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VARIABLE SPEED WIND TURBINE

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Abstract

Wind energy is currently the fastest-growing renewable source of energy in India; India is a key market for the wind industry, presenting substantial opportunities for both the international and domestic players. In India the research is carried out on wind energy utilization on big ways .There are still many unsolved challenges in expanding wind power, and there are numerous problems of interest to systems and control researchers. In this paper we study the pitch control mechanism of wind turbine. The pitch control system is one of the most widely used control techniques to regulate the output power of a wind turbine generator. The pitch angle is controlled to keep the generator power at rated power by reducing the angle of the blades. By regulating, the angle of stalling, fast torque changes from the wind will be reutilized. It also describes the design of the pitch controller and discusses the response of the pitch-controlled system to wind velocity variations. The pitch control system is found to have a large output power variation and a large settling time.

Index Terms: *wind turbine, HAWT, VAWT, pitch control, cut in speed, cut out speed, angle of attack, wind turbine aerodynamics.*

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1. INTRODUCTION

The global wind markets have grown by an average 28% per year in terms of total installed capacity during the last decade. The IEA's Reference scenario suggests that growth rates for wind power would decrease substantially in the coming years, and that 2010 would see an addition of only 26.8 GW. However, in reality the global wind industry added 35.8 GW during the year13. The Indian market grew by almost 68% on a year- n-year basis with 2,139 MW of new capacity installed between January and December 2010. This made India the third largest annual market after China and the USA for 2010. With more than 13 GW of total installed capacity at the end of 2010, India ranks fifth in the world in terms of cumulative installed capacity. India has installed wind energy by December 2011 was 16078 MW. For a country like India these figures are not enough as India has a large potential and it must be utilized. [1] There are two types of wind turbine horizontal axis and vertical axis wind turbine but in this article the horizontal axis wind turbine is studied as it is most commonly used and has more advantages than vertical axis wind turbine. Horizontal axis wind turbines have an advantage over vertical axis wind turbines in that the entire rotor can be placed atop a tall tower, where it can take advantage of larger wind speeds higher above the ground. Some of the other advantages of horizontal axis wind turbines over vertical axis wind turbines for utility-scale turbines include pitch able blades, improved power capture and structural performance, and no need for guy wires (which are tensioned cables used to add structural stability). Vertical axis wind turbines are much more common as smaller turbines, where these disadvantages become less important and the benefits of reduced noise. [2]

2. WIND TURBINE TYPES

Wind turbines can be broadly classified into two types:

a. Horizontal axis wind turbine

The main rotor shaft and electrical generator are generally at the top of a tower for a horizontal axis wind turbine (HAWT).

Figure 1: Horizontal Axis wind Turbine

A horizontal axis wind turbine has a design which demands that it should be pointed to the wind to capture maximum power. This process is called yawing. The turbine shaft is generally coupled to the shaft of the generator through a gearbox which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator

b. Vertical axis wind turbine

The vertical axis wind turbines, as shown in Fig. 2, have the main rotor shaft arranged vertically. The structure of these wind turbines are such that they can capture wind irrespective of its direction. Thus, it is of great benefit in places where the wind direction keeps varying. Unlike the HAWT where the gearbox and generator are placed on top of the tower, the generator and gearbox are generally placed near the ground. This makes it more accessible and easier for maintenance. But they do not come without any drawbacks. Some designs produce pulsating torque which results in fatigue. It is also difficult to mount vertical-axis turbines on towers. They are often installed nearer to the base on which they rest. As the wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine.

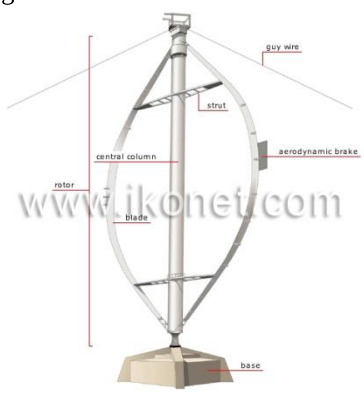

Figure 2: Vertical axis wind turbine

2.1. Wind Turbine Characteristics

Cut-in speed- At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the cut-in speed and is typically between 3 and 4 meters per second. Rated output power and rate output wind speed. As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly as shown. However, typically somewhere between 12 and 17 meters per second, the power output reaches the limit that the electrical generator is capable of. [3] This limit to the generator output is called the rated power output and the wind speed at which it is reached is called the rated output wind speed. At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level and there is no further rise in the output power. How this is done varies from design to design but typically with large turbines, it is done by adjusting the blade angles so as to keep the power at the constant level. Typical wind turbine power output with steady wind speed is shown in figure 3.

