time, air velocity (inlet to the nozzle) and temperature…..etc.] and by PcLap2000SE device (time and voltage) were gathered together in one Microsoft Excel file.

2- The data were sorted according to the time, wherever there were values of both air velocity and voltage, and the power was calculated according to the relation "Power in watt = V^2/R", Where V is the voltage and R is the used resistance = 6.6 Ω and tabulated as shown in table 1.

Table 1: Recorded data were sorted according to the time.

Time	Inlet air velocity (m\s)	Voltage (V)	Power (W)
12:25:34	1.4	2.94	1.31
		2.59	1.01
12:25:36	1.4	2.82	1.21
		3.53	1.89
12:25:38	1.6	4.00	2.42
		4.24	2.72
12:25:40	1.8	4.47	3.03
		4.82	3.53
12:25:42	1.6	5.06	3.88
		4.47	3.03

3- Curves were drawn for the relation between both air velocity and power vs. time, and any odd values were deleted and a modification was done when necessary to adjust the relation, as shown in Fig. 4.

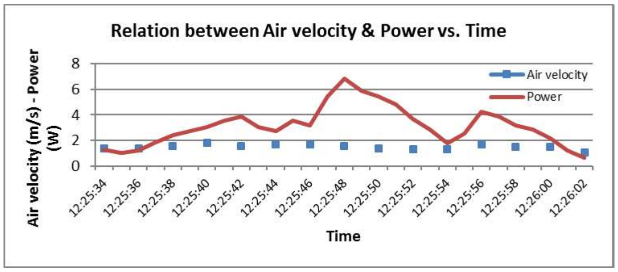

Figure 4: Relation between air velocity & power vs. Time.

4- The data sorted by the air velocity; and all the values of air velocity = 0 or blank the rows were deleted.
5- A curve of the relation between air velocities vs. power was drawn by Microsoft Excel software and a fitted power curve was drawn as a guide, and then all the odd points (which too far from the curve) were deleted.
6- The values of air velocity and power were copied in DataFit software and were solved by adjusted solution setup in 'single model' and solver selection was 'nonlinear' with formula Y= a* X^b where Y represents the power and X represents the air velocity.
7- The detailed of the results (constants a, b) and the Standard Error of the Estimate were got.
8- The new powers were calculated - according to the gotten constants (a, b) – and the percentage of deviation between the calculated powers and the actual powers were calculated according to the relation (deviation =100*(P_m-P_{cal})/P_m), where P_m is the measured power and P_{cal} is calculated power and then the high deviations were deleted.
9- The steps 6 to 8 were repeated till the constant b=3.
10- The fitted curve of power 3 was drawn by using the final gotten 'a' and 'b' constants.

Power output from the rotor according to Bitz limit

As mentioned before that the power in the air is proportional to the air density 'ρ', the flow swept area 'A' and to the cubic power of the air velocity ' U_1^3'.

$$P_{avail} = \frac{1}{2}\dot{m}\, U_1^2 = \frac{1}{2}\rho A U_1^3 = constant * U_1^3 \qquad (4)$$

Where: P_{avail} is the available power in watt.

Assuming the air density is constant and equal to 1.1839 kg/m^3 which is the air density at lowest recorded temperature during the test which was 25°C, the swept area A is the outer area of the rotor.

The maximum power can be extracted from the air is limited by Betz limit $P_{i})_{BL}$ which is equal to about 59.3% of the available power in air flow through the swept area; for rotor's outer diameter = 0.5 m and 2 m as shown in Eqs. 5, 6 respectively.

$$P_{i})_{BL} = 0.0689 * U_1^3 \qquad (5)$$

$$P_{i})_{BL} = 1.1022 * U_1^3 \qquad (6)$$

Table (2, 3) show the $P_{i})_{BL}$ in different air velocities, the generator efficiency at load 6.6 Ω at the same velocities and the maximum power output from generator limited by Betz limit $P_{o})_{BL}$ at the same velocities for rotors with outer diameter =0.5 m and 2 m respectively.

