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Adaptive system design of wind turbine parameters based on Lyapunov stability

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Abstract: *When the wind turbine is running, parameters such as temperature, wind speed and wind direction are difficult to control using a PLC. In order to improve the power generation efficiency and minimise the parameter error, simulation experiments are carried out in SimKink in Matlab. An adaptive system based on MIT and Lyapunov function is designed to monitor and control the parameters of the wind turbine. The results show that the adaptive system based on the Lyapunov function can control the error of the temperature parameter to plus or minus 1 degree Celsius, the error of the wind speed parameter to plus or minus 10 rad/s and the error of the wind direction parameter to plus or minus 5 deg. The simulation results have good reliability and can provide theoretical guidance for actual production.*

Keywords: *MATLAB, MIT, Liapunov Stability, Adaptive Control, SimKlink*

1. Introduction

In recent years, with the continuous pursuit of green energy, solar energy, wind energy, tidal energy and so on, among which wind energy is gradually becoming one of the most important new energy sources, improving the efficiency of wind power generation is the main problem faced at present. The instability of operating parameters is a major factor in the lower efficiency of wind turbine power generation, and the traditional MIT adaptive system has the disadvantages of lower accuracy and poorer stability. It seriously affects the power generation efficiency of wind turbines, which requires more advanced technology. With the development of modern control theory, nonlinear adaptive system control has the advantages of high precision and good stability, and is widely used in wind turbines. Model-based control is a relatively active area of research in the development of wind turbines. The literature [1] proposes an independent pitch control method with adaptive model reference, which improves the efficiency of wind energy use to a certain extent, but still suffers from high fatigue loads on the main components. Literature [2] proposes a novel design approach using a predictive model with a simple structure, but a less stable system and less efficient use. In the literature [3], nonlinear robust control is used to improve the stability of the system, but the overall structure is more complex. All of these methods suffer from unstable system operation and low power generation efficiency, leading to unbalanced loads and reduced wind turbine efficiency.

This paper is based on the adaptive system created by Lyapunov function, which is mainly composed of PLC [4], sensors, etc. Using the adaptive system to control parameters such as temperature, wind speed, wind power, etc., the parameter signals are transmitted to the PLC by monitoring the sensors and the PLC receives the signals. The adaptive system is designed to operate so that the operating parameters of the wind turbine are close to the optimum operating range, so that the wind power efficiency of the wind turbine is stable.

2. Adaptive system components

2.1 The structure of Adaptive system components

Adaptive system mainly has integrator, adder, transfer function of the composition of a complete closed-loop system, its structure block diagram shown in Figure 1

Receive the analogue signal from the sensor, calculate and output a stable parameter signal through the set transfer function, integrator, etc., so that it is always stable in the vicinity of the operating

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parameters, thus maintaining a stable working condition.

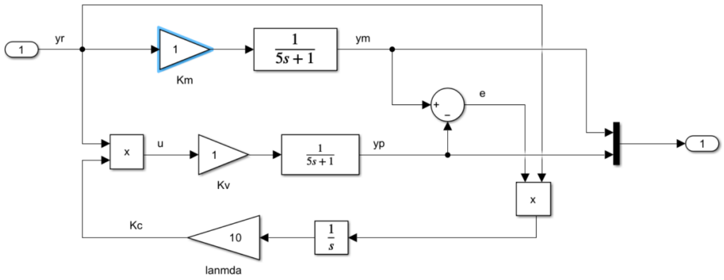

Figure 1: Block diagram of the structure of the adaptive system

The Lyapunov stability theorem is an approach to studying the stability of a control system using an adaptive algorithm derived from Lyapunov's second method, which guarantees global asymptotic stabilisation of the adaptive system. It mainly includes the following aspects.

(1) First-order linear system with adjustable gain

$$\begin{cases} D(s) = 1+Ts \\ N(s) = 1 \end{cases} \tag{1}$$

$$\begin{cases} E(s) = y_m(s)-y_p(s) = \left(\frac{K_m N(s)}{D(s)} - \frac{K_c K_v N(s)}{D(s)}\right) y_r(s) \\ D(s)E(s) = N(s)(K_m - K_c K_v) y_r(s) \\ T\dot{e}+e = (K_m - K_c K_v) y_r(t) = K(t) y_r(t) \end{cases} \tag{2}$$

