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Wind Energy and Role of Effecting Parameters

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ABSTRACT

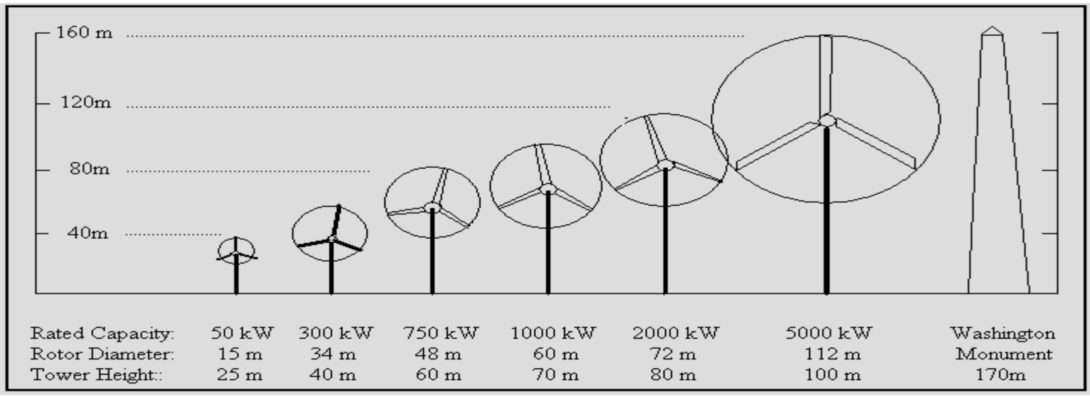
As the energy demand of industry grows exponentially, fabrication of wind energy system becomes a crucial point of concern. Many research activities about wind have been carried out by experimental methods and by theory and simulation. Wind energy parameters have been used to study the relation between the wind energy parameters and subsequent relative energy. Numerical simulation and theory with experimental analysis generate realistic and useful results. The results obtained by theoretical calculations are identical to the experimental results. Numerical simulation on wind energy and effect of wind energy factors/constraints are systemically investigated, by using experimental data. In this work different gases have been used to spawn medium, which contains velocity. The gases are injected on blades of wind turbines. The wind energy effecting parameters (types of gas, velocity of gas, diameter of blades etc) has been examined by taking combination of parameters. The outcome obtained by theoretical calculations is identical to the experimental results.

Key words: Wind energy, Diameter of rotor, properties of gases.

INTRODUCTION

The re-emergence of the wind as a significant source of the world's energy must rank as one of the significant developments of the late 20th century. The first windmills on record were built by Persians around 900 A.D. These vertical axis windmills were not very efficient at capturing the wind's power and were particularly susceptible to damage during high winds. During the middle Ages, wind turbines began to appear in Europe. These turbines resembled the 4-bladed horizontal axis windmill typically associated with Holland. The applications of windmills in Europe included water pumping, grinding grain, sawing wood and powering tools. Like modern wind turbines, the early European systems had 2 degree of freedom that allowed the turbine to turn into the wind to capture the most power. The use of windmills in Europe reached their height in the 19th century just before the onset of the Industrial Revolution. At this time, windmill designs were beginning to include some of the same features found on modern wind turbines including yaw drive systems, air foil shaped blades and a power limiting control system. Wind turbines have continued to evolve over the past 20 years and the overall cost of energy required to produce electricity from wind is now competitive with traditional fossil fuel energy sources. This reduction in wind energy cost is the result of improved aerodynamic designs, advanced materials, improved power electronics, advanced control strategies and rigorous component testing. Over the last 25 years, wind turbines have evolved and are now cost competitive with traditional energy sources in many locations. The size of the largest commercial wind turbines, as illustrated in Figure 1, has increased from approximately 50 kW to 2 MW, with machines up to 5 MW under design [1].

