

Study of Variable-pitch Wind Turbine based on MATLAB Simulation

Yang Chen

School of Electrical Engineering & Information, Northeast Petroleum University, Daqing 163318,
China

823271314@qq.com

Abstract. First, the analysis of developing status of wind turbine control strategy has been made; second, some mathematical models about aerodynamic parts are established according to the principle of the wind power generating units various parts. At the same time, some sub-modules of the wind turbine are established in MATLAB. At last, the control strategy based on Fuzzy controller is design and simulated by MATLAB/Simulink. Both in the low wind speed and high speed the power output of the generator can quickly reached a stability (about 4s), which improve the control system respondent time.

Keywords: wind power generation; fuzzy control; MATLAB simulation.

1. Introduction

Wind power is an important component of new energy, is an inexhaustible and renewable energy source, is hailed as a clean, green, green energy, and more and more people have recognized its advantages. Currently, wind power generation is the fastest growing green energy sources. Among them, the overall designs of wind turbine, blades, and electric control system and direct-drive type of wind turbine generator are the most critical technologies of Large-scale wind turbine's research and manufacture. International upwind turbine is developing towards large-scale, variable pitch and variable-speed constant-frequency. Megawatt wind turbine has become a mainstream product in the international wind power market^[1]. Wind turbine output power controls have two methods which are fixed pitch control (stall regulation) and variable pitch adjustment^[2]. With the development of large-scale wind power generating units, the shortcomings of stall regulation are gradually emerging, so variable pitch control technology has become one of the key technologies of wind power.

2. The development of control strategy of wind turbine generators

There are two major types of the research to the control strategy of wind turbine generators according to the different kind of controllers at the present time^[4]: the traditional method based on the mathematical model and modern control method. The modern control method includes variable structure control, robust control, Adaptive control, and intelligent control.

2.1 Traditional control method

In order to catch the maximum wind energy, we keep the windmill's speed ratio of leaf apex at the optimal value through regulating the Torque in DTC of generator and the blade pitch angle. It resorts linear control method which based on linear model. Its drawback is that the regulation is relatively backward when the wind speed changes quickly. This method does not apply to the wind power system with wide working range, big stochastic shocks, more uncertainties, and serious nonlinear based on some certain operating point of linear model method. It can only assure the control effect near the linear operating point.

2.2 Modern control method

(1) Variable structure control

The wind generator usually works between normal model and stall model. The variable structure control of the sliding mode is widely applied in wind power system for its quick response, insensitivity to the change of system parameters, simple designs.

(2) Robust control

Robust control method has the ability of dealing with multivariate statistical problem. Some problems can be solved directly in steady robust control. It includes the existence of modeling error, inaccurate parameter, and problem of interference position system.

(3) Fuzzy control

Fuzzy control is a typical intelligent control method and it is widely applied in natural science and social science. Its strongest characteristic is to change the expert’s knowledge and experience to linguistic rule that be used in control. It does not depend on the accurate mathematical model of the object, overcomes the influence of the nonlinear and has stronger Robust to the object. It is hard to accurately define the system model for the uncertainty of the aerodynamics and power electronic model and many other uncertain facts. So the fuzzy control is fit to the control of the wind turbine generators and researchers pay more and more attention to it.

3. Pitch-controlled wind turbine generators

When the wind acts on the axis wind turbine at a fixed speed and angle, the blade will turn for rotary torque. The wind energy will convert to the torque at the same time and then drive the speeder to make the generator produce the power.

According to the air characteristics of the blade, wind power coefficient C_p is a function which includes the speed ratio of leaf apex λ and the pitch angle β , $C_p = C_p(\lambda, \beta)$ and the experience formula is that:

$$C_p = (0.44 - 0.0167\beta) \sin\left[\frac{\pi(\lambda - 3)}{15 - 0.3\beta}\right] - 0.00184(\lambda - 3)\beta \tag{1}$$

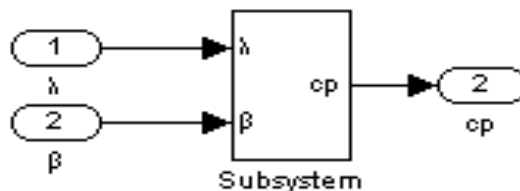


Fig. 1 the model builds in MATLAB

The useful power when the wind turbine generator catches the wind is that:

$$P_r = \frac{1}{2} \rho S C_p v^3 \tag{2}$$

In formula, P_r —the power that the blade absorbed, W; ρ —air density, kg/m³; S —the area the blade swept, m²; C_p —wind power coefficient; λ —the speed ratio of leaf apex; β —the pitch angle; v —the wind speed, m/s.