Cut-out speed- As the speed increases above the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the cut-out speed and is usually around 25 meters per second. Wind turbine efficiency or power coefficient. The available power in a stream of wind of the same cross-sectional area as the wind turbine can easily be shown to be

$$\frac{1}{2}\rho U^3 \frac{\pi d^2}{4}$$

If the wind speed U is in meters per second, the density ρ is in kilograms per cubic meter and the rotor diameter d is in meters then the available power is in watts. The efficiency, μ, or, as it is more commonly called, the power coefficient, cp, of the wind turbine is simply defined as the actual power delivered divided by the available power.

$$\mu = \frac{\text{Power}}{\frac{1}{2}\rho U^3 \frac{\pi d^2}{4}}$$

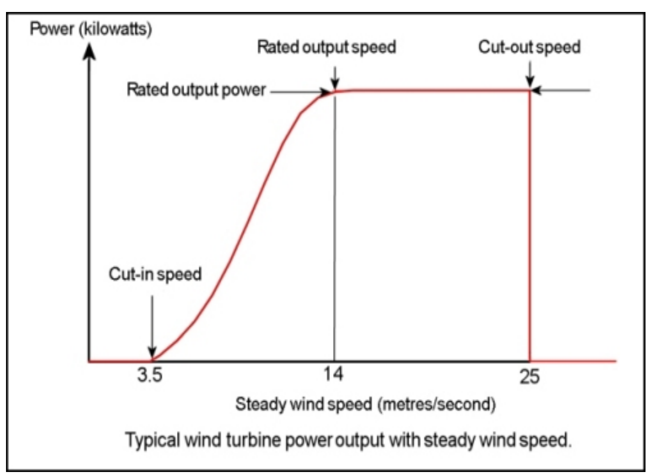

Fig. 3 Typical wind Turbine power output with steady wind speed

2.2. Wind turbine Aerodynamics

The heart of the wind turbine is the rotor. This is a device that extracts the kinetic energy from the wind and converts it into a mechanical form a wind turbine rotor is comprised of blades that are attached to a hub. The hub is in turn attached to a shaft (the main shaft) which transfers the energy through the remainder of the drive. Real wind turbine rotors are designed taking into account many factors, including but not only their aerodynamic performance. [4] In addition, the rotor must be controlled so as to generate electricity most effectively and so as to withstand continuously fluctuating forces during normal operation and extreme loads during storms. Accordingly, a wind turbine rotor does not in general operate at its own maximum power coefficient at all wind speeds. Because of this, the power output of a wind turbine is generally described by curve, known as a power curve, rather than an equation such as the one for *PWT* which given earlier. Figure 2 illustrates a typical power curve. As shown there, below the cut-in speed (3 m/s in the example) no power is produced. Between cut-in and rated wind speed (14.5 m/s in this example), the power increases significantly with wind speed. Above the rated speed, the power produced is constant, regardless of the wind speed, and above the cut-out speed (25 m/s in the example), the turbine is shut down

3. WIND TURBINE CONTROL

When a generator reaches rated power, the turbines must limit the mechanical power delivered to the generator. This is valid because the generator reaches the rated power at for instance 15 m/s while the maximum speed is typically 25 m/s for a wind turbine. Control is done by three different methods called stall, pitch and a combination called active stall. [5] There are no moving parts in the stall-controlled blades and the Challenge is in the construction of the blades to avoid vibration and make them stall gradually. The pitch angle is controlled to keep the generator power at rated power by reducing the angle of the blades. By regulating, the angle to be one of stalling, fast torque changes from the wind will be reutilized. The power captured by the turbine is given by

$$Pm = Pw \times Cp$$

3.1 Wind turbine controller

The name of the controller for the wind turbine is the multi processor controller, which is an abbreviation of multi processor controller. The controller monitors and controls all functions in the turbine, in order to ensure that the performance of the turbine is optimal at any wind speed. The control will stop the turbine if supervision detects an error. At an operator panel, data of current operation is displayed. The multi processor controller is divided in to two parts:

1. Ground controller and **2**. Top-controller.

Ground processor takes care of cut in and cut-out of the generator and the capacitors and of current and voltage measurement. Top processor takes care of the tasks in the nacelle, example: Speed, pitch and power control yawing and internal temperature control. [6]The multi processor controller collects continuously data about the performance of the turbine example:

1. Rotor and generator speed
2. Wind speed
3. Hydraulic pressure
4. Temperature
5. Power and energy production and
6. Pitch

If some irregularities or errors arise, the data is stored in a LOG and/or an ALARM LOG, making it possible to analyze errors in the turbine.

3.2 Wind Turbine Rotor control

The rotors are controlled so as to generate electricity most effectively and as such must withstand continuously fluctuating forces during normal operation and extreme loads during storms. Accordingly, in general a wind turbine rotor does not operate at its own maximum power coefficient at all wind speeds. Because of this, the power output of a wind turbine is generally described by a relationship, known as a power curve. A typical power curve is shown in figure 2. Below the cut-in speed no power is produced. Between cut-in and rated wind speed the power increases significantly with wind speed. Above the rated speed, the power produced is constant, regardless of the wind speed, and above the cut-out speed the turbine is shut down often with use of the mechanical brake.

Two main types of rotor control systems exist: pitch and stall. Stall controlled turbines have fixed blades and operate at a fixed speed. The aerodynamic design of the blades is such that the power is self-limiting, as long as the generator is connected to the electrical grid. Pitch regulated turbines have blades that can be rotated about their long axis. Such an arrangement allows more precise control. [7] Pitch controlled turbines are also generally quieter than stall controlled turbines, especially at higher wind speeds. Until recently, many turbines used stall control. At present, most large turbines use pitch control. Appendices A and F provide more details on pitch and stall. The energy production of a wind turbine is usually considered annually. Estimates are usually obtained by calculating the expected energy that will be produced every hour of a representative year (by considering the turbine's power curve and the estimated wind resource) and then summing the energy from all the hours. Sometimes a normalized term known as the capacity factor (CF) is used to

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characterize the performance. This is the actual energy produced (or estimated to be produced) divided by the amount of energy that would be produced if the turbine were running at its rated output for the entire year.

3.2 Software

The software to the MP-controller system is basically constructed so that all variables can be initialized. Examples of parameters are power 68 reference, various alarm limits, calibration values for anemometer etc. To every type of turbine and variants, a set of parameters is present, which is selected by start-up of the turbine.

3.3 Overall control strategy

When the wind is very low and the rotor does not rotate with a very low speed, the pitch angle will be approximately 450. This will give maximum start moment to rotor, which gives a quicker start, when the wind increases. The MP-controller will then pitch the blades to 0 (into the wind). [8]The rotating speed for the rotor and the generator will increase towards the nominal, which the multi processor controllers will try to keep (speed control).the power curve for wind turbine is shown in figure 4. The same situation occurs with connected generator. When the wind decreases and the produced power become negative, the generator will be disconnected from the grid and the MP controller will control the speed.

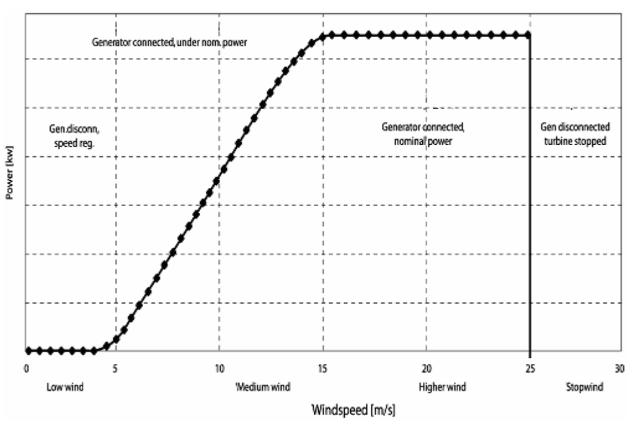

Fig. 4 Power curve

If the wind decreases even more then the rotating speed will decrease below nominal value and the rotor will run freely. At medium wind speed, the rotating speed is regulating to the nominal value and if the pitch angle can be kept at 50 (which says that there would be enough energy in the wind), [9] the generator is connected to the grid. With the generator connected and but enough energy in the wind to produce nominal power, the pitch angle is regulated as a function of the wind speed.