Figure 1



Wind turbine technology, dormant for many years, awoke at the end of 20th century to a world of new opportunities. Developments in many other areas of technology were adapted to wind turbines and have helped to hasten their re-emergence. A few of many areas which have contributed to the new generation of wind turbines include materials science, computer science, aerodynamics, analytical methods, testing, and power electronics. The total installed capacity in the world as of year 2005, as shown in figure 2, was approximately 60,000 MW, with majority of installations in Europe [1].

Offshore wind energy systems are also under active development in Europe. Design standards and machine certification procedures have been established, so that there liability and performance are far superior to those of 1970s and 1980s. The cost of energy from wind has dropped to the point that in some sites it is competitive with conventional sources, even without incentives. In those countries where incentives are in place, the rate of development is strong.

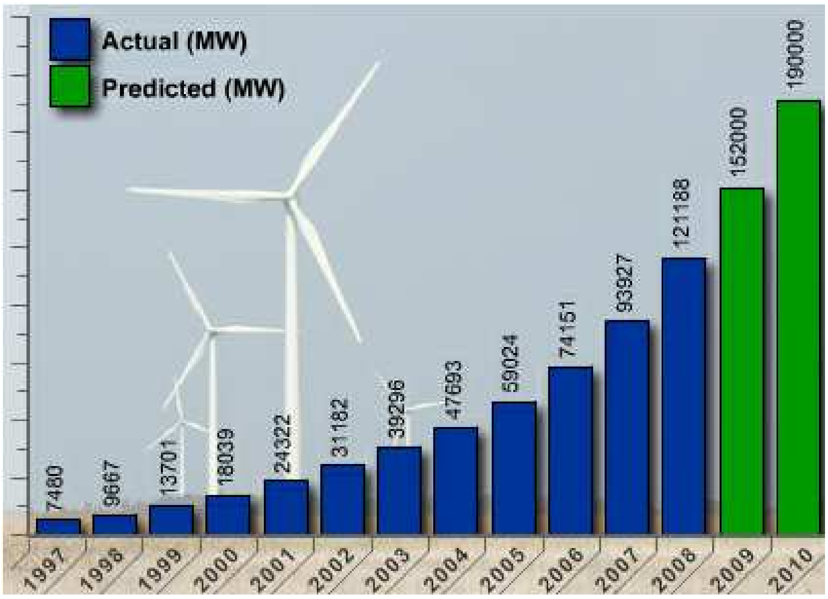


Figure 2

Most of the turbines have a horizontally mounted hub with two or three blades. As the blades become longer to capture more power, the static and dynamic loads on the blades and other components increase. In general, a blade for a 1.5-MW turbine is 34 meters in length or greater and weighs as much as 6,000 Kg [1].

The sitting or placement of wind systems is extremely important. In order for a wind turbine system to be effective, a relatively consistent wind flow is required. Obstructions such as trees of hills can interfere with the rotors. Because of this, the rotors are usually placed on towers to take advantage of the stronger winds available higher up. Furthermore, wind speed varies with temperature, season, and time of day. All these factors must be considered when choosing a site for a wind powered generator.

The amount of wind energy available at any location depends on two se of factors:-

a) Climatic factors including: time of day, season, geographic location, topography, and local weather.
b) Mechanical factors including: diameter of rotor, and type of turbine.

Utility scale wind farms must have access to transmission lines to transport energy. The wind farm developer may be obligated to install extra equipment or control systems in the wind farm to meet the technical standards set by the operator of a transmission line [2]

Merits of wind energy
One of the greatest advantages of wind energy is that it is ample. Secondly, wind energy is renewable. Some other advantages of wind energy are that it is widely distributed, cheap, and also helps in reducing toxic gas emissions. Wind Energy is also advantageous over traditional methods of creating energy, in the sense that it is getting cheaper to produce wind energy. Wind energy may soon be the cheapest way to produce energy on a large-scale. The cost of producing wind energy has come down by at least eighty percent since the eighties. Along with economy, wind energy is also said to diminish the greenhouse effect. Also, wind energy generates no pollution. Wind Energy is also a more permanent type of energy. The wind will exist till the time the sun exists, which is roughly another four billion years. Theoretically, if all the wind power available to humankind is harnessed, there can be ten times of energy we use, readily available [3].

