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Research Article

Variable Speed Control Analysis of Direct-Drive Wind Turbines Incorporating the Variable Gain Pitch Knowledge Identification Algorithm

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For direct-drive wind turbines, effective methods can be adopted to reduce the generator speed fluctuation under the rated wind speed. However, there is a nonlinear relationship between the change of pitch angle of wind turbine and wind speed. In order to obtain the maximum power of the wind turbine, under the working condition of wind gust, this paper takes the principle of prior action of the pitch control and uses the variable gain pitch knowledge identification algorithm to achieve the effective control of the motor speed by designing the power pitch generator on the pitch controller to ensure that the pitch angle can be operated quickly under the rated power, and at the same time, the nonlinearities are added to the speed control process of the pitch angle generator. The gain factor of the pitch angle generator speed control process can ensure that the pitch control can work in advance under the wind gust environment. Finally, the simulation results show that the two gust control methods can achieve effective suppression of wind turbine generator in the case of overspeed, which can effectively increase the power generation of wind farms, reduce the load of wind turbines, and improve the operating stability of the system.

1. Introduction

Variable-speed and constant-frequency direct-drive wind turbines are the mainstream models at present, and the use of variable speed and distance control strategy can realize the effective control of direct-drive wind turbines. With the rapid development of power electronics, motor control, and computer control technology, the control technology of variable speed control analysis has improved simultaneously. The main control object of the variable speed control of direct-drive wind turbines is an automatic control system in which position, direction, speed, and other output state variables can be changed arbitrarily according to the command signal (or specified value) [1, 2]. The direct-drive wind turbine variable speed control is used on a large scale in industrial control, digital control processing, aerospace, and many other fields due to its high control accuracy, wide variable speed range, and high reliability. At the same time, with the continuous application of digital control, the variable speed control analysis has many features such as intelligence, digitalization, and multiple functions, which provide the basis for new control methods and algorithms. A basic direct-drive wind turbine analysis consists of a variable speed control analysis and a servo motor. The variable speed control analysis consists of the usual power supply board and the control board, which includes modules such as switching power supplies and IPM. The control board contains the main control chip and encoder modules, storage modules, etc. Applying a variable speed control to the motor current, to the encoder position, and to other information sampling and computing processing generates a new control signal, amplifies the signal, generates the output current to drive the motor, and then plays a role in controlling the servo motor. Although the DC motor has long been in the market dominance, it cannot be used directly in some flammable and explosive occasions because of many of its shortcomings that are gradually exposed, such as commutator, brush is relatively easy to damage, the need for regular testing and maintenance, because the commutator sometimes produces electric sparks, and the maximum speed of the motor and overload capacity will have a serious impact. Compared with the disadvantages of DC motors, AC direct-drive wind turbine variable-speed motors have a small rotor inertia, but a fast dynamic response. Typically, the output power of AC motors is about 10–75% higher than that of DC motors for the same volume. In addition to this, AC motors can be designed for larger capacities, allowing for higher voltages and faster rotation numbers. The current input and torque output of the induction motor are actually nonlinear. With the continuous research on the induction motor control algorithm, motor vector control can complete the decoupling of current excitation, but the testing process is complicated no matter what measurement method is used. The use of indirect measurement requires a high-speed microprocessor, but the rotor heats up during the operation of the motor making the corresponding parameters of the system change, reducing the accuracy of the operation and adding additional complexity to the control, as well as the need to absorb the lagging excitation current.

Since 1980, China has been actively learning from foreign countries about the advanced control technology of variable speed control analysis; especially, the content of the "8th Five-Year Plan" and "9th Five-Year Plan" proposed by the country includes the key research on variable speed control analysis, and at the same time has achieved breakthrough progress. Huazhong University of Science and Technology is a pioneer in China's variable speed control analysis and control industry, in response to China's "Eighth Five-Year Plan" during the earliest in-depth study of variable speed control analysis and control, and in 1996 took the lead in designing a direct-drive wind turbine analysis using a single-chip computer analog-digital hybrid. On this basis, a DSP microcontroller-based direct-drive wind turbine analysis and control device has been developed and successfully mass-produced, with sales leading the market in China [3]. Ltd. has independently designed the DSCU series variable speed control analysis and control unit after years of efforts, which has been used on a large scale in various industries and is able to feed the direct-drive wind turbine variable-speed power range of 20 W-7.5 kW, which can basically meet the requirements of enterprises [4]. Ltd. has also successfully mastered the advanced all-digital direct-drive wind turbine variable-speed AC technology through school-enterprise cooperation, mainly using a 32-phase microcontroller to achieve precise control of three-phase AC asynchronous motors, and then based on this research and development, it designed the IMS series direct-drive wind turbine variable-speed controller that can be programmed. This direct-drive wind turbine variable-speed controller can achieve effective control of motor position, speed, and output torque, and is widely used in machining, automotive manufacturing, aviation, and industrial automation. Many foreign manufacturers of direct-drive wind turbine variable-speed products have invested a lot of money in the research of variable speed control analysis technology. Bechtel Automation GmbH has developed and designed a variable speed control analysis with a modular core and a scalable structure. However, there is no self-designed modular variable speed control analysis control product in the domestic variable speed control analysis control industry so far.

In this paper, the pitch controller (PC) is designed to achieve effective control of generator speed by designing the power propeller pitch angle to ensure that the propeller can work quickly under the rated effect using the variable gain pitch knowledge identification algorithm to operate under gusty wind conditions with the principle of high speed and early action of the propeller, and using the increased nonlinear gain factor. The PC is used to complete the overshoot control of the wind unit under the gust condition. Finally, the experimental results through simulation tests show that the variable gain pitch knowledge identification algorithm used in this paper can achieve effective control of wind turbine overspeed, reduce the waste of power generation caused by its shutdown, and reduce the load of direct-drive wind turbine.

2. Methodology

2.1. Analysis of Wind Turbine Overspeed Mechanism. In the analysis and design of direct-drive wind turbines, it is crucial to use the appropriate direct-drive wind turbine variable-speed motor. As the actuator in the system, the wind turbine uses the controlled signal to convert the acquired system voltage or current into the corresponding speed. Therefore, the wind turbine overspeed analysis of the direct-drive wind turbine needs to ensure that the motor meets the characteristics of good response characteristics, smooth operation, and effective power control, which have been used on a large scale in various industries.

