A Passive Control Method of HAWT Blade Cyclical Aerodynamic Load Induced by Wind Shear

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***Abstract*— Modern wind turbines are mainly horizontal axis and operate in bottom atmospheric boundary layer driven by wind shear flow, therefore as the blades rotating the aerodynamic load vary cyclically, with horizontal axis wind turbine (HAWT) large-scaling the cyclical characteristic becomes more obvious, shortening blade life and increasing cost of wind turbine. As the development of wind turbine large-scaling is the essential trend, load fluctuation control is more and more critical in HAWT design and manufacture. In common, individual pitch control is introduced to solve the problem, but cost much energy from electric net. In this paper, a concept of telescopic blade root is introduced to reduce fluctuate load induced by wind shear passively, and considering the blades as rigid assessment is operated, meanwhile aerodynamic model based on blade element method in order to analysis the aerodynamic load on NREL Phase VI reference based blade. The result shows that after introducing the equipment the blade fatigue load can be released, lengthening blade life.**

Keywords- wind energy; wind shear; passive control; cyclical aerodynamic load

I. INTRODUCTION

For modern wind turbine, the manufacture of blades is about 15~20% of wind turbine production [1]. Meanwhile, wind turbine generators only utilize kinetic energy of wind, i.e. no fuel cost. To make it economically, two ways can be chosen, one is to decrease the cost of its manufacture and the other is to extend the working life of the key components. Herein the latter is chosen.

Fatigue load should be considered carefully for wind turbine blade design. As an example, the 2 MW wind turbine blades will rotate about 10^8 times during their 20-year design life, in each revolution they are experiencing gravity stress reversal combined effects of wind shear, yaw error, shaft tilt, tower shadow and turbulence. Therefore, in design of wind turbine blade fatigue load is much important factor, even exceed ultimate loads caused by extreme wind conditions and blade fault states [2].

Control systems for horizontal axis upwind turbines have traditionally been based on sensors, which are used to measur the wind speed and direction, rotor speed and power or torque, actuators for regulating generator torque, and yaw angle and collective pitch angle. By using this combination of sensors and actuators, a control scheme for power and speed regulation can be designed [2]. However, generator torque and collective pitch control schemes do not facilitate alleviation of the varying loads induced by vertical wind shear. Therefore, some modern wind turbine control systems have been augmented with sensory systems for measuring blade root bending moments to enable individual pitch control for load alleviation [3,4].Recent advances within inflow measurement technology, for example, light detection and ranging (LiDAR) sensor [5] has been introduced to the development of inflow measurement based control system for load alleviation. Individual pitch can efficiently reduce load variations, however, it rises as the uprising price of increased pitch actuation rate, and actuator requirements [6]. As a result, it is necessary to investigate more means of load alleviation that can be applied without increasing the actuator requirements. Load alleviation through modifications of the telescopic root has the potential of decreasing the load variations without increasing the pitch actuation rates, and is the topic of this study.

Priorstudies related to variable length wind turbine blade have primarily focused on enhancing power capture at low speed wind speeds through lengthen blades. P. Jamieson et al.[7] disclosed a system and method of variable diameter wind turbine rotor blades for changing wind turbine rotor diameters to meet changing wind speeds in sketch. S. Pasupulati et al. [8] invented a wind turbine blade concept that is variable in length in order to change the rotor's cross-sectional swept area and to regulate the amount of power intercepted from wind, and the increase in efficiency associated with this innovative development is found to increase production by as much as 25% over the blades replaced. R.N. Sharma and U.K. Madawala[9] made a cost analysis, showing that the concept would be feasible if the cost of the rotor could be kept less than 4.3 times the cost of a standard rotor with fixed length blades. L. Tartibu et al. [10] identified flap-wise, edge-wise and torsional natural frequencies of a variable length blade, claming that natural frequencies will not be close to the frequency of the main excitation forces in order to avoid resonance.