Demerits of wind energy
However, there are some disadvantages for wind energy, which may put a dampener in its popularity. Though the costs of creating wind energy are going down, even today a large number of turbines have to be built to generate a proper amount of wind energy. Though wind power is non-polluting, the turbines may create a lot of noise, which indirectly contributes to noise pollution. Wind can never be predicted. Even the most advanced machinery may come out a cropper while predicting weather and wind conditions. Since wind energy will require knowledge of the weather and wind conditions on long-term basis, it may be a bit impractical. Therefore, in areas where a large amount of wind energy is needed, one cannot depend completely on wind. Many potential wind farms, places where wind energy can be produced on a large-scale, are far away from places for which wind energy is best suited. Therefore, the economical nature of wind energy may take a beating in terms of costs of new substations and transmission lines. Wind energy depends upon the wind in an area and therefore is a variable source of energy. Some other demerits include bird kill and communication interference of signals [3].

A wind turbine is a machine which converts the power in the wind into electricity. This is contrast to a windmill, which is a machine that converts the wind's power into mechanical power. There are two great classes of wind turbines, horizontal- and vertical-axis wind turbines. Conventional wind turbines, horizontal-axis wind turbines (HAWT), spin about a horizontal axis, as the name implies, a vertical-axis wind turbine (VAWT) spins about a vertical axis. Today the most common design of wind turbine and the only kind discussed in this thesis in the view of aerodynamic behaviour is the horizontal-axis wind turbines. In this paper, detail information about the conventional horizontal-axis wind turbines will be given but before that some unconventional and innovative horizontal-axis wind turbine concepts will be mentioned [2].

Internal components of a wind turbine:
a. **Anemometer:** This device is used for measurement of speed. The wind speed is also fed to the controller as it is one of the variables for controlling pitch angle and yaw.
b. **Blades:** These are aerodynamically designed structures such that when wind flows over them they are lifted as in airplane wings. The blades are also slightly turned for greater aerodynamic efficiency.
c. **Brake:** This is either a mechanical, electrical or hydraulic brake used for stopping the turbine in high wind conditions.

d. **Controller:** This is the most important part of the turbine as it controls everything from power output to pitch angle. The controller senses wind speed, wind direction, shaft speed and torque at one or more points. Also the temp of generator and power output produced is sensed.
e. **Gear box:** This step-up or steps down the speed of turbine and with suitable coupling transmits rotating mechanical energy at a suitable speed to the generator. Typically a gear box system steps up rotation speed from 50 to 60 rpm to 1200 to 1500 rpm.
f. **Generator:** This can be a synchronous or asynchronous Ac machine producing power at 50Hz.
g. **High-speed shaft:** Its function is to drive the generator.
h. **Low-speed shaft**: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.
i. **Nacelle:** The nacelle is the housing structure for high speed shaft, low speed shaft, gear box, generator, converter equipment etc. It is located atop the tower structure mostly in the shadow of the blades.
j. **Pitch:** This is basically the angle the blades make with the wind. Changing the pitch angle changes weather the blades turn in or turn out of the wind stream.
k. **Rotor:** The hub and the blades together compose the rotor.
l. **Tower:** Towers are basically made up of tubular steel or steel lattice. Taller the towers greater is the amount of power generated as the wind speed generally goes on increasing with height.
m. **Wind direction:** Generally erratic in nature, hence the rotor is made to face into the wind by means of control systems.
n. **Wind vane:** Basically the job of a wind sensor, measuring the wind speed and communicating the same to the yaw drive, so as to turn the turbine into the wind flow direction.
o. **Yaw drive:** This drive controls the orientation of the blades towards the wind. In case the turbine is out of the wind, then the yaw drive rotates the turbine in the wind direction
p. **Yaw motor:** Powers the yaw drive [2].

