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Dynamic Calculation Design of Vertical Wind Turbine

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Abstract

The Nigeria power system is facing shortage of power due to poor generation. The country is now trying to shift to the utilization of renewable energy in the production of electrical power so as to have a mix energy generation system. One of the renewable energies is the kinetic energy of wind. For this energy to be properly utilized there is need for flexibility in the design of the turbine that will be used to convert the kinetic energy of the wind to electrical energy. Although, this work did not give enough wattage needed, it is still important to talk about the importance of the dynamic calculation of the wind turbine. However, for this flexibility to be achieved there is need for proper understanding of the dynamics of the turbine. This paper presents, from practical point of view, the dynamic calculation for a vertical wind turbine which is basically an implementation of the idea in [4].The site for this work is Benin City, Edo state Nigeria.

Keywords: Induction Motor, Turbine Blades, Mechanical Coupling, Wind Energy, Bearings..

1.0 Introduction

Over the years, Nigeria has been faced with the problem of shortage of power due to poor generating means. In an attempt to solve the problem, the country is trying to shift to using the renewable energy source for generating electricity. Part of the renewable energy source is using the kinetic energy of wind to generate electricity. Wind turbines for generating power have two main opposing constraints; the need to be structurally secured and must be of low cost [1]. The two constraints seem extreme, but reduction in mass brings about more cost effective turbine and consequently having a light weight structure with good degree of flexibility. In order to achieve such a cost effective flexibility, there is need for a better understanding of the dynamics of the system. This paper presents the dynamic calculation for the vertical wind turbine.

A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stone, the machine is usually called a windmill. If the mechanical energy is instead converted to electrical energy, then the machine is called a wind generator, wind turbine, wind power unit (WPU), wind energy converter (WEC) or aero generator. Wind machines were used in Persia as early as 200 B.C, the wind wheel of Heron of Alexandria marks one of the first known instances of wind powering a machine in history. However, the first practical windmills were built in sistan, Ivan, from the 7^{th} century. These were vertical axle windmills which had long vertical drive shafts with rectangular shaped blades made of six to twelve sails covered in reed metting or cloth material, these wind mills were used in the gristmilling and sugarcane industries [2,3,4].

A forerunner of modern horizontal axis wind generators was in service at Yalta, USSR in 1931. This was a 100kW generator on a 30m (100ft) tower, connected to the local 6.3kV distribution system. It was reported to have an annual capacity factor of 32 percent, not much different from current wind machines in the fall of 1941, the first megawatt class wind turbine was synchronized to utility grid in Vermont. The Smith-Putnan wind turbine only ran for 1100 hours. Due to war time material shortages the unit was not repaired.

The first utility grid connected wind turbine operated in the UK was built by John Brown and company in 1954 in the Orkney Islands. It had an 18 meter diameter, three-bladed rotor and a rated output of 100KW [5].

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A good criterion used in determining the best location of the wind turbine is called Wind Power Density (WPD).It is a calculation of the effective force of the wind at a particular location, frequently expressed in terms of the elevation above ground level over a period of time. It takes into account the wind velocity and mass.

2.0 Modern Wind Turbines

Turbines used in wind farms for commercial production of electricity (electric power) are usually three bladed and pointed into the wind by automatically controlled motors. These have high tip speeds of over 320km/h (200 miles per hour), high efficiency, and low torque ripple, which contribute to good reliability. The blades are usually light gray in colour for protection against the environment and range in length from 20 – 40 meters (65 to 130ft) or more. The tubular steel towers range from 60 to 90 meters (200 to 300ft) tall. The blades rotate at 10-22 revolutions per minute. At 22 rotations per minute the tip speed exceeds 300ft per second. A gear box is commonly used to set up the speed generator, although designs may also use direct drive of an annular generator. Some models operate at constant speed, but more energy can be collected by variable speed turbines which use a solid state power converter to interface to the transmission system. All turbines are equipped with shut down features to avoid damage at high wind speed.