$$V(e) = e^2 + \lambda K^2(t) \quad (\lambda > 0) \tag{3}$$

$$\frac{dV}{dt} = 2e\dot{e} + 2\lambda K\dot{K} \tag{4}$$

$$\dot{e} = -\frac{e}{T} + \frac{K y_r(t)}{T} \tag{5}$$

$$\frac{dV}{dt} = 2e\left(-\frac{e}{T} + \frac{K y_r(t)}{T}\right) + 2\lambda K\dot{K} = -\frac{2}{T}e^2 + \frac{2}{T}Key_r(t) + 2\lambda K\dot{K} \tag{6}$$

$$\frac{2}{T}Key_r(t) + 2\lambda K\dot{K} = 0 \tag{7}$$

$$\dot{K} = -\frac{1}{\lambda T} e y_r \tag{8}$$

$$K(t) = K_m - K_c K_v \tag{9}$$

$$\dot{K}(t) = -K_c \dot{K}_c \tag{10}$$

$$\dot{K}_c = \mu e y_r(t) \tag{11}$$

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$$\begin{cases} T\dot{e}+e = (K_m-K_cK_v)y_r(t) \\ \dot{K}_c = \mu e y_r(t) \end{cases} \tag{12}$$

(2) Second-order linear system with adjustable gain

$$D(s) = s^2+a_1s+a_2 \quad a_1,a_2>0 \tag{13}$$

$$N(s) = 1 \tag{14}$$

$$\ddot{e}+a_1\dot{e}+a_2e = Ky_r(t) \tag{15}$$

$$V(e,\dot{e}) = a_1a_2e^2+a_1\dot{e}^2+\lambda K^2(t) \ \lambda>0 \tag{16}$$

$$\frac{dV}{dt} = 2a_1a_2e\dot{e}+2a_1\dot{e}\ddot{e}+2\lambda K\dot{K} \tag{17}$$

$$2\lambda K\dot{K} = -2a_1\dot{e}_1Ky_r \tag{18}$$

(3) General n-order constant linear system

$$\{D(s) = s^n+a_1s^{n-1}+...+a_{n-1}s+a_n \tag{19}$$

$$N(2) = b_1s^{n-1}+...+b_{n-1}s+b_n \tag{20}$$

$$e^{(n)}+a_1e^{(n-1)}+...+a_{n-1}\dot{e}+a_ne = K(b_ny_r{}^{n-1}+...+b_ny_r) \tag{21}$$

$$\{\dot{X} = AX+KBy_r(t) \tag{22}$$

$$e = CX \tag{23}$$

$$V(e) = X^TPX+\lambda K^2 \quad \lambda>0 \tag{24}$$

$$\frac{dV}{dt} = \dot{X}^TPX+X^TPx+2\lambda K\dot{K} = X^T(PA+A^TP)\dot{X}+2X^TPBKy_r+2\lambda K\dot{K} \tag{25}$$

$$\dot{K} = -\frac{1}{\lambda}X^TPBy_r \tag{26}$$

$$\dot{K}_c = \frac{1}{\lambda K_v}X^TPBy_r \tag{27}$$

$$PB = (\alpha,0,0,...,0)^T \tag{28}$$

$$\dot{K}_c = \mu e y_r \tag{29}$$

2.2 Control requirements for adaptive systems

With the change of external temperature, wind speed and wind direction, the temperature, wind speed and wind direction of the wind turbine also change to a certain extent, the sensor monitors and collects the signal, and transmits the signal to the PLC, and the adaptive system begins to work. Through the process of integration, derivation, transfer function, gain, etc., the temperature is controlled at the optimum working temperature +-0.1 degree Celsius, the wind speed is controlled at the optimum working wind speed +-2ad/s, and the wind direction is controlled at the optimum working wind direction +-5 degrees.

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3. Hardware design of the adaptive system

3.1 PLC Selection

PLC is the core device of wind turbine, through a series of selection, Siemens S7-200 series CPU226CN Figure 2 model PLC can form a powerful control system through the expansion module. Expandable 7 control modules, 40 input/output points, 2 RS232-485 communication interfaces, cost effective, more expansion ports, can be used for more points, higher control requirements of the control system. It can realize the control function of single machine and networking, which is more in line with the requirements of the system, so we choose Siemens S7-200 CPU226CN PLC.

Figure 2: Siemens S7-200 Series CPU226CN

3.2 Sensor selection

Temperature Sensor: PT100 temperature sensor Figure 3, output current 4-20mA or output voltage 0-5V. When inserted into the medium temperature change will be the change in resistance, the change in resistance is proportional to temperature, and with the temperature in a linear change, the temperature rises, the resistance value rises; the temperature falls, the resistance value falls. At 0 degrees Celsius, the resistance is 100 ohms; at 100 degrees Celsius, it is approximately 138.5 ohms. This linear variation depends on the properties of the material (PT) itself, and PT is an inert material that does not normally react with other compounds. It is more in line with the requirements of the system, so the PT100 temperature sensor is chosen.

