

Control Strategy of DC Link Voltage Flywheel Energy Storage for Non Grid Connected Wind Turbines Based on Fuzzy Control

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Abstract

The large-scale development of wind power is an important means to reduce greenhouse gas emissions, alleviate environmental pollution and improve the utilization rate of renewable energy. At the same time, large-scale non grid connected wind power generation theory avoids the technical difficulties of wind power integration [1]. However, due to the randomness and uncontrollability of wind energy, the output power of the wind power generation system will fluctuate accordingly [2]. Therefore, the corresponding energy storage devices are arranged in the non-grid-connected wind power generation system to ensure the power quality, and it has become the key to full utilization of renewable energy. In the case of wind speed fluctuation, the DC bus control strategy of the wind turbine is proposed in this paper. It can reduce the impact on the unit converter and the power load; this ensures safe and stable operation of non-grid connected wind turbines.

Keywords

Non-Grid Connected Wind Power Generation, DC Bus Voltage, Control Strategy

1. Introduction

Wind power has been recognized by the world, but also the closest to commercialization, as a strong market competitiveness of renewable energy technology; because, it occupies less land, less social disputes, environment-friendly, can quickly achieve large-scale and industrialization [3] [4]. The terminal load of large-scale wind power is no longer power grid. The small stand-alone power supply system with the battery is also different, but the wind power is directly

transported to some high-energy carrying enterprises, 100% energy conversion is realized to solve the problem of wind power utilization that cannot be connected to the network. Because the terminal load of non-grid connected wind power generation unit has certain requirements for power quality; so, a control scheme of flywheel energy storage system based on fuzzy control is proposed in this paper. This scheme can stabilize the DC bus voltage of the non-grid connected wind turbine, improve the working condition of the unit post converter, and improve the power supply quality to the terminal load.

2. System Composition and Configuration

Figure 1 is a structural diagram of a non-grid connected wind turbine generator system supported by flywheel energy storage system. The system consists of flywheel energy storage, variable pitch direct drive wind turbine, converter, load and so on, in which flywheel energy storage system is connected in parallel with DC bus.

3. System Control Strategy

The system control strategy is shown in **Figure 2**. When $V_{dc} < V_{dcref}$, the angular velocity of the flywheel rotor decreases, and the flywheel motor is used as the generator. The flywheel energy storage system converts the mechanical energy into electrical energy, and the DC bus capacitor is provided to improve the DC bus voltage. When $V_{dc} > V_{dcref}$, the angular speed of the flywheel rotor rises and the flywheel motor acts as the motor. The flywheel energy storage system absorbs excess energy from the intermediate bus capacitor and convert into mechanical energy and stored in the flywheel rotor.

4. Speed Limiting Strategy of Flywheel Energy Storage System

Storage of flywheel energy storage system/Released Energy:

$$E = \frac{1}{2}J(\omega + \Delta\omega)^2 - \frac{1}{2}J\omega^2 \quad (1)$$

Here, J is the inertia moment of flywheel rotor in flywheel energy storage system, ω is Initial value of rotation angular velocity for flywheel, $\Delta\omega$ is the Change of angular velocity of flywheel. In the control strategy of this paper, the maximum energy storage of flywheel energy storage system is 120% of its rated value, and the maximum and minimum limit of flywheel speed must be satisfied:

$$\omega_{\max}^2 - \omega_{\min}^2 = 1.2\omega_{\text{rate}}^2 \quad (2)$$

Here, ω_{\max} , ω_{\min} , ω_{rate} are the maximum, minimum and rated values of flywheel speed, respectively. When the maximum speed of the flywheel is 110% (1.1 pu) of the rated speed, the minimum speed of the flywheel determined by the formula is 0.1 pu. The speed limit rules of flywheel energy storage system are shown in **Table 1**.

Table 1. Rule of speed limit for flywheel energy storage system.

