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Power Optimal Control of Wind Turbine Based on Genetic Algorithm

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Abstract

In order to improve smooth control of output power of megawatt variable pitch controlled wind turbine at high wind speed, an optimized fuzzy PID algorithm is proposed which includes PID and fuzzy control. The initial and the adjusted values of three parameters of this controller are given by Ziegler-Nichols tuning method and fuzzy control method. At the same time, variable weight synthesis of integrated time and absolute error (ITAE) index, overshoot index and settling time index of the system is used for establishing the objective function. Genetic Algorithm (GA) is used for optimizing fuzzy rules of fuzzy PID controller and obtaining the optimized parameters. A simulation validates the proposed method. We take a 1.5MW doubly fed induction wind generator (DFIG) as the subject. With calculation and comparison of the standard deviation of output power before and after rules optimization, it indicates that smoothness of output power becomes better. The control effect has been further improved as well.

Keywords*: Wind turbine, Active power, Smooth control, Fuzzy PID, Genetic algorithm, Standard deviation*

1. Introduction

With continuous development and expansion of wind turbine scale, the capacity of the generator is constantly increased which leads to the pitch controlled wind turbine becomes the mainstream in the development of concerning large scaled wind turbine. Appropriate design regarding reliability and stability is part of the key technologies for high-efficient and reliable operation of variable pitch controlled wind turbine. Because of uncertainty of wind and characteristics related to wind turbine, output power of wind turbine is fluctuated excessively, which makes a negative influence on power quality. With the ever-increasingly enlargement of wind energy, it is of great significance to adopt advanced control strategy and controllers, undoubtedly, with better performance to improve the smoothness of wind turbine output power.

In recent years, foreign and domestic scholars conduct scientific researches in smooth control of the wind power, such as power electronic technology [1] and the energy storage element [2-4], they are used to inhibit the fluctuations of wind turbine output power, however, extra hardware devices are prerequisite, which increases the cost and difficulty of control system. Literatures [5,6] realize the maintain smoothness of active output power by controlling the variable propeller device, but when the wind speed changes fast, the whole power system response delay and can't achieve ideal control effect because of the wind turbine and the pitch angle adjusting device with large inertia. References [7,8] use variable propeller and variable speed control to realize wind turbines power smoothing control under all wind speed, but when the wind speed changes quickly, the control strategy of quickly switch causes the fluctuation of power, even the system instability.

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Reference [9] puts forward an algorithm based on fuzzy exponential moving average smooth control strategy which balances the requirement among system stability, active power smoothness and wind energy utilization, but this method only has carried on the qualitative description, there is no quantitative description of the degree of power smoothness.

Fuzzy PID controller not only has adaptability and robustness of the fuzzy controller, but also has the advantages of high precision of PID controller. It has been used in the wind turbines active power control [10-12], but the rules of fuzzy controller are relied on expert experience, does not guarantee to get good control effect, therefore, in order to improve the smoothness of wind turbine output power, this paper proposes an optimized fuzzy PID control algorithm, in which the fuzzy control rules of fuzzy PID controller are optimized based on GA by using its ability of searching in whole range to get a more reasonable fuzzy control rules, and also realize the output power smooth control of variable pitch controlled wind turbine, and the standard deviation of active output power is used for quantitative description of active power smoothness.

2. Modelling of Power Optimization Control System

2.1. Wind Turbine Model

Wind turbine is a complex system with strict requirements and works under the unpredictable wind speed condition. In view of control perspective, it mainly includes wind rotor model, drive chain model and generator model [13].

2.1.1. Wind Rotor Model

When natural wind flows through the wind rotor axially, the power, aerodynamic torque and rotor power coefficient obtained from wind are as follows [14]

$$P_{\mathrm{r}} = 0.5\rho V^3 S C_{\mathrm{P}}(\lambda,\beta) \tag{1}$$

$$T_{\mathrm{r}} = 0.5\rho S C_{\mathrm{P}}(\lambda,\beta) V^3 / \omega \tag{2}$$

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

$$\lambda = \frac{2\pi n R}{V} = \frac{\omega R}{V} \tag{4}$$

where P_{r} is mechanical power of wind turbine; ρ is air density; S is wind turbine heating area; C_{p} is rotor power coefficient; λ is tip speed ratio; β is pitch angle; V is wind speed; T_{r} is aerodynamic torque; ω is principal axis speed of turbine; R is rotor radius.

