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Design Of Wind Turbines

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ABSTRACT

There is huge activity in wind power, pan-India with the installed capacity increasing to 10,000 MW. India today has the fifth largest installed capacity of wind power in the world with 11087MW installed capacity and potential for on-shore capabilities of 65000MW. However the plant load factor (PLF) in wind power generation is very low, often in the single digits. The increase in interest in wind energy is due to investment subsidies, tax holidays, and government action towards renewable energy playing a big part in nation's energy system. There is a need to generate environment friendly power that not only raises energy efficiency and is sustainable too.

The time has come for moving to generation based subsidies and understanding the drawbacks associated with wind power in India. The capital cost of wind power is third higher than conventional thermal power; further electrical problems like voltage flicker and variable frequency affect the implementation of wind farm. However advances in technologies such as offshore construction of wind turbines, advanced control methodologies, and simulation of wind energy affecting overall grid performance are making a case for wind energy.

CHAPTER-1: INTRODUCTION

1.1 Background

The wind turbine first came into being as a horizontal axis windmill for mechanical power generation, used since 1000 AD in Persia, Tibet and China. Transfer of mechanical windmill technology from the Middle East to Europe took place between 1100 and 1300, followed by further development of the technology in Europe. During the 19th century many tens of thousands of modem windmills with rotors of 25 meters in diameter were operated in France, Germany and the Netherlands, most of the mechanical power used in industry was based on wind energy. Further diffusion of mechanical windmill technology to the United States took place during the 19th Century.

The earliest recorded (traditional) windmill dates from the year 1191 at the Abbey of Bury St Edmunds in Suffolk. It replaced animal power for grinding grain and other farm activities like drawing water from well, the popularity of wind turbines increased tremendously and they soon dotted the landscape.is witnessed on the tops of hills andmountains than in low level areas. Even more locally, wind velocities are altered by obstacles such as trees or buildings. For any location there is variation of wind pattern, wind speed may vary from year to year, also wind distribution will change from decade to decade. These long-term variations are not well understood, and thus make it difficult to make predictions of the economic viability of wind-farm projects. Wind distribution is more predictable over shorter time spans like a year, but on shorter time frame like few days the wind energy is difficult to predict. These variations are due to the weather systems. Depending on location, there may also be considerable variations with the time of day (diurnal variations), which are fairly predictable. These variations are important to be considered because they can affect production of large scale wind energy and consequent integration into grid, also associated power generation systems must be prepared for these variations. Also we must take into account the fact that short term turbulence cause variations in the quality of power delivered.

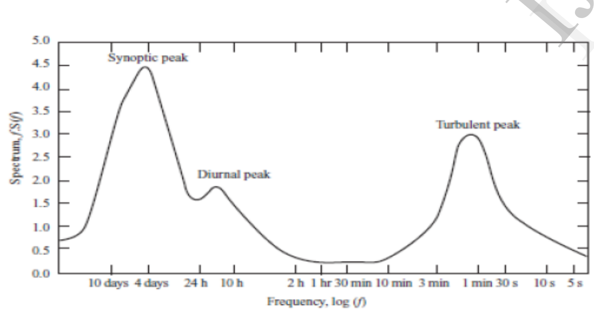

Figure 1 : Van der Hoven Wind Spectrum Curve

Van der Hoven (1957) created a wind-speed spectrum from long- and short-term records at Brookhaven, New York, showing clear peaks corresponding to the synoptic, diurnal and turbulent effects referred to above. The 'spectral gap' between the diurnal and turbulent peaks shows that these variations can be treated quite distinct from the higher-frequency fluctuations of turbulence.

Major factors that have accelerated the wind-power technology development are as follows:

1. Development of high-strength fiber composites for constructing large low-cost blades.
2. Reduction in prices of the power electronics components such as converters.
3. Variable-speed operation of electrical generators to capture maximum energy.
4. Improved plant operation, pushing the availability up to 95 percent.
5. Economy of scale, as the turbines and plants are getting larger in size.
6. Accumulated field experience (the learning curve effect) improving the capacity factor.

The total power generating capacity has grown to about 11087MW as of March 2010 thus placing India at fifth place in terms of installed capacity.