Bus Voltage	$V_{dc} < V_{dcref}$	$V_{dc} > V_{dcref}$
Flywheel Speed		
$\omega > 1.1$ pu	Reduce the speed, release the energy	Limit current speed at 1.1 pu
1.1 pu $> \omega > 0.1$ pu	Reduce the speed, release the energy	Increase the rotational speed and absorb the energy
$\omega < 0.1$ pu	Limit current speed at 0.1 pu	Increase the rotational speed and absorb the energy

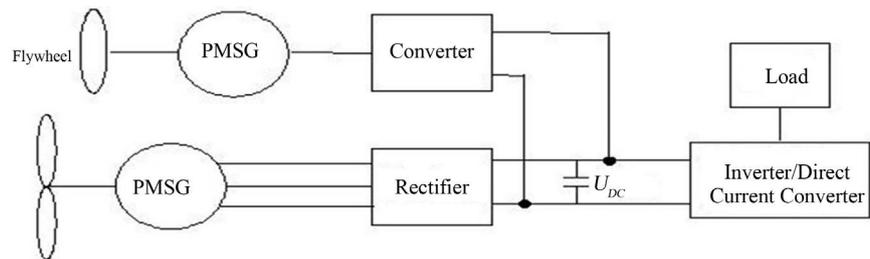


Figure 1. Structure diagram of wind turbine generator system.

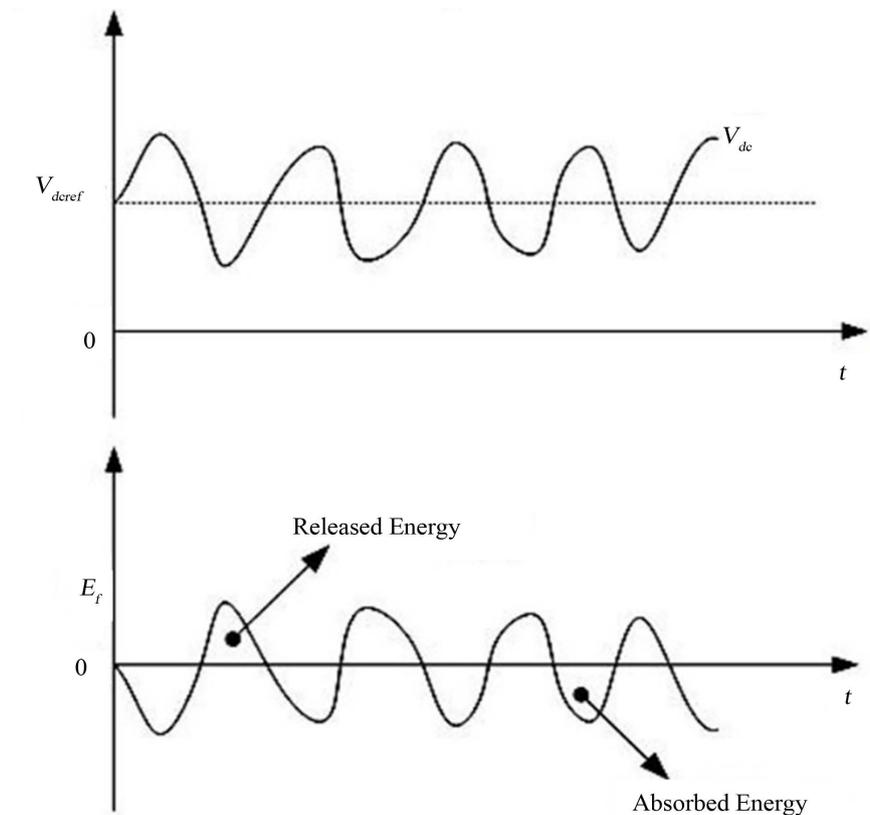


Figure 2. Schematic diagram of control strategy for flywheel energy storage system.

5. Vector Control of Permanent Magnet Synchronous Motor Based on Rotor Flux Linkage

Based on the d_q rotating coordinate system, the stator voltage equation and flux linkage equation of permanent magnet synchronous motor (PMSM) are:

$$\begin{cases} u_d = r i_d + p L_d i_d - \omega L_q i_q \\ u_q = r i_q + p L_q i_q + \omega L_d i_d + \omega \psi_f \end{cases} \quad (3)$$

$$\begin{cases} \psi_d = L_d i_d + \psi_f \\ \psi_q = L_q i_q \end{cases} \quad (4)$$

Three-phase permanent magnet synchronous motor output torque:

$$T_e = p_m (\psi_d i_q - \psi_q i_d) \quad (5)$$

Here, p_m Number of motor pole pairs, ψ_d, ψ_q are the equivalent flux chains on the d-axis and q-axis, respectively.

Three-phase permanent magnet synchronous motor (PMSM) has uniform air gap permeance distribution, have $L_d = L_q = L$, The Formula (5) can be simplified as:

$$T_e = p_m \psi_f i_q \quad (6)$$

It can be seen from the Formula (6) that permanent magnet synchronous motor is based on rotor flux oriented vector control, The stator current vector is located on the q-axis without d-axis component, and the electromagnetic torque is completely controlled by the stator current. In this paper, the hysteresis current control is used to track the reference value of the flywheel motor speed given by the fuzzy controller, and the speed of the motor is adjusted.