2.1.2. Drive Chain Model

According to the aerodynamic performances of wind rotor, it's aerodynamic torque T_{r} acts on on wind turbine generator. Wind rotor is connected to generator through a gear box, the generator will produce a revert-torque T_{e}, because of the rigid connection between wind rotor, input shaft and the gear box, therefore, the total friction force and relative angular displacement of output shaft in transmission system can be ignored [15].

For the non-direct drived wind turbines, the dynamic equation of the low speed shaft near to the wind rotor can be defined as

$$J_{\mathrm{r}} \frac{\mathrm{d}\omega}{\mathrm{d}t} = T_{\mathrm{r}} - nT_{\mathrm{m}} \tag{5}$$

where, J_r is the wind rotor moment of inertia; T_m is the torque of gear box passed from the rigid gear shaft; n is growth box gear ratio.

Near to the high-speed shaft side of generator, ignoring the mechanical resistance from the generator itself, the dynamic equation can be described as

$$J_g \frac{d\omega_g}{dt} = T_m - T_e \tag{6}$$

where, J_g is generator rotor inertia; T_e is electromagnetic torque of generator; ω_g is rotation speed of the generator.

Substituting Eq.6 into Eq.5, we obtain the equation of wind turbine driving chain

$$(J_r + n^2 J_g)\frac{d\omega}{dt} = T_r - nT_e \tag{7}$$

2.1.3. Generator Dynamic Mathematical Model

The generator in the study is DFIG, it changes the generator torque and rotational speed to realize variable speed by changing the stator voltage, a simple model is as follows [12]

$$T_e = \frac{g m_1 U_1^2 R_2}{(\omega_G - \omega_1)[(R_1 - \frac{C_1 R_2 \omega_1}{\omega_G - \omega_1})^2 + (x_1 + C_1 x_2)^2]} \tag{8}$$

where, g is generator pole pairs; m_1 is phase number; U_1 is stator voltage; C_1 is correction factor; ω_G and ω_1 are generator equivalent angular velocity and synchronous angular velocity, respectively (ω_G=2ω_g); R_1 and x_1 are resistance and leakage reactance of the stator windings; R_2 and x_2 are resistance and leakage reactance of the stator windings after the reduction.

2.1.4. Electric Variable Pitch Actuator Model

The model of electric variable pitch actuator describes the dynamic state of the pitch angle index to its excitation from the controller. The mathematical model can be equivalent to a first-order system [16]

$$G(s) = \frac{\beta(s)}{\beta_{ref}(s)} = \frac{K_\beta}{1 + \tau_\beta s} \tag{9}$$

where, β is the actual value of pitch angle; β_{ref} is the reference value of pitch angle; K_β is proportionality coefficient and τ_β is time constant.

2.2. Power Optimization Control Model

The error of output power is used as the input of the control system in this paper, with GA to optimize fuzzy rules, get optimal control parameters, by controlling the pitch angle, and finally achieve a smooth control of output power. The block diagram of power optimization control of variable pitch controlled wind turbine is shown in Figure 1.

