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Power Coordination Control Method of Wind Turbine Considering Power Demand Characteristics of Hydrogen Production System

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ABSTRACT

Among the relatively mature new energy generation technologies, wind power has attracted widespread attention for rich reserves and pollution-free emissions. However, wind power generation has randomness and volatility, posing a huge challenge to power quality and stability. With the rapid development of technologies such as water electrolysis and breakthroughs in key technologies, wind energy hydrogen production technology provides new ideas for solving problems such as poor power quality and strong voltage fluctuations in wind power generation systems. This paper fully considering the electrolyzer dynamic power variation requirements and the wind turbine output power variation characteristics, designs a constant bandwidth MPPT control strategy to achieve on-demand power output of the wind turbine; at the same time, smooth the output power, achieve dynamic coordination of power between the wind turbine and the electrolyzer system. Finally, the effectiveness of the proposed coordinated control method is verified through simulation.

Keywords: power coordination control, wind turbine control, constant bandwidth MPPT control, wind power hydrogen production system

1. INTRODUCTION

In the past few years, the energy crisis has become increasingly severe. Under the international background of carbon neutrality, countries have begun to seek renewable and clean energy to change the current energy consumption structure. Among the more mature new energy power generation technologies, wind power generation has been widely concerned because of its abundant reserves and no pollutant emission. However, wind power generation is greatly affected by the environment, resulting in poor output power quality, strong randomness, and low prediction accuracy. When the wind speed in the external environment changes randomly, the output power of the wind turbine also fluctuates, which brings great challenges to the power quality and stability [1-2]. And hydrogen energy storage, due to its high energy density and ease of storage, has become the best choice for solving problems such as poor power quality and strong voltage fluctuations in wind power generation systems. With the rapid development of electrolyzer hydrogen production and the breakthrough of key technologies, the wind energy hydrogen production technology provides a new idea for the utilization of wind energy [3-4].

In recent years, countries all over the world are actively carrying out research on the key technologies of wind power generation hydrogen production system. For the high-frequency power change of the wind turbine, its change time scale is in the millisecond/second level, while for alkaline electrolyzer, its dynamic response time scale is in the minute level, when its input power change rate is higher than the dynamic time, its electrode coating may fall off, and then affects its service life. In addition, although the high-frequency power of the wind turbine can be suppressed by the external energy storage link, due to the limitation of the charge and discharge cycle of the energy storage system, the use of energy storage to absorb high-frequency power will affect the life of the energy storage system, increase the replacement frequency of the energy storage system [5-8]. Previously, relevant literature has been studied and proposed coordinated control methods [9-14].

Therefore, it is necessary to optimize the wind turbine control system design, so that does not respond to the high-frequency wind speed change, and then the output power does not contain the high-frequency power caused by the tracking of the fast-changing wind speed, which can well meet the energy demand of the electrolyzer. Based on these, this paper proposes a

