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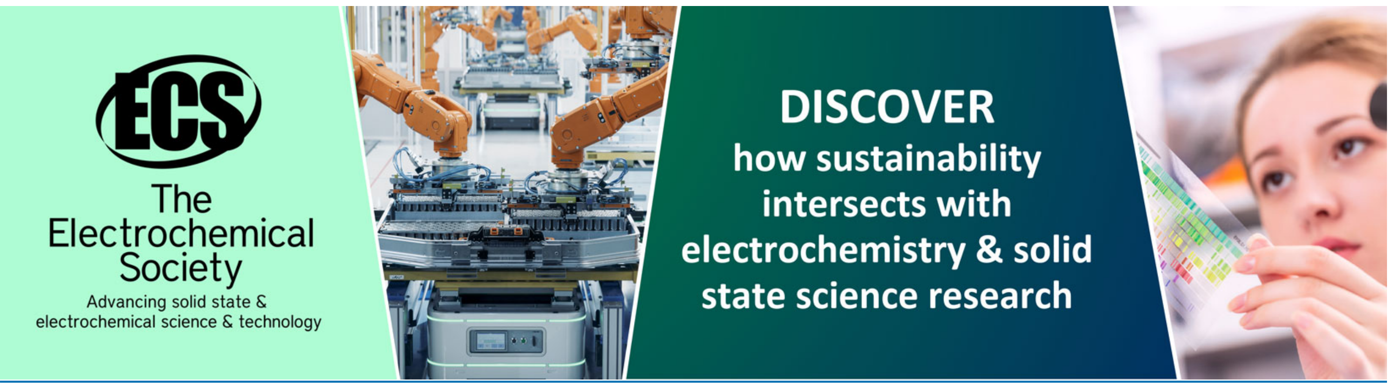

Research on Control Strategy of Polar Unmanned Vehicle Wind Power Generation System

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Abstract: Due to the abundant scenery resources in Antarctica, for the unmanned vehicle working in the polar region, the scenery power supply system is built on it, and the control strategies for wind power systems is studied. The max power of the system is tracked by the climbing method, and the variable pitch control ensures that the output power of the generator is near the rated power when the air speed exceeds the rated air speed of the wind turbine. The system is modeled using Matlab/Simulink, and the two control methods are simulated. The simulation results of the system as a whole show that the control strategy can ensure the stable and reliable operation of the system under the environmental conditions of extreme cold and strong wind.

1. Introduction

The small unmanned vehicles currently working in the Antarctic are mostly powered by batteries, and the continuous low-temperature environment will have a negative impact on the battery life [1]. (1) Therefore, building a scenery power supply system on the polar unmanned vehicle not only makes effective use of the rich scenery resources in Antarctica but also, under normal conditions, the system supplies power to the vehicle equipment, reducing the power output of the vehicle battery; under extreme conditions, when the vehicle battery power is insufficient, the system supplies power to the unmanned vehicle so that the unmanned vehicle can move without being buried by heavy snow and causing damage.

(2) Currently applied in the Antarctic region of renewable energy and battery combined power supply, mostly used in the station area, large and joint power supply with diesel engines, less dependence on renewable energy, the control speed, accuracy and energy utilization of the system are relatively low, not applicable to the scenery power supply system that will be built on an unmanned vehicle. (3) The Antarctic cold and windy natural environment will have a significant impact on the power output of the system, so the system's control is particularly important. To improve the energy utilization and reliability of the system, ensure the safety and stability of the system during operation in harsh environments,this paper proposes to use the mountain climbing method to track the max output power of the system to ensure the tracking speed while taking into account the tracking accuracy; and to use the variable pitch control to ensure that the system will not overload when the air speed exceeds the rated air speed of the wind turbine.

2. Wind power systems

The advantage of a permanent magnet synchronous generator is that it does not require a gearbox for transmission, which is highly reliable; no excitation device is required, no excitation losses, and high power generation efficiency; and it can be started at low wind speeds [2]. In view of the above advantages, the structure of permanent magnet direct drive wind power system used in this paper is shown in Figure 1. It mainly made up of a wind turbine, PMSG, rectifier circuit, DC/DC converter. The rectifier circuit adopts three-phase diode rectification. To ensure the full utilization of wind energy and make the wind power system have an energy output at low wind speed, the DC/DC converter in this paper adopts a Boost circuit [3]. In the control strategy, on the one hand, the duty cycle of the Boost circuit is perturbed to achieve max power tracking,ensure maximum utilization of wind energy; on the other hand, the pitch angle is controlled to ensure that the output power remains near the rated power when the air speed exceeds the rated air speed of the wind turbine.