Direct-drive wind power units actually convert wind energy into mechanical energy in the process of wind power generation into electrical energy [5, 6]. For the wind turbine dynamics of the direct-drive wind turbine, the wind power force obtained by the windmill is shown as follows:

$$P_t = 0.5\pi\rho C_p(\lambda,\beta)R^2 v_w^3. \tag{1}$$

In the above equation, P_t denotes the mechanical energy that can be obtained by the wind wheel of a direct-drive wind turbine; ρ denotes the air density; R denotes the radius of the wind wheel of a direct-drive wind turbine; v_w indicates the wind speed; $C_p(\lambda,\beta)$ represents the wind energy use factor of the wind turbine, which is a variable associated with the blade tip speed ratio λ and the pitch angle β. The blade tip speed ratio of a direct-drive wind turbine represents the ratio of the linear speed to the wind speed at the tip of the blade, $\lambda = \omega_r R/v_w$; ω_r indicates the mechanical angular speed of the turbine impeller for direct-drive wind turbines. Among them, the following expressions can be used for $C_p(\lambda,\beta)$.

$$C_p(\lambda,\beta) = (0.44 - 0.0167\beta)\sin\left(\frac{\pi(\lambda-3)}{15-0.3\beta}\right) - 0.0184(\lambda-3)\beta, \tag{2}$$

$$\lambda = \frac{\omega_r R}{v_w}. \tag{3}$$

According to the above expression, if the radius of the wind turbine and the wind speed of the direct-drive wind turbine are determined, the relationship between the calculated power and the power factor of the fan blade car is proportional to $C_p(\lambda, \beta)$. Therefore, to obtain the maximum power possible from the fan, as shown in Figure 1, the maximum power factor and the blade speed ratio of the direct-drive wind turbine can be used.

According to the $C_p - \lambda$ curve in Figure 1, it is known that if the smaller the pitch angle of a direct-drive wind turbine, the higher the power factor obtained and the higher the energy conversion efficiency of the fan.

The corresponding fixed pitch angle of a direct-drive wind turbine has an optimal blade tip speed ratio to ensure that it obtains the maximum power factor.

According to the unit pitch control theory, by changing the propeller blade, the most suitable number of rotations for the blade pitch ratio can be obtained; the wind turbine of direct-drive wind turbine can operate the propeller pitch angle with the minimum power, indicating that the characteristics of direct-drive wind turbine have some influence on the operating characteristics of the unit.$C_p(\lambda, \beta)$ according to the expression (2) can be derived from the gain of the system using $dC_p/d\lambda$, and then, $dC_p/d\lambda$ at different wind speeds are not the same value.

The controller of the direct-drive wind turbine mainly contains the torque controller (TC) and PC, and the structural block diagram is shown in Figure 2, according to which ω_{rate} indicates the rated generator speed; β_{ref} indicates the pitch angle is given; $\beta_{\text{max-min}}$ indicates the maximum and minimum pitch angle limits; P_{rate} is expressed as the rated power of the WTGs; ω_{set} indicates the rated speed set for the generator; ω_g is denoted as the real-time speed of the generator; T_g denotes the given torque at the output of the proportional-integral PI controller; and $T_{\text{max}-min}$ indicates the maximum and minimum torque limit values.

According to Figure 2, the purpose of torque control and pitch control is to effectively regulate the generator speed, where AB represents a straight line, BC represents a quadratic curve, CE represents a straight line, and DEF represents an inverse proportional curve. ω_{min} indicates the minimum generator speed, T_{rate} is the rated generator torque, k_{opt} indicates the optimal modal gain coefficient. In the rated wind speed of direct-drive wind turbine, the maximum power point tracking control that can be achieved according to point E of Figure 3 is used to achieve its constant power amount control with a given wind speed. Usually, the speed difference in the generator is used as the control input variable of the system, and the rated torque of the generator is used as the output of the system mainly by using the PI controller; when the rated torque of the generator needs to set the upper and lower limit values according to the current generator rotation, it is also possible to obtain the control of the maximum wind power and constant power amount in the case of constant power. According to the basic torque, the torque of the drive chain can be effectively suppressed by increasing the ripple torque, thus reducing its mechanical load.

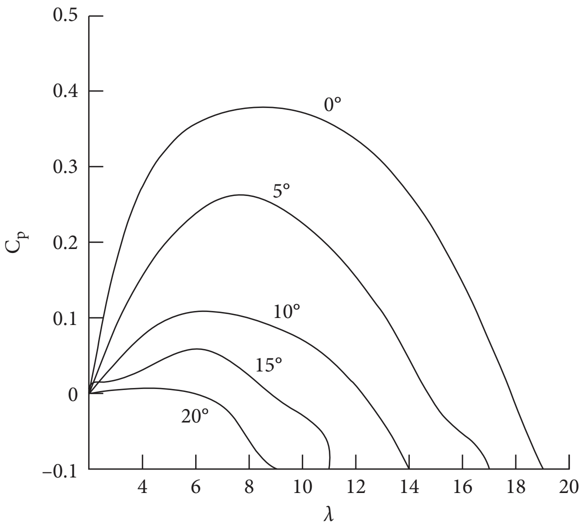


Figure 1: $C_p - \lambda$ curve.

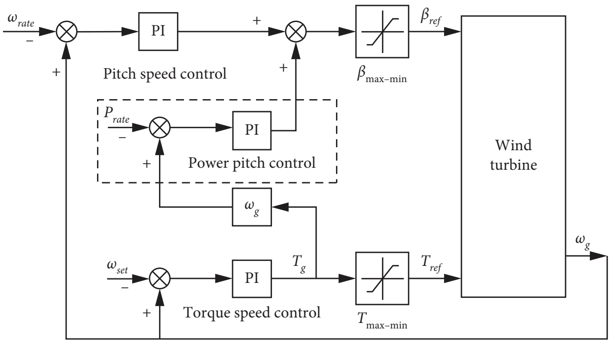


Figure 2: Block diagram of the basic principle of torque control and propeller control.

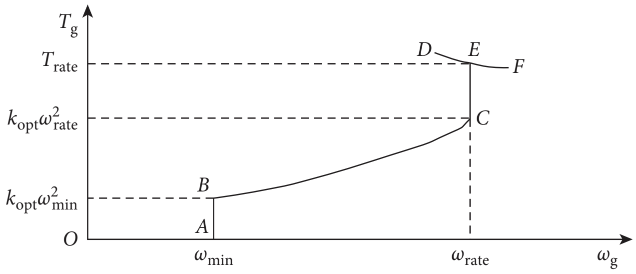


Figure 3: Torque-speed diagram of a direct-drive wind turbine.