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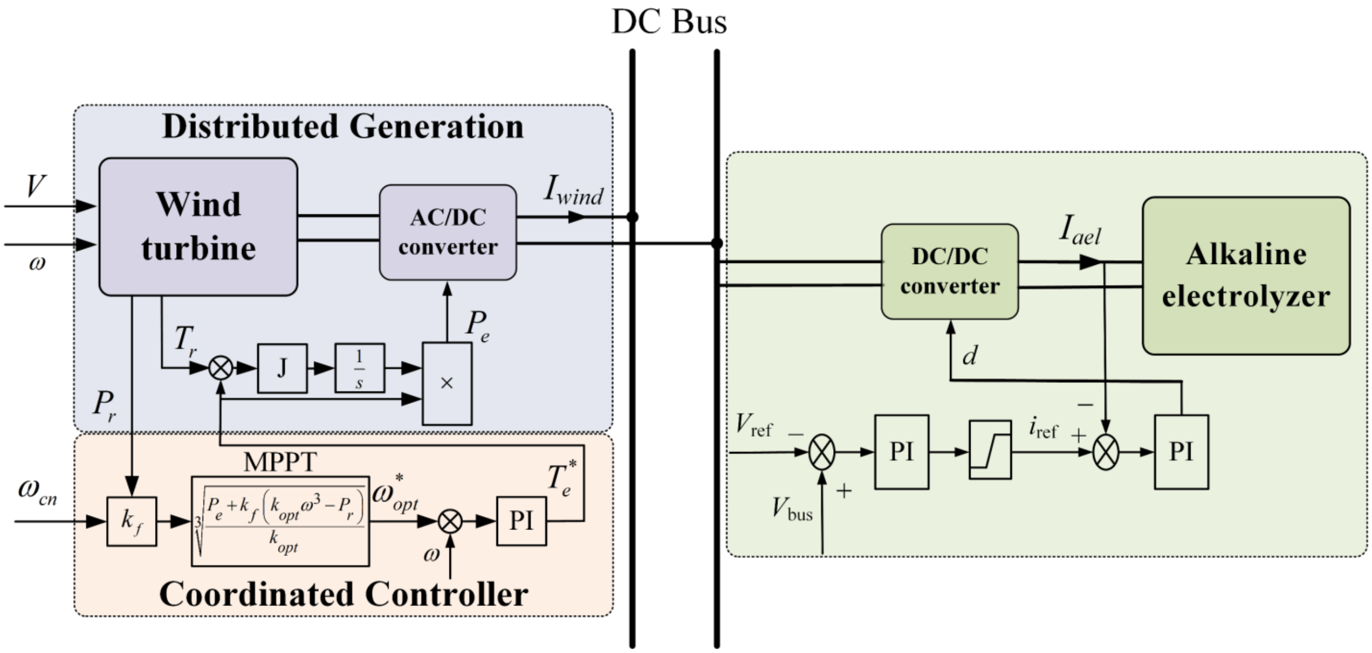

Fig. 1 Power coordination control method of wind turbine considering power demand characteristics of hydrogen production system

coordination method based on constant bandwidth MPPT control, through the coordinated control in the hydrogen production system of wind power generation, the system can keep running smoothly when the external environment or load power fluctuations, and the bus voltage and frequency in the system remain stable, so as to achieve the coordinated control.

The rest of this paper is organized as follows: Section 2 clarifies the system main structure, then in Section 3, the system is modeled and simulated, and the simulation results are analyzed. In the end, the conclusion is presented in Section 4.

2. SYSTEM STRUCTURE

2.1 System structure

Fig. 1 shows the topological structure of off-grid microgrid system of power coordination control method of wind turbine considering power demand characteristics of hydrogen production system. The distributed power supply as the source side input of the system includes wind turbine, which converts wind energy into electric energy and is incorporated into the DC bus in the form of current source. The water electrolysis cell for hydrogen production is the main load of the system and is connected to the bus by the front DC/DC converter. Through the power required by the electrolyzer, the output power of the wind turbine does not contain the high-frequency power caused by tracking the fast-changing wind speed, which meets the energy demand of the electrolyzer, and keeps the bus voltage and frequency in the system stable to achieve the coordinated control of the system.

3. SYSTEM MODELING AND SIMULATION ANASYSIS

In order to verify the effectiveness of the power coordination control method of the system mentioned above, according to the mathematical models and topological structure, the state-space averaged equation modeling is adopted.