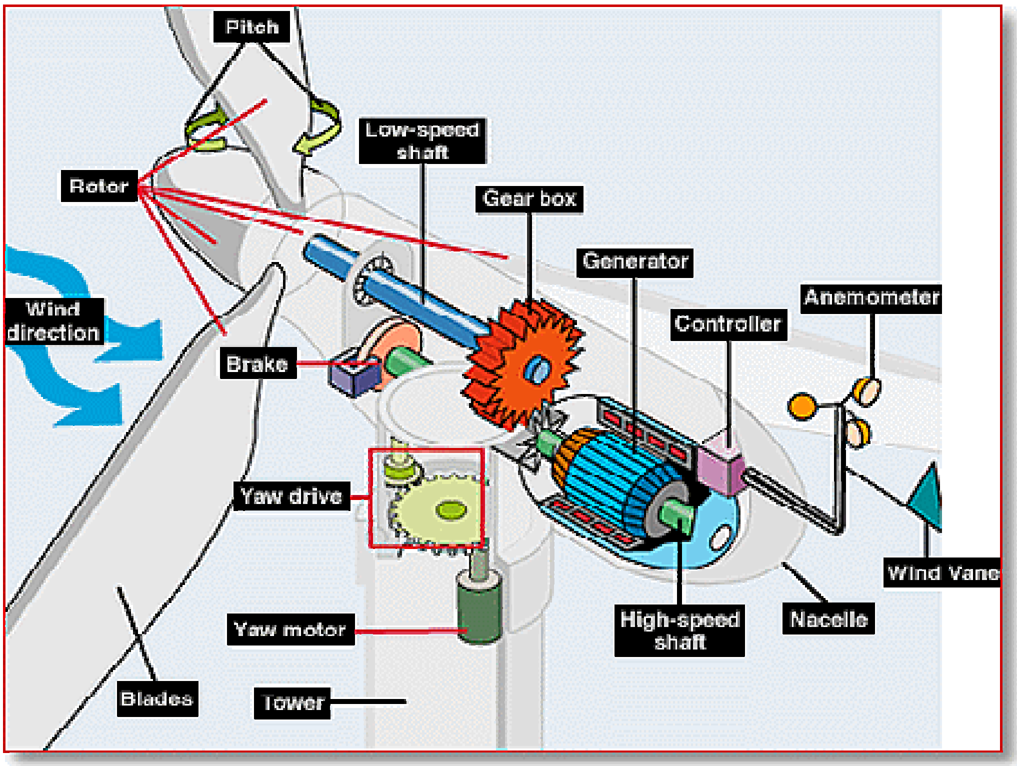


Figure 3(Internal parts of a wind turbine)

Theories of wind energy:
The principles concerned with converting the potential energy of fluids into useful power relies on three basic fundamentals: conservation of mass, energy and momentum, so it is useful to discuss these before examining the operation of wind turbines

Conservation of Mass

The continuity equation applies the principle of conservation of mass to fluid flow. Consider a fluid flowing through a fixed conduit having one inlet and one outlet as shown in figure 4.

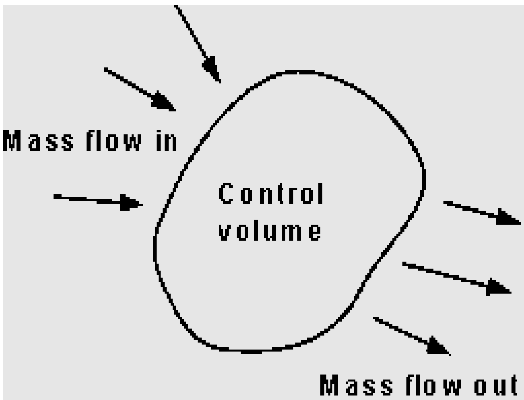
If the flow is steady i.e. no accumulation of fluid in the control volume, then the rate of fluid flow at entry must be equal to the rate of flow of fluid at the exit for mass conservation. If the flow cross-sectional area A (m^2), and the fluid parcel travels a distance dL in time dt then the volume flow rate (V_f, m^3/s) is given by [4]

