



RESEARCH ARTICLE

PERFORMANCE ANALYSIS OF DIFFUSER AUGMENTED HORIZONTAL AXIS WIND TURBINE.

Shiv Kumar Tripathi.

Research Scholar, Department of Electrical Engineering, Maulana Azad National Institute of Technology, Bhopal, India.

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Abstract

Diffuser augmented horizontal axis wind turbine design with a diffuser ring with a broad-ring flange at the exit periphery and a wind turbine inside it. diffuser ring helps for collecting and accelerating the approaching wind into wind turbine. The diffuser ring generates a low-pressure region in the exit neighborhood of the diffuser by vortex formation and draws more mass flow to the wind turbine inside the diffuser ring. To obtain a higher power output of the diffuser augmented wind turbine we have examined the optimal form of the flanged diffuser ring wind turbine. As a result a shrouded wind turbine equipped with a flanged diffuser has been developed and demonstrated power augmentation for a given turbine diameter and wind speed which is increased as compared to a standard (bare) wind turbine. In a field experiment using a three bladed wind turbine with a flanged diffuser shroud the output performance improved from standard (bare) wind turbine. The effect of diffuser's shape performance greatly influenced and maximum wind speed increased 1.7 times with the selection of the appropriate diffuser shape. We conducted field tests using a real examination device with a diffuser and confirmed that the output power of the wind power generator increased by up to two times compared to that of a conventional turbine.

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Introduction:-

The development and application of clean renewable energy resources have become a very important research Subject in recent past years. development of clean renewable energy resources are strongly accepted due to the limited availability of fossil fuels like coal, petrol, diesel and gases etc. and its negative impact on environment such as Global Warming, greenhouse gases emission etc. now a days clean renewable energy resources become a important contributor for reducing the world's CO₂ emissions. Many governments have set target for future electricity generation from renewable such as 20% of electricity for Australia, 30-35% of electricity for the UK being generated by 2020 and 90% of electricity for the new zealand being generated from renewable sources. Among all clean renewable energy resources the wind energy has developed rapidly and about strongly play big role in new energy field.

Wind energy output from wind turbine is directly proportional to the swept area (A) of turbine and cube of the wind velocity (V) in the turbine, as fallows[1].

$$P = \frac{1}{2} A V^3$$

Corresponding Author:- Shiv Kumar Tripathi.

Address:- Research Scholar, Department of Electrical Engineering, Maulana Azad National Institute of Technology, Bhopal, India.

Therefore output power P can increase by raising the wind speed velocity and enlarging swept area of turbine (A). since the output power is proportional to the cube of wind velocity so large output power will be obtained if the wind velocity slightly raised. we can increase the wind velocity with utilize the fluid dynamic nature around a structure or topography. which will substantially increase the power output of a wind turbine. a diffuser ring attach to the wind turbine have the shape of a ring-wing with high lift aero foil section, or a bell shape increase wind speed that passes through wind turbine. diffuser augmented wind turbine (DAWT) concept offer possibility to cope with such low wind-speed regimes for electricity generation. It is a horizontal axis wind turbine which is equipped with hollow ducting shroud. Diffuser augmented wind turbine configuration expand inside cross section with equipped additional flange attached at the trailing edge of the shroud .additional flange produce a power augmented of 4 to 5 times for a wind speed and given turbine diameter as compared to the standard wind turbine. Shroud diffuser increased the flow rate of air by virtue of sub-atmospheric pressure at the diffuser exit plane in wind turbine. Diffuser mechanism controls the expansion of turbine area which is unrestricted in bare turbine case. When atmospheric pressure falls then diffuser provide a greater mass flow rate through a kind of vacuuming effect in wind turbine[2]. Ohya et al. show various result in laboratory for different shape flange in wind turbine vortices.

Next section of this paper deal introduction of diffuser augmented wind turbine. then identified design of experimental setup and performance analysis of wind turbine discussed in. Result of experimental setup discussed in final section . End of this paper conclusion and perspective given in last section.