3.1 Mathematical modeling

3.1.1 Mathematical model of wind turbine

The wind turbine blades convert wind energy into mechanical torque acting on the hub, and then capture the maximum wind energy and convert it into mechanical energy, which contains a lot of complex aerodynamic knowledge and is not the key consideration. Therefore, this modeling uses the wind energy conversion coefficient *Cp* to simplify the establishment of the aerodynamic model, and the wind turbine torque is as follows

$$T_\omega = \frac{0.5\pi\rho R^2 V^3 C_p}{\omega} \tag{1}$$

where T_ω is the mechanical torque of the wind turbine from the wind energy, ρ is density of air, R is radius of wind wheel, V is actual wind speed, ω is the angular velocity of the wind wheel, Cp is wind energy conversion factor. In this case, the captured power is

$$P = 0.5\pi\rho R^2 V^3 C_p \tag{2}$$

The maximum power tracking (MPPT) control of wind turbine under low wind speed adopts a single closed-loop PI control. The error between the pneumatic power and the current optimal power is sampled, and then the output power is superimposed by feedforward coefficient k_f to accelerate the MPPT tracking speed. The PI controller takes the optimal speed output of MPPT and the measured speed of wind turbine as input. PI controller for wind turbine output electromagnetic torque, the governing equation is as follows:

$$T_e = k_{\mathrm{p}}(\omega - \omega_{opt}) + k_{\mathrm{i}}\int_0^t (\omega - \omega_{opt})d\tau \tag{3}$$

where T_e is the electromagnetic torque of wind turbine; ω_{opt} is the optimal angular velocity output by MPPT, ω is the measurement value of wind turbine angular velocity; k_p and k_i are PI parameters.

3.1.2 Mathematical model of the alkaline electrolyzer

Alkaline electrolyzer is a complex system, in which the electrochemical model reflects the electric response of the alkaline electrolyzer, which is mainly established in this paper. At any temperature, the U-I equation of the alkaline electrolyzer is

$$\begin{aligned} U_{cell} &= U_{rev} + \frac{r_1 + r_2 T_{el}}{A} I \\ &+ (s_1 + s_2 T_{el} + s_3 T_{el}^2) log(\frac{t_1 + t_2 / T_{el} + t_3 / T_{el}^2}{A} I + 1) \end{aligned} \tag{4}$$

where r_1、r_2 are electrolyte ohm resistance parameters, T_{el} is electrolyzer temperature, A is electrolytic module area, s_1、s_2、s_3 are electrode overvoltage coefficients, t_1、t_2、t_3 are electrode overvoltage coefficients.

3.1.3 Pre-stage DC/DC converter of the electrolytzer

The control of unidirectional DC/DC converter of the alkaline electrolyzer adopts double closed loop PI control, the outer loop is the voltage loop, the inner loop is the current loop; The outer loop PI controller takes the nominal value of the DC bus voltage and the measured value of the DC bus voltage as the input, and the inner loop PI controller outputs the driving signal to the switching tube of the unidirectional DC/DC converter of the alkaline electrolyzer. In addition, the output end of the outer loop is limited to ensure that the maximum current input reference of the alkaline electrolyzer is the rated current value; the governing equation of the the alkaline electrolyzer is:

$$\begin{cases} d = k_{\mathrm{ip}}(i_{\mathrm{ref}} - i_{\mathrm{ael}}) + k_{\mathrm{ii}}\int_0^t (i_{\mathrm{ref}} - i_{\mathrm{ael}})d\tau \\ i_{\mathrm{ref}} = k_{\mathrm{vp}}(V_{\mathrm{ref}} - V_{\mathrm{bus}}) + k_{\mathrm{vi}}\int_0^t (V_{\mathrm{ref}} - V_{\mathrm{bus}})d\tau, \\ 0,\ I_{\mathrm{aelmin}},\ \textit{Select according to the situation} \end{cases} \tag{5}$$

where V_{ref} is the nominal value of the DC bus voltage; V_{bus} is the measurement value of bus voltage; i_{ref} and i_{ael} are the inner loop current reference and battery current measurement values respectively. The selection of i_{ref} is based on the control strategy, and I_{aelmin} is the lowest hydrogen production current. When i_{ref} selects this value, it indicates that the alkaline electrolyzer is working at the lowest hydrogen production power. d is the duty cycle of the switching tube S of the DC/DC converter; k_{ip} and k_{ii} are inner loop PI parameters, k_{vp} and k_{vi} are outer loop PI parameters, respectively.