6. System Modeling

6.1. Flywheel Energy Storage System Model

Flywheel energy storage system includes flywheel motor, power electronic converter and so on, which is the same as wind turbine. The flywheel motor also adopts the permanent magnet synchronous motor model provided by MATLAB Simulink; the power electronic converter uses the Universal Bridge module. According to the control strategy shown in **Figure 2**, the speed control of the flywheel motor is carried out by the speed loop and the current hysteresis controller to realize the charging and discharging of the flywheel energy storage system, and **Figure 3** is the structural diagram of the simulation model.

6.2. Simulation Model

A complete schematic diagram of the system simulation model can be obtained with the combination of wind turbine model and flywheel energy storage system model, as well as with the proposed fuzzy controller and control strategy of flywheel energy storage system for DC bus voltage of stabilized wind power generation system. This diagram is shown in **Figure 4**.

7. Simulation Verification

7.1. System Parameters

The parameters of the wind turbine are: The sweep radius of the wind turbine is

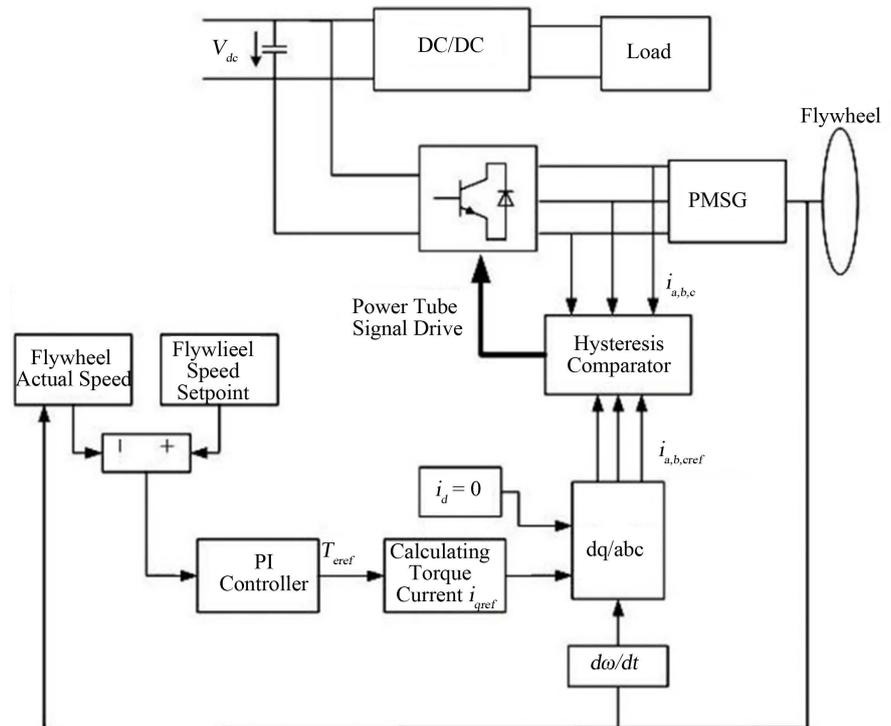


Figure 3. Schematic diagram of flywheel energy storage system simulation model.

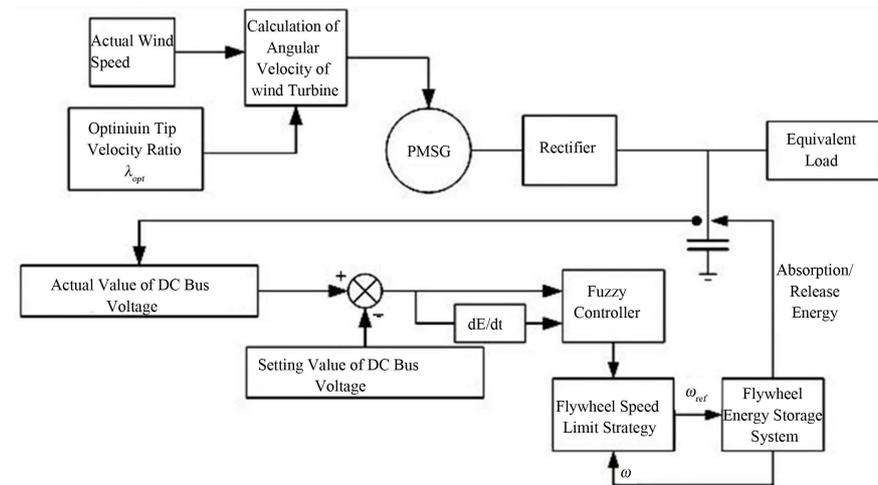


Figure 4. Schematic Diagram of DC Bus voltage simulation model for stabilized non-grid connected wind turbine of flywheel energy storage system.

