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WIND ENERGY & ITS OPTIMISATION

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ABSTRACT

At present the major challenge for the world is to produce energy that is sustainable. We have been dependent upon the non-clean or non-renewable sources of energy from quite a long period of time which has created havoc into the environment. Now, we need to shift to renewable sources of energy (wind, solar, etc.).

Wind energy is free but requires some science to get implemented. The major problem in obtaining energy from the wind turbine is the cost of construction which needs to be optimized. The essential part of the whole system are the blades of the wind turbine which requires a deep understanding of physics and math in its designing and simulation. The energy obtained from the turbine is based on Bernoulli's principle of lift force. The turbine we have constructed as our final year project works on the principle of thrust force which is simple in design and construction but less efficient than the prior one. Wind energy can not only be used for electricity generation but can also be used for grinding mills, water pumps, etc. It has been used since long period of time but now with the help of technology and science it is also being used to generate electric energy around the world.

Keywords: *COP (Coefficient of Performance), Optimum pressure (Popt), flash intercooler.*

I. INTRODUCTION

Wind energy is the cleanest form of energy still wind and solar energy simultaneously contribute to less than 2 percent of the total energy of the world. Still lot of research and development are going around the world to optimize the whole system and make it feasible. Generally there are two types of turbine one is vertical axis (Darrieus rotor) and second is horizontal axis wind turbine. Generally, horizontal axis turbines are used to produce power.

Types of wind turbine, the structural design, materials, forces, airfoil design, maximum efficiency, etc. have been presented in the paper. These are the major factors responsible for the design and development of the blades of the turbine.

There are several methods of increasing the efficiency of the wind blades to obtain maximum power from it.

Failure theories of blades plays an important role in preventing the failure of blades from breaking apart that is also done through finite element analysis. The blades are designed on the same concept as the blade of an airplane and the working principle is almost the same, the only difference is that the blade of turbine is rotating and the blade of aircraft is stationary which provides the lift force to the plane.

A. Types of wind turbines:

1. Horizontal axis wind turbine

This is the most commonly used turbine nowadays. These have generally three blades, each are about 90-100 feet long and with varying width. The wind turbine is as tall as 20 story building which makes its assembling a bit difficult.

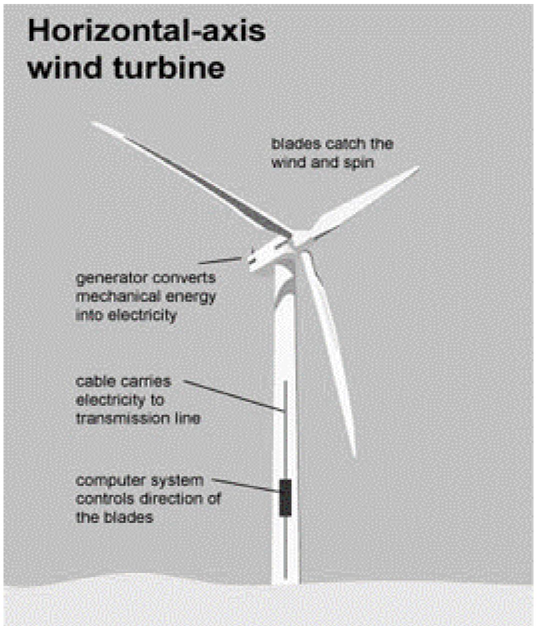

Figure 1 horizontal axis wind turbine

2. Vertical axis wind turbine

It has blades attached to the top and bottom of the vertical rotor. It works on the principle of thrust force. It is also called the Darrieus wind turbine named after the French engineer George Darrieus. They are as tall as 100 feet and 50 feet wide. They have become obsolete because they are not as efficient as the horizontal axis wind turbines.