3.2 System coordinated control algorithm

The power coordination control method of the wind turbine considering the power demand characteristics of the electrolyzer hydrogen production system is characterized in that, after adding the power error feedforward branch, the relationship of the power feedback MPPT strategy is as follows:

$$\omega_{opt} = \sqrt[3]{\frac{P_e + k_f\left(k_{opt}\omega^3 - P_r\right)}{k_{opt}}} \tag{6}$$

in the formula, ω_{opt} is the optimal angular velocity output by MPPT, ω is the measurement value of wind turbine angular velocity, P_e is the output electrical power of the unit, P_r is the aerodynamic power of the unit, k_f is the feedforward coefficient, k_{opt} is the optimal power coefficient.

Moreover, the power coordination control method of the wind turbine considering the power demand characteristics of electrolyticzer hydrogen production system adds the power error feedforward branch, the feedforward coefficient k_f is adjusted to ensure the constant bandwidth of the system, and then the response speed of the unit to the wind speed is designed according to the unit situation and the dynamic response requirements of the electrolyzer. The feedforward coefficient k_f adjustment method is as follows:

$$k_f = \frac{J\omega_{cn}}{3k_{opt}\omega_Q} - 1 \tag{7}$$

where k_f is the feedforward coefficient, J is the moment of inertia of the wind turbine, k_{opt} is the optimal power coefficient, ω_Q is the steady-state wind turbine angular velocity, and ω_{cn} is the required bandwidth of the control system.

Table I System Parameters

System Parameters	Parameters			
	Rated power of wind turbine P_{wind}	***DC bus voltage V_{bus}***	***Rated power of alkaline electrolyzer P_{AEL}***	***Required control bandwidth ω_{cn}***
Value	*10kW*	*540 V*	*≤10kW*	*1.2rad/s*