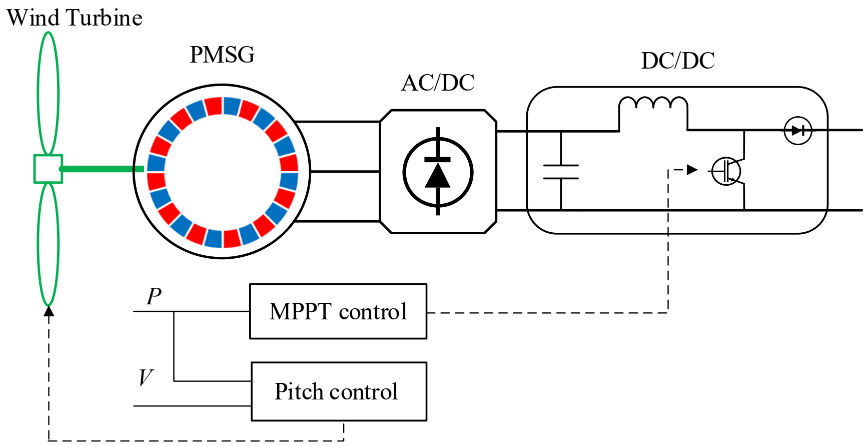


Figure. 1 Structure diagram of the permanent magnet direct drive wind power generation system

2.1. Wind speed model
To better simulate natural winds and better represent the random and intermittent nature of natural winds, spatial and temporal modeling of wind speed variation is needed. the wind speed model is considered here as a combination of basic, gust, asymptotic and random wind speeds [4]:

$$V(t) = \overline{V} + V_{\mathrm{g}}(t) + V_{\mathrm{r}}(t) + V_{\mathrm{n}}(t) \tag{1}$$

In the above equation: $\overline{V}$ - basic wind speed, $V_{\mathrm{g}}(t)$ - gust wind speed, $V_{\mathrm{r}}(t)$ - asymptotic wind speed, and $V_{\mathrm{n}}(t)$ - random wind speed, all is m/s.

The basic wind speed is generally taken as a constant during the simulation calculation.

The gust wind speed can be expressed as [5]:

$$V_{\mathrm{g}} = \left\{ \frac{A_{\mathrm{g}}}{2}\left[1-\cos 2\pi\left(\frac{t-t_{\mathrm{g1}}}{T_{\mathrm{g}}}\right)\right] \quad t_{\mathrm{gs}} \le t \le t_{\mathrm{gs}} + T_{\mathrm{g}} \right. \tag{2}$$

Where: A_{g} (m/s) is the gust amplitude, t_{gs} (s) is the gust onset time, and T_{g} (s) is the gust period.

The asymptotic wind speed can be expressed as:

$$V_r = \begin{cases} A_r \dfrac{t-t_{\mathrm{rs}}}{t_{\mathrm{re}}-t_{\mathrm{rs}}} & t_{\mathrm{rs}} \le t \le t_{re} \\ A_r & t_{re} < t \le t_{re} + t_{\mathrm{s}} \end{cases} \tag{3}$$

Where: A_r (m/s) is the gradual wind amplitude, t_{rs} (s) is the wind speed start change time, t_{re} (s) is the wind speed end change time, and t_{s} (s) is the duration after the wind speed end change time.

The random wind speed can be expressed as:

$$V_{\mathrm{n}} = A_{\mathrm{n}} R_{\mathrm{am}}(-1,1)\cos\left(\omega_{\mathrm{v}} t + \varphi_{\mathrm{v}}\right) \tag{4}$$

Where: A_{n} (m/s) is the random wind amplitude and $R_{\mathrm{am}}(-1,1)$ is a random number between -1 and 1.

The wind speed model is built in Simulink according to the above wind speed equation and encapsulated, as shown in Figure 2.