The wind turbine generators can be divided to three subsystems according to the control system: Vertical Axis Wind Turbine, Dynamic characteristics of the transmission system, generator model [5-7].

Vertical Axis Wind Turbine. In the system, we consume that the blade is rigid. The dynamic model of the Axis Wind Turbine can be described with the equation like that:

$$J_r \frac{d\omega_r}{dt} = T_r - nT_m \tag{3}$$

In formula, J_r —the moment of inertia of the axis wind turbine, kg·m²; ω_r —the angular velocity, rad/s; T_r —aerodynamic torque, N·m; n —speed ratio of the gear case; T_m —torque, N·m.

The relationship between the torque and the power of the axis wind turbine is like that:

$$T_r = \frac{P_r}{\omega_r} = \frac{1}{2} \rho \pi R^2 C_p \frac{v^3}{\omega_r} \tag{4}$$

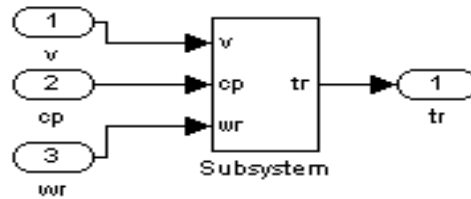


Fig. 2 the torque model of the axis wind turbine built in MATLAB

(1) Dynamic characteristics of the transmission system

According to the dynamic characteristics of the axis wind turbine, the torque T_r made by axis wind turbine acts on the axis wind turbine with the moment of inertia J_r . The axis wind turbine connects to the generator with the moment of inertia J_g through the speeder with the n speed increasing ratio. Then the generator will produce a reversal torque T_e . For the rigid connection between the axis wind turbine and input shaft and speeder, we neglect the total friction and the relative angular displacement on the output shaft.

(2) Generators

The research related to the generators which is the winding three-phase induction generator, Therefore, we change generator's counter-torque and rotational speed by changing the stator voltage to achieve the speed change.

$$T_e = \frac{pm_1 U_1^2 r_2}{(\omega_g - \omega_1) \left[\left(r_1 - \frac{C_1 r_2 \omega_1}{\omega_g - \omega_1} \right)^2 + (x_1 + C_1 x_2)^2 \right]} \tag{5}$$

In formula, p -generator pole pairs number; m_1 -stator phase number; U_1 -grid voltage, V; C_1 -corrected factor; ω_g - generator rotating angular velocity, rad/s; ω_1 -generator synchronous speed, rad/s; r_1, x_1 -, respectively are stator winding resistance and leakage reactance, Ω ; r_2, x_2 - respectively are the counted rotor winding resistance and leakage reactance, Ω ;

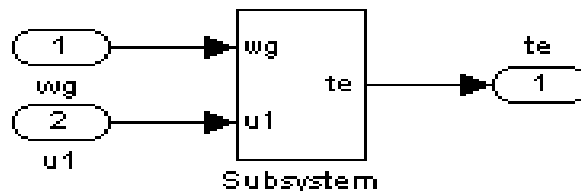


Fig. 3 generating anti-torque module built in MATLAB

Generator rotation equation is:

$$J_g \frac{d\omega_g}{dt} = T_m - T_e \text{ One is } \omega_r = \frac{\omega_g}{n} \tag{6}$$

(6) collating (3) and (6)-type we get:

$$\omega_r = \int \frac{T_r - nT_e}{T_r + n^2 J_g} dt \tag{7}$$

Pitch-body model can be regarded as a first-order inertia link as follows:

$$\frac{d\beta}{dt} = \frac{1}{T_\beta} (\beta_{ref} - \beta) \tag{8}$$

In formula, T_β is the time constant; β_{ref} is a referenced input; β is the output of the executing agency (pitch angle).

4. The design and simulation results of Fuzzy controller

4.1 The selection of fuzzy controller

The bias and bias rate of change are usually selected as fuzzy controller's input variables, and the changes in controlled value is selected as the value of output [3]. Now the two-dimensional fuzzy controller is widely used. This paper also used two-dimensional fuzzy controller, and its specific structure shown in Figure 4. First we input fuzzy quantification, get fuzzy variables E and E_c ,

according to the rules of fuzzy control we make fuzzy decision and get the fuzzy controlled value U , then after solving the fuzzy and scaling, finally we get actual control output.