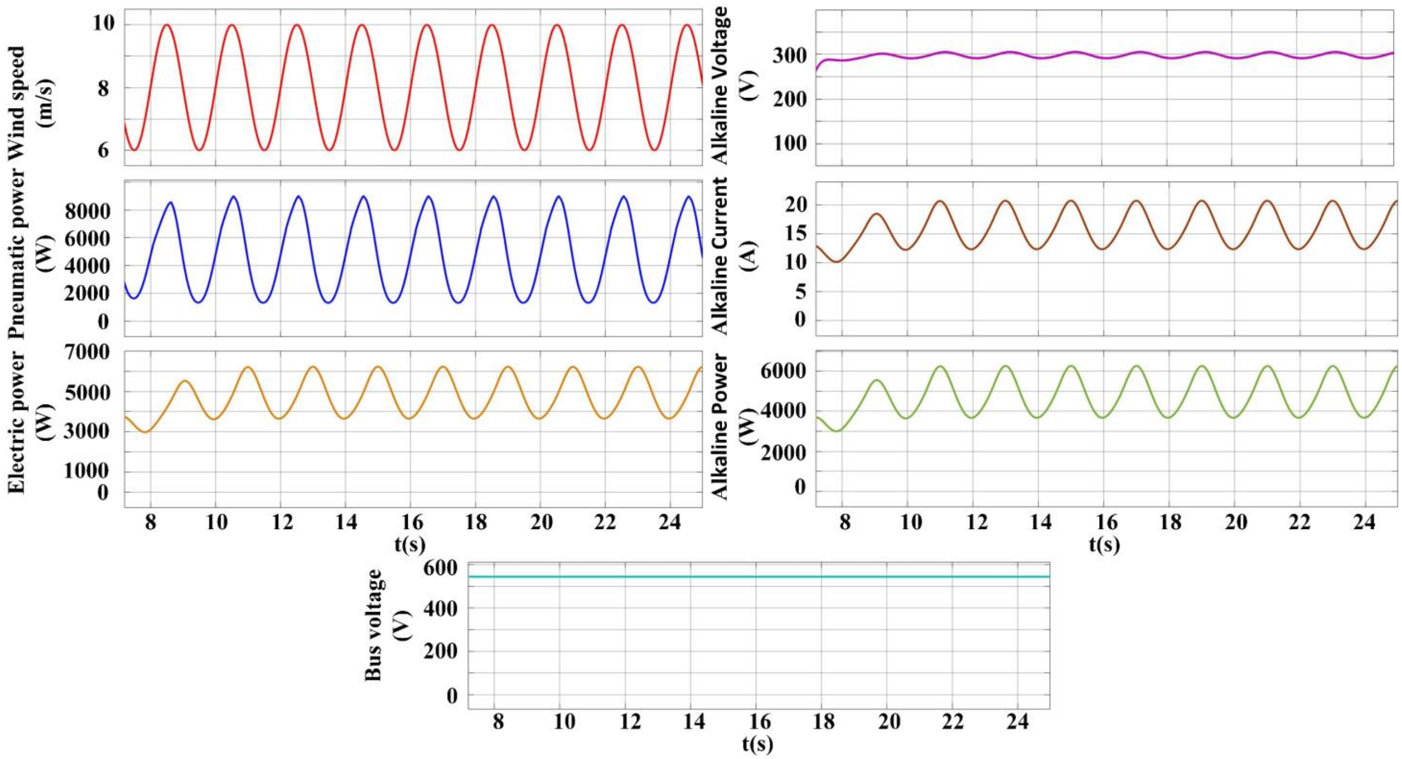

Fig. 2 System simulation results under sinusoidal wind input

In order to achieve coordinated control, the required ω_{cn} can be set based on the dynamic response time of the alkaline electrolyzer (manufacturer parameters, during hot backup) to control and smooth the output power of the wind turbine, and then meet the response requirements of the electrolyzer.

3.3 System simulation analysis

3.3.1 System simulation results under sinusoidal wind input

Based on mathematical models, a simulation model of power coordination control method of the microgrid is built on the MATLAB/Simulink simulation platform, through which verifies the effectiveness of the proposed control method and the stability of system operation.

As mentioned above, the rated power of the wind turbine is set as 10kW, and the rated power of the alkaline electrolyzer is set to be less than 10kW. Besides, the simulation time is set to 25s, and the bandwidth of the control system is set to 1.2rad/s under the sinusoidal wind input with an average wind speed of 8m/s and a frequency of 0.5Hz. The coordinated control and constant bandwidth MPPT control of the system are simulated and analyzed.

Fig.2 shows the system simulation results. Ignoring the starting process, it can be seen that the pneumatic power varies sinusoidal from 1340W to 9000W with the sinusoidal wind, which cannot meet the energy demand of the electrolyzer. Through the coordinated control, the output power of the wind turbine varies sinusoidally from 3650W to 6230W, and the output power does not include high-frequency power caused by tracking fast changing wind speed. The operating power of the alkaline electrolyzer also varies roughly between 3650W and 6230W. The input of the system meets the power demand of the alkaline electrolyzer, and the system runs smoothly, with the bus voltage and frequency maintaining stability. By the simulation results, it can be concluded that the coordinated control of the system is realized, and the effectiveness of the proposed control method is verified.