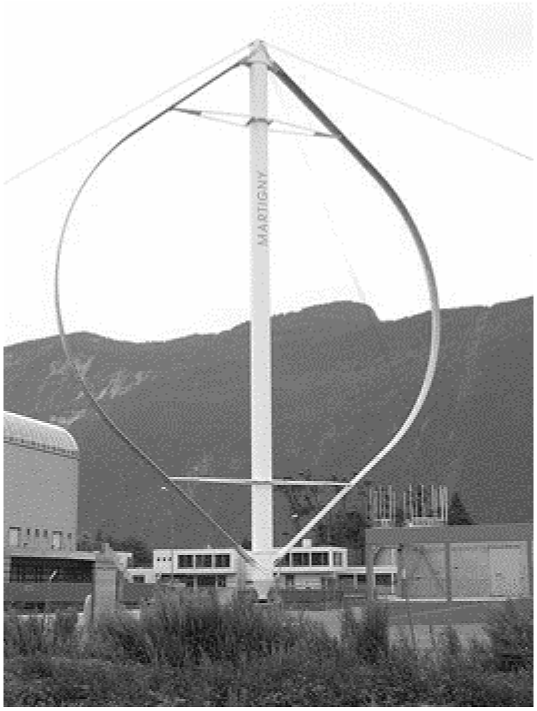

Figure 2 vertical axis wind turbine

B. Basic concept of wind turbine

Wind turbine converts rotational energy into electrical energy through blades that rotate through lift force provided on each blades. The power produced by the blades is given by:

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

ρ : Density of air
A: Swept area
V: Velocity of wind
C_P: Coefficient of power

Betz limit on power coefficient

$C_P \leq \frac{16}{27} \sim 59\%$

Derived from 1D momentum theory without considering the rotational effects.

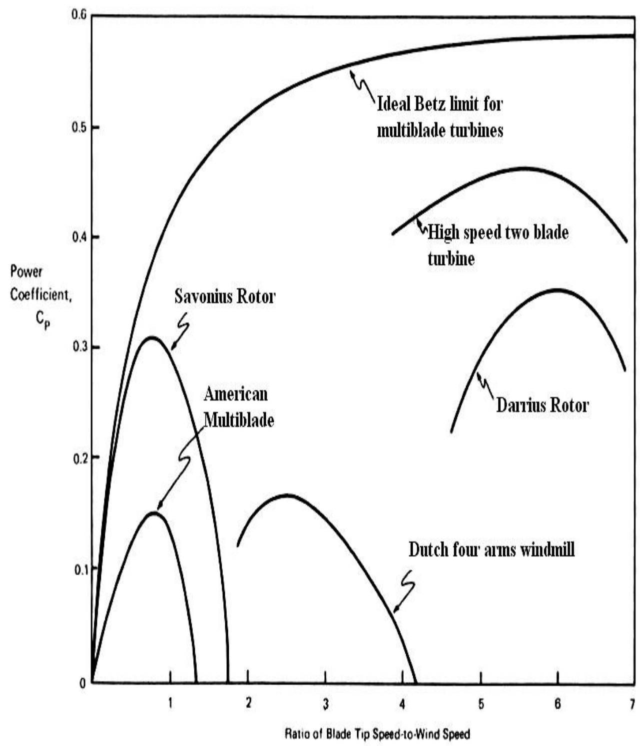

Figure 3 power coefficient vs tip speed ratio

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C. The structural design

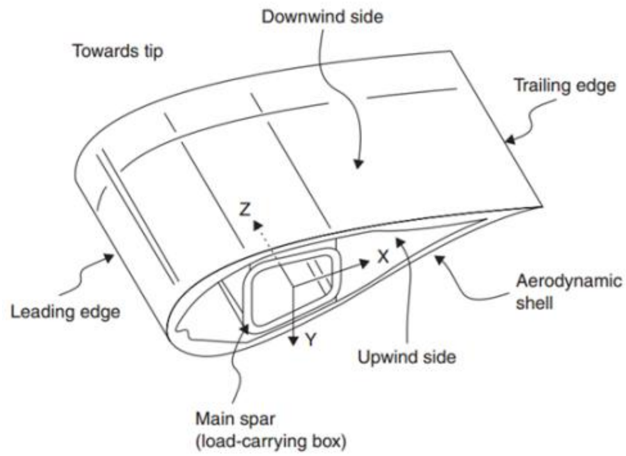

Figure 4 wind blade structure

Blades are compromise between aerodynamic and structure requirement. From aerodynamic point of view we want thin foil but from structural point we want thick foil to sustain heavy loads.