Table 2: The maximum power can be extracted from the air, the generator efficiency and the maximum output power at different air velocities; for rotor's outer diameter = 0.5 m.

Air velocity (m/s)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$P_{i})_{BL}$	0.0086	0.0689	0.2325	0.5511	1.0764	1.8600	2.9536	4.4089	6.2775	8.6111
$\eta_{Gen.}$	0	0	0	0	0	0.030	0.080	0.140	0.237	0.304
$P_{o})_{BL}$	0	0	0	0	0	0.056	0.236	0.617	1.488	2.618

Table 3: The maximum power can be extracted from the air, the generator efficiency and the maximum output power at different air velocities; for rotor's outer diameter = 2m.

Air velocity (m/s)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$P_{i})_{BL}$	0.1378	1.1022	3.7199	8.8176	17.2219	29.7594	47.2568	70.5408	100.438	137.775
$\eta_{Gen.}$	0	0	0	0.304	0.374	0.393	0.402	0.402	0.402	0.402
$P_{o})_{BL}$	0	0	0	2.681	6.441	11.695	18.997	28.357	40.376	55.386

Operating condition

Table (4) shows the minimum, maximum and average air temperature during the test for 3, 4, 5 and 6 blade rotors. Also it shows the minimum, maximum and average air velocity at the entrance of the nozzle during the test for 3, 4, 5 and 6 blade rotors.

Table 4: The min., max. and average air temperature recorded during the test, and the min., max. and average air velocities during the test.

	Min. temp. ° C	Max. temp. ° C	Average temp. ° C	Min. air velocity m\s	Max. air velocity m\s	Average air velocity m\s
3 blades	25.7	29.3	27.2	0	3.3	1.3
4 blades	26.3	29.6	27.8	0	3.5	1.6
5 blades	26.9	31.3	29.6	0	3.2	1.1
6 blades	26.3	29.1	27.7	0	3.6	1.5

5. Results and Discussion

Field test data were analyzed to determine the efficiency of the rotors and the constant of power equation for different rotors with different number of blades and get out the air velocity at which the blades start to rotate. At the end a comparisons were done for different rotors and get out the most efficient rotor.

5.1 Effect of number of rotor blades:

Figure 5 indicates the relation of air velocity and power for rotor with 3 blades. The constant for this three blades case is 0.09646 according to Eq. (4). From the figure the minimum air velocity at which the rotor started to rotate, and the generator generate energy was 0.8 m\s at an average power 0.05 W. The experimental results showed that at air velocity 2.2 m/s the average power was 1 W. Furthermore, the maximum power was 2.1 W and it was obtained at air velocity of 2.8 m\s. Consequently, the estimated average power at air velocities of 3, 4 and 5 m\s were 2.6, 6.2 and 12.1 W, respectively.

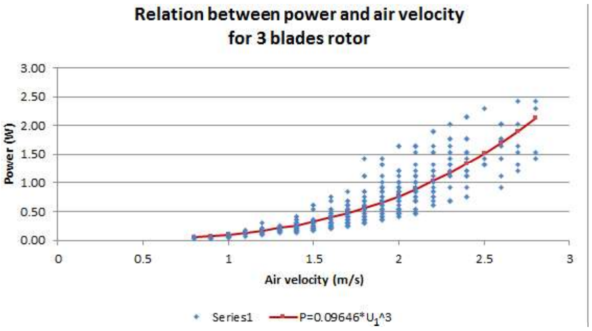

Fig. 5: indicates the relation between power vs. air velocity for 3 blades rotor.

Figures 6, 7 and 8 represented the indicated power from rotors with 4, 5 and 6 blades, respectively. As mentioned before for the rotor with three blades the constants were calculated according to Eq. (4). Table 5 summarize the main results from each rotor.