The PC can function at a given wind speed, mainly to achieve the effective control of the generator speed. The design approach adopted is mainly to use the difference in the generator speed as the variable input and the magnitude of the pitch angle as the output of the system. Due to the aerodynamic nonlinear characteristics of the paddles of the direct-drive wind turbine, the gain of the PC's ratio coefficient to the time constant of integration is constantly changing and can be obtained according to the set pitch angle with the corresponding relationship calculation.

Since the parameters can be set at the same point between TC and PC, decoupling control can be achieved using both controllers, subject to the following conditions: if the torque is set in such a way that the pitch angle is maintained at the optimal pitch angle β_{fine} and if the obtained pitch angle is not less than the optimal pitch angle, then the rated torque can be maintained to operate at the rated torque [7, 8].

If a direct-drive wind turbine operates at the set wind speed, once a gust occurs, the generator speed of the wind turbine will exceed the limit value of 1.2 times, which will cause the unit to have a differential speed and lead to a shutdown. Therefore, when the wind speed of the direct-drive wind turbine rises sharply, the speed of the generator sometimes rises sharply, but the power does not reach the rated power at this time, as shown in Figure 3. The control of the generator speed is achieved in this case. If the direct-drive wind turbine operates at the rated wind speed, the wind turbine will operate in the PC phase mainly because of the large inertia of the wind turbine, and there will be a lag of about 1 second between the appearance of the wind gust and the change of the generator speed, because the propeller aerodynamics is a nonlinear feature. In this case, the wind speed of the direct-drive wind turbine will rise rapidly, which will slow down the paddle retraction rate and prevent the effective control of the wind speed overspeed.

2.2. Direct-Drive Wind Turbine Variable Speed Control Strategy. For the two gust overspeed cases of below rated wind speed and above rated wind speed, the gust control method is designed under the effective use of the gain propeller knowledge identification algorithm: PPGSL (Power Pitch Generator Speed Loop) is added on PC to make the propeller work earlier below rated wind speed; and NGF is added in the propeller ratio term to make the propeller act faster. It can be done on PC by adding PPGSL as shown in dashed box in Figure 4, in pitch angle rating because pitch generator speed PPGSL (asphalt generator speed cycle) is determined by PI controller, then pitch generator speed PPGSL in this part of the composition will be converted from one PI controller to dual PI controller to make wind speed faster. The use of pitch angle is accelerated in the process of rapid rise to avoid the instantaneous speed of torque rise to the limit value [9, 10].

The difference between the actual power and the rated power of the system input variable used by PPGSL will be used as the output PI controller of the system according to the pitch angle, as shown in Figure 4, which can be obtained in practice based on the product of the output original torque and the generator rotation number of the TC system. Because of the gust of wind, the generator rotation number will rise rapidly, which will lead to the greater rated generator rotation value than the rated torque value; because the proportional term of the power control loop is greater than the integral term, it will cause the pitch angle increment $\Delta\beta_2$ output to become negative, which will make the pitch angle increment $\Delta\beta_1$ output positive at this moment; and because the pitch angle increment $\Delta\beta$ output is negative, it will make the pitch angle constrained to the optimal pitch angle.

As shown in Figure 4, $\Delta\beta_1$ denotes the pitch angle increment of the PPGSL system output. $\Delta\beta_2$denotes the pitch angle increment of the PPGSL output. $\Delta\beta_2$a0, a1, b0, and b1 denote in turn the coefficients obtained after numerical discretization of the PI controller. $a0 = \text{KITS}/2 + \text{KP}$, $a1 = \text{KITS}/2\text{-KP}$, $b0 = \text{KIQTS}/2 + \text{KPQ}$, and $b1 = \text{KIQTS}/2\text{-KPQ}$. T_S indicates the sampling time of the system. KIQ and KPQ denote the points and scaling factors of PPGSL.

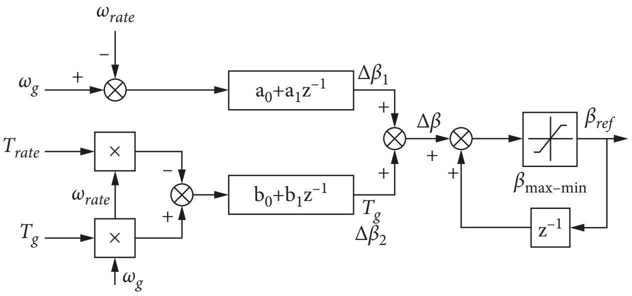


Figure 4: Block diagram of a dual PI controller structure.

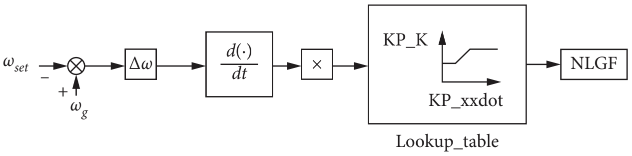


Figure 5: Nonlinear gain factor of the pitch scale term.

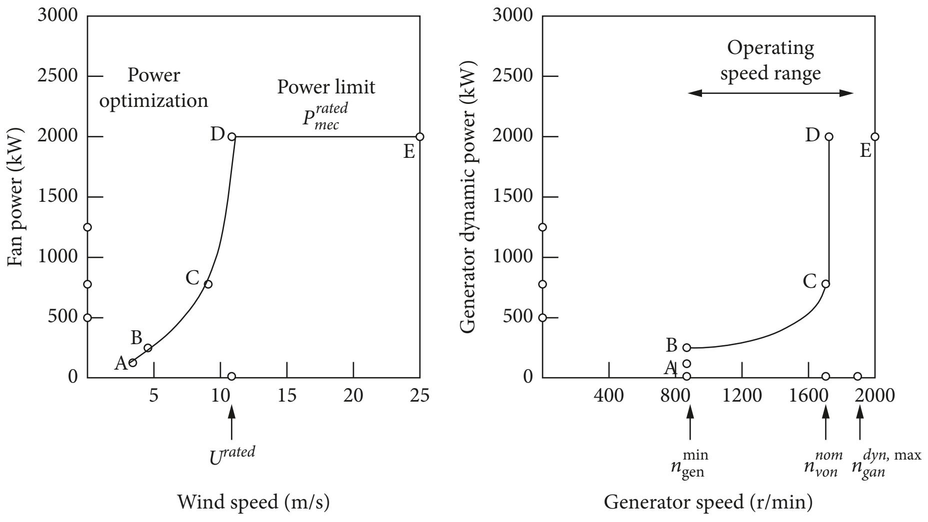
In gusts above the rated wind speed, the generator speed is much larger than the rated generator speed, and the deviation continues to increase, when the proportional gain of the PC decreases as the propeller pitch angle increases, resulting in an increase in the speed of the windmill [11, 12].