$$V_f = A.dL/dt$$

But since dL/dt is the fluid velocity (V, m/s) we can write V_f=V.A

The mass flow rate (m, kg/s) is given by the product of density and volume flow rate. Between any two points within the control volume, the fluid mass flow rate can be shown to remain constant:

$$\text{or} \quad \rho_1 A_1 V_1 = \rho_2 A_2 V_2 \qquad (1)$$



Conservation of Energy

Conservation of energy necessitates that the total energy of the fluid remains constant, however, there can be transformation from one form to another.

There are three forms of non-thermal energy for a fluid at any given point:-

a. The kinetic energy due to the motion of the fluid.
b. The potential energy due to positional elevation above datum
c. The pressure energy, due to absolute pressure of the fluid at that point.

If all the terms are written in the form of head, i.e. in metres of fluid, then conservation energy principle also known as Bernoullis equation gives

$$\frac{1}{2}\rho v^2 + \rho g z + p = \text{Constant} \qquad (2)$$

The above equation holds true for two bodies close to each other and neglects losses.

Conservation of Momentum

Consider a dust of length L, cross-sectional area A_c, surface area A_s, in which a fluid of density ρ**,** is flowing at mean velocity V. the forces acting on a segment of the dust are that due to pressure difference and that due to friction at the walls in contact with the fluid.

If the acceleration of the fluid is zero, the net forces acting on the element must be zero, hence

$$(P_1 - P_2).A_C - (f\rho V^2/2).A_s = 0$$

or $P_1 - P_2 = \rho g h_f$

where $h_f = f.(A_s/A_f).V^2/2g$

Also for a pipe $A_s/A_f = 4L/D$

Hence $h_f = (4fL/D).V^2/2g$ (3)

This is known as Darcy formula.

The value of friction factor (f) depends mainly on two parameters namely Reynolds number and surface roughness. and Reynolds number $R_e = \rho VD/\mu$

Power of wind turbine:
A windmill extracts power from the wind by slowing down the wind. At stand still, the rotor obviously produces no power, and at very high rotational speed the air is more or less blocked by the rotor, and again no power is produced. The power produced (P) by the wind turbines is the net kinetic energy change across the wind turbine (from initial air velocity V_1 to a turbine exit air velocity of V_2) is given as:

$$P = (1/2)m[V_1^2 - V_2^2]$$

The mass flow rate of wind is given by the continuity equation as the product of density, area swept by the turbine rotor and the approach air velocity as:

$$m = \rho A V_a$$

hence the power becomes

$$P = (1/2).\rho.A.V_a[V_1^2 - V_2^2]$$

Since the rotor speed is the average speed (V_a) between inlet and outlet

$$V_a = (1/2).[V_1 + V_2]$$

Hence power is

$$P = (1/2).\rho.A.[(V_1 + V_2)/2].[V_1^2 - V_2^2] = (1/4).\rho.A.(V_1^3).[1 - (V_2/V_1)^3 - (V_2/V_1)^2 + (V_2/V_1) \quad (4)$$

To find the maximum power extracted by the rotor, differentiate above equation with respect to V_2 and equate it to zero

$$dP/dV_2 = (1/4).\rho.A.[(-3.V_2^2) - (2.V_1.V_2) + (V_1^2)] = 0$$

Since the area of the rotor (A) and the density of the air cannot be zero, the expression in the bracket of above equation has to be zero. Hence the quadratic equation becomes:

$(3V_2 - V_1)(V_2 + V_1) = 0$

Also $V_2 = -V_1$ is unrealistic solution so above equation yields

$V_2=(1/3)V_1$

Substitution of above result in equation 4

$$P = (0.5925).(1/2).[\rho.AV_1^{\,3}]$$

A wind turbine can only extract part of the power from the wind, which is limited by the Betz limit (i.e. .5925 or a maximum of 59%). This fraction is described by the power coefficient of the turbine, C_p, which is a function of the blade pitch angle and the tip speed ratio. Therefore the mechanical power of the wind turbine extracted from the wind is

$$P = (1/2).[C_p(\beta,\lambda)].[\rho.AV_1^{\,3}]$$

Where C_p, is the power coefficient of the wind turbine, β is the blade pitch angle and λ is the tip speed ratio. The tip speed ratio is defined as the ratio between the blade tip speed and the wind speed V_1.

The theoretical maximum fraction of the power in the wind which could be extracted by an ideal windmill is, therefore the fraction 0.5925 is called Betz Coefficient. Because of aerodynamic imperfections in any practical machine and of mechanical losses, the power extracted is less than that calculated above. Efficient wind turbines depend on the production of that optimum speed ratio giving maximum or near the maximum power possible [4].

The formula clearly specifies that:
a. The power is proportional to the density of air (ρ) which varies slightly with altitude and temperature.
b. The power is proportional to the area (A) swept by the blades and thus to the square of the radius of the rotor.
c. The power varies with the cube f the wind speed (V^3). This means that power increases eight fold when the wind speed is doubled. Hence, one has to pay particular attention in site selection [5].

Diameter of the rotor [5]:
Since the power generated is directly proportional to the square of the diameter of the rotor, it becomes a valuable parameter. It's basically determined by the relation between the optimum power required to be generated and the mean wind speed of the area.

Power generated,

$P= \eta_e\eta_m C_p P_0$

$=1/2\eta_e\eta_m C_p\, A\rho V_\infty^{\,3}$ where, η_e= efficiency of electrical generation
$=1/8\eta_e\eta_m C_p\pi\, \rho V_\infty^{\,3}D^2$ η_m= efficiency of mechanical transmission

In the absence of concrete data, the following empirical formulae can be used:

$P=0.15\, V_\infty^{\,3}D^2$, for slow rotors
$=0.20\, V_\infty^{\,3}D^2$, for faster rotors

Choice of the number of blades:
The choice of the number of blades of a wind rotor is critical to its construction as well as operation. Greater number of blades is known to create turbulence in the system, and a lesser number wouldn't be capable enough to capture the optimum amount of wind energy. Hence the number of blades should be determined by both these constraints and after proper study of its dependence. Now, let $\mathbf{t_a}$ be the time taken by one blade to move into the position previously occupied by the previous blade, so for an n-bladed rotor rotating at an angular velocity, **ω** we have the following relation:

$t_a=2\pi/n\omega$

Again let $\mathbf{t_b}$ be the time taken by the disturbed wind, generated by the interference of the blades to move away and normal air to be established. Now this will basically depend on the wind speed, on how fast or how slow the wind flow is. Hence it depends on the wind speed V & the length of the strongly perturbed wind stream, say d, here we have:

$t_b = d/V$

For maximum power extraction, t_a& t_b should be equal, hence
$t_a = t_b$

Hence: $2\pi/n\omega = d/V$
$d = 2\pi V/n\omega$
d, has to be determined empirically.

Choice of the pitch angle:
The pitch angle is given by
α=I-i (where I is the angle between the speed of the wind stream and the speed of the blades and "i" is a constant.)

Now as I varies along the length of the blade, α, should also vary to ensure an optimal angle of incidence at all points of the blade. Thus the desirable twist along the blade can be calculated easily. This method yields a twisted blade which basically has different pitch angles at different distances from the axis [5].