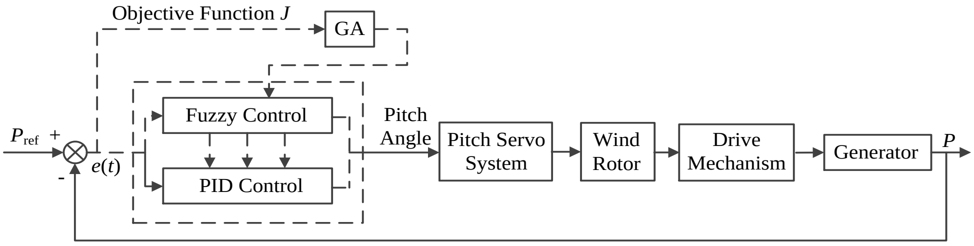

Figure 1. The Power Optimization Control Structure of Wind Turbine

3. Fuzzy PID Control based on GA

3.1. Establishment of Objective Function

The integrated time and absolute error (ITAE) performance index has penalties for error in time of the system, the latter the setting time of the error is, the bigger the time coefficient which multiplied to the index is. In this paper, a weighted comprehensive evaluation index which consists of ITAE index, overshoot index and settling time index, is proposed to measure maximum dynamic deviation and settling time of the system. The objective function is established as follows

$$J = a_1 \int_0^\infty t\left|e(t)\right|dt + a_2\sigma_1 + a_3 t_s \tag{10}$$

where a_1, a_2 and a_3 are weight values; $e(t)$ is the power error; σ_1 is the overshoot and t_s is settling time.

3.2. Design of the Fuzzy PID Controller

Fuzzy PID controller is the combination of fuzzy controller and PID controller, it regards the output power error e and the rate of error change ec as input variables, so it can meet the requirements of PID parameters self-tuning in different moments. Fuzzy PID control schematic is shown in Figure 2 [17].

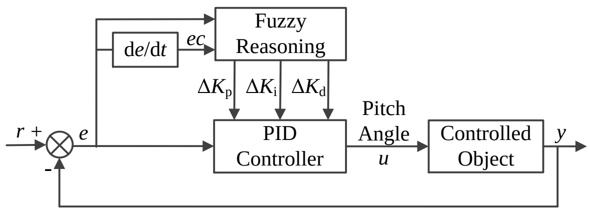

Figure 2. The Structure of Fuzzy PID Control

Fuzzy adaptive parameters tuning is to seek the relationship between three parameters of PID and the system power error *e* and the rate of error change *ec*. When during the simulation, continuously detecting *e* and *ec*, then according to the results of fuzzy reasoning to modify the three parameters of PID controller to meet the different control parameters *e* and *ec* under different requirements, so that the control system has a good performance, to guarantee the better transient and steady-state performance of the system. After adjustment the PID parameters are as follows

$$K_p = K_{p0} + \Delta K_p \tag{11}$$

$$K_i = K_{i0} + \Delta K_i \tag{12}$$

$$K_d = K_{d0} + \Delta K_d \tag{13}$$

Where, K_{p0}, K_{i0} and K_{d0} are initial values of regulator parameters calculated with Ziegler-Nichols tuning method, and ΔK_p, ΔK_i and ΔK_d are three fuzzy controller output parameters.

In this paper, *E* is the fuzzy linguistic values of the variables *e*, *EC* is the fuzzy linguistic values of the variables *ec*, ΔK_{pf}, ΔK_{if} and ΔK_{df} are the fuzzy linguistic values of variables of PID increments ΔK_p, ΔK_i and ΔK_d. According to the error range of PID controller in most practical application and value of PID parameters, the variable universe of discourse of power error *e* and the rate of error change *ec* is taken as {-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6}, then divided it into 7 levels , the linguistic values of the 7 fuzzy sets are taken as {NB, NM, NS, ZO, PS, PM, PB}, that is {Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium, Positive Big}. Comparing the actual measured power and the desired power, the practical range of error *e* and the rate of error change *ec* are [-*e*, *e*] and [-*ec*, *ec*], The parameters of the model are fuzzily processed by quantitative factor, the quantitative factor of *e* is K_e=6/*e*, and the quantitative factor of *ec* is K_{ec}=6/*ec*.

In this paper, triangular function is chosen as membership functions, mamdani reasoning model is used for fuzzy reasoning and the centroid method for defuzzification.

The basic principle of fuzzy control rules selection is based on existing empirical knowledge, when the error *E* becomes large, the major task of the controller is to reduce the error as quickly as possible, so that the parameter added to error *E* should be large. When the error *E* is small, system becomes closed to the steady state, such the major task of the controller is to make system steady as soon as possible and avoid overshoot, as a result, in the control rules, the parameter added to the rate of error change *EC* should be large. According to this principle to make a series of control rules, and combine with the characteristics of the regulation of the system, summarize these control rules as a Table, and get the fuzzy control rules Table.