In Figure 5, $\Delta\omega$ indicates the speed deviation calculated by the system; $d(\cdot)/dt$ indicates the result of differentiation of the speed deviation; Lookup_table indicates the set lookup table, where KP_K indicates the proportional gain factor, and KP_xxdot indicates the product of the speed deviation of the generator and its rate of change (see Figure 5).

From the theoretical analysis, it can be seen that the direct-drive wind turbine function can work according to the maximum power factor, but in practice, because of the influence of the mechanical strength of the direct-drive wind turbine, its physical characteristics are limited, and the output power of the system is also affected, because exceeding this limit will seriously affect the stability and safety of the wind power module, making the variable-speed wind power module receive this function. The variable-speed wind power module is affected by this feature.

Considering the above constraints, since the control of the paddle speed of the variable-speed fan requires the use of a zonal segment control method, if the control method of the variable-speed fan can be divided into two, then the curve of the relationship between fan power and wind speed is shown in Figure 6(a), and the curve of the relationship between generator power and speed is shown in Figure 6(b).

In this paper, we use a segmented torque control strategy for variable speed control by integrating two curves.



(a) (b)

Figure 6: Curves for two different control strategies. (a) Power curve and (b) p-n curve.

As shown in Figure 6, the operation of the variable-speed electric power generation function operation is divided into three main different phases according to the wind speed condition.

The first phase is the starting phase, where the engine speed will rise from standstill to the cut-in point speed, where the generator is at a stop at the wind speed of the cut-in point, and where the direct-drive wind turbine is mechanically rotating under the wind speed, so it will not be discussed in this phase without considering the control of the generator speed.

The second stage is the direct-drive wind turbine under the rated wind speed after grid connection.

The third stage is after the wind turbine is connected to the grid to the operation state below the rated wind speed.

The two constraints mentioned above make the region divided into three stages: constant-speed region AB, variable-speed operation region BC, and constant-speed region CD. AB segment is the minimum speed of the generator; BC segment is the speed of wind power operation in the case of variable speed, using the constant region of regulation to make the wind turbine run according to $C_{p\max}$; and CD segment is the speed of the generator operating at the rated speed, and then, the torque can be adjusted to ensure that the power of the wind turbine can become larger.

Electricity obtained from the blade car of the wind turbine can be expressed as follows:

$$P_t = \omega_r T_t. \tag{4}$$

From (1) and (4), the torque of the fan can be derived as follows:

$$T_t = 0.5\pi\rho C_p(\lambda,\beta)\frac{R^2 v_w^3}{\omega_r}. \tag{5}$$

The dynamic equation of the transmission system can be expressed as follows:

$$J_t\frac{d\omega_r}{dt} = T_t - K_t\omega_r - T_g, \tag{6}$$

where J_t is the turbine rotational inertia; K_t is the total damping; and T_g is the generator torque.

$$\begin{aligned}\omega_g &= G\omega_r,\\ n_g &= \frac{60}{2\pi}\omega_g = \frac{60}{2\pi}G\omega_r,\end{aligned} \tag{7}$$

where ω_g is the angular speed of generator rotation; G is the gearbox speed increase ratio; and n_g is the generator speed.

For the AB section, the speed is constant, and with (6), we get the following:

$$T_g = T_t - K_t\omega_r. \tag{8}$$

For point A, the cut-in wind speed is v_{wcutin}; the wind wheel speed is constant $\omega_{r\min}$; substituting into (7) yields the following:

$$T_{gA} = \frac{0.5\pi\rho C_{pA}(\lambda,\beta)R^2 v_{\text{wcutin}}^3}{\omega_{r\min}} - K_t\omega_{r\min}. \tag{9}$$

For point B, the speed remains unchanged as $\omega_{r\min}$; from point B onwards, the optimal tip speed ratio control phase is entered, and the wind speed at point B can be derived from the optimal tip speed ratio λ_{opt}.

$$v_{wB} = \frac{\omega_{r\min}R}{\lambda_{opt}}. \tag{10}$$

Bringing in (7) yields the following:

$$T_{gB} = \frac{0.5\pi\rho C_{pB}(\lambda,\beta)R^5\omega_{r\min}^2}{\lambda_{opt}^3} - K_t\omega_{r\min}. \tag{11}$$

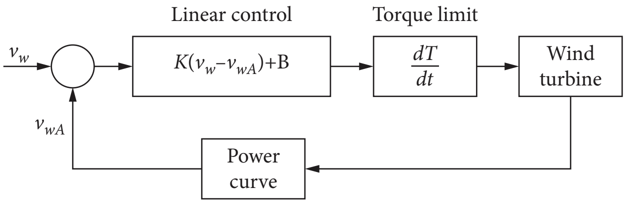


Figure 7: Line controller.

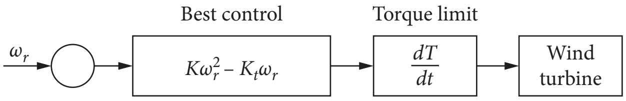


Figure 8: Optimal control.

From the power curve, we can see that for the AB section, we can use linear control (Figure 7), the control input is the wind speed, and the control output is the torque.

$$T_g = \frac{T_{gB} - T_{gA}}{v_{wB} - v_{wA}}\left(v_w - v_{wA}\right) + T_{gA}. \tag{12}$$

Based on the same principle, the same control strategy can be applied for the CD segment.

Regarding BC section, as can be seen from (1), the fan captured power at a fixed air speed is proportional to the power factor, so the control strategy for this section is for the fan to use variable-speed operation to track the maximum power curve operation.