5 m, the stator resistance of permanent magnet synchronous wind generator is 0.175Ω , d-axis inductance is 3.6 mH , q-axis inductance is 3.6 mH , the excitation flux of the permanent magnet is 3.332 Wb , and the inertia of motor is 0.028 kg/m^2 , number of pole pairs of the motor is 4. The parameters of steel low speed flywheel and flywheel motor are: The permanent magnet synchronous flywheel generator/motor stator resistance is 0.175Ω , d-axis inductance is 3.6 mH , q-axis inductance 3.6 mH , Excitation flux 0.3332 Wb of permanent magnet, motor and flywheel inertia 0.328 kg/m^2 , number of pole pairs of the motor is 4.

7.2. Simulation Results and Analysis

According to the given step curve of the simulated wind speed, a simulation model of the DC bus voltage of the non-grid connected wind turbine generator is built based on the fuzzy control of the flywheel energy storage system; and simulation results can be obtained. As shown in **Figure 5**, the simulated wind speed step curve is given, at 0.2 s, the wind speed jumps from 10 m/s to 8 m/s and back to 10 m/s at 0.23 s; at 0.5 s, the wind speed jumps from 10 m/s to 12 m/s and goes back to 10 m/s at 0.53 s. **Figure 6** is the DC bus voltage waveform of the non-grid connected wind turbine when the flywheel energy storage system is not introduced. It can be seen that when the flywheel energy storage system is not introduced, the DC bus voltage fluctuates up and down with the wind speed jump, which seriously affects the power supply quality to the terminal load. **Figure 7** is the DC bus voltage waveform after the flywheel energy storage system is

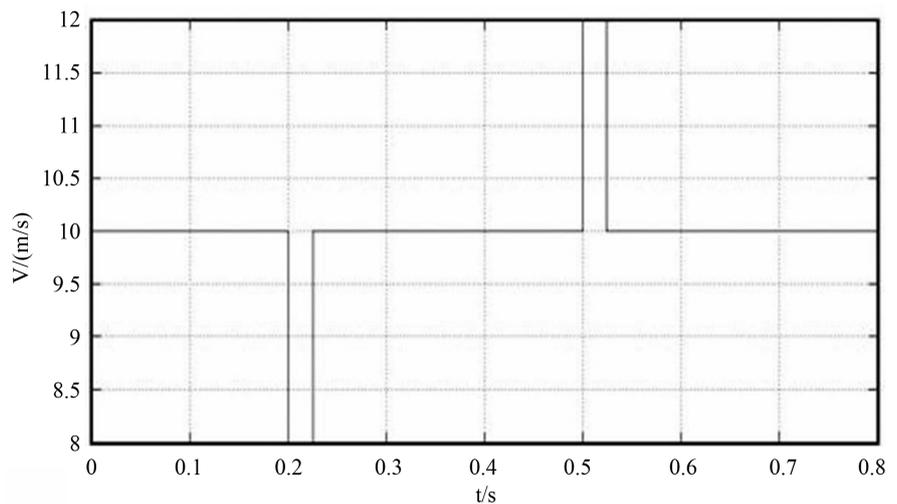


Figure 5. Wind speed step simulation curve.