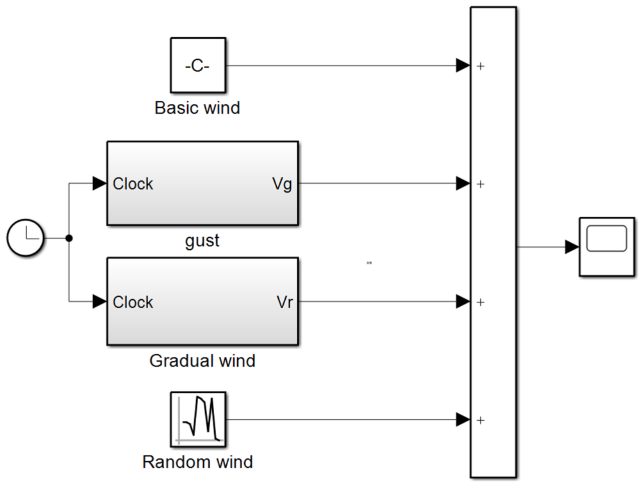


Figure 2 Combined wind speed model

2.2. *Wind power system model*

The wind turbine's model includes mainly an aerodynamic model as well as a wind energy utilization coefficient model.

The wind turbine's will convert the input wind energy into the mechanical energy for output, the specific conversion relationship can be expressed as follows:

$$P_{\mathrm{m}} = \frac{1}{2}\rho S v^3 C_{\mathrm{p}} \tag{5}$$

Where: ρ (kg/m^3) - air density; S (m^2) - swept wind area; v (m/s) - wind speed; C_{p} - wind energy utilization factor.

To further analyze C_{p}, the concept of leaf tip speed ratio is introduced here.

$$\lambda = \frac{R\omega}{v} \tag{6}$$

Where: R (m) - blade diameter; ω (rad/s) - blade speed; v (m/s) - wind speed.

In a fixed pitch fan, leaf tip speed ratio is the only factor that affects C_{p}, while in a variable pitch fan C_{p} is related to both λ and the blade pitch angle β (°). By adjusting β for pitch fans, the wind force captured by the fan can be changed, thus regulating the fan power. C_{p} can usually be expressed as [6]:

$$\begin{cases} C_{\mathrm{p}}(\lambda,\beta) = C_1\left(\dfrac{C_2}{\lambda_i} - C_3\beta - C_4\beta^{C_5} - C_6\right)\mathrm{e}^{\frac{C_7}{\lambda_i}} \\ \dfrac{1}{\lambda_i} = \dfrac{1}{\lambda + C_8\beta} - \dfrac{C_9}{\beta^3+1} \end{cases} \tag{7}$$

Where: $C_1 \sim C_9$ is the fitting parameter, which varies in different types of wind turbines.

Based on the above analysis, the model of C_p is built in Simulink, which shows in Figure 3.

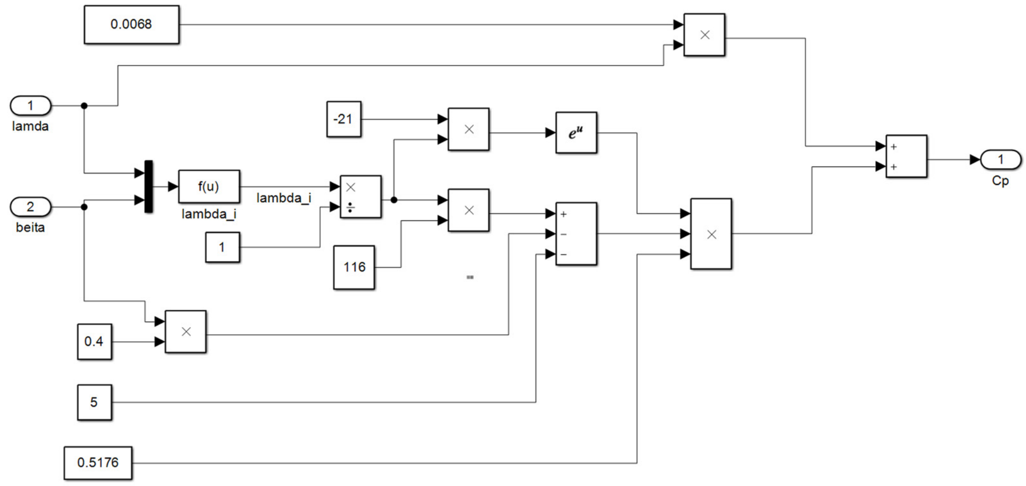


Figure 3 Wind energy utilization coefficient model

According to the above relationship between the power captured by the turbine and C_p, pneumatic system can be modeled, and its model in Simulink, which is shown in Figure 4.