According to the rules selection principle of traditional PID controller, control rules adjustment of *E*, *EC*, ΔK_{pf}, ΔK_{if} and ΔK_{df} in this paper are shown in Tables 1 to 3.

Table 1. The Fuzzy Rules Table of ΔK_{pf}

ΔK_{pf}		*EC*						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	PB	PB	PM	PM	PS	ZO	ZO
	NM	PB	PB	PM	PS	PS	ZO	NS
	NS	PM	PM	PM	PS	ZO	NS	NS
	ZO	PM	PM	PS	ZO	NS	NM	NM
	PS	PS	PS	ZO	NS	NS	NM	NM
	PM	PS	ZO	NS	NM	NM	NM	NB
	PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2. The Fuzzy Rules Table of ΔK_{if}

ΔK_{if}		*EC*						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	NB	NB	NM	NM	NS	ZO	ZO
	NM	NB	NB	NM	NS	NS	ZO	ZO
	NS	NB	NM	NS	NS	ZO	PS	PS
	ZO	NM	NM	NS	ZO	PS	PM	PM
	PS	NM	NS	ZO	PS	PS	PM	PB
	PM	ZO	ZO	PS	PS	PM	PB	PB
	PB	ZO	ZO	PS	PM	PM	PB	PB

Table 3. The Fuzzy Rules Table of ΔK_{df}

ΔK_{df}		*EC*						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	PB	NS	NB	NB	NB	NM	PS
	NM	PS	NS	NB	NM	NM	NS	ZO
	NS	ZO	NS	NM	NM	NS	NS	ZO
	ZO	ZO	NS	NS	NS	NS	NS	ZO
	PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
	PM	PB	NS	PS	PS	PS	PS	PB
	PB	PB	PM	PM	PM	PS	PS	PB

3.3. Fuzzy Control Rules Optimization based on GA

GA is a search algorithm based on the mechanics of natural selection and natural genetics. The searching process is similar to the natural evolution of biological creatures in which successive generations of organisms are given birth and raised until they themselves are able to breed, through simple operation such as selection, crossover and mutation repeatedly to achieve the goal of evolution, to obtain the optimal solution of problems [18]. The traditional fuzzy control rules of fuzzy PID controller selected merely rely on existing empirical knowledge, cannot achieve better control performance, therefore, it is necessary to use GA and it's random optimization search ability to optimize fuzzy control rules in order to get higher performance.

In this optimum design, a string of 3 binary digits represents linguistic values, that is {NB, NM, NS, ZO, PS, PM, PB}={001, 010, 011, 100, 101, 110, 111}. Four binary numbers can be used to represent a rule, the first one is for control bit, and the last three refers to rules. In this way, the control rules described with binary code to get the rules of the chromosome is controlled by the 49 control genes and 3×49 rules genes. By controlling the control gene to realize the single control of the rules gene, namely, the first bit is 0 for the corresponding rules don't work, while 1 for the corresponding rules applies.

In optimization search, GA is based on fitness function, using the fitness value of each individual in a population. The fitness function is the reverse of the objective function which could be expressed as $F=1/J$, after G iterations, the genetic algorithm fitness will reach the highest, substituting the optimized fuzzy rules into fuzzy PID controller, to obtain the optimized control effect of fuzzy PID controller, by adjusting the pitch angle, to achieve the smooth control of output power at high wind speed.

The initial settings for the operation of the GA should be defined. In this paper, the population size M=25, genetic algebra G=100, mutation probability p_m=0.1, and crossover probability p_c = 0.95.

4. Simulation and Analysis

The performance of a 1.5MW DFIG wind turbine control system is tested under a random wind with rated speed 12.5m/s, the wind velocity range is 3~25m/s, and the rotor radius and air density are 35.25m and 1.25kg/m^3, respectively. The Input variables varying range of fuzzy PID controller are e=[-30kW, 30kW] and ec=[-60kW, 60kW], and the output variables varying range are ΔK_p=[-0.3, 0.3], ΔK_i=[-0.06, 0.06], ΔK_d=[-3, 3], respectively. After optimization the fuzzy control rules are shown in Tables 4 to 6.