Diffuser augmented wind turbine-(DAWT):-

Developmental concept of the Diffuser-Augmented Wind Turbine (DAWT) came up as a modification form of Horizontal-Axis Wind Turbine (HAWT) system. A hollow shroud-ducting is added to cover the rotor blades in diffuser augmented wind turbine. The idea behind this modification is to collect and accelerate the approaching wind as strikes the rotor blades in wind turbine. Shroud realizes a collection of wind as well as accelerating wind speed for formation of vortices in wind turbine. Additional flange at the exit periphery of diffuser will enhance the formations of vortices at regions behind the shroud. These vortices, having low pressure regions around, will subsequently draw more wind to flow through the diffuser. The diffuser increases the speed of the wind passing through turbine which resulting in higher output power [3]. The principle behind the increase in wind speed is that the wind flowing outside the diffuser causes more density drop at the diffuser exit than at entrance show in figure 1. Difference in density causes wind flow with high speed from the entrance toward the low-density exit side and speed of the wind passing through the diffuser is increased.

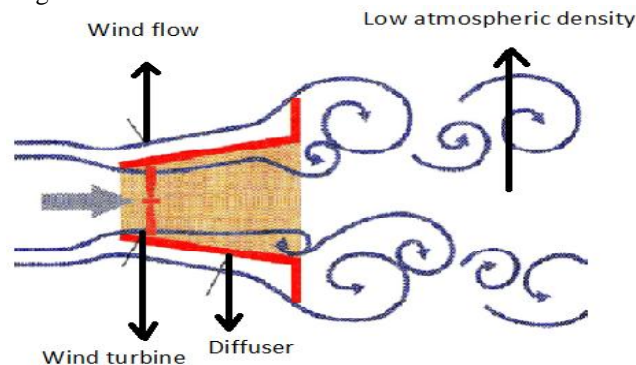


Figure1:-Diffuser mechanism

Augmentation of a wind turbine:-

The following technique of augmenting a wind turbine results from two fundamental concentrator mechanisms: increased mass flux, and wake mixing with the external flow. In the former, increased mass flux is created by exertion of a cross-wind force on the primary mass-flow which is not present in the conventional bare turbine energy exertion Process. This mechanism occurs in vortex augmented wind turbine, tip-vanes and shrouded wind turbine. The latter augmentation mechanism referred by P.R. Ebert. as the ejector systems technique which increased energy extraction per unit of primary mass-flow caused by the mixing of wake and external flows at a pressure below ambient. This mechanism occurs in both tip-vanes and shrouded turbine devices [4].

The technique conceptually outward radial forces present for increased mass flux mechanism which deflect radially flow of outward downstream in the turbine and thereby cause a diffuser effect. As mass continuity must hold for the stream tube bounding the rotor tips and the enlarged diameter of the downstream stream tube of the rotor must result

in an enlargement upstream stream tube of the rotor compared to that present on a conventional bare turbine. Therefore, the addition of radial forces result in an increased mass-flow through the turbine and get a larger power output compared with a conventional HAWT of the same blade diameter.

Alternatively, the increased mass flux can be considered from a vorticity point of view. Essentially, the aerodynamic force acting radially inward on the diffuser applies outward force on the air associated with the circulation of the body. The radial forces correspond to a distribution of vortex rings lying in the blade-plane. This vorticity confined to the immediate vicinity of the blade-plane and causes a net circulation setting up a venturi-type flow with the turbine in the narrowest part of the stream tube. Result of which is increased mass flow through the turbine[5]. The second mechanism, whereby the energy extraction per unit of primary mass-flow is increased a transfer of momentum uses from the external flow passing through the rotor to drive out the mixing product of both core and external flows into the ambient atmosphere. This is ensuring a positive mass-flow through the turbine. This equates to an increase in the disc loading or thrust coefficient which may now become higher than unity as was found to be the case in the experimental work on tip-vanes by A. D. Peacock.