Figure 3: PT100 temperature sensor

Wind speed sensor: ultrasonic wind speed sensor Figure 4 is beneficial to the speed of sound propagation in the air, if the ultrasonic speed and sound speed in the same direction, the speed is accelerated; Therefore, under certain conditions, the speed of ultrasound and the speed of sound can correspond to the wind speed function, and the magnitude of the wind force can be calculated. Since the propagation of sound in the air is easily affected by the air, the two opposite directions on the duct are monitored by the wind speed sensor, so the error caused by temperature on the speed of sound waves is negligible[5].

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Figure 4: Ultrasonic wind speed sensor

As the wind direction changes, the resistance changes accordingly and the angle or direction of the wind can be calculated. Normally the wind sensor is installed together with the anemometer. The wind sensor needs to be at a higher level, which is more in line with the system requirements, so the resistive wind sensor is chosen [6].

Figure 5: Resistive wind direction sensor

4. Software Simulation of Adaptive Systems

The software simulation of the adaptive system Figure 6 is carried out in MATLAB, and to further verify the stability of the adaptive system, simulation experiments are carried out on the three parameters of temperature, wind and wind direction respectively, and the values of each parameter are selected for simulation [7].

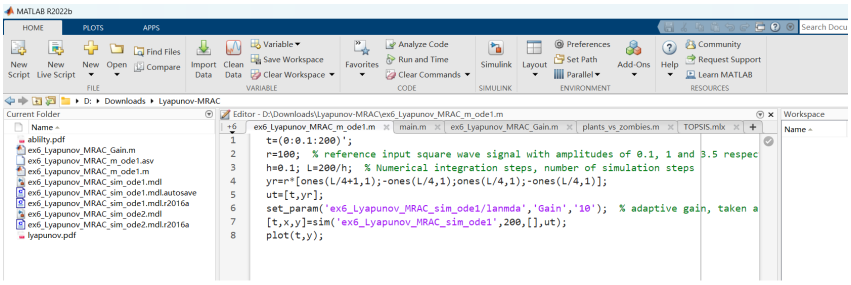

Figure 6: Simulation process of the adaptive system

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4.1 Temperature adaptive system

The temperature sensor collects temperature signals and collects three temperature signals, 15 degrees Celsius Figure 7, 25 degrees Celsius Figure 8 and 30 degrees Celsius Figure 9. The temperature signal is transferred to the temperature adaptive system via digital-to-analogue conversion, and the temperature signal controlled by the adaptive system is output via a series of integrators, adders and transfer functions.