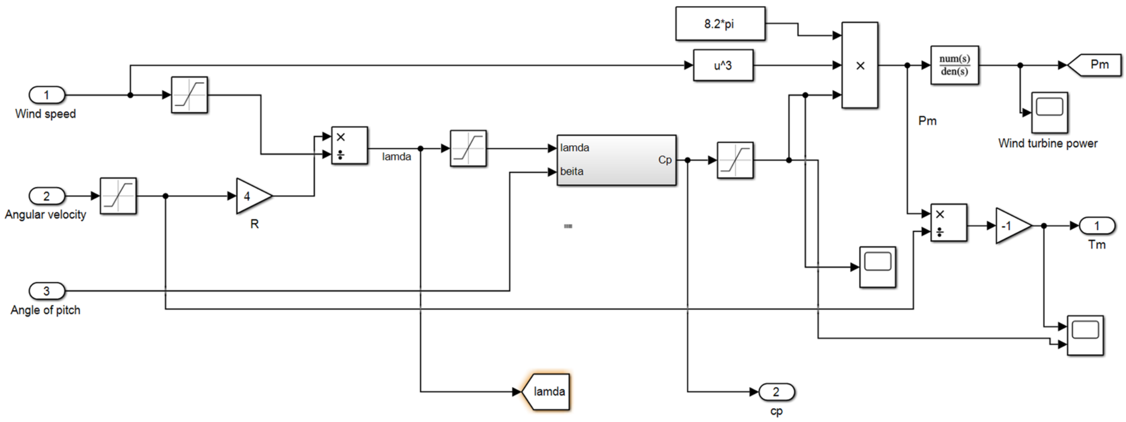


Figure 4 Pneumatic system model

3. Control strategies for wind power systems

3.1. Analysis and modeling of the mountain climbing method

The optimal blade tip speed ratio method, the power feedback method and the mountain climbing method all have more applications in the max power tracking of wind turbines. However, the optimal leaf tip speed ratio method and the power feedback method require additional measurement devices and a certain optimal parameter in the regulation process, which makes both methods much more costly and complex. So these two methods are more suitable for large wind power systems. The mountain climbing method, which does not require any measurement parameters and is simple and flexible, is widely used in small wind power systems.

According to the derivation of Li's work, combined with the Boost circuit used in this paper, the perturbation of the duty cycle of the Boost circuit is used here to indirectly replace the perturbation of the fan speed to achieve the tracking of the max power of the fan. When losses are neglected, the mechanical power of the fan P_m can be approximated as equal to the electromagnetic power P_e, which can be expressed as:

$$\begin{cases} \dfrac{dP_{\mathrm{m}}}{d\omega} \propto -\dfrac{dP_{\mathrm{e}}}{dD} \\ \dfrac{dP_{\mathrm{m}}}{d\omega} = 0 \rightarrow \dfrac{dP_{\mathrm{e}}}{dD} = 0 \end{cases} \tag{8}$$

Based on the above analysis, the model of the hill climbing method is built in Simulink, as shown in Figure 5.

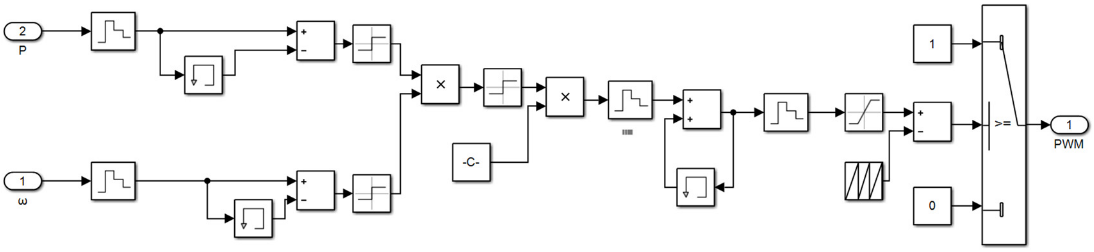


Figure. 5 Hill climbing method

3.2. *Pitch control analysis and modeling*

Due to the randomness and sudden change of natural wind, when the air speed exceeds the rated air speed of the wind turbine, the pitch control system needs to adjust the pitch angle to ensure that the output power of turbine remains near the nominal power, ensure the safety and stability of the system during operation [7]. The power-based pitch control is used here, where the rated power of the generator P_{ref} , is compared with the actual output power of the system P_{e} . The PID control of the pitch angle is performed by comparing the rated power of the generator P_{ref} , with the actual output power of the system P_{e} , and using the error between them as a signal. The overall closed-loop control principle is shown in Figure 6.