Flapwise load is taken by the box made into the blades and the edgewise load that comes mainly due to gravity is taken by strengthening the leading edge and trailing edge.

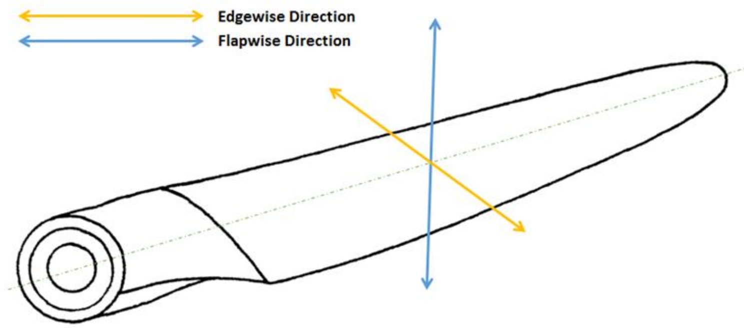

Figure 5 edgewise and flapwise

The blades are strongest in flapwise direction and weakest in edgewise direction towards the trailing edge.
The blades are designed such the load is within critical load, and value of loads are higher in flapwise direction than in edgewise direction.

When testing is done on the blade it is found that the blade fails along trailing edge. Critical point of the blade is trailing edge and it fits correctly with the result of finite element analysis done on the blades.

D. Working of wind blade

The blade rotates by the lift provided by the wind flowing across the blades. When the air flows over the foil, the pressure decreases above the foil and increases below the foil simultaneously which creates a pressure difference across the blades generating a lift force for the blade and cause the rotation.

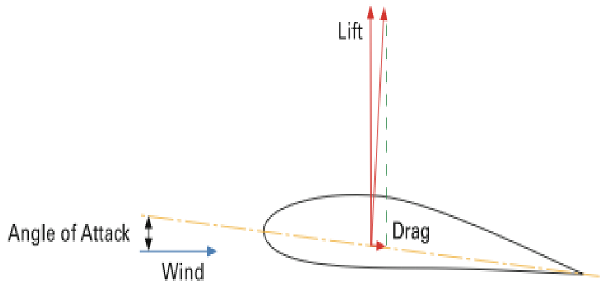

Figure 6 forces on a blade

The upper chamber is more pronounced than the lower chamber. The yellow line passing from the leading edge (round) to trailing edge (narrow and tapered) is called chord line above which is the mean chord line which divides the blades in equal upper and lower surfaces.

The angle of attack is the angle between the chord line and the flow of air along the leading edge of the wing. This angle varies along the blade to obtain the maximum power throughout the rotation.

Tip speed ratio (TSR)
It is the ratio of the rotating tip of blade to the free steam velocity of wind.

$$TSR = \frac{\omega R}{U}$$

ωR: Rotational speed in m/s
U: Wind free stream velocity

Generally, ≤ 3 blades are used in the wind turbine, this is because higher the no. of blades higher the blockage of flow. In the limit of infinite blades the rotor would be a solid disc with no air going through.

Similarly, there is a limit to the rotational speed of wind, higher the rotation of speed higher the blockage of the wind. A wind turbine rotating faster does not necessarily produce more power.

TSR defines the velocity at which optimum power is produced. TSR tells how fast the blade is moving with respect to the wind.