Factors influencing the cost of energy:-

In the experimental although the above techniques can be used to augment the power output of a wind turbine, they do not necessarily produce a reduction in cost of energy. In order to do so and therefore to be commercially viable such concept must show one or more of the following characteristics: improved performance, reduced capitalization, reasonable life, reliability, accessibility, and serviceability must be considered including the applicability and interface adaptability of such systems to a wide variety of structures and environments as well as their aesthetic and environmental impact.

Advantages of diffuser ring horizontal axis wind turbine:-

1. By the use of diffuser ring around the blade turbine the wind velocity is increased from which the output power also increase two to three times as compared with conventional wind turbines due to concentration of the wind energy [6].
2. Since the vortices generated from the blade tips are considerably suppressed through the interference with the boundary layer within the diffuser shroud, the aerodynamic noise is reduced substantially. Therefore significant reduction in wind turbine noise.
3. Wind turbine rotating at a high speed which is shrouded by a structure and is also safe against damage from broken blades.
4. Allows the energy to be harvested from the diffuser (high speed/lower torque) instead of the center.
5. Supports variable pitch mechanism to vary the blade pitch with changing wind speeds.
6. Allows variable blade "twist" to provide the ideal angle of attack for the entire leading edge at all wind speeds.
7. Flywheel diffuser effect smooth's out electrical generation.
8. The unique patented diffuser ring which is circles the blade tips incredible acoustic performance with shedding the turbulent air currents which flow from the blade tips and noise is removed. These patented acoustic suppression dynamics ensure that the DAWT operates below background noise and making it virtually inaudible in all wind conditions.
9. The DAWT has both mechanical and electrical safety mechanisms and has been rigorously tested under extreme wind conditions.

Experimental Set-Up:-

The experimental rig has been designed with detachable diffuser allowing comparison of bare turbine with and without shrouded turbine with diffuser design variations to be made. The model has three blades horizontal axis wind turbine. Design of the rotor takes into account the stability consideration in wind turbine system. In current study wind blades are of constant length of 36cm and the rotor diameter is 72cm. wind blade and diffuser ring are designed by standard NACA 63-210 aerofoil profile and other parameter also made with standard profile[7].

Blade set for DAWT 0.36 m length truck-testing-prototype has been investigated in this study. Blade sets have been designed by the present Aerodynamics methodology. Descriptions of blade sets are presented in below table. Manufacturing process used in the production of blade sets ensured accurate reproduction of the prescribed geometries. A three-dimensional solids model was used to create tool paths for the Computer Numerically Controlled (CNC) machine. Timber blade sets were produced and finished with either an epoxy varnish for the 0.36 m length of each blade. This process produced a high degree of accuracy for each individual blade. It should be

noted, however, that the small physical dimensions of the wind blade meant that some variation from the desired section profiles was unavoidable.

Table I:- Blade parameter

Chord line length	Lower camber width	Upper camber width
1c.m	1 c.m.	1c.m.
12c.m.	.8 c.m.	1 c.m.
18 c.m.	.6 c.m.	.9 c.m
25 c.m	.4 c.m.	.7 c.m.
36 c.m.	.2 c.m	.5 c.m

A 0.36meter diameter aluminium ring is used for diffuser ring in three blade horizontal axis wind turbine. The diffuser ring is shrouded around the wind blade with the touch the each blade tip vane. The circumference of diffuser ring is 1.1304m and width of ring is 7 c.m. inner surfaces had three boundary layer control slots all positioned of the blade-plane with the 0.36m diameter wind tunnel three blade DAWT. Diffusers inlet-area-ratio (IAR) and an exit-area-ratio (EAR) are same values. The geometrical accuracy of the DAWTs was ensured by using laser cut internal ribs in the 0.36 m diameter wind tunnel DAWT. A tower that supports the nacelle and rotor hub at its top. These are made from tubular steel, concrete, or steel lattice. Height of the tower is an important in design of HWAT because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity[8]. Generally output power of the wind system increase with increase in height and also reduces the turbulence in wind. In our experimental setup we use free standing tower which made from welding different size steel pole together. The height of the tower is 2.5m.