II. THE FATIGUE CONTROL METHOD

To balance wind rotor load in the whole cycle, utilizing gravity and pneumatic force, the concept of telescopic root is introduced, whose structure and components are depicted in Figure 1. And the blade tip trail is drafted in Figure 2.

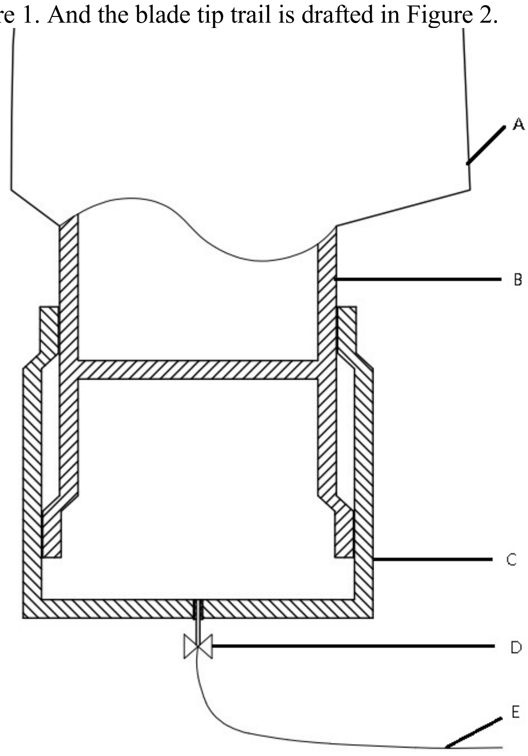

Figure 1. Draft of telescopic blade root concept (a) blade; (b) blade root; (c) air cylinder; (d) valve; (e) air tube

As shown in Figure 1, the blade root (b), which is usually designed as cylinder, is connected as piston to air cylinder (c) which is fixed to or even as flange and then the rotor hub. So the blade root can slide in and out of air cylinder, as a result the blade tip swipe radius varies as shown in Figure 2. Details are stated as following.

Herein the rotor rotate in clockwise, as the blade rotate from upper position to lower position of the cycle, in effect of gravity of blade, air between blade root and air cylinder in Figure 1 is expanded, and the blade root slides out along air cylinder, as a result blade rotating radius lengthen gradually as shown in Figure 2 lower right, hence capture more wind energy. As it got to the limit position of the cylinder, radius lengthen is stopped as shown in Figure 2 bottom of lower right and lower left, until the blade is in horizontal, i.e. it will goes from lower position to upper position.

While the rotor rotate from lower position to upper position, again in effect of gravity of blade, air between blade root and air between blade root and air cylinder in Figure 1 is compressed, and the blade root slides back in along air cylinder, as a result blade rotating radius shorten gradually as shown in Figure 2upper left, hence capture less wind energy. As it got to the bottom position of the cylinder, radius shorten is stopped as shown in Figure 2 headpiece of upper left and upper right, until the blade is in horizontal, i.e. it will goes from lower position to upper position. Then the blade goes to the lower position, in another cycle.