Table 4. The Fuzzy Rules Table of ΔK_{pf} after Rules Optimization

ΔK_{pf}		*EC*						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	PM	PS	NS	NS	NB	NM	PM
	NM	NB	NS	NM	NM	ZO	PM	ZO
	NS	NS	ZO	ZO	NB	NB	NB	NS
	ZO	NS	PS	NM	PB	PM	PS	PB
	PS	NM	PM	ZO	ZO	ZO	NB	PB
	PM	ZO	NB	PS	PB	PB	NS	PB
	PB	PM	NS	NB	ZO	NM	NS	PB

Table 5. The Fuzzy Rules Table of ΔK_{if} after Rules Optimization

ΔK_{if}		*EC*						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	PM	PS	NB	ZO	PS	NS	NS
	NM	PM	NS	NS	ZO	PM	NS	PB
	NS	NS	PM	ZO	PM	PS	NS	PM
	ZO	NB	NM	PB	ZO	PB	NB	ZO
	PS	NM	NB	NM	NB	PS	ZO	NM
	PM	NS	NS	PM	NB	PS	NB	PS
	PB	PM	PB	PS	PS	PM	NS	NS

Table 6. The Fuzzy Rules Table of ΔK_{df} after Rules Optimization

ΔK_{df}		*EC*						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	ZO	ZO	NB	NM	ZO	NM	NB
	NM	NB	NM	NS	NM	NS	PM	NS
	NS	NM	ZO	NB	PM	PB	ZO	PM
	ZO	PM	NB	PS	NB	NM	ZO	NS
	PS	NB	NB	NS	ZO	NB	PS	PM
	PM	NS	PM	NB	NS	NB	ZO	NS
	PB	ZO	NS	PM	NB	PB	NS	NB

A fuzzy PID simulation model of wind turbine power control is established using MATLAB/SIMULINK. Wind speed simulation is shown in Figure 3. The turbine pitch angle beta, rotor power coefficient C_p and output power are shown in Figures 4 to 6, respectively. In the Figures, the solid lines represent the response curves of the system before rules optimization, while the dotted lines represent the system response curves after rules optimization. As can be seen from the Figures, when the wind speed is higher than the rated, the pitch angle of the wind turbine greaten as wind speed increases, while the rotor power coefficient decreases accordingly, reducing the output power fluctuations to maintain the output power at rated power and improve power quality. From Figure 6, we can see that the output power is smoother and the control performance is better after rules optimization.