Performance Analysis Of Wind Turbine:-

Reactive Calculation for Reynolds Number:-

Reynolds number (Re) is defined as the ratio of inertia force to the viscous force. Reynolds number signifies the relative predominance of the inertia to the viscous forces occurring in the flow system[9]. The higher the value of Re. greater will be the relative contribution of inertia effect. Reynolds number is given by:-

$$Re = \rho L V / \mu$$

for various wind velocity the value of Re is listed below

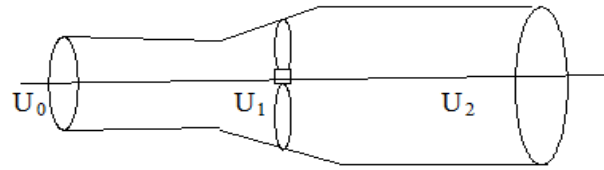
Table II:- Reynolds number for different wind velocity

V(m/s)	Re	C _D
1	24.75x10 ³	0.5
2	49.50x10 ³	0.5
3	74.25x10 ³	0.5
4	99.00x10 ³	0.5
5	123.75x10 ³	0.2
6	148.50x10 ³	0.2
7	173.25x10 ³	0.2
8	198.00x10 ³	0.2
9	222.75x10 ³	0.2
10	247.50x10 ³	0.2
11	272.25x10 ³	0.2
12	2297.00x10 ³	0.2

- Value of drag coefficient for Re 1000 to 100,000 is 0.5 and
- Value for drag coefficient for Re more than 105 is 0.2
- For the convenience we have taken value of drag coefficient for all Reynolds number and velocity is 0.2

Perturbation factor:-

Perturbation factor is defined as the fractional decrease of wind speed at the turbine[10].

**Figure2:-** Wind turbine tunnel

Perturbation factor 'a' = $(U_0 - U_1) / U_0$, $U_1 = (1 - a) U_0$

Also we know that,

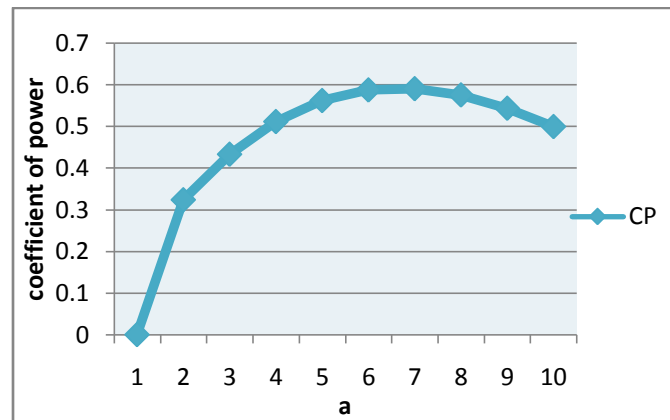
$$U_1 = (U_0 + U_2) / 2$$

Therefore we get,

$$a = (U_0 - U_2) / 2U_0$$

Power coefficient

$$C_p = 4a(1-a)^2$$

**Figure 3:-** Coefficient of power for different perturbation factor.

A. Lift and drag force for horizontal axis wind turbine

The lift force can be calculated as

$$F_L = \frac{1}{2} C_L \rho w^2 (bc)$$

Where C_L is the "coefficient of lift", ρ is the density of air, w the relative wind speed, b the width of the blade section and c the length of the chord line

Similar for the drag force

$$F_D = \frac{1}{2} C_D \rho w^2 (bc)$$

The coefficient of lift and drag both depend of the angle of attack, For angles of attack higher than typically 15-20° the air is no longer attached to the blade, a Phenomenon called "stall".