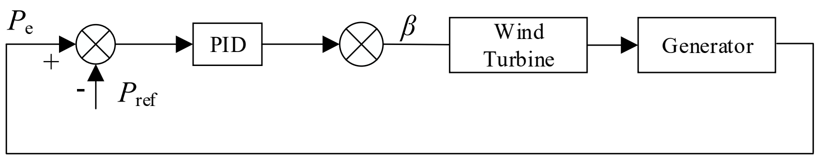


Figure. 6 Pitch control for wind power systems

For the PID control module in Figure 6, build its overall model in Simulink as shown in Figure 7.

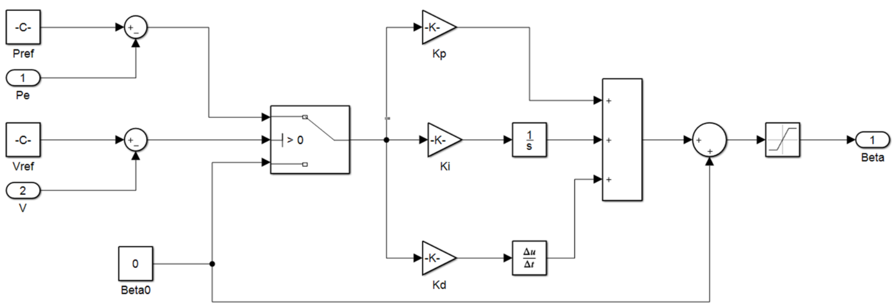


Figure. 7 PID module model of pitch control system

Where the parameters of the PID regulator are: K_p = 1.138, K_i = 2.500, and K_d = 0.121.

4. Control strategy simulation verification

Based on the above analysis and modeling, the parameters of the wind speed model, aerodynamic system model, hill climbing method model and pitch control model are tuned, and then the subsystems are packaged for each part. The overall simulation model of the system is then built in Simulink as shown in Figure 8, where the permanent magnet synchronous motor model is the self-contained model in the Simulink component library.

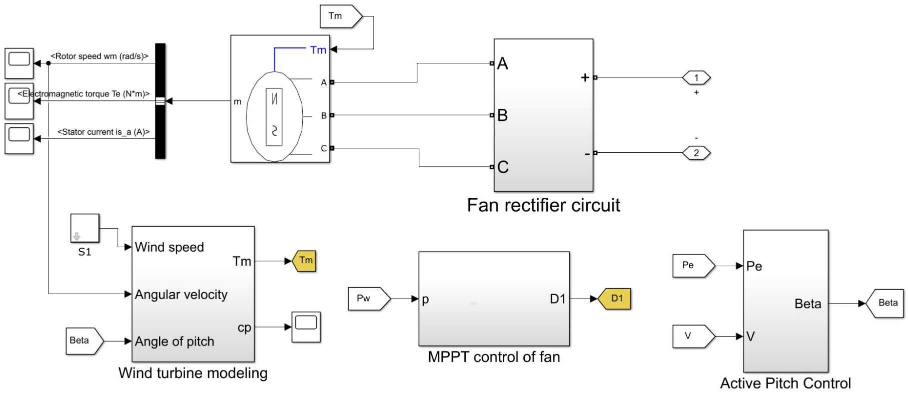
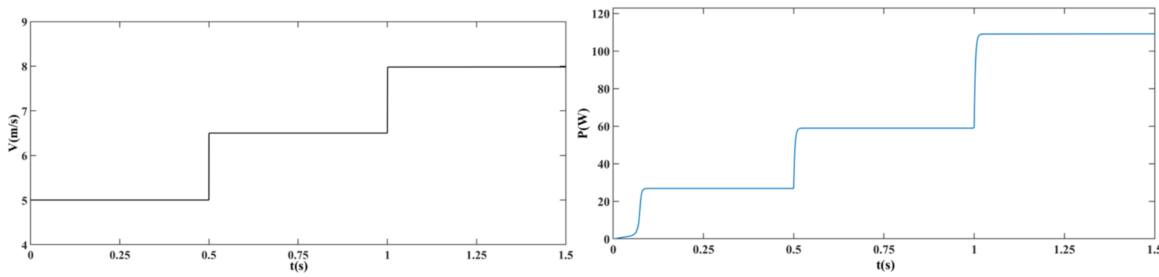


Figure. 8 Overall models of wind power system

Next, the simulation model built is used to verify the correctness and feasibility of the above control strategy by assigning different input parameters to the system.