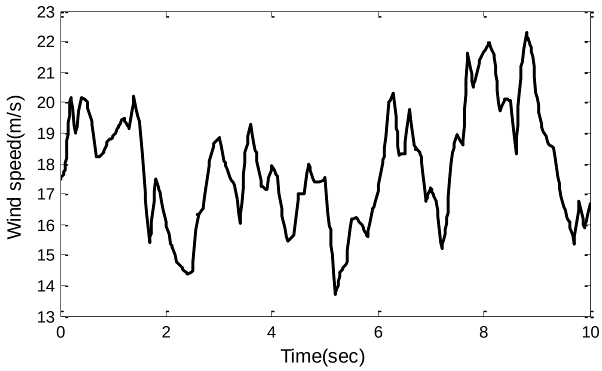

Figure 3. The Simulation of Wind Speed Curve

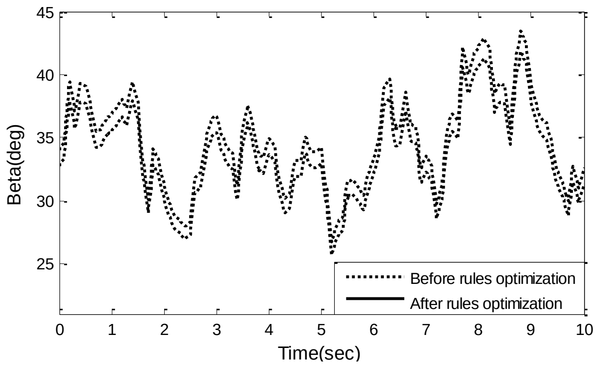

Figure 4. The Curves of Pitch Angle

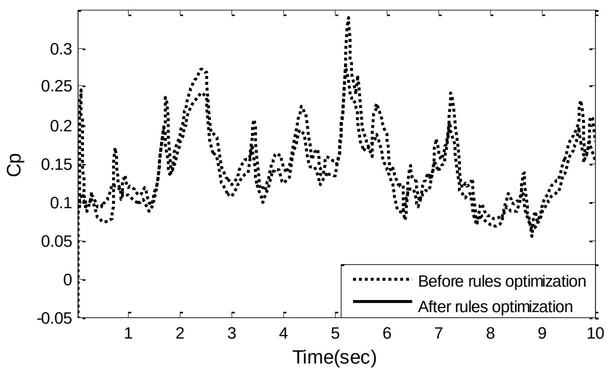

Figure 5. The Curves of Rotor Power Coefficient C_p

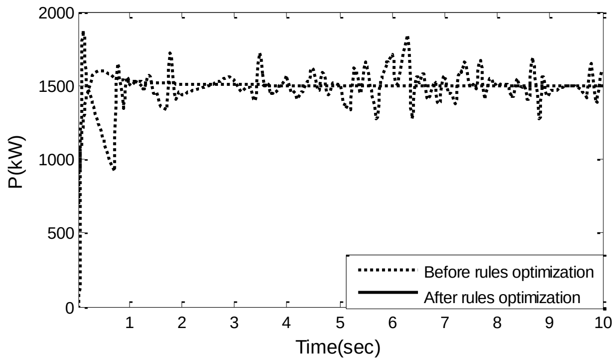

Figure 6. The Curves of Output Power

Comparing the sample values and rated output power of the wind turbine, and by calculating the standard deviation to measure the volatility of output power.

Power standard deviation calculates as follows

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{14}$$

where, x_i is the ith sample value; σ is the standard deviation of output values; N is the degrees of freedom; μ is the average value of a set of data, for rated power of wind turbine.

Sampling 50 values of wind turbine output power, by calculation, the standard deviation of output power before rules optimization is 196.9kW, and the deviation degree to the rated power is 13.13%, while the standard deviation after rules optimization is 17.13kW, and the deviation degree is 1.14%, the results indicate that the optimized power control precision is higher than before rules optimization, optimal control achieved good control effect.

5. Conclusion

As the characteristics of complex, nonlinearity, multi-variable and strong coupling of WTGS, a fuzzy PID controller is designed as the wind power controller at high wind speed, by using GA to optimize the fuzzy rules of fuzzy PID controller, the limitation of fuzzy rules selection merely rely on existing knowledge and experience of the operator in traditional is solved. With continuously adjusting fuzzy rules of fuzzy PID controller, better control parameters are got. The running experiment is done based on a 1.5MW DFIG wind turbine, and the standard deviation of output power is calculated. The results show that the output power is smoother after rules optimization, and verified the effectiveness of the proposed method.