The ratio C_L/C_D is called the "glide ratio", i.e.

$$GR = C_L/C_D$$

Coefficient of lift

$$C_L = A_1 \sin(2\alpha) + A_2 \cos^2(\alpha) / \sin(\alpha)$$

Where $A_1 = B_1/2$

$$A_2 = [C_{LS} - C_{Dmax} \sin(\alpha_{st}) \cos(\alpha_{st})] \sin^2(\alpha_{st}) / \cos(\alpha_{st})$$

Coefficient of Drag

$$C_D = B_1 \sin^2(\alpha) + B_2 \cos(\alpha) + C_{DS}$$

Where C_{DS} is the coefficient of drag at the beginning of stall, α_{st} , and

$$B_1 = C_{Dmax} , B_2 = 1 / \cos(\alpha_{st}) [C_{DS} - C \sin^2(\alpha_{st})]$$

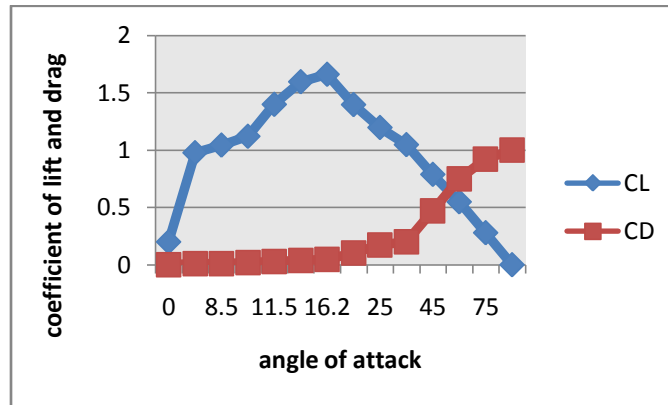


Figure4:- Coefficient of lift and drag

Therefore we calculated lift and drag force (per meter blade width) for a standard attack angle 8.5° and different velocity.

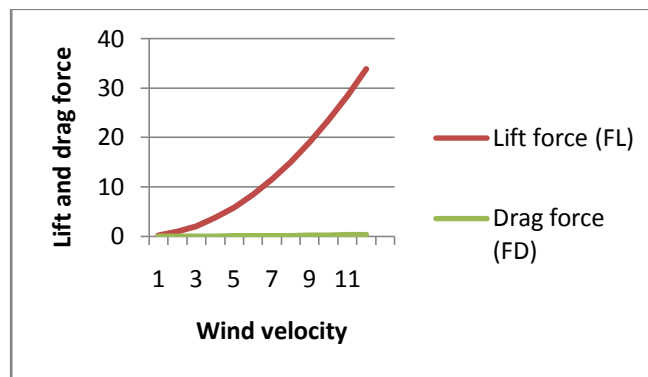


Figure5:- Lift and drag force for different wind velocity.

B. torque in horizontal axis wind turbine

In horizontal axis wind turbine torque equal to multiplication of the axial force (thrust) on the rotor and perpendicular distance of application force[11].

$$T = F_T \times \text{distance (blade length)}$$

The axial force (thrust) on the rotor can be calculated as

$$F_T = \frac{1}{2} \rho w^2 A C_T$$

Now coefficient of axial force[35].

$$C_T = 4a(1-a)$$

An axial interference factor 'a' has an optimum at about 0.333 (exactly 1/3). Therefore calculate the value of axial force (thrust) on rotor and torque on wind blade at different velocity and $C_T = 0.89$

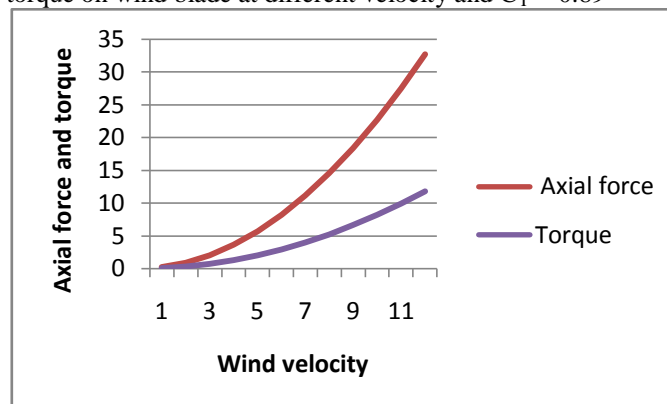


Figure 6:- Axial force and torque for different wind velocity

C. Mechanical power in horizontal axis wind turbine

The power generated by the mechanical device is called mechanical power. It is usually less than ideal power i.e. air power (P_a).