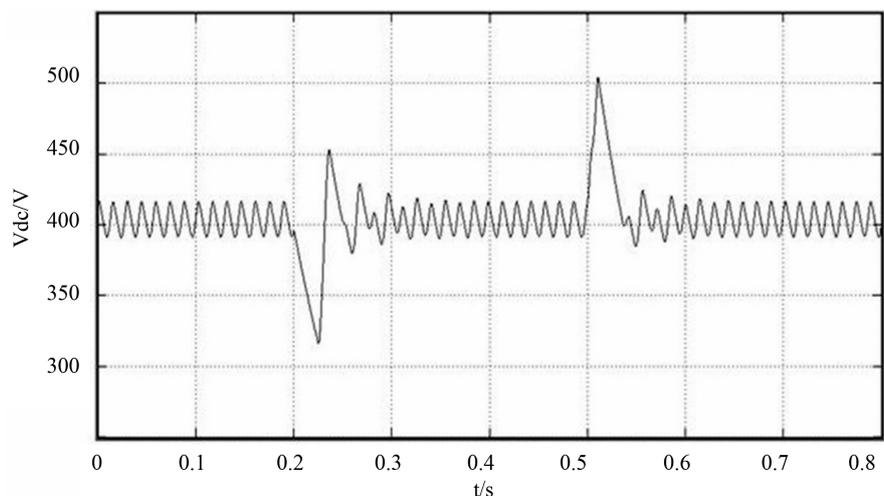


Figure 6. DC Bus voltage waveform without flywheel energy storage system.

introduced. It can be seen that the DC bus voltage fluctuates with the wind speed jump, which is effectively suppressed, and the working condition of the post stage converter of the wind turbine is improved.

Figure 8 shows the speed change curve of flywheel. It can be seen that the actual speed of the flywheel can better track the reference value of the flywheel speed given by the fuzzy controller. Due to the larger rotational inertia of the flywheel itself, the actual speed of the flywheel cannot change greatly in a very short period of time, so the actual speed of the flywheel is more stable than the reference value given by the fuzzy controller.

8. Conclusion

This paper presents a fuzzy control based flywheel energy storage system control program which can stabilize non-grid-connected wind turbine DC bus voltage, improve the working conditions of the unit after the converter, and improve the

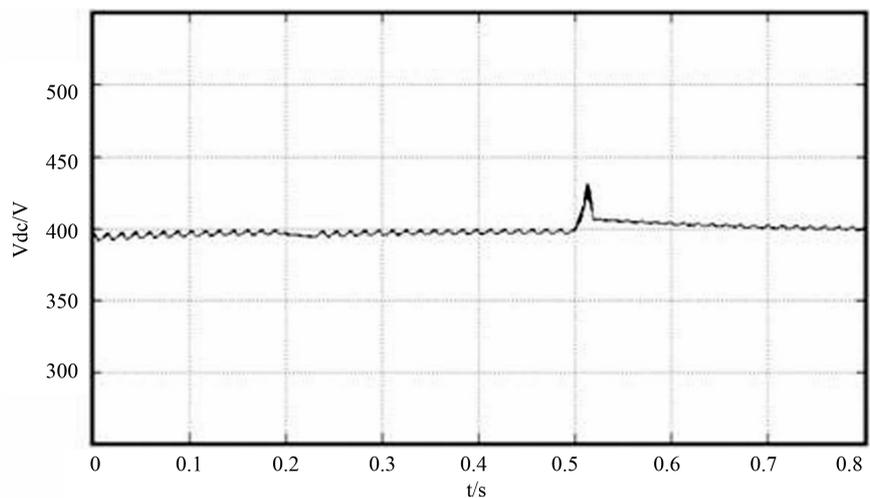


Figure 7. DC bus voltage waveform with flywheel energy storage system.

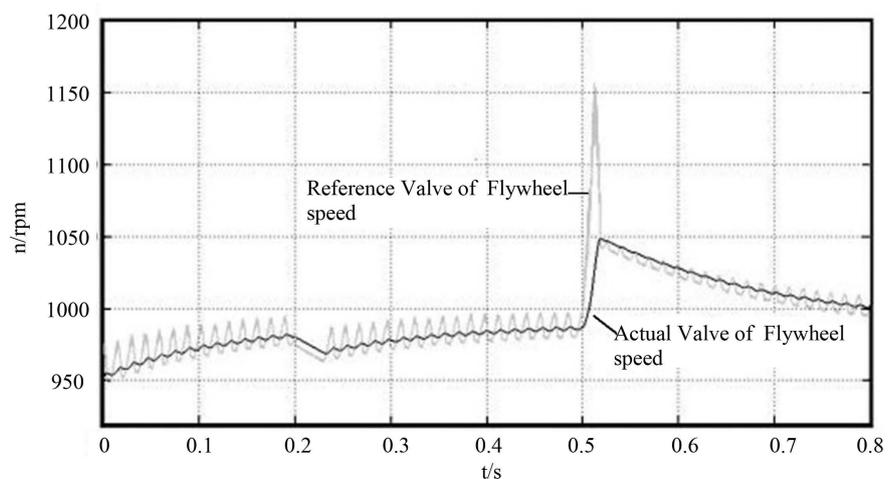


Figure 8. Flywheel speed change curve.

quality of the power supply to the terminal load.

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