Acknowledgments

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References

[1] K. Ushiwata, S. Shishido, R. Takahashi, T. Murata and J. Tamura, "Smoothing Control of Wind Generator Output Fluctuation by Using Electric Double Layer Capacitor", International Conference on Electrical Machines and Systems, Seoul, South Korea, **(2007)**.
[2] X. S. Zhang, J. P. Gu, Y. Yuan, M. Wang, Y. Cao, L. Hua and Z. Li, "Strategy of Smoothing Wind Power Fluctuation Based on Battery Energy Storage System", Proceedings of the CSEE, vol. 34, no. 28, **(2014)**, pp. 4752-4760.
[3] H. M. Hasanien, "A Set-membership Affine Projection Algorithm-based Adaptive-controlled SMES Units for Wind Farms Output Power Smoothing", IEEE Trans. on Sustainable Energy, vol. 4, no. 4, **(2014)**, pp. 1226-1233.
[4] W. Li, G. Ioos and I. Belanger, "Real-time Simulation of A Wind Turbine Generator Coupled with A Battery Supercapacitor Energy Storage System", IEEE Trans. on Ind. Electron, vol. 57, no. 4, **(2010)**, pp.1137-1145.
[5] H. Geng and G. Yang, "Output Power Level Control of Variable-speed Variable-pitch Wind Generators", Proceedings of the CSEE, vol. 28, no. 25, **(2008)**, pp. 130-137.
[6] A. Uehara, A. Pratap, T. Goya, T. Senjyu, A. Yona, N. Urasaki and T. Funabashi, "A Coordinated Control Method to Smooth Wind Power Fluctuations of A PMSG-based WECS", IEEE Trans. On Energy Conversion, vol. 26, no. 2, **(2011)**, pp. 550-558.
[7] B. Chen and Z. Q. Wu, "Power Smoothing Control Strategy of Doubly-fed Induction Generator Based on Constraint Factor Extent-limit Control", Proceedings of the CSEE, vol. 31, no. 27, **(2011)**, pp. 130-137.
[8] Y. Liao, J. B. He, J. Yao and K. Zhuang, "Power Smoothing Control Strategy of Direct-driven Permanent Magnet Synchronous Generator for Wind Turbine with Pitch Angle Control and Torque Dynamic Control", Proceedings of the CSEE, vol. 29, no. 18, **(2009)**, pp. 71-77.
[9] W. L. Deng, G. P. Cui, T. Yuan, M. Z. Long, G. A. Shao, B. H. Hu and W. L. Jiang, "Active Power Smoothing Optimization Control of Direct-driven Permanent Magnet Synchronous Wind Power Generation System Based on Two-stage Matrix Converter", Power System Technology, vol. 37, no. 12, **(2013)**, pp. 3419-3425.
[10] J. SU, Y. L. ZHAO and W. X. FU, "Research on Advanced Control Strategies for Wing Turbine Variable-Pitch System", 2013 25th Chinese Control and Decision Conference (CCDC), Guiyang, China, **(2013)**.
[11] X. Gang, "Research on Application of Fuzzy PID in Collective Pitch Control System", 2011 International Conference on Control, Automation and Systems Engineering (CASE), Singapore, **(2011)**.
[12] D. X. Li, B. Li and L. N. Liu, "The Simulation of VSCF Wind Power System Based on Fuzzy-PID Controller", 2011 International Conference on Computer Distributed Control and Intelligent Environmental Monitoring, Changsha, China, **(2011)**.
[13] X. Y. Zhang, J. Wu, J. M. Yang and J. Shu, "H-infinity Robust Control of Constant Power Output for The Wind Energy Conversion System Above Rated Wind", Control Theory and Applications, vol. 25, no. 2, **(2008)**, pp. 321-324.
[14] E. S. Abdin and W. Xu, "Control Design and Dynamic Performance Analysis of Wind Turbine Induction Generator Unit", Energy Conversion and Management, vol. 3, no. 15, **(2000)**, pp. 91-96.
[15] H. Y. Ye, Editor, "The Control Technology of Wind Turbine", Machinery Industry Press, Beijing, **(2002)**.
[16] B. Zhu, X. Zhang, F. C. Zeng and R. X. Cao, "Research on Electric Pitch Control System of Wind Turbine", Journal of Hefei University of Technology, vol. 33, no. 8, **(2010)**, pp. 1157-1160.
[17] X. K. Wang, Z. L. Sun and L. Wang, "Design and Research Based on Fuzzy PID-parameters Self-Tuning Controller with MATLAB", 2008 International Conference on Advanced Computer Theory and Engineering, Phuket, Thailand, **(2008)**.
[18] X. Y. Zhou, H. Wang and B. W. Yao, "Realization of Genetic Algorithm in Optimization of Fuzzy-control Rules", Journal of UEST of China, vol. 29, no. 2, **(2000)**, pp. 161-163.

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