It is calculated by the relation

$$P_m = T \omega$$

$$= T \times 2\pi N / 60$$

The wind velocity is measured by the anemometer and the rpm of the shaft is measured by tachometer.

Result and Discussion:-

in this study we focused on the wind flowing factor affects output with diffuser and without diffuser, and also the performance of wind turbine from above experiment result we see many factor which is discuss here. Lift and drag distribution of an airfoil against angle of attack it is seen that with an increase in angle of attack C_L increases linearly. The C_L values increase linearly from 0.9 to 1.6 for a range of $0^\circ - 15^\circ$ angle of attack. Then it decreases linearly and reaches 0° at 90° angle of attack. The drag coefficient is also increase with angle of attack but very small value in comparison of Lift coefficient. it increase from 0.008 to 0.04 for a range of $0^\circ - 16.2^\circ$ angle of attack. Then after it suddenly increase and reach 1 at 90° angle of attack. for optimum perturbation factor 0.33 and blade design 8.5° angle of attack. we determine the axial force and torque on the rotor in graph we see the axial force reach 27.46N – 32.68N and torque reach 9.88N-m - 11.68 N-m at rated wind velocity 11m/s - 12m/s. Power in wind increase inversely proportional to cube of wind velocity And directly proportional to swept area. For turbine swept area 0.4073 m² the power in wind is 0.255 W in 1m/s and finally its reach in maximum 440 W at rated wind speed 12 m/s.

D. Turbine rotation with wind velocity

Wind turbine start rotation in cut in speed 2m/s and increase rotation with wind velocity .here we examine the rotation of wind turbine with diffuser and without diffuser.

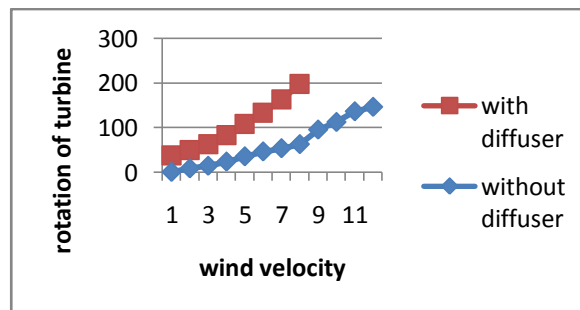


Figure7:- Comparison output of turbine rotation

From above graph we see the turbine rotation is approximately two to three times increase with the use of diffuser ring. In rated velocity 12 m/s the speed of turbine with diffuser 197.6 RPM and without diffuser 133 RPM. That means the use of diffuser increase wind velocity near the turbine and therefore turbine rotate more than speed comparison conventional wind turbine.

E. Power coefficient with wind velocity

Power coefficient defined as how much power Extract by the turbine . by the betz limit the maximum power can extract wind turbine is 59.7% for rated wind velocity of the wind turbine.

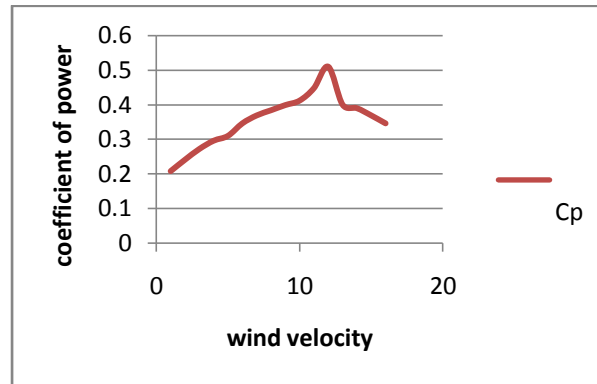


Figure8:- Power coefficient with different wind speed

From above graph we see the power of coefficient increase with wind velocity at rated velocity 14m/s its maximum value 0.5 then after its value decrease.