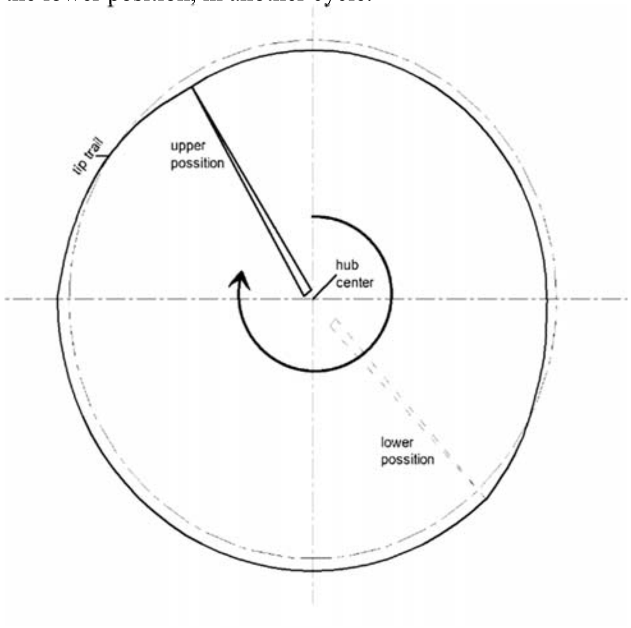

Figure 2. Draft of blade tip trail

In order to seal air between the blade root and air cylinder, piston rings can be used. Position of the separator in blade root can also be designed as needed. In order to fix the orientation of the blade to face elliptical cylinder design can be chosen for (b) blade root and (c) air cylinder.

The air tube in Figure 1(e) can be connected to other air cylinders of the rotor's telescopic blade root facility or compressed air tank, so as to control the progress of each blade telescoping by valves installed on air cylinders as shown in Figure 1(d), and blade tip trail in Figure 2 can be controlled sophisticatedly so as to reduce blade load.

III. ESTIMATION OF TELESCOPIC ROOT FOR NREL PHASE VI REFERENCE BLADE

According to blade element method (BEM), a basic theory of wind turbine aerodynamics, the blade can be considered as infinite number of sections staggered, and the flow is simplified as stream lines, ignoring three dimensional effects, forces on a blade element can be calculated by means of two-dimensional air foil characteristics using an angle of attack determined from the incident resultant velocity in the cross-sectional plane of the element. To modify errors at the root and tip of rotor blade, root loss and tip loss correction are introduced by Prandtl et al. The theories can be found in monograph on wind turbine aerodynamics such as [11, 12], therefore in this paper they are not discussed.

In order to estimate on the blade telescopic root concept, NREL Phase VI reference blade is introduced herein, and four blade telescopic root length, i.e. 0.1 m, 0.2 m, 0.3 m, 0.4 m, as depicted in Figure 3,are discussed, taking the blade with 5.732 m radius as reference blade.

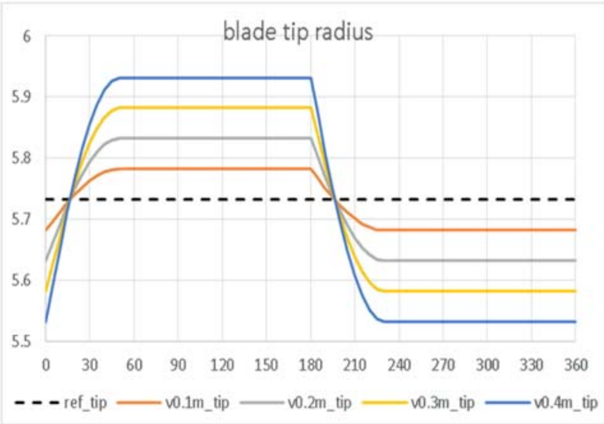

Figure 3. Blade tip radius varies with angular phase for reference and telescopic root blades

The vertical wind shear can be expressed in exponential form, as shown below:

$$V_z = V_h \left(\frac{z}{z_h} \right)^{\alpha}$$

Where V_h is the wind speed at the hub height z_h, herein $z_h = 12.192\,\mathrm{m}$ and $V_h = 8\ \mathrm{m/s}$, z is the vertical distance above ground , and the IEC Standard exponent of $\alpha = 0.2$ is assumed. Taking 0.8 rotating radius as reference mean wind speed radius, reference blade mean wind speed can be estimated, as shown in Figure 4. Blades with telescopic root experience lower mean incoming wind speed generally, especially around 90^{o}, 270^{o}.