E. Blade Pitch Control

The pitch control rotates the turbine blades around the blade central line whenever wind speed changes. The airplane wings and wind turbine blades works on the same aerodynamic principle called lift but, the airplane wings are straight and turbine wings are twisted. This is because the pitch control mechanism keep the rotation speed of turbine constant for changing wind speed. This is necessary to keep the rpm of generator constant. If there were no pitch control, the rotation speed of turbine would change with change in wind speed.

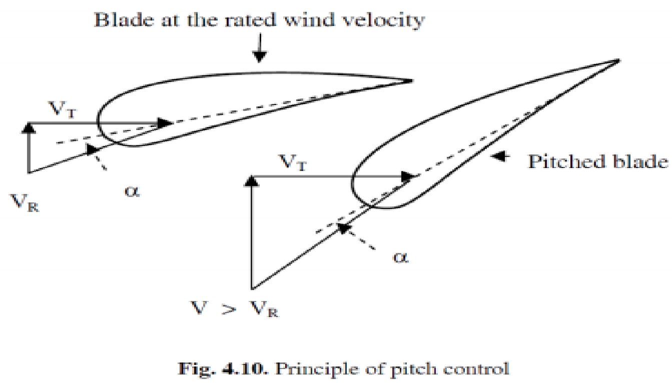

Figure 7 pitch control

F. Blade Materials

The key material requirements are:

- High stiffness
- High fatigue resistance (strength)

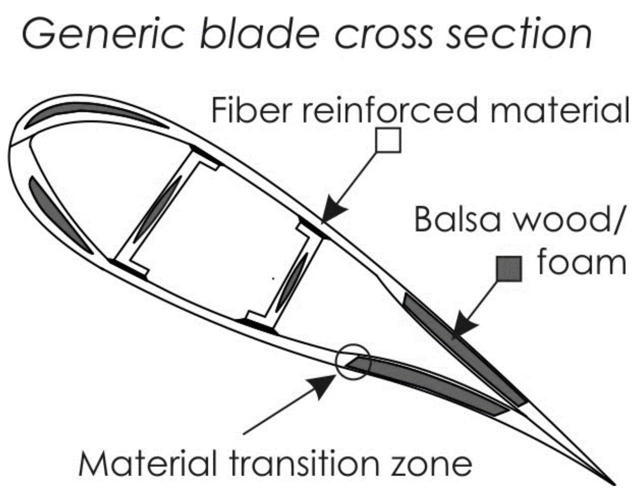

Figure 8 materials used for blade parts

The materials used also depend upon the size of wind turbine and amount of power to be produced. Generally, the turbines used today uses glassfibre-reinforced-plastic to produce the rotor blades. Steel is also used to manufacture the shaft of the rotor. Composites and woods also used for several parts. Blades are manufactures by fiber-reinforced epoxy or unsaturated polyester. Nacelle (housing of gearbox, generator and other components) and the hub are also made up of polyester.

The materials used are costly which makes the whole system less economical, but once it is set up it can produce electricity for around 20-25 years without polluting the environment. Over years some components may require replacement.

The blade material should withstand the large fatigue stresses and moments during the operation of the turbine which requires proper finishing of the blade and less notches in the design.