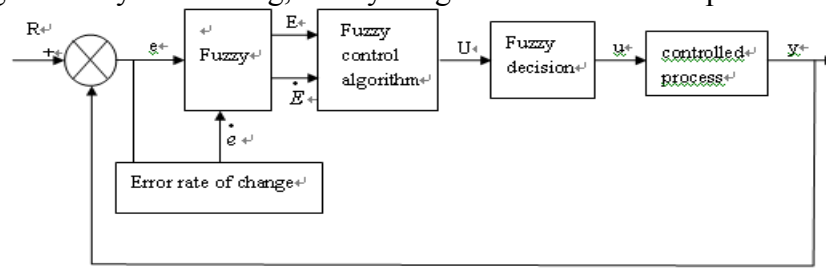


Fig. 4 Two-dimensional fuzzy controller structures

In this design, the two controllers for low wind speed and high-speed regions were respectively designed. From Cong Feng farm experimental data we can see that when pitch angle is 0, tip-speed ratio is 9, the power factor value C_p is the biggest. Therefore, when at low wind speed, in order to get the biggest wind energy, we should make tip speed ratio λ is constantly at 9, to get the maximum output power requires two real-time measured values, namely, tip speed ratio and its rate of change. At high speed, in order to maintain the allowed maximum power, blade pitch angle should be adjusted so that the wind energy utilization factor to achieve an appropriate value, so we need two real-time measured values, namely, rate of change of power and power.

4.2 The base of Wind power fuzzy control rule was established

Fuzzy controller is often in the form of query table, and the table is based on fuzzy control rules. Through fuzzy control algorithm we get fuzzy control input and output value which given the relationship between discrete points on the corresponding form. To be able to produce this form, we need to transform the language variable domains from continuous domains into priority integer discrete domain.

In order to discretize the domain, we let deviation of E be expressed in eight languages variable: {Positive big (PB), Positive middle (PM), and Positive small (PS), Positive zero (PZ), negative zero (NZ), negative small (NS), negative middle (NM), negative big (NB)}

We use seven linguistic variables for the change rate of deviation and controlled values U : {Positive big (PB), Positive middle (PM), and Positive small (PS), zero (ZR), and negative small (NS), negative middle (NM), negative big (NB)}

We should let the language value E be normalized to the interval $[-6,6]$, discreted into eight files.

Suppose the domain of deviation E is $[a, b]$, we selected the E 's domain which is: $X = (-6, -5, -4, -3, -2, -1, -0, +0, 1, 2, 3, 4, 5, 6)$, Through the formula $x' = \frac{12}{b-a}(x - \frac{a+b}{2})$, we transform the actual input into the $[-6,6]$'s fuzzy control domain, which is used as a fuzzy controller input^[5].

Similarly we choose change rate of deviation E_c and the controlled value U 's domain is: $X = (-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6)$, which transformed by the appropriate conversion formula.

Using triangular membership functions (trimf) to describe the membership function of fuzzy sets (Figure 5), and thus linguistic variables E , E_c and the assignment sheet of U can be established.

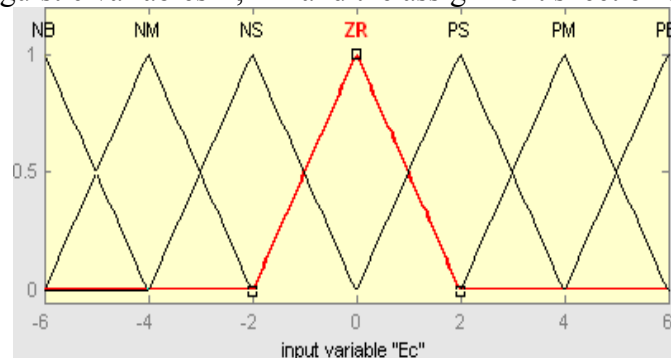


Fig. 5 fuzzy sets membership function

General principles in selecting the value of control changes are: when the errors large or larger,

choose the value of control to mainly eliminate errors as soon as possible; when the error is small or smaller; the chosen value of control need to avoid overshoot, in order to ensure system stability.

When the at low wind speed, control rules of fuzzy controller in wind power generation control system can be described in Table 1.

Table 1 when low-speed fuzzy control rule table

E U Ec	NB	NM	NS	NZ	PZ	PS	PM	PB
NB	PB	PB	PM	PS	PS	PS	ZE	ZE
NM	PB	PB	PM	PS	PS	ZE	ZE	ZE
NS	PB	PB	PS	PS	ZE	ZE	NS	NM
ZE	PB	PM	PS	ZE	ZE	NS	NM	NB
PS	PM	PS	ZE	ZE	NS	NS	NB	NB
PM	ZE	ZE	ZE	NS	NS	NM	NB	NB
PB	ZE	ZE	NS	NS	NS	NM	NB	NB

The fuzzy control rule table is established above (can also be used to represent the fuzzy control statements), which is prepared for the application in MATLAB Fuzzy Logic FIS Editor window. Finally, this paper adopts the area center law so that fuzzy value transform into a clear digital.

