A Review on Different Pitch Angle Control Methods for Wind Turbines

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Abstract - Th*is paper summarizes current research and applications of wind turbine individual pitch control, reviews the basic concepts and working principles of individual pitch control methods, analyses the individual pitch control strategies for reducing the load, and mitigating grid voltage fluctuations, finally, the possible development prospects of wind turbine individual pitch control are discussed.*

Key Words: individual pitch control; pitch angle; unbalanced load; power fluctuations

1. INTRODUCTION

Wind turbines develop to large-scale with the installed capacity of wind turbines rapidly develop, Currently offshore wind turbines have a diameter of over 100 meters. Such as: the wind turbines Vestas V164-8MV was produced by VESTAS company, it has diameter of 177m and length of 80m for each blade, the first prototype unit was installed in northern Denmark in January 2014[1], and the first industrial units are scheduled for installation in 2016 off the coast of the UK[2]. The rotor blades to produce a wide range of moments, at the same time, wind turbine blade have to subject to turbulent, wind shear, tower shadow etc. The impacts become more significant with the diameter increase, large-scale wind turbines are subject to more complex unbalanced load. When megawatt generators runs at rated wind speed, the absorbed power can be 20% difference [3], between the highest position and lowest position of the wind turbine blade. The unbalanced load aggravates the mechanical stress and shortens lifetime of wind turbine, at the same time, the output power of wind turbines will fluctuate.
Currently, the pitch control has been implemented for large and medium-sized wind turbines. In general, the wind turbine blade pitch angles are adjusted in response to random variation of wind speed, so as to realise the optimum utilization of wind energy within a certain range of the wind speed. The pitch control may be classified into two types, collective pitch control and individual pitch control. In a collective pitch control system implements to synchronization adjustment control system, all the three blades of a wind turbine are adjusted in the same speed and the same degree. Obviously collective pitch control cannot be well adjusted to the above situation. Clearly, only individual pitch control can solve the above problems, because each blade has a set of independent variable pitch drive system in Individual pitch control system, and can be adjusted to the different situation of each blade.

2. CURRENT RESEARCH AND APPLICATION OF THE INDIVIDUAL PITCH CONTROL TECHNOLOGY

Individual pitch control has been studied since the beginning of this century, after the development in a few years, some of universities, research institutes and industrial companies have now involved the research and development about the individual pitch control. Such as: Aalborg University in Denmark, Technical University of Denmark, Vestas Wind Systems A/S in Denmark, GL Garrad Hassan in the United Kingdom, Shenyang University of Technology, North China Electric Power University, State Key Laboratory of Fluid Power and Control at Zhejiang University and also researchers at Norway, Germany, France, the United States, the Netherlands, New Zealand and other countries have conducted the research activities, and obtain a lot of results about the individual pitch control. At present, the most studies of individual pitch control are at the stage of the simulation, a number of studies get into a stage of the semi-physical simulation, a very few of research and development studies are in the stage of field test. Such as: In China, State Key Laboratory of Fluid Power Transmission and Control, Zhejiang University and Zhejiang Windey Wind Generating Engineering Co., Ltd. jointly conducted VSCF individual pitch control research and development based on semiphysical simulation[4] In China Hangzhou, State Key Laboratory of wind power system and Zhejiang Windey Co., Ltd. Hangzhou have conducted the joint simulation study and field test on individual pitch control technology of large scale wind turbine[5]. In UK, validation of individual pitch control by field tests on two- and three-bladed wind turbines has been reported.[6] The results demonstrate convincingly that the predicted load reductions can be achieved in practice; the output voltage has been stabilizing too.

3. THE FOUNDATION OF INDIVIDUAL PITCH CONTROL

Wind energy is converted into mechanical energy by the rotation of the wind rotor that is driven by the wind, then mechanical energy drives generator to output power.

According to Betz theory, the wind turbin8e obtain

$$P = \frac{1}{2}\rho\pi r^2 C_p(\lambda, \beta)V_w^3$$

$$\lambda = \frac{R\Omega}{V_w}$$

Here P_a is the wind power converted in to electrical power, πr^2 is the rotor swept area, C_p is the power co-efficient, λ is the tip speed ratio, β is the pitch angle and V_w is the wind speed. The tip speed ratio is defined as the ratio between the blade tip speed and the wind speed V_w
Where Ω is the turbine rotor speed and R is the radius of the wind turbine blade.

