

The Control Strategy of DFIG Combined with ESS in Islanded System

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Abstract—For Double Fed Induction Generator (DFIG) in islanded system, a design is proposed which adds Energy Storage System (ESS) in the direct current side of the back-to-back converter and changes the capacity of the load side converter. The generator-side converter of the system uses the power decoupling control strategy to achieve maximum power tracking. The load-side converter uses the constant voltage and frequency control strategy to achieve the constancy of voltage and frequency in islanded system. When switched to grid-connected mode, the phase synchronization control strategy based on frequency disturbance is applied to achieve the rapid phase synchronization of the grid and the islanded system. A simulation model is build and the results shows the effectiveness of the control strategy for the stable operation of islanded sys-tem and the rapid phase synchronization when the system is connected to the grid.

Keywords- DFIG; isolated system; mode switching; phase synchronization

I. INTRODUCTION

Because of the depletion of nonrenewable resources, more attention has been paid to new energy technologies. As one of the environment-friendly and inexhaustible renewable resources, the wind power technologies has been widely used around the world [1-2].

Double Fed Induction Generator (DFIG) is the mainstream of wind power generation. The study of DFIG generation system in islanded system is of much significance. This system can provide uninterruptable power during grid failure, improve the reliability of power supply. It also decrease long-range power transportation thus reduce the line loss. The introduction of wind power also optimizes the energy structure [3]. The stability control is the crucial mean to ensure the electricity quality of island sys-tem. Literature [4] proposes a variable pitch angle control of wind turbine combined with energy storage to limit wind power to overcome the disturbance of the wind speed to the micro grid operation. Literature [5]

presents a forced stator-flux-oriented control strategy and build the control model, but the stator voltage control operate inefficiently and cannot achieve maximum wind power extraction. Literature [6] proposes the introduction of energy storage as the adjustment for power to suppress the fluctuation of both the wind power and the load.

This paper proposes a new design of back-to-back converter with an energy storage system for DFIG, a power control strategy for generator-side convertor and a constant voltage and frequency control strategy for load-side convertor. It also present a phase synchronization control strategy based on frequency disturbance. Simulation results shows that the design meet the stability requirement of islanded power supply system.

II. MODELING AND CONTROL STRATEGY

A. System Structure

The randomness of wind speed lead to the fluctuation of wind power and adverse effect to electricity quality. The disturbance of wind turbine or wind farm with reasonable capacity to the main grid when connected is limited due to the support of voltage and frequency from the main grid. When islanded and without the support, the imbalance between the power wind turbine generates and the power load consumes as well as the fluctuation of wind speed will adversely affect the electricity quality. The introduction of energy storage system plays an important role for the improvement of electricity quality in the islanded wind power system [7-8].

The structure of DFIG combined with energy storage system is shown in Fig .1. The generator-side convertor controls the rotor flux, indirectly controls the active power, the reactive power and the voltage frequency of the stator of DFIG . The DC-side of the load-side convertor connects to the energy storage system, which consists of series-parallel connected batteries with protection and equalization circuit [9]. The power density of the batteries are low and the cycle

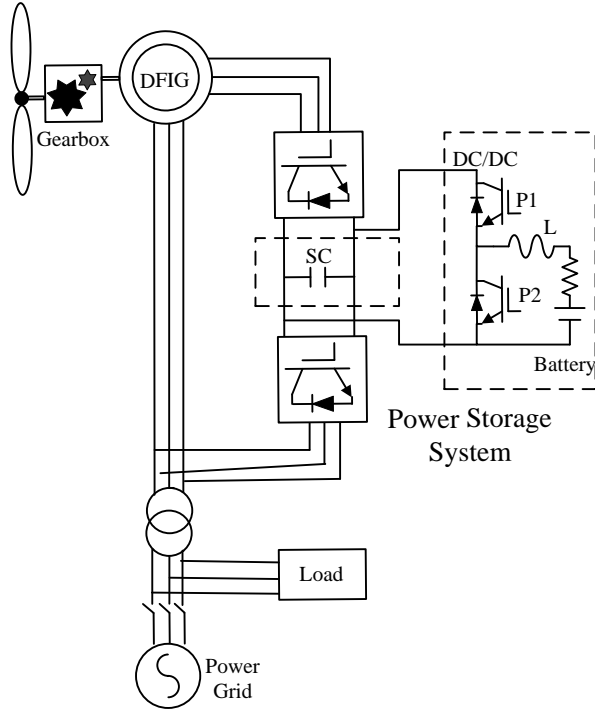


Figure 1. Structure of isolated system with wind generator

life are short, but the input cost is easily accepted. The super capacitors possess high power density and long cycle life but are expensive. A power storage module consists of these two equipment can rapidly and dynamically respond to the change of power and achieve long-time power management at the same time, with the performance of power storage improved, the life of batteries pro-longed, and the cost of the module save. In Fig .1, when DC/DC convertor P1 conducts, the batteries are charged by the DC bus. When P1 breaks, they are charged by the inductance. When P2 conducts, the batteries release energy to the inductance and when P2 breaks, the batteries and the inductance re-lease energy to the DC bus at the same time. On the one hand this module excites the rotor and deals with the change of the rotor slip power, on the other hand it connects the large-capacity load-side convertor to provide voltage and frequency support and equilibrate the unbalanced power of the isolated sys-tem. This paper proposes the phase synchronization control strategy based on frequency disturbance to achieve rapid synchronization when the isolated sys-tem parallels in the grid.