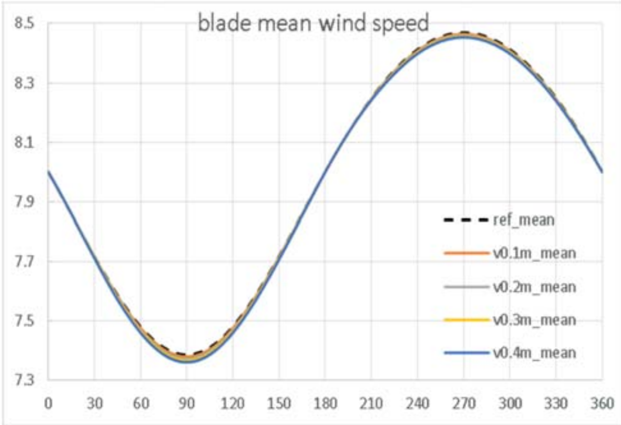

Figure 4. Estimated blade mean wind speed with angular phase for reference and telescopic root blades

Steady state inflow of referenced and telescopic root series blades characteristics are analyzed in BEM method, representing blade loads, blade torque and thrust corresponding to mean wind speed with angular phase are analyzed, which are depicted in Figure 5 and Figure 6.

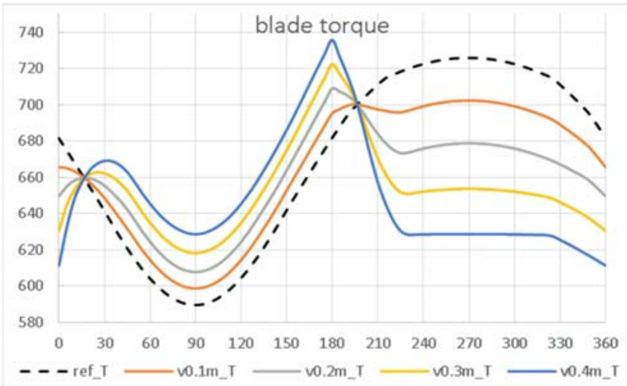

Figure 5. Blade torque varies with angular phase for reference and telescopic root blades

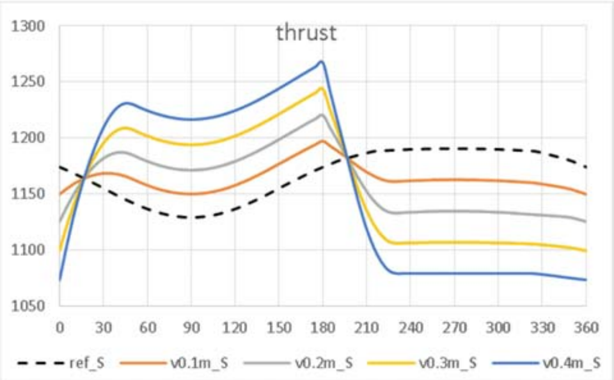

Figure 6. Blade thrust varies with angular phase for reference and telescopic root blades

From Figure 5 and Figure 6, telescopic root blade max load increases as its length, so as too load range. Comparing with reference blade, load on 0.1 m length telescopic root blade varies narrower and lower max value, load on 0.2 m length telescopic root blade varies narrower and lower torque than reference blade. Torque on blade with 0.3 m telescopic root varies narrower than reference blade, while the thrust range exceeded in value. Load on blade with 0.4 m length telescopic root exceeds reference both in max value and range.

Therefore, telescopic root concept can reduce blade root load induced by vertical wind shear while the length varies in limited range, as load is sensitive to blade rotating radius, load exceed reference while telescopic root length increase, but can be controlled by cooperate of valves on different blade roots.

IV. Conclusions

The concept of HAWT blade telescopic root was stated, and a simple estimation based on BEM theory on NREL Phase VI reference blade was made. The results showed that the concept can reduce aerodynamic load, and keep power output, while the root telescope rage should be limited, and control strategy should be special designed.

As the telescopic root blade varies its radius, wind flow is unsteady, and set mean wind speed as appointed radius inflow speed is not exact the truth. Further step research should be taken on telescopic root blades.

Control strategy and means herein is simple, and can be study further.

Acknowledgment

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