Tip speed ratio
The tip speed ratio (TSR) of a wind turbine is defined as,

$\lambda = 2\pi RN/V_\infty$

where, V_∞ = Speed of Wind without any rotor intervention
R=Radius of the Rotor, which signifies the swept area
N=Rotational speed of the rotor in rps
λ = Tip Speed Ratio

The tip speed ratio (λ) for wind turbines is the ratio between the rotational speed of the tip of a blade and the actual velocity of the wind .It's basically non dimensional in nature and high efficiency 3-blade-turbines have tip speed ratios of 6–7.

Coefficient of power
The coefficient of power (C_p) of a wind turbine basically signifies the conversion efficiency of the wind energy of the wind into mechanical energy, which in turn is used to drive the generators. It differs from the overall system efficiency as it doesn't include the losses in transmission (mechanical) and in electrical power generation. In horizontal axis machines the theoretical limit is known as Betz limit, which is around .593

Torque speed characteristics
Now we know that the Torque and power curves are related as follows:

$T_m = P_m/\omega;$

Using the above value for $P_m = 0.5C_p\,\pi\,(R^5/\lambda^3)\,\omega^3\rho;$
We have, $T_m = P_m/\omega;$

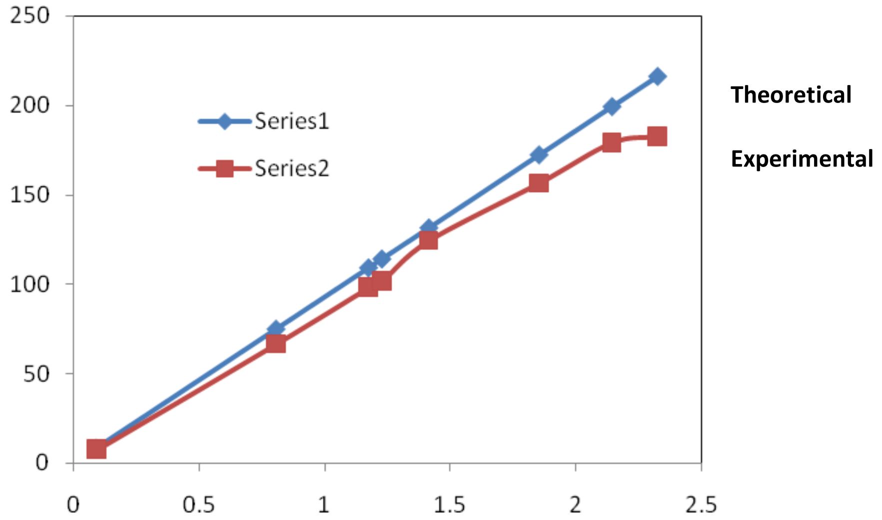
$T_m = 0.5C_p\,\pi\,(R^5/\lambda^3)\,\omega^2\rho$

RESULTS AND DISCUSSION

1 Graph and table between density of medium and power output

Table: density versus power

S.No	Medium	Density(kg/m^3)	Theoretical power generated(Kw)	Experimental power generated(Kw)
1.	Hydrogen	0.0899	8.362	7.47
2.	Steam	0.804	74.79	66.6
3.	Nitrogen	1.172	109.022	98.1
4.	Air	1.225	113.952	101.7
5.	Oxygen	1.412	131.34	124.45
6.	Carbon di-oxide	1.85	172.09	156.52
7.	Ozone	2.14	199.068	179.1
8.	Sulphur di-oxide	2.321	215.905	182.75