From (1) and (4), we have the following:

$$T_t = 0.5\pi\rho C_p(\lambda, \beta)R^2\omega_r^2. \tag{13}$$

A unique tip speed ratio exists relative to the maximum power factor $C_{p\max}$.

$$\lambda_{opt} = \frac{\omega_{ropt}R}{v_w}. \tag{14}$$

Thus,

$$\begin{aligned} v_w &= \frac{\omega_{ropt}R}{\lambda_{opt}}, \\ \omega_{ropt} &= \frac{\lambda_{opt}v_w}{R}. \end{aligned} \tag{15}$$

Then, the maximum tracking power can be expressed as follows:

$$P_{topt} = 0.5\pi\rho C_{p\max}R^2\left(\frac{\omega_{opt}R}{\lambda_{opt}}\right)^3. \tag{16}$$

Or it can be expressed as

$$P_{opt} = K\omega_{ropt}^3, \tag{17}$$

where

$$K = 0.5\pi\rho R^5\frac{C_{p\max}}{\lambda_{opt}}. \tag{18}$$

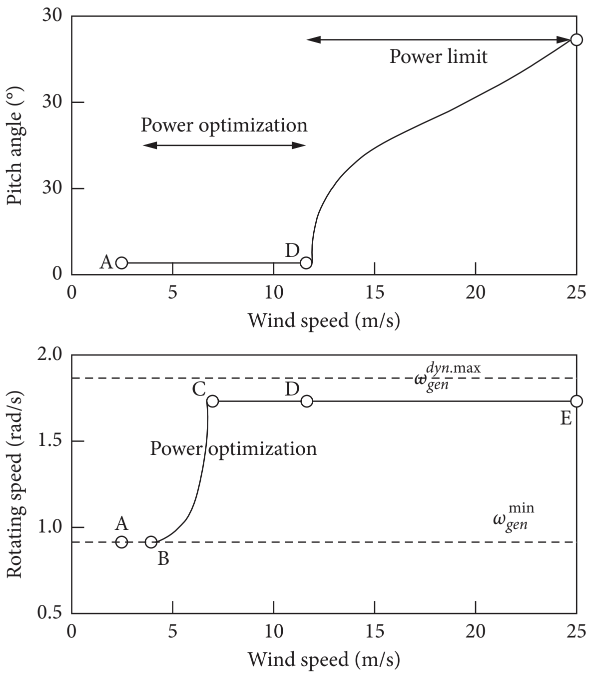


Figure 9: Curves of rotational speed and pitch angle with wind speed.

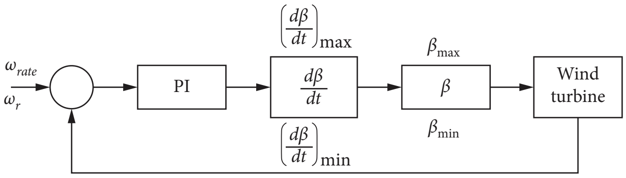


Figure 10: : Pitch angle controller.

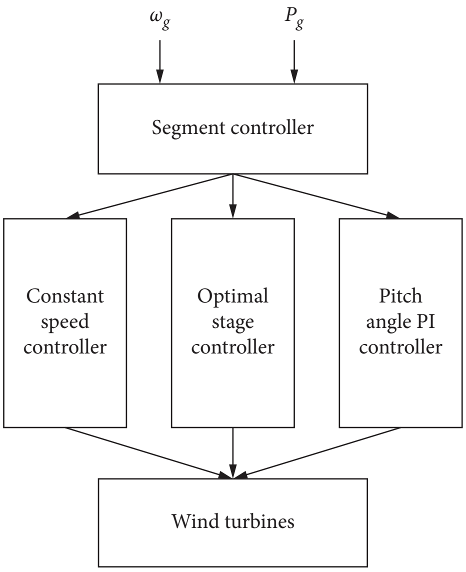
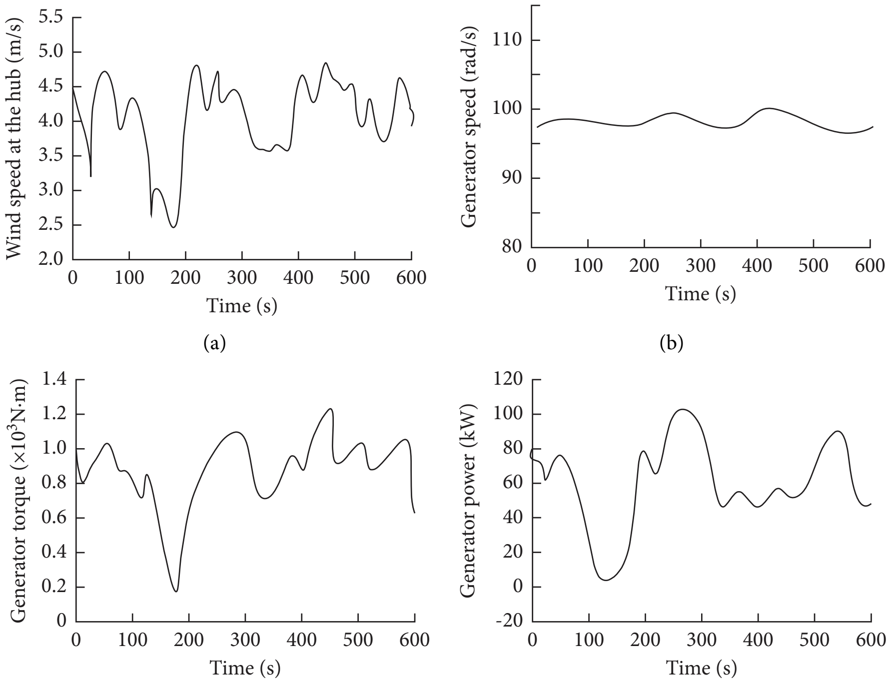


Figure 11: Total control strategy.

Table 1: Fan parameters for simulation.

Parameter name	Value
Power rating (MW)	15
Cut-in speed (m/s)	35
Cut-out speed (m/s)	25
Wind wheel diameter (m)	83.05
Minimum generator speed (r/min)	945
Rated speed of generator (r/min)	1732.5
Gearbox gear ratio	105



(a) (b) (c) (d)

Figure 12: Wind turbine characteristic curve at 4 m/s wind speed. (a) Wind speed curve. (b) Generator speed. (c) Generator torque. (d) Generator power.

Bringing in (5) yields

$$T_{topt} = K\omega_{ropt}^2. \tag{19}$$

The resulting control strategy for this stage is to indirectly adjust the number of rotations by controlling the generator torque so that the fan acts with the best blade front-end ratio tracking the maximum power factor curve (Figure 8).