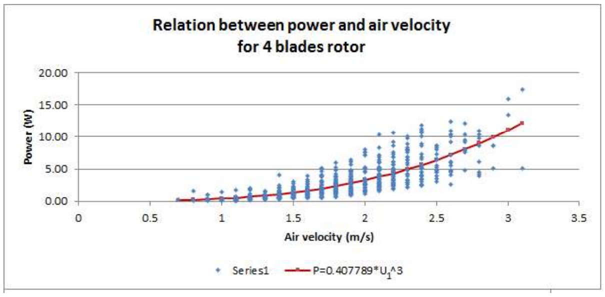

Fig. 6: indicates the relation between power vs. air velocity for 4 blades rotor.

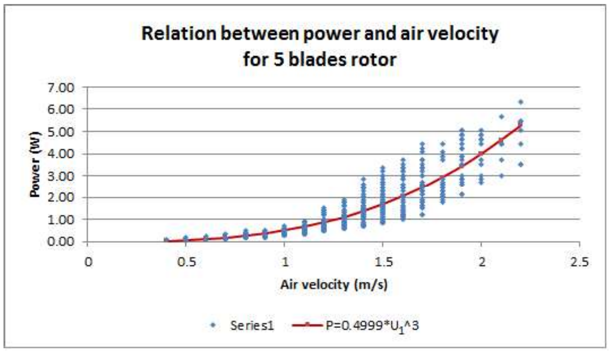

Fig. 7: indicates the relation between power vs. air velocity for 5 blades rotor.

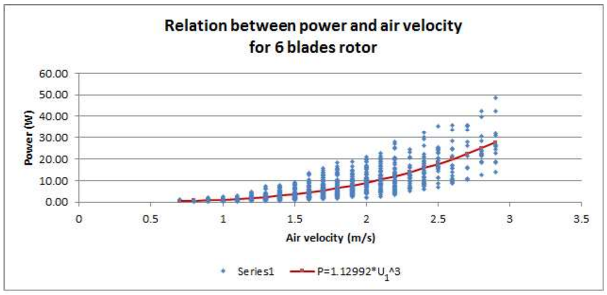

Fig. 8: indicates the relation between power vs. air velocity for 6 blades rotor.

Table 5: Main experimental results from the tested rotors.

	Min. velocity m/s	Power Watt	**Power =1 Watt** Velocity (m/s)	Max. Power (W)	Max. air velocity m\s	Constant from Eq. (4)
3 blades	0.8	0.05	2.2	2.1	2.8	0.09646
4 blades	0.7	0.14	1.43	12.1	3.1	0.40779
5 blades	0.7	0.17	1.35	5.04	2.2	0.49989
6 blades	0.7	0.39	0.96	27.6	2.9	1.12992

5.2 Comparison between the rotors with different blades

Figure 9 indicates the relation between power vs. air velocity for rotors with 3, 4, 5 and 6 blades. The rotor with 6 blades has much power than the other rotors at the same air velocities. Then the rotor with 4 and 5 blades come in the second and third rank of power at the same velocity respectively. Finally, the rotor with 3 blades has lesser power than the other rotors at the same air velocities.

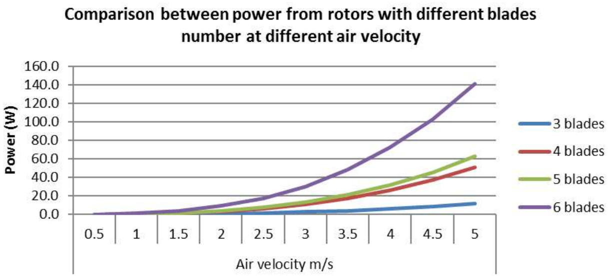

Fig. 9: Relation between generated energy vs. air velocity for rotors with 3, 4, 5 and 6 blades.