3.3.2 System simulation results under random wind input

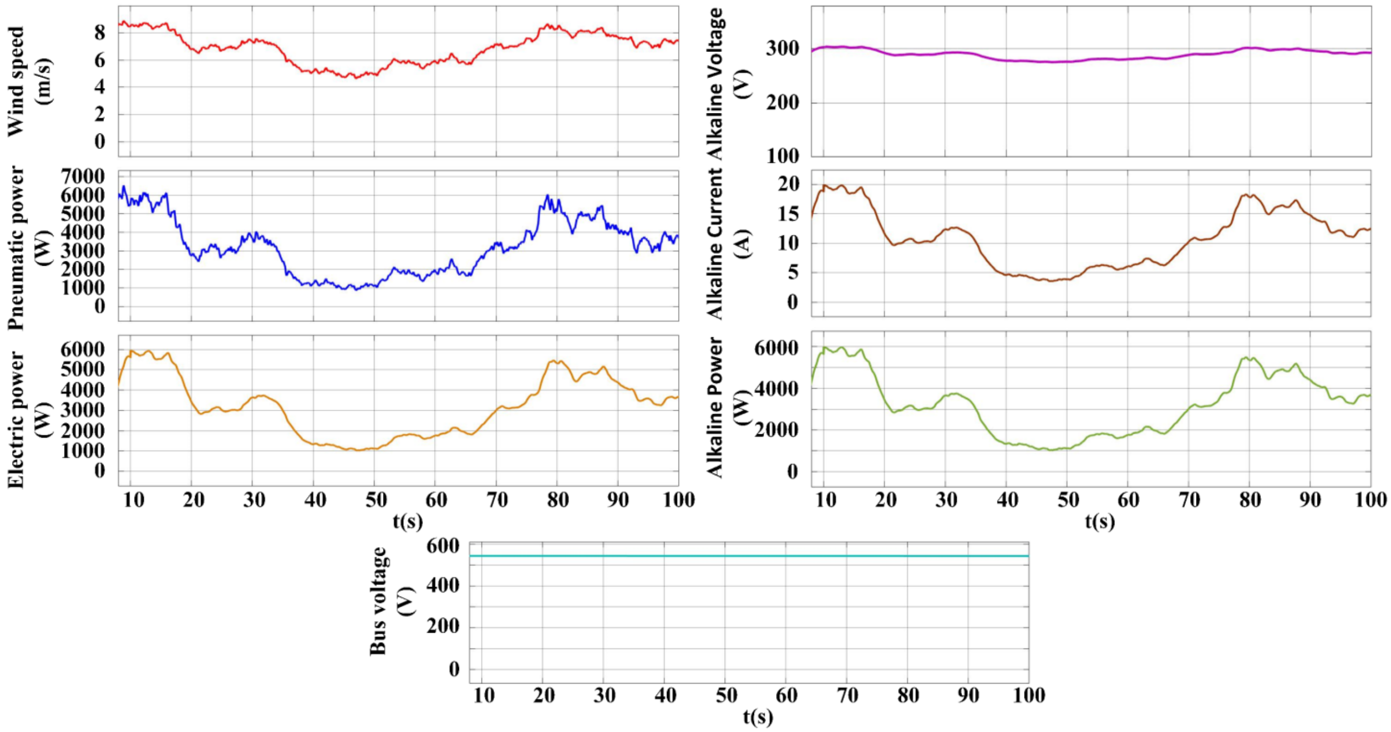

Fig. 3 System simulation results under random wind input

In order to better verify the effectiveness of the proposed control method and the stability of system operation, under the input of random wind speed, the average wind speed of the random wind is set to 8m/s, and the simulation time is 100 seconds. The simulation analysis of the system is carried out. The operating results of the system are shown in Fig.3.

Under the random wind with an average wind speed of 8m/s, the system runs smoothly, the bus voltage maintains constant. From Fig. 3, it can be seen that the pneumatic power varies with the sinusoidal wind, including the high-frequency power caused by tracking fast changing wind speed, which cannot meet the alkaline electrolyzer power demand; however, through the coordinated control, the electric power output becomes smoother, meeting the response needs of the alkaline electrolyzer. Based on this, the feasibility of the system coordinated control method and the stability are verified.

4. CONCLUSION

In this paper, a simple and optimized coordinated control method is proposed for wind turbine considering power demand characteristics of hydrogen production system. By adding the power error feedforward branch, adjusting the feedforward coefficient to ensure the constant bandwidth of the system, and then designing the response speed of the wind turbine to the wind speed according to the unit situation and the dynamic response requirements of the electrolyzer, the coordinated control of the system is realized; besides, the system runs stably and the bus voltage remains unchanged, which certifies the effectiveness of the system coordination control.

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