Then, we get the following:

$$T_g = K\omega_r^2 - K_t\omega_r. \tag{20}$$

The wind speed continues to increase in stage 3, and the torque at point D reaches its rated state, which is the power stabilization region. By stage 3, if the wind speed continues to vary in the high wind speed phase, the power is adjusted by propeller pitch adjustment to maintain the rotational speed and torque at the operating point of point D-E (Figure 9).

If the rotational speed of the unit is greater than the rated wind speed, then the rotational speed and torque of the generator will be in the state of rated speed; when the rotational speed is running under the rated value, the rotational speed within this stage will be vibrating at high-speed rotation, then the rotational speed of the generator decreases. Therefore, the pitch angle of the propeller is changed to change the input power of the system. At this time, the input power of the system and the power of the motor will be in a balanced state, and the fan of the motor will operate at a certain speed. If the wind speed of the motor exceeds the rated wind speed at this time, then the power and torque reach the rated value (Figure 10):

$$\beta = K_p\varepsilon + K_i\int \varepsilon\, dt. \tag{21}$$

As mentioned above, as shown in Figure 11, the combined control strategy for the entire operating area of the direct-drive wind power unit is what can be collectively called torque control until the variable-speed fan reaches power and torque ratings, and propeller control for the fan after power and torque ratings are reached, where the boundary that defines the two intervals is whether power and torque ratings are reached. The controller required for

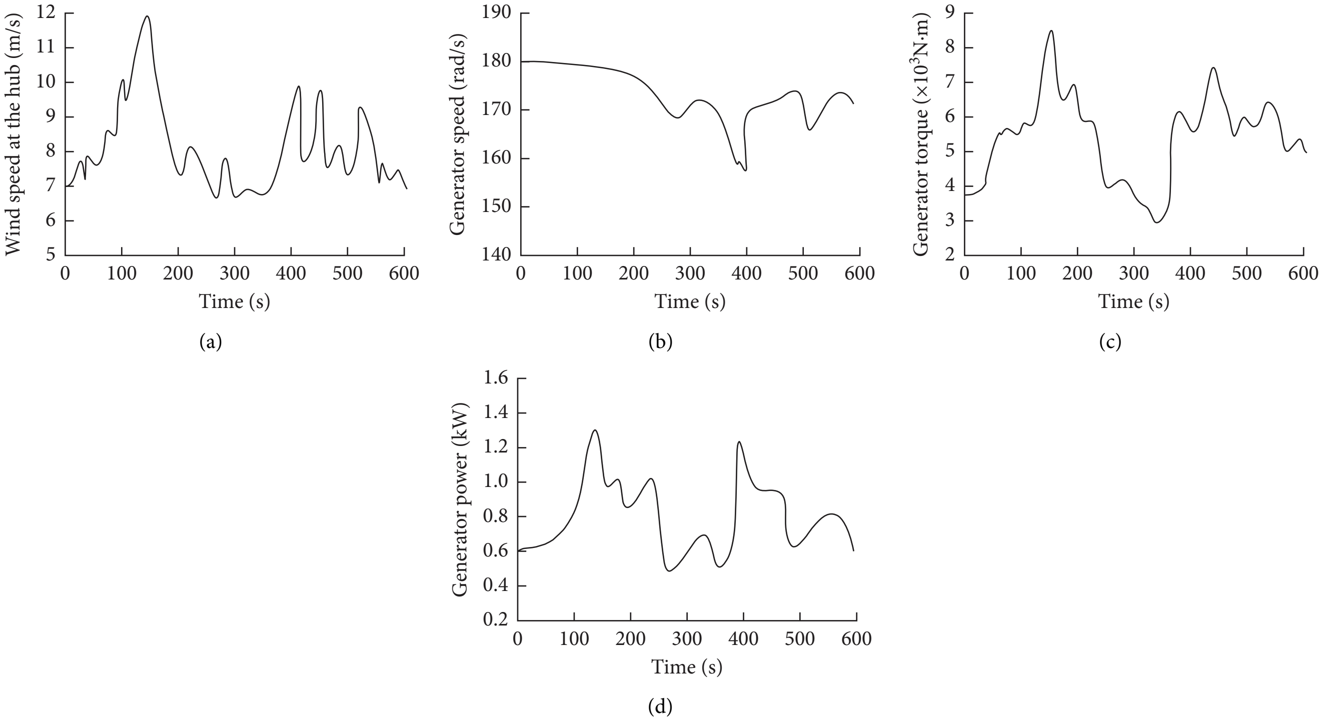


FIGURE 13: Wind turbine characteristic curve at 8 m/s wind speed. (a) Wind speed curve. (b) Generator speed. (c) Generator torque. (d) Generator power.

