Comparative Study of PID, Fuzzy and Adaptive Fuzzy-PID Controller for Pitch Angle Control of Wind Turbine

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Abstract- To increase the power capacity of the wind turbine, larger rotors are being built which increases the aerodynamic loads across the blades. With the help of good pitch angle controllers, the lift profile of the rotor blades can be improved. The main study in this paper is to design an optimum controller to control the pitch angle of the wind turbine system to improve the performance, efficiency and power output daily of the wind turbine. Using principles of control engineering, the study selects Proportional-Integral-Differential Controller (PID), Fuzzy Controller, and mixed Fuzzy-PID controller. The optimal control possible through these methods are analyzed and compared. The comparison is done through MATLAB SimPowersystems.

Keywords: *Adaptive controller design, pitch angle control, fuzzy controller etc.*

I. INTRODUCTION

Wind energy as a renewable energy is brought attention to countries all over the world, however, because of the randomness of the wind speed and direction, output power of wind turbines will frequently fluctuate, thus influencing quality and stability of electrical power network. The blades of fixed-pitch wind turbines are fixed on the rotors, so when wind speed is higher than rated wind speed, pitch angle is non-adjustable. Fixed-pitch wind turbines have disadvantages of high start-up wind speed, large impact stress when it stops and so on, therefore variable pitch wind turbines arise at this historic moment. Pitch angle of variable pitch wind turbines can be adjusted along with wind speed, In order to keep output power get rated value, pitch angle can be increased to reduce windward area of wind rotors under high wind speed. This feature can effectively reduce the blade stress, as much as possible to absorb wind energy into electricity, and improve the power coefficient; these advantages make variable pitch wind turbines as the best choice for large wind turbines.

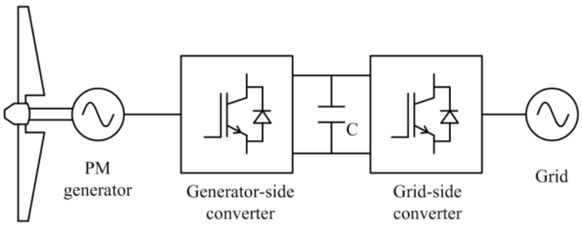


Fig.1. Block diagram Representation of Power system model

In the variable pitch wind turbine, pitch controller is the key to keep output power of generator constant. On the other hand, as wind turbines develop in the direction of large-scale, rotational inertia of blades become larger, it will brings difficulty and challenge to control power fluctuations which is caused by rapidly variable wind through pitch angle control.

II. WIND ENERGY GENERATION DETAILS

Power Capture in Horizontal-axis Wind Turbines, extracts energy by converting a part of the kinetic energy of the wind into mechanical work. The ratio of the power extracted from wind to the energy flowing through the area swept by the rotor in unit time is termed as the Coefficient-of-Power.

$$P = \frac{1}{2} C_P \rho A v^2$$

Where P, is the mechanical power captured, ρ is density of air, A is rotor area and *v*, is free-stream wind velocity. The maximum achievable in horizontal-axis wind turbines is 0.59. In practice, wind turbines have achieved power capture efficiencies of around 0.4. It can be shown that C_p is a function of the tip speed ratio, λ the ratio of linear velocity of blade tip to that of wind velocity. The variation of C_p with λ, for a typical three-bladed, horizontal-axis wind turbine is shown in figure below.

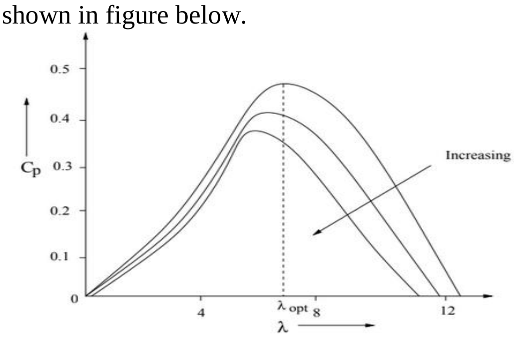


Fig.2 - Variation of C_p with tip speed ratio for a typical three bladed wind turbine

It can be seen that for a fixed pitch angle, the maximum value of C_p occurs at a particular value, λ_{opt}, of the tip speed ratio. To maximize energy capture it is desirable that the turbine operates close to the condition corresponding to $\lambda_{opt.}$