2.1 Vertical Axis Subtypes

“Eggbeater” turbines or Darrieus wind turbines velocity often increases at higher altitudes. The tower hinders the airflow at the lowest point in the circle, which produces a local dip in force and torque. These effects produce a cyclic twist on the main bearings of a horizontal – axis wind turbine (HAWT). The combined twist is worst in machines with an even number of blades, where one is straight up when another is straight down. To improve reliability, teetering hubs must be used to allow the main shaft to rock through a few degrees, so that the main bearings do not have to resist the torque peaks.

The rotating blades of a wind turbine act like a gyroscope. As it pivots along its vertical axis to face the wind, gyroscope precession tries to twist the turbine disc along its horizontal axis. For each blade on a wind generator turbine, progressive force is at a minimum when the blade is horizontal and at a maximum when the blade is vertical. Vertical – axis wind turbine (VAWT) have the main rotor shaft arranged vertically, key advantages of this arrangement are that the turbine does not need to be pointed into the wind for effectiveness. This is an advantage on sites where bending stresses, straight, V, or curved blades may be used.

2.2 Vertical axis Wind Turbine Advantages

A massive tower structure is less frequently used, as VAWTS are more frequently mounted with the lower bearing mounted near the ground. The alternator of a VAWT can be located nearer the ground, making it easier to maintain the moving parts.

Vertical - axis Wind Turbines have lower wind setup speeds than HAWTs. Typically, they start generating electric power at 6 m.p.h. (10km/h). VAWTs may be built at locations where taller structures are prohibited. CAWTs situated close to the ground can take advantage of locations where mesas, hilltops, ridgelines, and passes funnel the wind and increase wind velocity. VAWTs may have a lower noise signature.

2.3 Vertical Axis Wind Turbine Disadvantages

A VAWT that uses guy – wires to hold it in place puts stress on the bottom bearing as all the weight of the rotor is on the bearing. Guy wires attached to the top bearing increase downward thrust in wind gusts. Solving this problem requires a superstructure to hold a top bearing in place to eliminate the downward thrusts of gust event in guy wired models.

Having rotors located close to the ground where wind speeds are lower due to the ground surface drag, VAWTs may not produce as much energy at a given site as a HAWT with the same footprint or height. VAWTs have good efficiency, but produce large torque ripple and cyclical stress on the tower, which contributes to poor reliability. They also generally require some external power source, or an additional servonius rotor to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in a higher solidity for the rotor. Solidity is measured by blade area divided by the rotor area.

3.0 Material and Method

The data used for this work are partly gotten from Nigerian Meterological Agency (NIMET) and field at which the construction was carried out is Benin City Edo State Nigeria.

3.1 Wind Power Density

In order to calculate wind speed at one height, if it is known at another height, we can use.

$$V_2 = V_1 \left(\frac{h_2}{h_1} \right)^n \quad (1)$$

Where n is the ground surface friction coefficient and takes on different values according to the nature of the terrain. h_1 and h_2 are predetermined height and the new height for the unknown wind speed to be measured respectively. V_1 and V_2 are the wind speed corresponding to height h_1 and h_2 respectively. See Table 1.

Table 1:

City downtown: n	Speed Corresponding to Predetermined height V_1/m/s	Predetermined Height h_1/m	New Height to Measure the New Wind speed h_2/m
0.4	2.135	25	15.52

Source: Nigerian Meterological Agency (NIMET)

Substituting the data into (1) gives

$$V_2 = 1.786\ m/s\ .$$

For the air density we will use the ideal gas law

$$\circ = \frac{P}{RT} \tag{2}$$

where ρ is the air density, P is the atmospheric pressure, R is the gas constant and T is the air temperature.

