Development of Megawatt Wind Turbine Based on Codesys Variable Pitch PID Controller

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Development of Megawatt Wind Turbine Based on Codesys Variable Pitch PID Controller

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Abstract. The paper mainly studies the control strategy of megawatt wind-power generator variable pitch control system. Based on the comparisons between the incomplete total differential PID control-algorithm-developing controller and the traditional PI controller through building mathematical models, an optimized variable pitch control strategy is put forward. By running the actual fan program to conduct full wind speed simulation through Codesys programming software that is commonly used in engineering application, the optimized control algorithm has advantages of small overshoot, high precision in control and smooth output angle after comparison, which can provide design ideas and solutions for the optimization of variable propeller pitch control system strategy.

Keywords: variable pitch control; control strategy; PID controller.

1. Introduction
Variable speed and variable pitch control system is the important part of the wind turbine generator system. In recent years, wind power industry has developed rapidly, directly contributing to the research and development of this system. The performance of the system mainly depends on whether the control strategy is adaptive to the controlled objects or not. Currently, practical engineering often adopts conventional PI controller to control the angle of output pitch. This controller is easy to realize, but may have big overshoot phenomenon. As a complicated multivariable and non-linear system, wind generating set cannot get satisfactory control effects if only single control is adopted[1]. Adopting more suitable set controller plays an important role in reducing wind load, avoiding mechanical resonance, capturing wind energy to the maximum extend and ensuring good electricity quality of electrical grid.

The controllers introduced in this paper are all developed on the basis of Codesys programming language. Compared with traditional control algorithm, they have applied 3 PID controllers to choose the output control strategies in combination with control of rotation speed, pitch angle and accelerated speed to achieve the variable speed and pitch control. Finally I made a simulation test
in combination with practical operation data of the fans and had verified the feasibility of the control strategies.

2. Introduction of aerodynamic principles of the wind turbine generators

2.1. Utilization factor of wind energy $C_P$

Under the action of the wind energy, wind turbine rotates to make the generator produce electric energy. However, not all the wind energy can be captured in the swept area in practical operation of the wind turbines, so that there is the concept of wind power coefficient $C_P$, which represents the size of the energy that wind turbine absorbs from the nature wind energy.

$$C_P = \frac{P}{0.5 \rho S v^3}$$  \hspace{1cm} (1)

In Formula (1), $P$ is the power produced by wind generator set with the unit of W; $\rho$ is air density with the unit of kg/m$^2$; $S$ is rotor swept area with the unit of m$^2$; $v$ is the upstream wind speed with the unit of m/s.

In the unit of variable pitch control system, the major thing is to control the power output. And the fast or slow speed of power adjustment depends on the sensitivity of variable pitch control system to a great extent. It can be seen from formula (1) that power is proportional to the cube of wind speed. Therefore, the change of slower wind speed may arouse the change of greater wind energy, so that the power of unit output remains in continuous changes. When the change of wind speed is in the condition of too large amplitude, in order to maintain the smooth operation of fan, the variable pitch control system will make corresponding frequent actions because this system's response to wind is impossible to be made immediately but will have a certain time delayed. For example, when gust occurs, the operation of fan will be seriously affected if the variable pitch system doesn’t make actions timely within a short time. Thus, the sensitivity of variable pitch control system is an important index to measure the unit control strategies [3].

2.2. Tip speed ratio $\lambda$

Tip speed ratio $\lambda$ is used to show the status of wind turbine in different wind speeds and is measured by the ratio between the tip peripheral speed of vane and wind speed.

$$\lambda = \frac{2 \pi n R}{v}$$  \hspace{1cm} (2)

In formula (2), $n$ is the wind turbine's rotate speed and its unit is rad/s; $R$ is the radius of wind turbine and its unit is m; $v$ is the wind speed and its unit is m/s.

The relationship among utilization factor of wind energy $C_P$, tip speed ratio $\lambda$ and pitch angle $\beta$

$$C_P = 0.22 \left[ \frac{116}{\lambda+0.085} \frac{0.4975}{\beta^4+1} - 0.4975 \right] \rho \left( \frac{125}{\lambda+0.085} - 5 \right)$$  \hspace{1cm} (3)

In formula (3), it is the tip speed ratio $\lambda$, the speed of the top of the wind turbine blade; it is the pitch angle $\beta$[4]. The power characteristic curve of unit $C_P-\lambda$ can be acquired from formula (3), which is as graph 1.
The following conclusion can be obtained from graph 1:
1) For the fixed pitch angle $\beta$, there exists the unique maximum $C_{p\text{max}}$ of wind-power utilization coefficient.
2) With the increase of pitch angle $\beta$, the wind-power utilization coefficient $C_p$ decreases [4].

3. The design and model of the traditional variable pitch controller
Signals that are used in controlling pitch angle are power, wind speed and generator speed. In the actual application, it is difficult to measure wind speed precisely because the anemograph is influenced by blade vortex and installation site. And the corresponding speed of variable pitch system is under restriction. As for the wind speed which changes rapidly, if we preset and give feedback simply by giving power, the actual effect will not be ideal. Therefore, in order to optimize power curve, the newly designed variable pitch wind generator sets mainly use rotating speed of the generator as the control variable, and then output pitch angle through the data conversion.

3.1. PID Controller
The control algorithm introduced in this paper is based on the traditional PID control algorithm of incomplete derivation. Its characteristic is that it not only can restrain high-frequency interference, but only overcomes the disadvantages of common numbers PID control. The differential action of digital regulator can play the role of the real differential in every operation cycle according to the output change trend with average error. The incomplete derivative PID control strategy is:

In equation (4), $K_p$ for the proportional gain; $T_i$ for the integral time constant; $T_v$ for the differential time constant; $T_d$ for the filter coefficient. The block diagram of the controller is shown in Figure 2.