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G. Forces in a blade

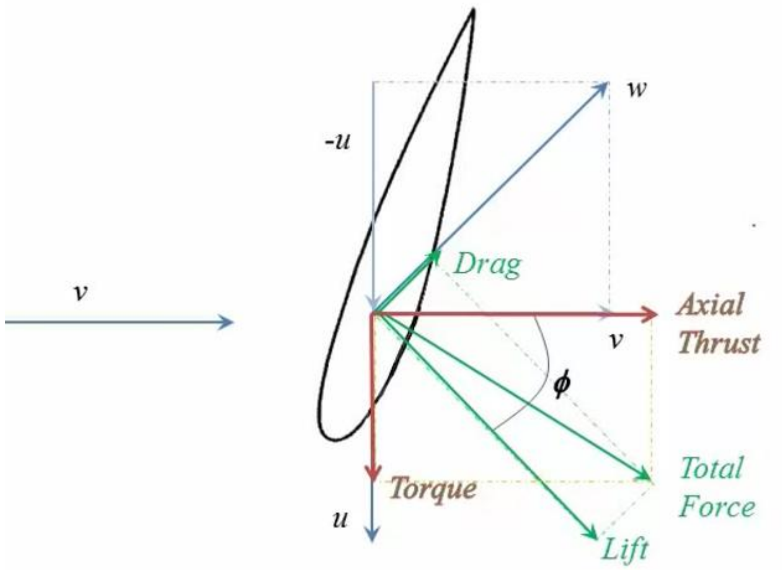
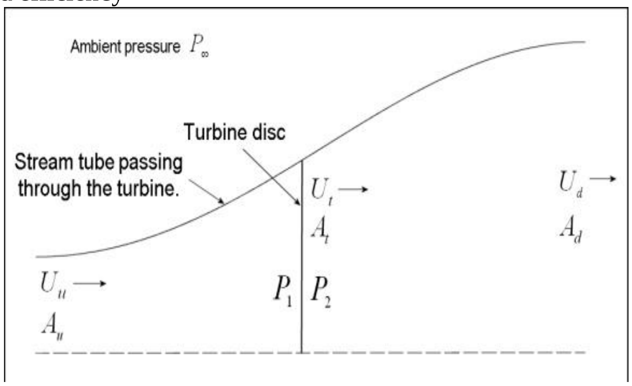


Figure 9 forces on a blade

The velocity of wind 'v' coming from left, 'u' is the velocity of the blade straight down, combining both we get the relative velocity 'w' that the wind turbine is experiencing.

Perpendicular to 'w' is the lift force and parallel to it is the drag force. The resultant of two forces gives the total force on the blade which will have two components in both 'u' and 'v' directions. One is torque causing the rotation of the wind turbine and the other is axial thrust which bends the blade towards the tower.
φ is the angle between thrust force and lift force of the blade.

H. Maximum power and efficiency



Considering a disc in between the upstream and downstream flow of the turbine. By applying continuity equation and Bernoulli's principle we can calculate the optimum power.

U_u: Upstream velocity
A_u: Upstream area
U_d: Downstream velocity
A_d: Downstream area
P_1: Pressure downstream of actual disc
P_2: Pressure upstream of actual disc
U_t: Velocity through disc
A_t: Area of disc
Due to continuity
$A_U U_u = A_t U_t = A_d U_d$
Force on turbine results in change in momentum:
$F = \dot{m} \times \Delta v$
$(P_1 - P_2)A_t = \rho A_u U_u \times (U_u - U_d)$
We can find $P_1 - P_2$ *at upstream and downstream by continuity equation.*
Applying Bernoulli's equation upstream and downstream:

$$P_1 - P_2 = \frac{1}{2}\rho(U_u^2 - U_d^2)$$

Equating the both pressure difference we get:

$$U_t = \frac{1}{2} \times (U_u + U_d)$$

Assuming $U_t = U_u$

$$power\ in = \frac{1}{2}\rho A_t U_u^3$$

$$power\ out = \frac{1}{2}\rho A_t U_u^3 (1 - \frac{U_d^2}{U_u^2})(1 + \frac{U_d}{U_u})$$

Efficiency=$\frac{power\ \ output}{power\ \ input}$
Substitute: $b = \frac{U_d}{U_u}$

$$\eta = \frac{1}{2}(-b^3 - b^2 + b + 1)$$

To maximize efficiency put $\frac{d\eta}{db} = 0$
Taking the positive value of $b = \frac{1}{3}$
$\eta = \frac{16}{27} = .593$

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This is the Betz' law for maximum efficiency