4.3 MATLAB simulation and the results of simulation

When we use fuzzy controller to control the system, we should build an overall system model and carry out simulation in MATLAB. Wind turbine parameters are as follows: Wind wheel diameter: 62m; rated wind speed: 15m /s; rated power: 1300kw; generator rated speed: 1519r/min; stator’s rated phase voltage: 690v; Number of motor pole pairs: $P=2$; the number of stator phase: $m1=3$; corrected factor: 0.81; air Density: 1.225kg/m³. When the wind speed changes, the output power of simulation results as shown in Figure 6, 7.

When lower than the rated wind speed, we use fuzzy controller to change the generator stator voltage, thereby regulating regulator anti-torque to change the rotational speed; when higher than the rated wind speed, in order to ensure a constant power output we use another fuzzy controller to adjust blade pitch angle to change the Cap values.

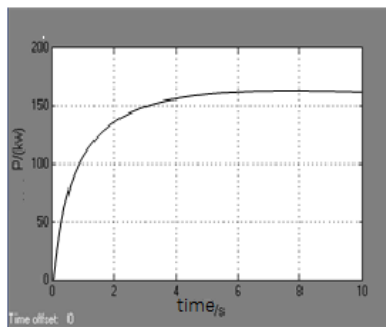


Fig. 6 when speed $v = 6\text{ m/s}$ the output power of asynchronous motor

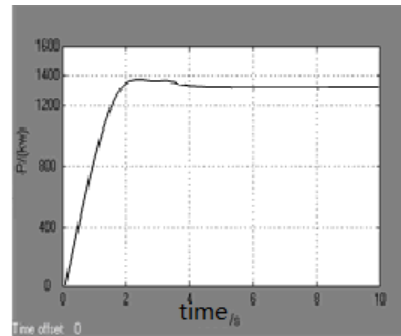


Fig. 7 when wind speed $v = 20\text{ m/s}$ the output power of asynchronous motor

5. Conclusions

From the simulation results can be seen: simulation results of the entire system control strategy obtained satisfactory, both in the low wind speed and high speed the power output of the generator can quickly reached a stability (about 4s), which improve the control system respondent time. Compared with the traditional control, fuzzy control can effectively suppress overshoot and fluctuations of output power at the initial stage, and can reach a steady state faster, meet better control requirements. In order to make sure that wind turbines can operate safely and smoothly, the fuzzy control is applied to wind power generation systems, which have a significant meaning for enhancing the development of wind power generation technology and developing wind power generation.

Acknowledgment

This work is supported by Scientific and Technological Research Project in Heilongjiang Province (GZ08A504), High School Young Academic Backbone Support Project in Heilongjiang Province (1154G052)

References

- [1] Wang, Baoe; Xu, Jianjun; Yan, Limei. Brittleness simulation of electric power systems based on chart theory [J]. Energy Education Science and Technology Part A: Energy Science and Research, v 31, n 3, p 1769-1778, 2013
- [2] Xu, Jianjun; Liu, Shengnan; Xu, Bin; et al. Numerical modeling for chaotic characteristics of oil pipeline pressure time series[J]. International Journal of Applied Mathematics and Statistics, v 47, n 17, p 131-139, 2013
- [3] Long, Xing; Jian-Jun, Xu; Li-Mei, Yan*. Study on the effect of pickled cabbage using freeze-drying protective agent [J]. Advance Journal of Food Science and Technology, v5, n10, p1404-1406, October 2013
- [4] Xu Jian-jun, XU Ai-hua, Yan Li-mei, et al. Grids State Estimation of Quadrature Kalman Filter Based on PMU/SCADA[J]. Energy Education Science and Technology Part A: Energy Science and Research, v 32, n 2, p 1033-1038, 2014
- [5] Nai-bo Zhang, Jian-jun Xu*, Chen-guang Xue. Core-shell structured microporous silica nanoparticles equipped with pyrene-based chemosensor: Synthesis, characterization, and sensing activity towards Hg (II) [J]. Journal of Luminescence, 2011, 131(9): p: 2021-2025
- [6] Xu Jian-jun, Xu Yan-chao, Yan Li-mei*, et al. Research on the method of optimal PMU placement [J]. International Journal of Online Engineering, v 9, S7, p 24-29, 2013
- [7] Liu Zhengliang, Xu Jianjun*, Li Hongyu. A kind of energy saving controller based on Y/ Δ change-over [J]. Sensors and Transducers, v 161, n 12, p 331-336, 2013