5.2.1 Comparison between the rotors in four cases and Bitz limit wind turbine

Comparisons between the rotors in four cases (with 3, 4, 5 and 6 blades) with a Bitz limit wind turbine done in two cases.

a- First case, a Betz limit wind turbine has outer diameter equal to 0.5 meter as the tested rotor. Fig. 10 shows that a Betz limit wind turbine has lesser power than the four cases at the same entering air velocity to the nozzle. The tested rotor has more power because of the amplification of air velocity at the outlet of the nozzle, i.e. at the entrance of the rotor.

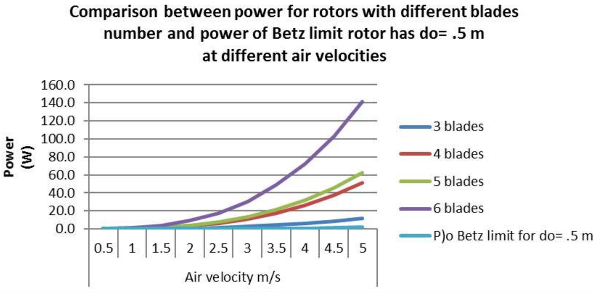

Fig. 10: Relation between power vs. air velocity for rotors with 3, 4, 5 and 6 blades.

b- Second case, a Betz limit wind turbine has the outer diameter equal to the side length of the nozzle's entrance (2 meter). Fig. 11 shows that a Betz limit wind turbine has much power than the 3 blades rotor and equal to the rotor with 4 blades. But, the tested rotor with 5 and 6 blades has more power than a Betz limit wind turbine because of the amplification of air velocity at the outlet of the nozzle, i.e. at the entrance of the rotor.

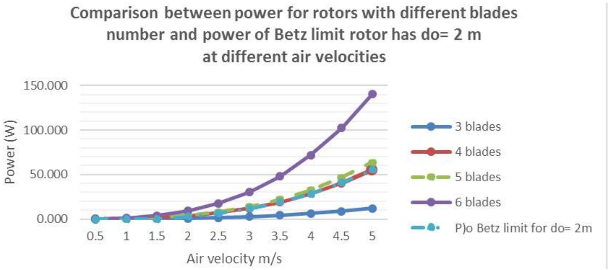

Fig. 11: Relation between power vs. air velocity for rotors with 3, 4, 5 and 6 blades.

The rotor with 6 blades is more efficient than the rotor with 3, 4 and 5 blades. The rotor with 6 blades is also more efficient than the Betz limit rotor with outer diameter equal to the inlet length side of the wind cube nozzle, i.e. 2 meter; as well as the Betz limit rotor with outer diameter equal to the outlet diameter of the wind cube nozzle, i.e. 0.5 meter.

The minimum air velocity at which the rotor started to rotate and generate energy is 0.7 m/s and the power was equal to 0.14, 0.17 and 0.39 W for the rotor with 4, 5 and 6 blades respectively. Whereas, Tony Burton et al., deduced that the cut-in air velocity of the wind turbine in normal case is about 4 m/s [15]. It means that the wind cube can be constructed on the suitable roof of the building (which has no obstacles) in cities, offering a green energy of electricity.

6. Conclusion

The experimental proto type in the present work introduces the effect of different rotors on the performance of HAWT. Four different rotors with different number of blades three, four, five and six have been tested. A stainless-steel cone nozzle is used before entering the wind rotor to increase the entering air velocity. The following outcomes were obtained from the present work and it could be drawn as following:

- The rotor should be shorter to produce low vibration which will increase the life time of the rotor.
- The rotor will have high efficiency more than the Betz limit rotor of the same diameter.
- The results showed that the rotor with six blades produced the maximum power compared to the other rotors.
- Moreover, the results showed that, the minimum air velocity to start the rotation is 0.7 m/s and the power was equal to 0.14, 0.17 and 0.39 W for the rotor with 4, 5 and 6 blades, respectively.

7. References

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