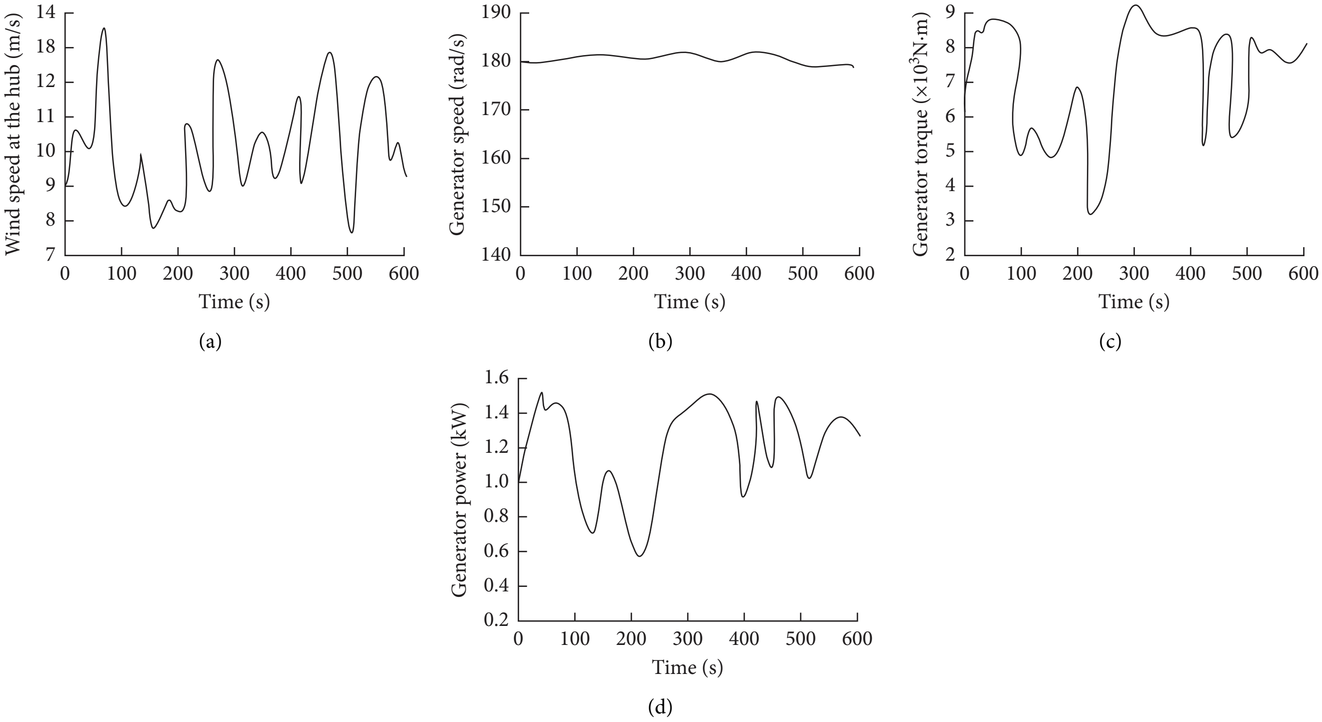


FIGURE 14: Wind turbine characteristic curve at 10 m/s wind speed. (a) Wind speed curve. (b) Generator speed. (c) Generator torque. (d) Generator power.

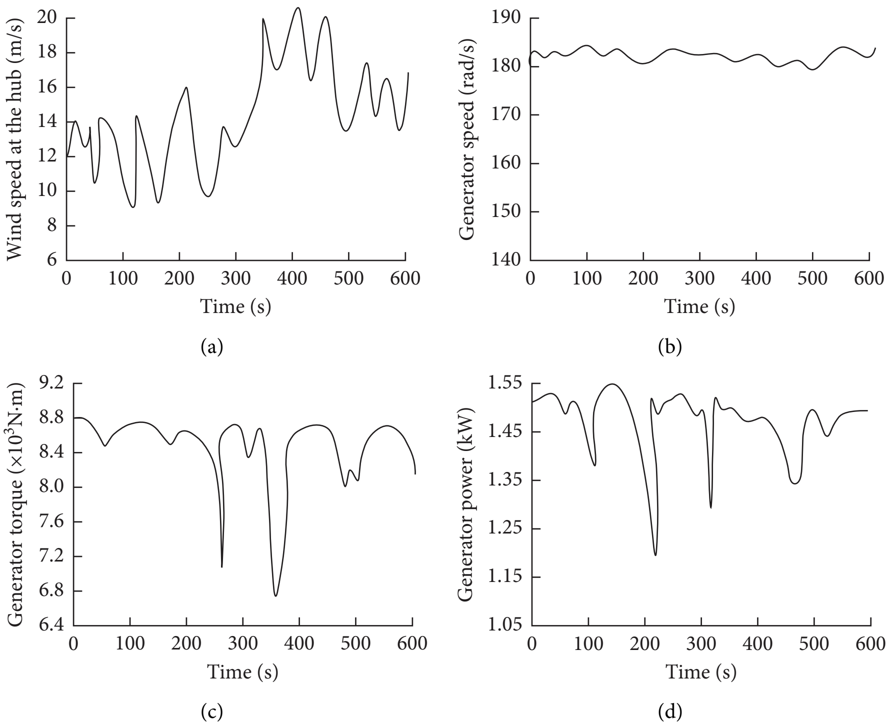


Figure 15: Wind turbine characteristic curve at 12 m/s wind speed. (a) Wind speed curve. (b) Generator speed. (c) Generator torque. (d) Generator power.

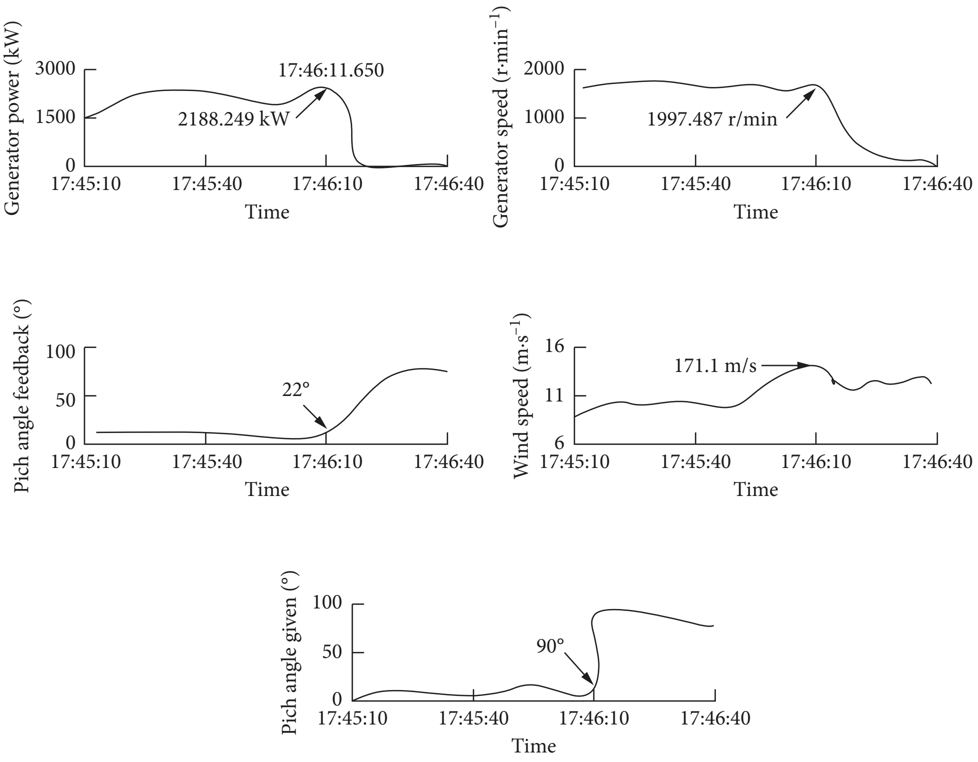


Figure 16: Wind turbine gust conditions of overspeed stop recording chart.