4. POWER FACTOR CORRECTION

An asynchronous generator contains no permanent magnet and is not separately excited. That means, that an asynchronous generator has to get exciting current from the grid and the magnetic field is only established, when generator is connected to the grid. When the generator excites current from the grid, the generator consumes reactive power from the grid. The current in the cable to the generator will consist of two parts,

1. Active current corresponding to the active power production (KW) and
2. Reactive current corresponding to the reactive power Consumption (KVAr).

Because of the exciting current, there is a phase shift between the current and the voltage. The current delayed compared to the voltage by an angle (θ). A term of the phase shift is the power factor (cos θ). [10] A part of the generator's exciting current / reactive power is delivered from the capacitors, which are called power factor correction. The capacitors are connected to the grid a little later than the generators are disconnected, before the generator is disconnected from the grid. The advantage of the power factor correction is that the loss in the grid decreases, because the grid current decreases. At no-load the grid current is about zero Amps, because the generator's no-load current (only reactive current) is delivered from the capacitors.

5. PID CONTROLLER

The algorithm used for the Adaptive PID Control based Pitch Actuator System is as follows

1. Set first set of values for Kp, Ki and Kd
2. Read the value of wind speed.
3. Calculate value of TSR.

TSR = Ratio of speed of tip of blade to wind speed

For a fixed speed wind turbine, blade tip speed is constant. (A constant gear ratio between generator and blades is assumed)

4. For values of pitch angle between 0 and 90 degrees, calculate Cp.
5. Find out the value of pitch angle for which Cp is maximum.
6. Sample and hold this value of pitch.
7. Send this value of pitch as command value to the PID Controller for the duration „t1".
8. The integration of the PID output gives the pitch angle output.
9. From the PID response, estimate rise time tr (or peak time tp), peak overshoot Mp, settling time ts and steady state error ess.
10. Based on the values of the time response parameters calculated, tune the values of

Kp, Ki and Kd for the next time cycle.

The system is allowed to operate for a period of 100 units of time in each cycle after which the time response parameters are evaluated and necessary changes are inflicted to the Proportional, integral and derivative gains[11]

FUTURE WORK

For adapting the usage of the pitch angle mechanism of the stepper motor in place of the hydraulic actuator, following mechanism is involved given below:
1. Stepper motor – 10 Kg torque, 60 RPM, 24 V and 2 amps, 10 degree.
2. Single axis travel mechanism.
3. Piston inside the shaft.
4. Converter for linear movement to circular movement. Based on the RPM sense, the stepper motor will rotate clockwise or 86 anti-clockwise of travel mechanism.[12] The travel mechanism will move the piston to front and back (that is some linear movement). The linear movement of the piston gets converted to circular movement of the blade axis by reciprocating links and it is an easy mechanism. This converts linear moment to circular moment, there by making the blade rotate circularly.

CONCLUSION

We can easily change pitch, but the response is deliberate as compared to output power variation. Therefore the response of pitch control is slower. Therefore fast changes caused by powerful winds will affect the generator. The speed range of the generator is depending on the converter voltage and the load situation. A higher voltage available for the converter in the rotor circuit, will give a higher range of speed. A speed was chosen to make the generator choose the mechanical speed, which gives the best power output related to the wind speed. A rate limiter was chosen to avoid fast changes in the mechanical speed. The scaling of the converter could be investigated and compared with the winding ratio of the machine, to find the optimal winding ratio compared with bus voltage in the converter. The response time is mainly dictated by the hydraulic actuator, which limits the performance of the system. The controller should be used in conjunction with the pitch control system to avoid large losses during steady state operation. The pitch angle mechanism of the steeper motor is also discussed.

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