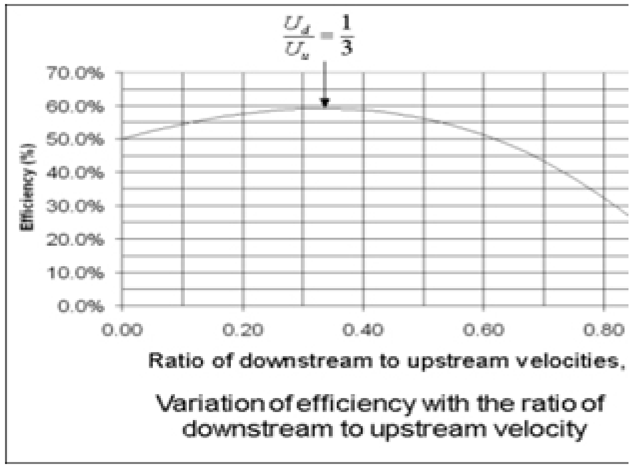
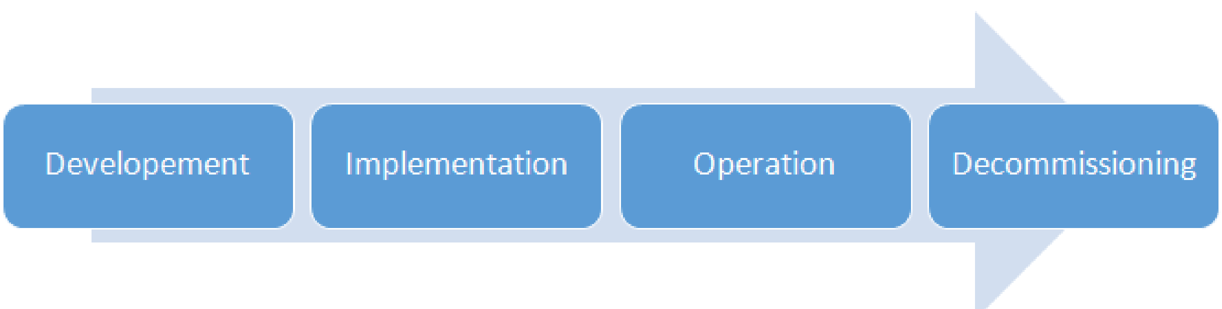


Figure 10 η vs b curve

I. Economics of wind energy

Wind turbines are expensive generating investments and the cost of production of electricity is very much dependent upon the cost of installment.

Wind turbine uses less than 1acre of land and the land is free for animals to graze around.
The initial cost of setup is still very high which prevents the developing countries in investing into the renewable source of energies. China is the leader in the wind energy production around the globe.



Development:
- finding a site
- financing
- wind farm design
- licensing
- site characteristics

Implementation:
- construction

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Operation:
- operation
- maintenance
- surveillance

Decommissioning:
- remove
- replace

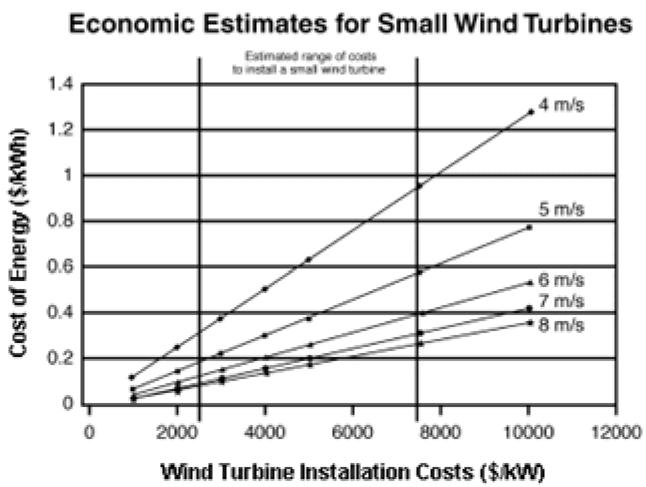

Figure 11 cost analysis of construction of wind turbine

It can be easily observed from the figure that the cost of energy production is proportional to the cost of installation of the wind turbine, but the slopes are different each time.

Slope is maximum when wind speed is minimum and vice-versa.