![PID Controller diagram](image)
The proportional element P: Proportional control is a kind of simple control mode, and the error signal of the controller’s input and output is proportional relation.

The integration element I: The error signal of the controller’s input and output is integral relation. In a control system, it is necessary to include integral terms if steady-state error exists after entering steady state. The integral terms primarily depend on the integration of error over time and the integral terms will increase as time increases. Thus, even if the error is very small, the integral term will increase as time increases, which drives the output of the controller to increase, further reducing the steady-state error until it reaches zero. Therefore, Proportion plus Integration (PI) controller can reduce the steady-state error after the system enters stable state, which is also common control strategy in variable pitch control.

Differentiation element D: The output of the controller is proportional to the differentiation of the error signal (the rate of change of the error) at the input. In general, oscillation or destabilization may occur during the adjusting process which aims at overcoming the error. It is because there is a rather big inertial element or a hysteresis element. The controller with differential terms added can predict the tendency of the error change, while the scale plus the differential PD controller can improve the dynamic feature of the system in the adjusting process [5].

3.2. The algorithm of the traditional variable pitch control

The pitch angle control strategy of the master control of the traditional wind generator set is shown in graph 3. On the side of the signal input, using speed deviation notch filter to get rid of the interference signal of rotation speed with specific frequency in advance. Immediately use the PI controller to control, as the change of the pitch angle is non-linear for the wind speed. If it is near the rated wind speed, a relatively small change in the wind speed requires the pitch angle to have a big change for a steady output. Therefore, when it is near the rated wind speed, it needs to increase and gain. Generally, the machine manufacturer will design several sets of PID parameters to be used in different running statuses.

![Fig.3 PI Controller of generator rotor speed](image)

The PI controller, with advantages of simple mathematical model, being easy to control and rapid to respond, is widely used in the practical use. And, its disadvantages are as follows: Its overshoot is big; fast adjustment can lead to the oscillation of the set; the controlling curve of the pitch angle is quite steep, which can cause mechanical fatigue of the actuator of the control system, and when the revolving speed is slow, it can lead to speeding oscillation, resulting in the imbalance of the set.

4. Combined variable pitch PID control algorithm

Optimized algorithm consists of two PD controllers and one P controller which respectively control generator speed, pitch angle and acceleration. The arithmetic uses three controllers as output, ultimately outputting and sending out to the actuator in the form of pitch angle through filtration of certain conditions and operation status.
4.1. **Pitch angle control**

Normally before grid-connection, this controller is used when the unit is in a state of start-up or self-inspection, because at that moment the generator is operating at a low speed and not stable yet, and there may be some errors in the speeds calculated by programs. Thus choosing current pitch angle as the control variable can achieve a better control precision, and the control structure is as shown in Figure 4.

![Fig.4 Controller of pitch angle](image)

4.2. **Generator rotational speed control**

When the whole set is in stable operation state around rated wind speed, most control operation is done by this controller. Use generator rotation speed as the control variable, and apply a low-pass filter to the signal input to filter the instantaneous changes in the rotation speed. Use a PT1 low-pass filter to smoothen the output rotation speed signal after the output of the PD controller. The pitch angle is transformed from the current rotor speed output through data conversion. The controller structure is shown in Figure 5.

![Fig.5 Controller of generator rotor speed](image)

4.3. **The acceleration control of generator rotation speed**

In the control, make real-time comparisons between the acceleration of rotational speed and the output of rotational speed controller. If the acceleration is higher than the rated value, that is, the speed deviation is too large, start using this acceleration controller to adjust. The structure of the controller is shown in Figure 6.
The use of this controller plays an important role mainly when generator speed deviation is too large or when we need to quickly pass the mechanical resonance region during the startup phase, which realizes the maximization of the power and avoids mechanical fatigue damage that long-time vibration may bring to the machine set.

5. The data simulation and analysis of the variable pitch control model

The controlled object studied in this paper is 1.5MW wind turbine generator system, which is three-vanned and double-fed with variable speed constant frequency. It conducts simulation and analysis by employing the software platform based on Codesys2.0, using the embedded controller based on PC as the hardware and comparing the pitch angle outputs by combining with the practical draught fan control program. The main technical parameters of the controlled object are shown in Table 1.

| Table.1 Technical Parameters of WTGS |
|-------------------------------------|
| parameter                           | Numerical value |
| Rated power /MW                     | 1.5             |
| Cut-in/out wind speed m.s^{-1}      | 3/25            |
| Rated wind speed /m.s^{-1}          | 11              |
| Rated rotor speed /r.min^{-1}       | 17.4            |
| Dia.of rotor /m                      | 77.36           |

Simulate the wind speed by using the wind speed simulation program, observe the starting procedure when wind speed is higher than specified and observe output pitch angle by using the two different controllers that introduced in this report. See Figure 7.

As can be seen from Fig.7, the use of optimized control algorithm can handle the output of pitch angle more smoothly, so as to avoid unnecessary mechanical damage that the vibration brings to the machine set. By contrast, the traditional controlling method with the weaknesses of adjusting too fast near the dial 0 can easily lead to vibration of the set, making the control carve steeper, inclines to make the variable pitch actuator operate wearily.
6. Conclusion

Compare optimized PD control and the traditional PI control. The optimized PD controller can make transitional running of the set smoother. This controller features in good dynamic response, strong adaptability, high control accuracy and so on. With good robustness and stability, it can effectively decrease the shock when the set starts, and make response curve smoother.

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