1.3 Power in a wind stream

A wind stream has total power given by $P_t = m.(K.E._w) = 0.5m.V_i^2$

Where, m = mass flow rate of air, kg/s

V_i = incoming wind velocity, m/s

Air mass flow rate is given by

$m = \dot{\rho} A V_i$

Where, $\dot{\rho}$= Density of incoming wind, kg/m^2 = 1.226 kg/m^2 at 1 atm, 15^oC

A = Cross-sectional area of wind stream, m^2

Substituting the above and accounting for the constants, we arrive at the following:

$P_W = 0.5\rho\pi R^3 V_w^3 C_P(\lambda,\beta)$

Where,

P_w = extracted power from the wind,

ρ= air density, (approximately 1.2 kg/m^3 at 20¤ C at sea level)

R = blade radius (in m), (it varies between 40-60 m)

V_w = wind velocity (m/s) (velocity can be controlled between 3 to 30 m/s)

Cp = the power coefficient which is a function of both tip speed ratio (λ), and blade pitch angle, (β) (deg.)

Power coefficient (Cp) is defined as the ratio of the output power produced to the power available in the wind.

1.4 Betz Limit

Betz limit is the theoretical limit assigned to efficiency of a wind turbine. It states that no turbine can convert more than 59.3 % of wind kinetic energy into shaft mechanical energy. Thus the value of Cp is limited to Betz limit. For a well designed turbine the efficiency lies in the range of 35-45 %.

1.5 Capacity Factor

Capacity factor is a term used to denote the utilization rate of a wind turbine or any power generating source for that matter. It is the ratio between power produced to the power that could have been produced if the generation source operated at 100% efficiency.

Capacity Factor = Actual amount of power produced over time / Power that would have been produced if turbine operated at maximum output 100% of the time

A conventional plant utilizing fossil fuels will naturally have a larger capacity factor as it is a continuous process. If the plant is laid idle or under maintenance then only will the capacity factor drop down.

For a Wind turbine however it is more of a question of the availability of the wind, as the wind is random in speed and direction, therefore a wind turbine may not always operate at maximum output condition. Also there lies a cut-in and furl in speed which means the turbine only acts within a specific window. The capacity factor of turbines is typically low around 40 %.

Also, for a fuel powered plant capacity factor denotes the reliability of the plant, but in case of wind turbines it encompasses the design aspects of wind turbines. Due to randomness in wind turbines, there exist two options of lower generator rating with higher capacity ratio or higher generator rating with lower capacity ratio. Generally the last option is preferred because of higher electricity produced per rupee invested.

CHAPTER-2: WIND TURBINE

2.1 Wind Turbines

A wind turbine is a rotating machine which converts the wind kinetic energy into mechanical energy. If the mechanical energy is then converted to electricity, the machine is called a wind generator, wind turbine.

Wind turbines can be separated into two types based by the axis in which the turbine rotates as Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines. The former are more commonly used due to several inherent advantages, the latter being used in small scale.

Figure 2: Horizontal Axis Wind Turbine

2.2 Wind Turbine Generator units

Turbine subsystems include:

•Rotors which convert wind energy into mechanical energy of the shaft

•Nacelle (enclosure) which contains all the conversion equipment, generator ,gear shaft etc.

•Tower, to increase the height of the turbine systems so that higher wind speeds are captured.

• Control equipment, Cables and other Civil works.

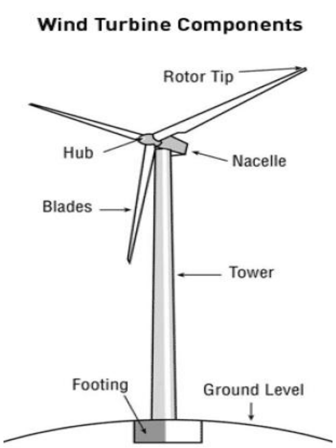

Fig 3: HAWT Components

2.2.1 Horizontal Axis Wind Turbines (HAWTs)

Horizontal-axis wind turbines (HAWT) get their name from the fact that their axis of rotation is horizontal. They have the main rotor shaft and electrical generator at the top of a tower, and are pointed into the wind. The variability of wind distribution and speed brings up the requirement of a gear system connected to the rotor and the generator. The gear system enables a constant speed of rotation to the generator thus enabling constant frequency generation. Turbine blades are made stiff in order to prevent the blades from being pushed into the tower by high winds. Downwind machines have also been built, as they no longer require a yaw mechanism to keep them facing the wind, and also because in high winds the blades can turn out of the wind thereby increasing drag and coming to a stop. Most of the HAWTs' are upwind as downwind systems cause regular turbulence which may lead to fatigue.

HAWT advantages

• Variable blade pitch, which gives the turbine blades the optimum angle of attack.
Changing the angle of attack provides greater control over power generated and enables maximum efficiency.