From the above graph it is clear that construction of wind turbine will prove economical if the site is selected properly where the availability of wind is easy and in abundance.

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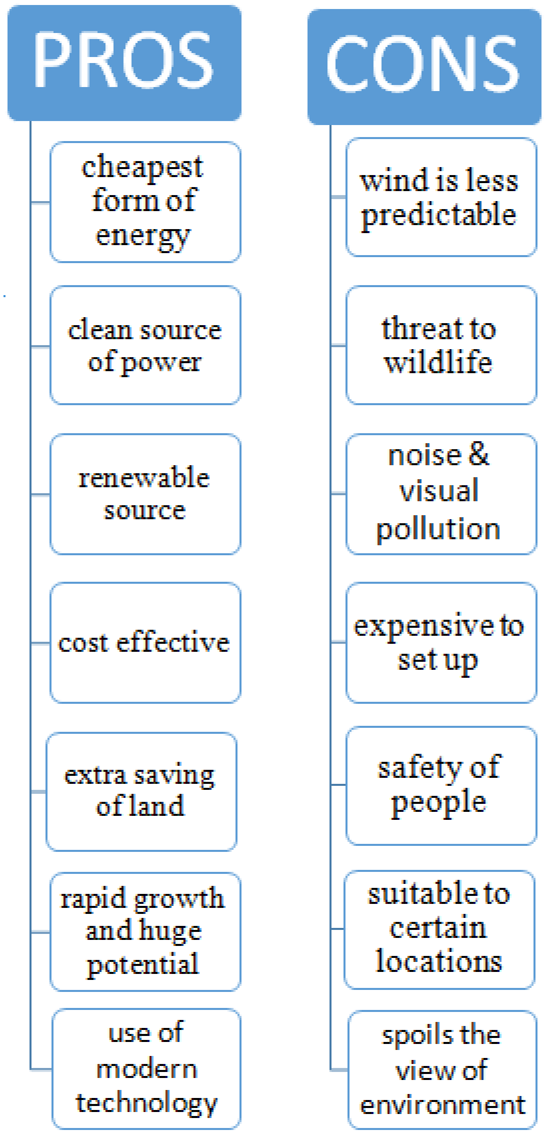
J. Pros & Cons of Wind Turbine:



K. Factors affecting wind turbine performance:

- Blade strength, blade and performance of wind turbine is the major factor. Installation of turbines at high altitude, use of yawing mechanism are used for this purpose
- Economic characteristics of wind power which depends mainly on the wind speed
- Cost of wind power is affected by factors like reliability, efficiency, cost of materials, and geographic location of wind turbine.
- Effect of winter on wind power generation i.e. during winter, in some locations, wind speed increases which affects wind power production. The wind speed fluctuates over the year which affects the power generation.
- Wind power production tax credits, subsidies and rebates.

Production tax credit is a government policy under which government pays fraction of cost to generate electricity. Subsidies aim to lower the upfront cost of electricity to the end user to encourage more to purchase it, and also to encourage people to construct subsidized power plants.

II. CONCLUSION

Although it is the cleanest form of renewable energy despite that it is not the major source of energy production in any of the countries. Still there are doubts about its economic feasibility and its optimization. Still a lot of research is going all around the world on how to optimize the design of blade and make the system more efficient above the Betz limit. It is as cheap as fossil fuels in some parts of the world.

A lot of research is going on the design of vortex generator which offers a shift from today's traditional design of the turbine. Vortex design uses less material than conventional turbines which makes it less noisy and also less materials are required. So, this could be the future of wind energy production. In the last two decades the wind energy sources had increased and the cost of wind energy has gone down which is good sign for this energy to develop at rapid rate in the coming years.

The renewable energy is not capable of generating large employment opportunities as coal or oil based plants. The reason is simple that is the wind blows naturally and everything is automatic so no manual work is required once the turbine is being installed at the site.

It is believed that over next 20 years the advanced material for airfoils, better control and operating strategies better design will eventually reduce capital costs as well as operational cost

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