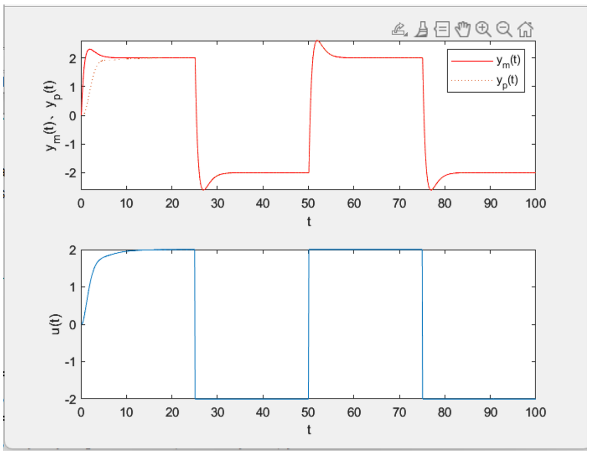

Figure 7: Performance curve of the 15 degree Celsius temperature adaptive system

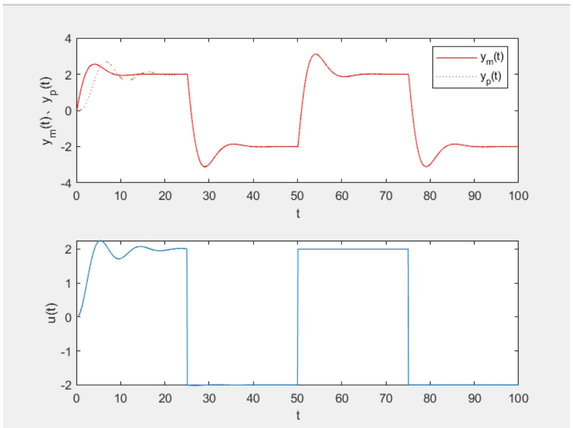

Figure 8: 25 degree Celsius temperature adaptive system power curve

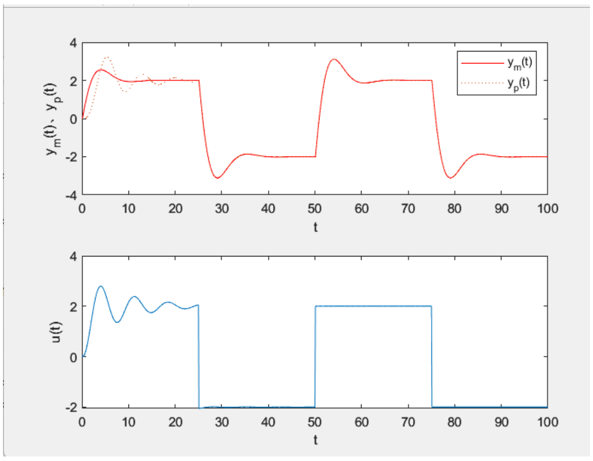

Figure 9: 30 degree Celsius temperature adaptive system power curve

Based on the analysis of the image waveforms, it can be seen that the output curve of the temperature adaptive system with a parameter of about 25 degrees Celsius best meets the control requirements of the adaptive system, with an error of +-0.1 degrees Celsius.

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4.2 Wind Speed Adaptive System

The wind speed sensor collects the temperature signal and collects three wind speed signals, 5m/s Figure 10, 10m/s Figure 11 and 15m/s Figure 12, and transmits the wind speed signals to the wind speed adaptive system via digital-to-analogue conversion. A series of integrators, adders and transfer functions output the wind speed signal controlled by the adaptive system.

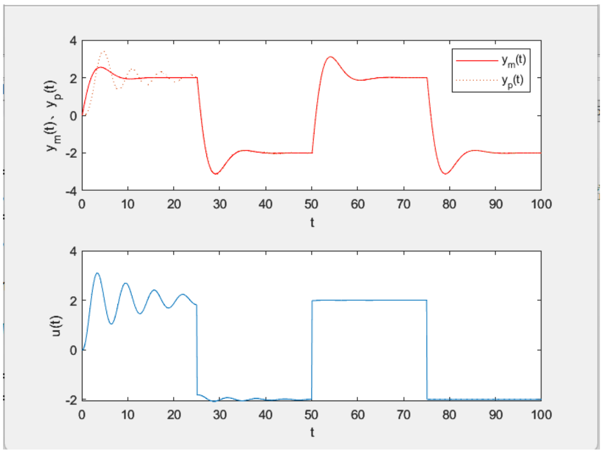

Figure 10: Wind Speed Adaptive System Output Curve for 5m/s

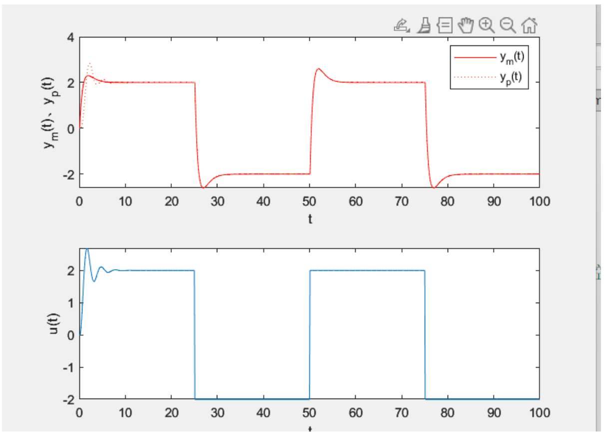

Figure 11: Wind Speed Adaptive System Output Curve for 10m/s

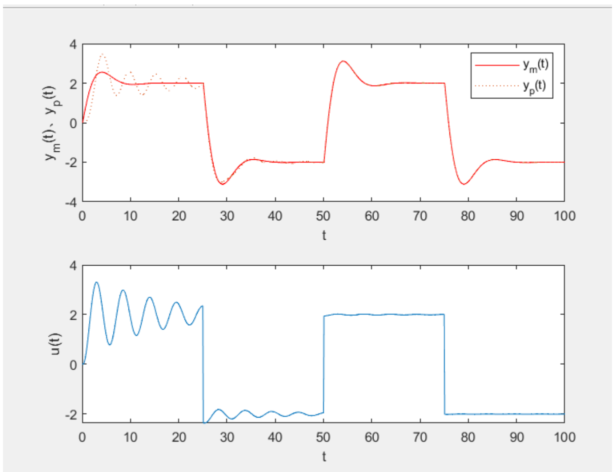

Figure 12: Wind Speed Adaptive System Output Curve for 15m/s

Based on the analysis of the image waveforms, it can be seen that the output curve of the wind speed adaptive system with a parameter of about 10m/s best meets the control requirements of the adaptive system, and the error is between +-2m/s.