Hence $\circ = \dfrac{101}{(8.314/29)(298)} = 1.18\ kg/m^3$

3.2 Power Generated from the Wind Turbine

The following data are the data recorded from the site of installation of the wind turbine

Rotor diameter = 106mm
Blade length = 2.5m
Speed of wind = 1.786m/s
Speed of motor = 1400 rpm

The power of the windcan be calculated from.

$$W = \frac{1}{2} \circ AV^3 \tag{3}$$

Where A = $D_{rotor} \times L_{blade}$ = 106 x 2.5 = 265m^2

The efficiency will come from the tip speed ratio (TSR) equation which is given as

$$TSR = \frac{W \times R_{Rotor}}{V} = \frac{(1400/60)(2®)(106/2)}{1.786} = 4.350 \tag{4}$$

Tip Speed ratio is the ratio of the blade tips to the speed of the wind

Substituting into (3) gives

$$W = \frac{1}{2} \circ AV^3 = \frac{1}{2}\ x\ 1.18\ x\ 265\ x\ 1.786^3 = 890.72W$$

3.2 Kinetic Energy of the blade in Air

$$K.E = \frac{1}{2} MV^2 \tag{6}$$

Where M = Mass, Assume M = 4, V = Velocity = 1.786m/s

Substituting into equation (6) gives

$$K.E = \frac{1}{2}\ x\ 4\ x\ (1.786)^2 = 6.38J \tag{7}$$

3.3 Solidity

Solidity is usually defined as the percentage of the circumference of the rotor which is filled by rotor blade. A 0.15 meter diameter rotor has 3 blades each 0.1 meter wide. Its solidity is calculated as

$$Solidity = \frac{3\ x\ 0.1}{®\ x\ 106}\ x\ 100 = 9\% \tag{8}$$

The greater the solidity of the rotor the slower it needs to turn to intercept the wind. A two or three blade turbine has a very low solidity and therefore need to rotate quickly to intercept the wind. Otherwise a lot of wind energy would be lost through the large gaps between the blades.

Assume that the air parcel is very large with the shape of a huge hockey puck that is, it has the geometry of a collection of air molecules passing through the plane of a wind turbines blades (which sweep out a cross-sectional area **A**), with thickness (**D**) passing through the plane over a given time.
Area of blade (A) is given by equation (9)

$$A = \circledR L^2 = \circledR \; x \; 2.5^2 = 19.63m^2 \qquad (9)$$

4.0 Conclusion

Conclusively, the dynamic calculation for a wind turbine has being presented. For a more flexible wind turbine, the dynamic calculation must well be understood and the design of the turbine must be in such a way that the maintenance of the turbine will not be difficult. However, installation of this particular wind turbine, basically an implementation of the idea in [4], was not successful due to low wind speed in the selected area of installation. Nevertheless it can be concluded that the greater the solidity of a turbine rotor, the lesser the blade speed needed to cut the magnetic flux resulting for the generation of electricity. Therefore, dynamic calculation of wind turbine is highly important and it is needed to have an economical generation of electricity.

5.0 References

[1] E.I Okhueleigbe and A.O Okhueleigbe (2014) "Renewable Energy, the Bedrock of Power Stability in Nigeria (A case study of wind Turbine) Journal of Advancement in Engineering. Vol. 2, ISSN: 2348-2931

[2] H. Stiesdal (Autumn 1999) The Wind Turbine Components and Operation, Bonus Energy A/S Fabriksvej 4, Box 170, 7330 Brande

[3] R.T.Cowgill, J.Fouts, B.Haley, C.Whitham "Wind Turbine Rotor Design" A Final Design Report Submitted to College of Engineering Boise State University, USA, 2006

[4] D.S. Chauhan and S.K. Srivastava " Non-Conventional Energy Resources", Second Edition, New Age International(P) Limited, Publishers, ISBN: 812441768X, pp 153-158.

[5] J.F. Manwell, J.G. McGowan and A.I. Rogers "Wind Energy Explained – Theory, Design and Application, John Willey & Sons, 1998, ch 7.

[6] http://www.reuk.co.uk/Use-a-Cycle-Computer-to-Measure-Turbine-RPM.htm Accessed; 15th February, 2010.

[7] T. Beisheim JASS, St. Petersburg, Investigations on current mills and wind turbines (March 9th-19th2008)