• As wind energy increases with height, the tall tower in the HAWT gives access to higher wind speed. In some cases increase of even 10m height leads to increase in wind speed by 20 %

•In HAWTs' the blades move horizontally that is perpendicular to the wind and hence have minimum drag and they receive power throughout the rotation.

HAWT disadvantages

•Due to inherent large structures, construction costs are very high and so are transportation costs.

•Civil construction is costly due to erection of large towers.

•Wind turbine operation often leads to production of electronic noise which affects radar sites.

• In case of downwind HAWTs' the regular turbulence produced leads to structural failure.

• HAWTs require an additional yaw control mechanism to turn the blades toward the wind.

2.2.2 Types of HAWTs:

 Mono-Blade Horizontal Axis Wind Turbine (HAWT)

Features:

1. They have lighter rotor and are cheaper.
2. Blade are 15-25 m long and are made up of metal, glass reinforced plastics, laminated wood, composite carbon fiber/ fiberglass etc.
3. Power generation is within the range 15 kW to 50 kW and service life of plant is 30 years.

Advantages:

1. Simple and lighter construction.
2. Favorable price
3. Easy to install and maintain.

Disadvantages:

1. Tethering control necessary for higher loads.
2. Not suitable for higher power ratings.

Applications:

1. Field irrigation
2. Sea-Water desalination Plants
3. Electric power supply for farms and remote loads.

 Twin-Blade HAWT

1. They have large sizes and power output in range of 1 MW, 2 MW and 3MW.
2. These high power units feed directly to the distribution network.

 3-Blade HAWT

1. 3 blade propeller type wind turbines have been installed in India as well as abroad.
2. The rotor has three blades assembled on a hub. The blade tips have a pitch control of 0 – 30 for controlling shaft speed.
3. The shaft is mounted on bearings.
4. The gear chain changes the speed from turbine shaft to generator shaft.

2.2.3 Vertical axis Wind Turbines

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically as the plane of rotation is vertical. Blades are also vertical in this arrangement. The biggest advantage of VAWTs is they don't require a yaw control mechanism to be pointed into the wind. Thus these are useful in sites where wind direction is random or there is presence of large obstacles like trees, houses etc. Also VAWTs' don't require a tower structure and can be placed nearby a ground enabling access to electrical components. Some drawbacks are the low efficiency of wind production and the fact that large drag is created for rotating the blades in a vertical axis.

VAWT advantages

• A massive tower structure is not required, as VAWTs' are mounted closer to the ground

• They don't require yaw mechanisms.

• These are located closer to the ground and hence easier to maintain.

• These have lower startup speeds than their horizontal counterparts. These can start at speeds as low as 10Kmph.

• These have a lower noise signature.

VAWT disadvantages

•VAWTs' have lower efficiency as compared to HAWTs' because of the additional drag produced due to rotation of blades.

• Even though VAWTs' are located closer to the ground, the equipment now resides at the bottom of the turbines structure thus making it inaccessible.

•Because of their low height they cannot capture the wind energy stored in higher altitudes.

2.2.4 Types of VAWTs

 Persian Windmill:

1. The Persian windmill was the earliest windmill installed. (7th Century A.D. – 13th Century A.D. in Persia, Afghanistan, and China)

2. It is a vertical axis windmill.

3. This windmill was used to grind grains and make flour.

 Savonius Rotor VAWT:

1. Patented by S.J. Savonius in 1929.

2. It is used to measure wind current.

3. Efficiency is 31%.

4. It is Omni-directional and is therefore useful for places where wind changes direction frequently.

 Darrieus Rotor VAWT:

1. It consists of 2 or 3 convex blades with airfoil cross-section.

2. The blades are mounted symmetrically on a vertical shaft.

3. To control speed of rotation mechanical brakes are incorporated. Those brakes consist of steel discs and spring applied air released calipers for each disc.