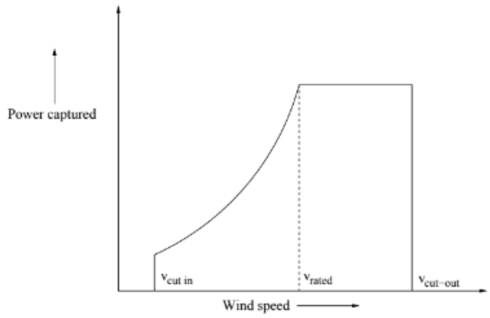


Fig. 3- Power Curve of a typical large wind turbine

Figure 3 shows a typical "Design Power Curve" of large HAWT. The smallest wind speed at which useful power capture becomes possible is termed as the cut-in wind speed. As expected, with an increase in wind speed, power captured by the turbine increases along with the mechanical loads on the turbine structure. At a pre-chosen wind speed, called as "rated" wind speed, the power extracted reaches rated power of the wind turbine. Above rated wind speed, power captured by the turbine is kept limited to the rated power so that the loads on the turbine structure are kept within design limits.

III. PITCH ANGLE CONTROL SYSTEMS

a) Traditional PID Control- PID control is the most widely used and mature traditional control strategy on variable pitch control of wind turbines. The simulation results show when the wind speed is higher than the rated, gain adjustment link can effectively improve the control performance of wind turbines. A PI controller is designed to control the speed of variable speed and constant frequency wind turbines in order to adjust the pitch angle. PID controller has simple structure, high reliability and good stability, but it excessively relies on model parameters of controlled objects and robustness is not so good. For variable pitch control has disadvantages, for examples, model structure and parameters can't be obtained accurately, and it has strong nonlinear, PID controller is difficult to gain satisfactory control performance.

b) Sliding Mode Variable Structure Control- Sliding mode variable structure control can be seen as discrete switch control, it can overcome the nonlinear effects of control system, so this control method is suitable for variable pitch control system of wind turbines which is nonlinear, strong-coupling and insensitive to the change of system parameters. It can be used for variable structure control strategy to control variable pitch system of wind turbines. Simulation shows that under high speed using multivariable sliding-mode variable structure control method can solve the influence of uncertain parameters in wind turbines control system and effectively ensure stability of wind turbines operation. Due to the sliding mode variable structure control is essentially a discrete on-off control, system is prone to chattering, which resulted in increasing static error.

c) *Fuzzy Controller-* Rule-based FLC is useful when the system dynamics are not well known or when they contain significant non-linearities, such as with wind containing large turbulence.

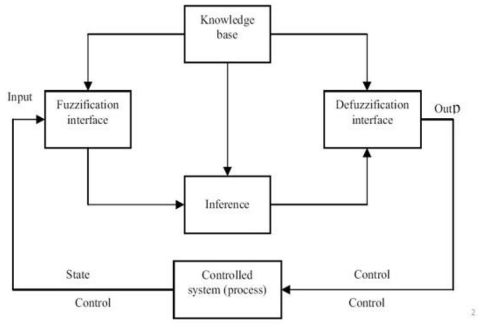


Fig. 4- Block diagram of Fuzzy Controller

FLC applies reasoning similarly to the way in which human beings make decisions; the controller rules thus contain expert knowledge of the system. The design process for a FLC consists of (i) determining the inputs, (ii) setting up the rules, and (iii) designing a method to convert the fuzzy result of the rules into output signal, known as de-fuzzification. De-fuzzification involves designing a method to convert the fuzzy results of the rules into output signals. The weighted average method is adopted to obtain accurate FLC output.

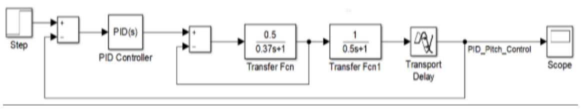
d) Adaptive Control- Based on new theory and new technology, fuzzy adaptive control is an effective method to solve the problem of PI parameters' online self-tuning. The idea of fuzzy adaptive PI control is combines a conventional PI controller with FLC. On the one hand, it has adaptive ability, which enables it to automatically identify the controlled process parameters, set control parameters, and adapt to the changes of process parameters. On the other hand, it also has the advantages of the PI controller, such as simple structure, high reliability and familiarity to practical engineering-design personnel.

Adaptive control is a control strategy which can identify reference control model. When dynamic changes appear in the process of system operation, adaptive control system once feel these changes, it will adjust parameters or control algorithms of controller in real time, in order to make specified performance index as close as possible to the optimum and maintain optimal. Therefore, considering the modeling uncertainty of the variable pitch control of wind turbines, adaptive control has a broad application prospect. Adaptive fuzzy control with variable universe, system adjusts the pitch angle of wind turbines by controlling the deviation and the deviation change of generator rated speed and feedback speed. The simulation results show that when wind speed or parameters change, this control method can effectively keep generator speed and output power constant.