From the above equations it is concluded that:

- When pitch angle is constant, the maximum value CPmax of the wind power coefficient is unique;
- The wind power coefficient is at maximum values when the blade pitch angle is about zero for any the tip speed ratio. The wind power coefficient is significantly reduced with the blade pitch angle ǜ increasing.

The theoretical base of the VSCF pitch control has been provided by (1), (2) as discussed above: When the wind speed is lower than the rated wind speed, the blade pitch angle remain at β=0 by the pitch control. The rotor speed of the generator changes with wind speed by the VSCF equipment, so that The wind power coefficient is remain at C_{Pma}x, the wind turbine captures the maximum wind energy, the frequency of output power remains constant; When the wind speed higher than the rated wind speed, the output power of generator are controlled by adjusting the blade pitch angle, so that the output power of generator remains as the rated power.

4. THE INDIVIDUAL PITCH CONTROL STRATEGY

A. The basic principle of individual pitch control

Object of the variable speed pitch control is to achieve the maximum wind energy when the wind speed is lower than the rated wind speed, and to remain the rated output power of wind turbine. In the collective pitch control of a wind turbine, the pitch angle is given by the generator power regulation. The block diagram of the basic principles of individual pitch control for large-scale wind turbine is shown in Figure 1. Individual pitch control system for large-scale wind turbines based on two separate loops, namely: collective pitch control loop and individual pitch control loop. The variable speed pitch control is achieved by the collective pitch control loop, the collective pitch control loop outputs the same desired value for three-blade pitch angles; The loads of the unbalanced wind rotor are mitigated by individual pitch control loop, tilt and yaw moment of the rotor are reduced by individual pitch control loop, individual pitch control loop outputs three mechanical power [7-8] as follows:
different desired compensation values for three-blade pitch angles.

B. The strategies of individual pitch control for load mitigation of the wind turbines

It is noted that the load of wind turbine has some similar characteristics to the three phase electrical power systems. The load in wind turbine system consists of the fundamental and higher harmonics, just like the voltage and current in a electrical system. Then the PR control method [10-11] in the electrical system can be utilised in the load mitigation of a wind turbine. The novel control strategy has been proposed for load reduction of unbalanced wind turbines. Namely: Control strategies using PI-R IPC [12]. Control scheme using PI-R IPC is shown in Figure 3. The control loop includes two PI-R controllers, and two transformations between the blade reference frame and the hub reference frame, and there is no need for a commonly used LPF (low pass filter). The configuration of control scheme is much simple, so that the speed of processing signal can be much faster. The strategy using PI-R IPC not only can mitigate the static harmonic of unbalance tilt and yaw moment, but also can mitigate the 1p, 3p harmonic components in tilt moment and yaw moment.

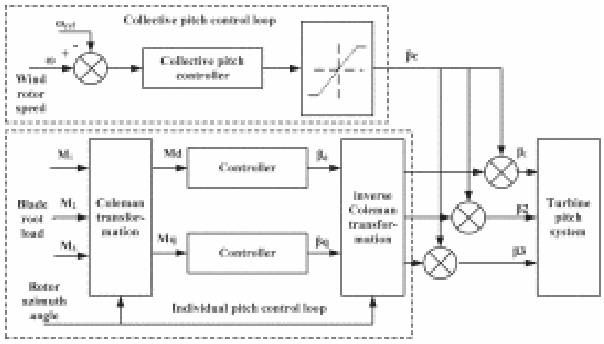

Fig. 1. The block diagram of the basic principles of individual pitch control.