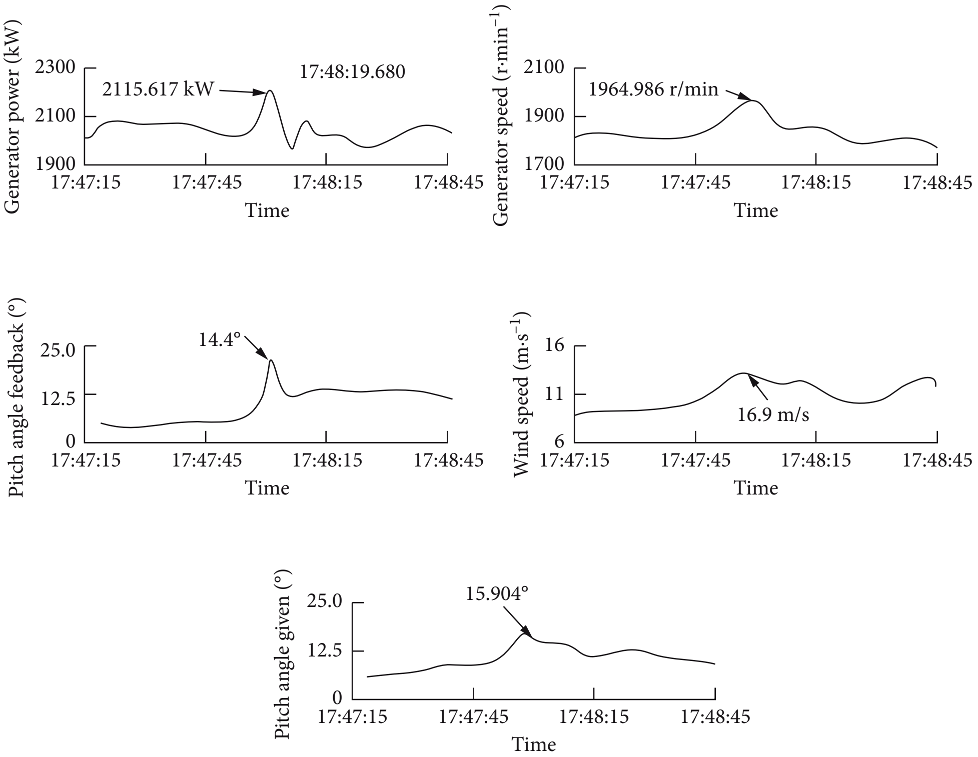


Figure 17: Normal operation of wind turbine under gust conditions.

external control programming is selected based on the determination of the operating zone in which the fan is set.

3. Simulation and Results Analysis

If the wind turbine design requirements, in the wind speed and wind direction constantly changing characteristics, and only the wind speed, due to the wind speed first rise and then fall, the limit array EOG can be obtained. This paper takes the simulation of wind power module for 2 MW variable-speed propeller; the unit parameters are set as follows on the horizontal axis: the rated power of the wind direction is 2000 kW, the cut-in wind speed is 3 m/s, the rated wind speed is 9.2 m/s, the number of blades is 4, the diameter of the windmill is 146 m, the height of the tower is 80 m, the control mode of the variable-speed propeller is used, the gearbox speed ratio is 130.17, the type of generator is a two-foot generator, and the bladed wind power design is used. The propeller control characteristics were calculated using the bladed wind power design tool for the load.

The modeling is defined by the GH Bladed software, and the direct-drive wind power unit model is constructed by defining parameters such as blades, airfoils, drive chain, control parameters, and wind speed [13–15].

The new controller can be easily tested by defining a Bladed external custom controller through simulations using the GH Bladed software, and the simulation parameters are shown in Table 1. The PI parameters of the simulated controller are adjusted by preliminary calculations, obtained after simulation adjustments.

The simulation results are shown in the wind turbine characteristic curves (Figures 12–15). Since the simulated wind speed is a three-dimensional turbulent wind field, it is difficult to represent it in curves [16, 17]. In this paper, the simulated wind speed signals at the center position are 4 m/s, 8 m/s, 10 m/s, and 12.5 m/s, respectively.

According to the above simulation curve, if the wind speed fluctuates, then the rotating speed will change due to the change of wind speed, which will indicate that the wind turbine will follow the best blade speed ratio in the BC section; if the rotating wind speed decreases, then it will make the rotating speed also decrease. The generator torque can be reduced by using the variable gain pitch knowledge recognition algorithm. If the rotating wind speed is greater than the rated speed, then the torque and power in the module will be maintained at the rated speed, so it shows the effectiveness of the proposed variable gain pitch knowledge recognition algorithm. If the rotating speed becomes larger, then it will make the rotating speed and the torque curve of the generator fluctuate up and down, which also shows the improvement in the algorithm in this paper [18–20]. In the case of choosing four wind turbines, two groups were used for control, and two units in each group will be close to each other. Sixteen shutdowns due to overspeeds were carried out in the selected gust control method, and the shutdowns were mainly due to the speed limit of the propeller as the speed became larger. The experimental test results show that after using the gust control method, it is possible to control the number of revolutions of the system function and reduce unnecessary downtime.

Figures 16 and 17 show the condition of the main limit array recorded by the controller, where the wind speed increases from 10 m/s to about 17 m/s within 5 s, and the windmill rotation number reaches 1980 r/min, which triggers the software over rotation number protection and stops off-grid. The wind power unit with propeller NLGF, with almost the same wind speed, successfully coped with this gust and the wind power unit continued to generate electricity.

4. Conclusions

The biggest advantage of variable-speed pitch wind turbine is that it can find wind energy and stable output power in a large range. The existence of this advantage makes it gradually become the main model of wind turbine. The mature technology of this wind turbine is also the main technology of megawatt wind turbine. By comparing the direct-drive type, according to the variable speed control of the wind power generation unit and the previous control methods, in this manual, by using the variable gain propeller knowledge recognition algorithm to add PPGSL on the PC, the propeller can work at the rated wind speed, the propeller can operate quickly or quickly and can effectively control the effect, and the gain scheduling control needs to be adopted. This control technology can make the throwing distance more sensitive and the output power greater and more stable. Using the load reduction control technology can better reduce the load in the wind turbine. This operation can bring the sharp generator more stable. Finally, the simulation results show that the variable gain pitch knowledge recognition algorithm proposed in this paper can improve the response speed of wind turbine in gust, reduce the operating load of wind turbine, improve the power generation, and enhance the stability of the system.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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