Based on variable pitch system of wind turbines, a controller is designed for a minimum variance self-tuning adaptive controllers; its characteristic is that controlled object and controller both adopts discrete form. According to the simulation result, this controller is strong in robustness when controlled object model is uncertainty. When system is disturbed or electrical power network is instable, adaptive controller has advantages over other industrial controllers and better control effect can be obtained, but real time parameters are difficult to predict and identify by using adaptive controller.

IV. COMPARATIVE EFFECTS

a) *Traditional PID Control*- A PI controller is designed to control the speed of variable speed and constant frequency wind turbines in order to adjust the pitch angle. The Simulink model of wind turbine pitch control system with conventional PID Controller is shown in Fig. 5 with the control parameters.



Controller parameters	
Source:	internal
Proportional (P):	1.29826371423059
Integral (I):	0.413650662438756
Derivative (D):	-2.18301377158872
Filter coefficient (N):	0.157826479197648

Fig.5 PID Simulation block

b) Fuzzy Logic Controller- A fuzzy control system is a control system based on fuzzy logic—a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0.

The input variables in a fuzzy control system are in general mapped by sets of membership functions similar to this, known as "fuzzy sets". The process of converting a crisp input value to a fuzzy value is called fuzzification. A control system may also have various types of switch, or "ON-OFF", inputs along with its analog inputs, and such switch inputs of course will always have a truth value equal to either 1 or 0, but the scheme can deal with them as simplified fuzzy functions that happen to be either one value or another.

c) *Adaptive Control*- The design process for a fuzzy adaptive PI controller consists of four parts: (i) determining of inputs and outputs, (ii) reasoning of fuzzification and fuzzy logic, (iii) defuzzification, (iv) parameters' online self-tuning of PI controller.

The fuzzy control system adjusts the parameter of the PI control by the fuzzy rule. Dependent on the state of the system, the adaptive PI realized is no more a linear regulator according to this principle.

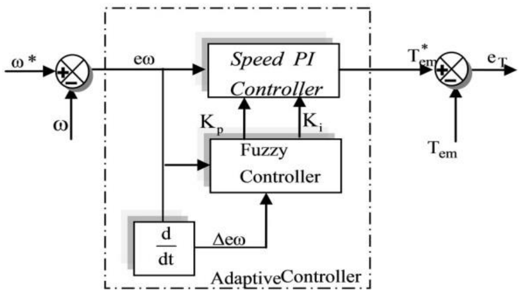


Fig.6 Control diagram for adaptive methods

V. CONCLUSION

Variable pitch control of wind turbines is the key technology which can regulate power coefficient effectively and keep output power of generators fixed under high wind speed. For nonlinear variable pitch control system, fixed parameters PID controller is difficult to obtain satisfactory control performance. The Advanced control strategies Adaptive control mechanisms, is favorable for variable pitch control system.

VI. REFERENCES

[1] C. Tan and H. Wang, "A Review on Pitch Angle Control Strategy of Variable Pitch Wind Turbines", Advanced Materials Research, vol. 772, pp. 744-748, 2013.
[2] J. Sarkar and S. S. Khule, "A study of MPPT schemes in PMSG based wind turbine system," *2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, Chennai, 2016, pp. 100-105
[3] Dunne, F. "Optimizing Blade Pitch Control of Wind Turbines with Preview Measurements of the Wind." Order No. 10108716 University of Colorado at Boulder, 2016.
[4] Han, Bing, Lawu Zhou, Fan Yang, and Zeng Xiang, "Individual Pitch Controller Based on Fuzzy Logic Control for Wind Turbine Load Mitigation," IET Renewable Power Generation, vol.10.5, pp.687-693, 2016.
[5] Sharma,R.D,. 'Feedforward Learning Control for Individual Blade Pitch Control of Modern Two-Bladed Wind Turbines,'2013.
[6] Tambat, Milind, Joydeep Sarkar and Pramod Yade. "Maximum Power Tracking of Permanent Magnet Synchronous Generator in Wind Technology." (2014).
[7] Y.Qi and Q. Meng, "The Application of Fuzzy PID Control in Pitch Wind Turbine", Energy Procedia, vol. 16, pp. 1635-1641, 2012.
[8] Zhang, Dahai, Philip Cross, Xiandong Ma, and Wei Li. "Improved Controlof Individual Blade Pitch for Wind Turbines." Sensors & Actuators, vol.8, pp. 12-18, 2013