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4.3 Wind Direction Adaptive System

The wind direction signal controlled by the adaptive system is output through a series of integrators, adders and transfer functions, as shown in Figure 13, Figure 14 and Figure 15.

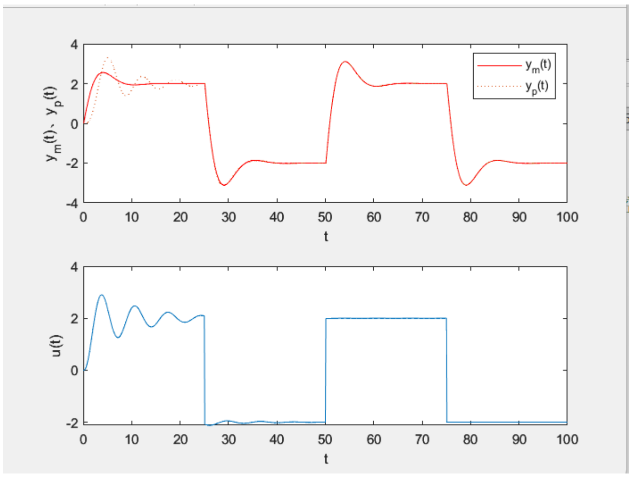

Figure 13: Wind Direction Adaptive System output curve for 5 degrees

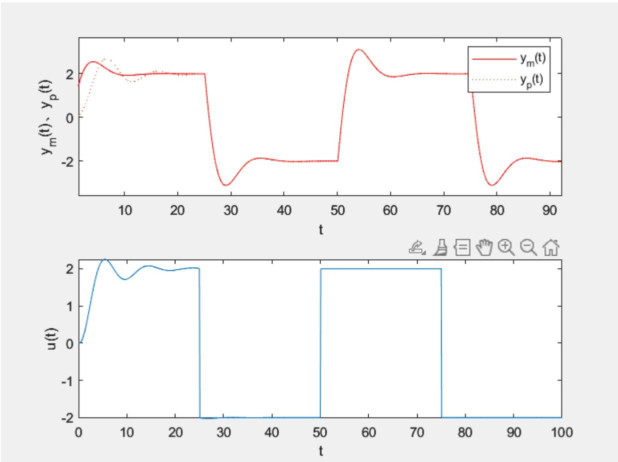

Figure 14: Wind Direction Adaptive System output curve for 10 degrees

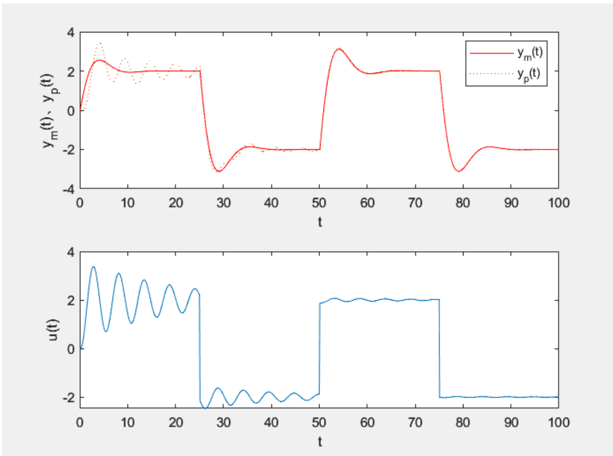

Figure 15: Wind Direction Adaptive System output curve at 15 degrees

From the image waveform analysis, it can be seen that the output curve of the wind direction adaptive system best meets the control requirements of the adaptive system with a parameter of about 10 degrees, and the error is between +-2 degrees.

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5. Conclusion

Aiming at the shortcomings of traditional PLC control, this paper designs and realizes a kind of wind turbine adaptive system based on Li Yapunov function, and improves the control mode of parameters, which reduces the error of wind turbine parameters to a certain extent and improves the control accuracy. In this paper, the parameters of temperature, wind speed and wind direction are collected by sensors, transmitted to the adaptive system, and through a series of calculations by adder, integrator and transfer function, the prediction is made.

With the development of nonlinear control theory, more control methods will emerge in nonlinear systems, for nonlinear systems, the control will achieve better control effects and improve the stability of the system itself work.

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