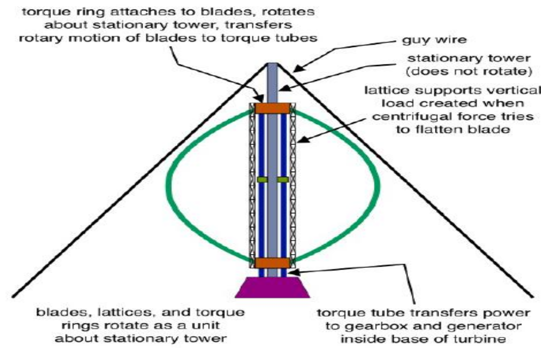

Figure 4: High Mechanical Efficiency Centrifugally Stable Darrieus Turbine

2.3 Internal Components of a Wind Turbine

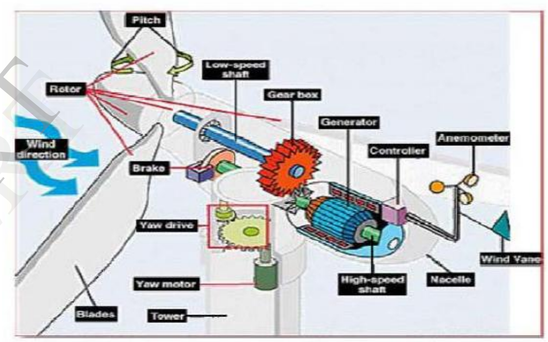

Figure 5: Internal Components of a Wind Turbine

 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

 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.

 Brake: This is either a mechanical, electrical or hydraulic brake used for stopping the turbine in high wind conditions.

 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

 Gear box: This steps-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

 Generator: This can be a synchronous or asynchronous Ac machine producing power at 50Hz

 High-speed shaft: Its function is to drive the generator.

 Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

 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.

 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.

 Rotor: The hub and the blades together compose the rotor.

 Tower: Towers are basically made up of tubular steel or steel lattice. Taller the towersgreater is the amount of power generated as the wind speed generally goes on increasing with height.

 Wind direction: Generally erratic in nature, hence the rotor is made to face into the wind by means of control systems.

 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 flowdirection.

 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

 Yaw motor: Powers the yaw drive.

CHAPTER-3: WIND TURBINE DESIGN PARAMETERS & CHARACTERISTICS

3.1Design Of The Wind Turbine Rotor

There are several parameters involved in the design of an efficient yet economical wind turbine.
Generally and efficient design of the blade is known to maximize the lift and minimize the drag on the blade. Now, minimization of the drag means that the aerofoil should face the relative wind in such a way that minimum possible area is exposed to the drag force of the wind. Furthermore the angle of this relative wind to the blades is determined by the relative magnitudes of the wind speed and the blade velocity. The thing to note here is that the wind velocity basically stays constant throughout the swept area but the blade velocity increases from the inner edge to the tip.
Which means the relative angle of the wind with respect to the blade is ever-changing.
Now the various parameters which determine the design of the wind turbine are noted below:

3.1.1 Diameter of the Rotor:

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= ηeηmCpP0

=1/2ηeηmCp AρV∞3

=1/8ηeηmCpπ ρV∞3D2

here, ηe = efficiency of electrical generation

ηm = efficiency of mechanical transmission

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

P=0.15 V∞3D2, for slow rotors

=0.20 V∞3D2,for faster rotors

3.1.2 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 on the TSR. Now, let ta 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:

ta=2π/nω

Again let tb be the time taken by the disturbed wind, generated by the interference of the blades to move away and normal air to be reestablished. 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:

tb= d/V

For maximum power extraction, ta & tb should be equal, hence

ta= tb

 2π/nω= d/V

 d= 2πV/nω

d has to be determined empirically.

3.1.4 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

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. The pitch angle should be such that tan E or Cd/Cl should be minimum at all points of the rotor. Some researchers suggest the use of Eiffel polar plots, where the tangent to the Eiffel plot gives the minimum Cd/Cl ,for this situation. However for the same scale this becomes inconvenient & as Cl is generally two orders of magnitude higher than Cd it's better to plot a graph of Cd/Cl versus i. Its minimum point will represent the optimal pitch angle.

This method yields a twisted blade which basically has different pitch angles at different distances from the axis for this system.

2. Pitch of blades: By changing the pitch of the blades we can keep a near-constant rotation rate under the ever varying wind speeds. Generally the control is done in a manner, such that the power-generation efficiency of the turbine is optimized.

Both the pitch of the blades and the Yaw control mechanism can act as brakes for the system in case it's hit by strong gusts of wind.

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.

REFERENCES

1. G.D Rai "Non Conventional Energy Sources" Khanna Publishers
2. S Rao, Dr. B.B Parulekar "Energy Technology" Khanna Publishers Fourth Edition,2005.
3. Wind Resource Assessment Unit, Centre for Wind Energy technology Chennai Sept 2005.
4. Papoulis, Pillai, "Probability, Random Variables, and Stochastic Processes", 4th Edition