F. Turbine Extracted power or mechanical power of wind turbine

Power extracted by the turbine is called turbine Extracted power. This power is always less than air power. In this experiment we determine the turbine Extracted power with diffuser and without diffuser with different wind velocity.

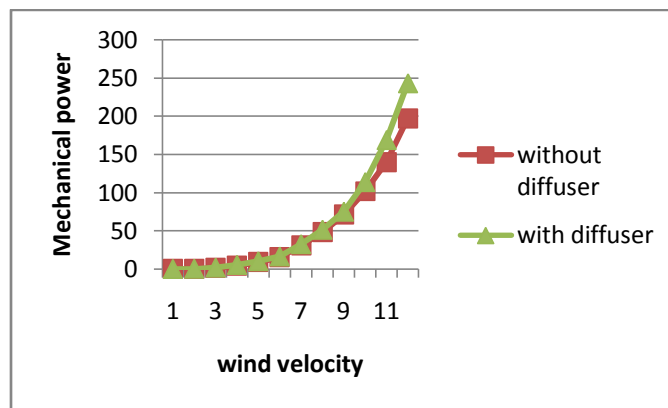


Figure9:- Comparison of output mechanical power

From above graph we see that the mechanical power of wind turbine with diffuser is more than without diffuser at rated wind velocity. Means that the effect of diffuser increases the power in wind turbine.

G. Turbine Electrical power output

In our experiment we use gear generator which is rated at 12v, 1000 RPM. For measurement of voltage and current we use multimeter and record their reading in different velocity and examine that the value of current and voltage is more in diffuser wind turbine in comparison without diffuser. From above recording we draw graph of electrical output.

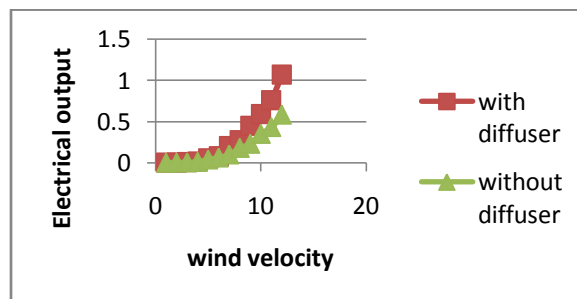


Figure10:- Comparison of output electrical power

From above graph finally we see the effect of diffuser in wind turbine with the use of diffuser ring the electrical output increased approximately two times from conventional wind turbine. at rated wind velocity 12 m/s the electrical output of wind turbine without diffuser is 0.584 W whereas electrical output with diffuser ring is 1.071 W which is approximately two times of the without diffuser wind turbine output.

Conclusion:-

We have developed a DAWT (diffuser augmented wind turbine) that can obtain a remarkably higher output compared to conventional wind turbine. First we examined the three blade horizontal axis wind turbine then after a diffuser ring attached to the blade tip of the turbine. It was confirmed that a diffuser structure is an effective for collecting and accelerating the wind .by the attached of the diffuser realize a remarkable increase in wind speed of 1.6-2.4 times. Those of the approaching wind speed. This is because the diffuser generates a low-pressure region in the exit area of the diffuser by vortex formation and draws the wind into the diffuser. Based on this idea of a diffuser, we conducted a demonstration experiment of power generation of a wind turbine with a flanged diffuser in the field experiments. To obtain a higher power output of the horizontal axis wind turbine, we investigated the optimal form of the flanged diffuser with a wind turbine installed.

The following results were obtained for a wind turbine with a diffuser.

- 1-We ascertained the effect on wind speed for each of the diffuser parameters. Results showed that the parameters were able to increase the maximum wind speed in the vicinity of the diffuser entrance by around 1.7 times.
- 2-The fitting of a diffuser improved the power curve and increased the energy production of the wind turbine. A maximum energy production ratio of around two times was obtained by collecting wind energy in the turbine.
- 3-The diffuser is useful at sites where the wind direction is comparatively steady, by setting the turbine in the direction of the wind.

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