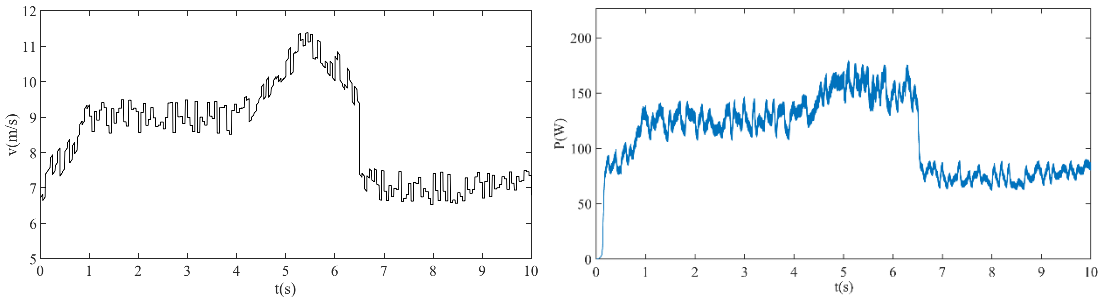
When the sudden change of wind speed is input, Figure 9(b) shows the simulation results of the system as a whole. When the starting wind speed was 5m/s, the wind turbine tracked the max power of about 30W in about 0.1s after starting; at 0.5s, the wind speed changed abruptly to 6.5m/s, and the wind turbine's output power quickly tracked the maximum power of about 60W after a short fluctuation; when the wind speed changed abruptly to 8m/s in 1s, the system could still track the max power at the current wind speed quickly When the wind speed suddenly changes to 8m/s in 1s, the system can still track the max power at the current wind speed quickly. It can maintain the current maximum power operation stably. The above simulation results prove that the track of max power for the PMD system by the mountain climbing method is completely feasible and it has fast dynamic response and good control performance.



(a) Sudden change in wind speed curve (b) Wind turbine output power

Figure. 9 Operation of wind power system under sudden wind speed change

To better simulate the polar wind conditions, the input wind speed is adjusted to the combined wind speed which shows in Fig. 10(a), the simulation result of the system is shown in Fig. 10(b). According to the simulation result graph, we can see that when the air speed is less than the rated air speed, the wind power system can always track the max power at the current air speed quickly and make effective output, and the power curve is good at tracking the wind speed curve. The power curve has good tracking effect on the wind speed curve; when the air speed exceeds the rated air speed of the wind turbine, the pitch control limits the output power of the wind turbine by adjusting the pitch angle of the wind turbine to keep it around 150W. After adjusting the input to the combined wind speed and simulating the system as a whole, we can see that by combining the mountain climbing method with the pitch control, it is possible to keep the system tracking the max power at the current wind speed while ensuring that the output power of the turbine does not cross the limit when the air speed changes.



(a) Combined wind speed profile (b) Wind turbine output power

Figure. 10 Operation of permanent magnet direct-drive wind power generation system at combined wind speed

5. Conclusion

(1) This paper proposes a control strategy for the wind power generation system of polar unmanned vehicles, taking into account the current situation of renewable energy utilization and environmental conditions in polar regions. (2) The conclusions obtained through the simulation are as follows: the wind turbine can track the max power by using the mountain climbing method, which is fast and has high steady-state accuracy, and can effectively improve the utilization of wind energy; the variable pitch control is used to ensure that the wind turbine's output power remains near the rated power when the air speed exceeds the rated air speed, which ensures the safe operation of the wind turbine under the cold and gusty wind environment in the polar regions. (3) In the subsequent research work, we expect to do further optimization of the control strategy to reduce the output loss of the system and build the hardware circuit of the system and conduct physical tests on the control strategy.

Acknowledgments

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