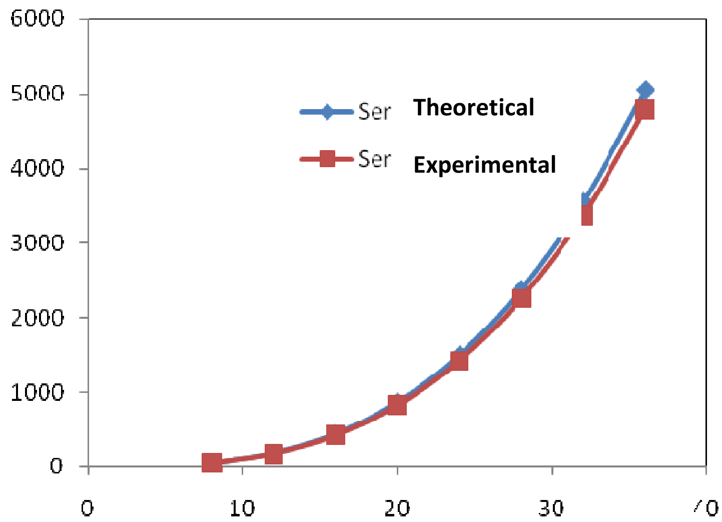


Taking variable densities of different mediums and considering wind speed of 10m/s for a rotor of radius 10m.

2 Graph and table between wind speed and power output

Table: density versus power

Sno.	Wind speed(m/s)	Theoretical power generated(Kw)	Experimental power generated(Kw)
1.	8	55.389	52.25
2.	12	186.93	176.7
3.	16	443.116	420
4.	20	865.46	821
5.	24	1495.51	1420
6.	28	2374.829	2255
7.	32	3544.93	3366
8.	36	5047.37	4794

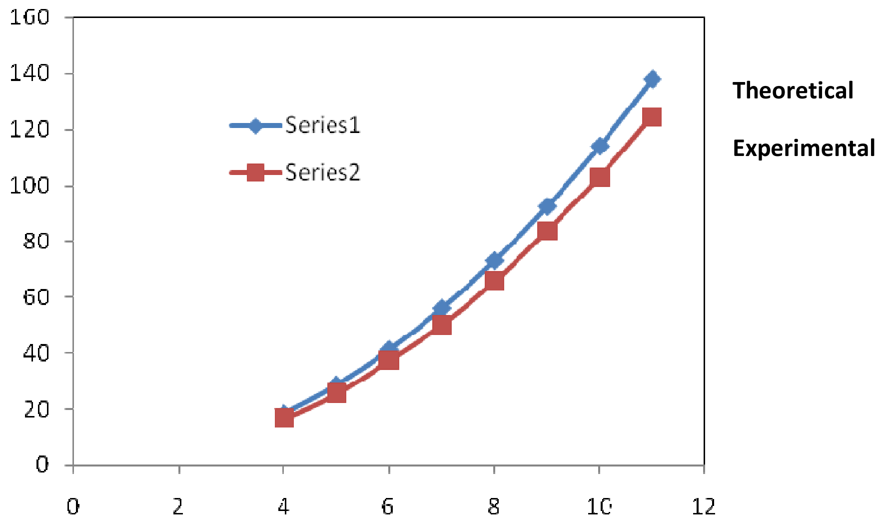


Taking variable wind speeds at a place and considering rotor of radius 10m and air as medium of operation.

3. Graph and table between rotor radius and power output:

Table: density versus power

Sno	Rotor radius(m)	Theoretical power generated(KW)	Experimental power generated(KW)
1.	4	18.232	16.38
2.	5	28.488	25.48
3.	6	41.022	37.31
4.	7	55.836	50.05
5.	8	72.929	65.52
6.	9	92.301	83.72
7.	10	113.952	102.83
8.	11	137.882	124.67



Taking variable rotor radius and considering wind speed of 10m/s with air as medium of operation.

CONCLUSION

The potential of wind power generation is immense, a historical source of energy, wind can be used both as a source of electricity and for irrigation and agricultural uses. In today's world, where a greener source of energy is the need of the hour, wind energy is a promising resource, waiting to be harnessed to its true potential. The study of wind turbine and its characteristics showed that how it can be properly designed and used to get the maximum output, even with the variable wind speeds. The development of offshore wind farms, which have both a better energy density and lesser interference with the local systems, is a definite step forward in realization of the wind potential. The Indian scenario is agog with Suzlon making rapid strides, and a lot of multinationals investing heavily. The analysis of different sites in the country shows how the wind energy density varies from place to place.

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