Control process of using PI-R IPC is as follows: The blade root load M1, M2, M3 can be determined by detection or by estimation. The three signals M1, M2, M3 are transformed to two orthogonal d-axes and q-axes by means of Coleman transformation which is d-axis M_d moment and q-axis M_q moment. Control target of PI-R IPC strategy is to minimize the load of unbalance wind turbines, the means is to minimize the d-axis M_d and q-axis M_q moment, Usually control target value of the d-axis Md and q-axis Mq Moment is set to zero. D-axis moment Mq and q-axis moment Mq, in the feedback control, are input PI-R controller respectively, then the d-axis desired pitch angle β_d and q-axis desired pitch angle β_q are outputs form PI-R controller, then the β_d , β_q are transformed to the pitch angle increments $\Delta\beta_1$,

$\Delta\beta_2$, $\Delta\beta_2$for the three blades by the inverse Coleman transformation, then, $\Delta\beta_1$, $\Delta\beta_2$, $\Delta\beta_2$ are each respectively summed with the collective pitch demand β giving the total pitch demand for three blades $\Delta\beta_1$, $\Delta\beta_2$, $\Delta\beta_2$.
PI-R IPC strategy can mitigate effectively loads of balanced or unbalanced wind turbines, and PI-R controller configuration is simple, the LPF is not used. The literature [13] shows that simulation studies are compared among the PI-R IPC, CPC, PI IPC. The simulation results demonstrate that PI-R IPC strategy can significantly reduce the fatigue loads of the wind turbines; The adaptive PI-IPC strategy are reported in literature[14], that has improved PI- R IPC strategy, so that the periodic loads of the unbalanced tilt moment and yaw moment almost completely are disappeared. PI-R IPC strategy can also be used to reduce higher frequency load, but require a higher rate pitching drive system.

C. The strategy of individual pitch control for Mitigating

Power Fluctuation of Wind turbines
When wind tower shadow and shear effects are taken into account, the aerodynamic torque of the wind turbines includes a component with frequency 3p, which means the aerodynamic torque will drop three times per revolution[15].
The overall wind turbine aerodynamic torque, which obviously shows the 3p effect. The aerodynamic torque has been reduced largest when one of the three blades is directly in front of the tower. So the generator output power will also decline three times in a cycle as well as the aerodynamic power of the wind turbine.
If the aerodynamic torque can be well controlled in a certain range, not only aerodynamic power for wind turbine but also output power for generator will only fluctuate in a very small extent, then the power fluctuations for wind turbine can be eased.
When the wind speed is above the rated wind speed, pitch angle should be turned by traditional collective pitch control, to maintain the output power at its rated value, so that the system is not overloaded, and usually the 3p are not considered into account. However, if we consider limiting the impact of the 3p and realising power oscillation attenuation, then each blade pitch angle can be superimposed a small pitch increment, that is depends on the azimuth of the wind turbine and the output power incremental of the generator. When the wind speed is below the rated wind speed, usually the control target of wind turbines is to achieve maximum power tracking by electromagnetic torque control of the generator, pitch control is not used in this condition.
However in order to mitigate the 3p effect, a small amount of the pitch angles need to be added for the angle control, the blade pitch may be adjust around residual pitch angles. This means part of the wind energy would be lost.
Based on the control concept, a novel individual pitch control strategy has been proposed [15].
The control scheme includes two control loops: collective pitch control loop and individual pitch control loop.

5. SUMMARY AND FUTURE TRENDS

Individual pitch control of wind turbines not only can mitigate the fluctuating loads of a balanced wind turbine or an unbalanced wind turbine, improve reliability of the equipment and extend the life time of the equipment; but also can reduce the output power fluctuation of the wind turbine, make the output power of the wind turbine stable, improve power quality of the grid. Studying the strategy of individual pitch control is very useful and important, individual pitch control is inevitable trend in development of wind turbine pitch control. Currently individual pitch control method mostly is single control strategy, which is difficult to comprehensive and effective control the dynamic loads of the wind turbine caused by random wind speed. In the future, the individual pitch control would have improved performance if a number of intelligent control and optimization control methods are combined in wind power systems. For example, the control method of reducing load of wind turbine is combined with the control method mitigating output voltage fluctuations would be a potential research direction. Currently the majority of the individual pitch control methods are in simulation stage, the results in experimental test and experience from real wind farm are very little. In future, the research for semi-physical model would be useful, especially the field test and research for the individual pitch control technology will be emphasized, in order to further promote the commercialization of the individual pitch control technology.
The individual pitch control will require the pitch system to move more frequently, therefore, more requirements and demands are expected on the pitch and its driving system, high reliable pitch system remains to be further studied.

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