B. The Model of DFIG

The direction of current and voltage of the stator winding follows the generator convention, and those of the rotor winding follows the motor convention. In the synchronous rotating reference frame, the voltage and flux equations of DFIG for vector control are given blow.

The stator voltage is

$$\begin{cases} u_{ds} = -r_s i_{ds} - \omega_1 \psi_{qs} + \frac{d}{dt} \psi_{ds} \\ u_{qs} = -r_s i_{qs} - \omega_1 \psi_{ds} + \frac{d}{dt} \psi_{qs} \end{cases} \quad (1)$$

While the rotor voltage is

$$\begin{cases} u_{dr} = r_r i_{dr} - (\omega_1 - \omega_r) \psi_{qr} + \frac{d}{dt} \psi_{dr} \\ u_{qr} = r_r i_{qr} + (\omega_1 - \omega_r) \psi_{dr} + \frac{d}{dt} \psi_{qr} \end{cases} \quad (2)$$

The stator flux is

$$\begin{cases} \psi_{ds} = -L_s i_{ds} + L_m i_{dr} \\ \psi_{qs} = -L_s i_{qs} + L_m i_{qr} \end{cases} \quad (3)$$

While the rotor voltage is

$$\begin{cases} \psi_{dr} = -L_m i_{ds} + L_r i_{dr} \\ \psi_{qr} = -L_m i_{qs} + L_r i_{qr} \end{cases} \quad (4)$$

Where u is the voltage, r is the resistance, i is the current, ω_1 and ω_r are the synchronous angular velocity and rotor angular velocity, respectively. ω_s is the flip angular velocity an d meet $\omega_s = \omega_1 - \omega_r$, ψ is the flux, L is the inductance, and L_r mutual inductance of rotor and stator. Subscript s and r represent stator-side quantities and rotor-side quantities, respectively, while subscript d and q represent the components of the two axes of the synchronous rotating reference frame.

C. The Control Strategy for Isolated System

1) The Control Strategy for the Generator-side Converter

The control strategy block diagram for the generator-side converter of DFIG in isolated system is shown in Fig .2. Stator flux orientation is applied for the DFIG in isolated system, and the stator resistance is ignored, i.e. axis d is in-phase with ψ_s . The stator voltage u is on the axis q, $\psi_{ds} = \psi_s$, $\psi_{qs} = 0$, $u_{ds} = 0$, $u_{qs} = U_s = \omega_1 \psi_s$, and substituted in the stator power equation of DFIG, then we can see that the active power of the stator is directly proportional with i_{qs} and the reactive power of stator is with i_{ds} . When the stator voltage U_s and synchronous angular velocity ω_1 are determined, ψ_s is ascertainable. According to the stator flux equation, when ψ_s is determined, the currents of stator and rotor are related. Then we can derive the equation of current and voltage of the stator and those of the rotor, and control the generator-side converter to achieve the decoupling control of the active and reactive power of DFIG [10-11]. The intelligent memory method with an on-line training process is described for maximum power point track (MPPT) [12].

The rotor voltage equation under decoupling control

$$\begin{cases} u_{dr} = u'_{dr} + \Delta u_{dr} \\ u_{qr} = u'_{qr} + \Delta u_{qr} \end{cases} \quad (5)$$

While the decoupling terms are

$$\begin{cases} u'_{dr} = r_r i_{dr} + L_r (1 - \frac{L_m^2}{L_s L_r}) \frac{d}{dt} i_{dr} \\ u'_{qr} = r_r i_{qr} + L_r (1 - \frac{L_m^2}{L_s L_r}) \frac{d}{dt} i_{qr} \end{cases} \quad (6)$$

And the compensate terms are

$$\begin{cases} \Delta u_{dr} = -\omega_s [(L_r - L_m^2/L_s) i_{qr} + \psi_{qs} L_m/L_s] \\ \Delta u_{qr} = \omega_s [(L_r - L_m^2/L_s) i_{dr} + \psi_{ds} L_m/L_s] \end{cases} \quad (7)$$

The power equation are

$$\begin{cases} P_1 = U_s i_{qs} \\ Q_1 = U_s i_{ds} \end{cases} \quad (8)$$

2) The Control Strategy for the Load-side Converter

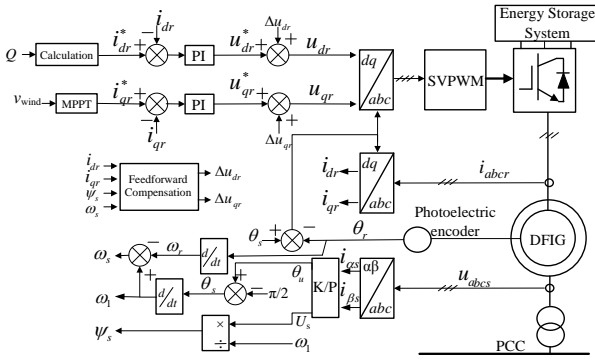


Figure 2. Control Strategy of the rotor-side converter

The capacity of traditional grid-side converters is relatively small for the capacity of DFIG and can-not meet the requirement to balance the power of isolated system.

Large capacity convertor is adopted as load-side converter in this paper. Cooperate with energy storage module, this convertor stabilize the voltage and frequency on the AC-bus of the isolated system. The control strategy of the load-side convertor is shown in Fig .3. The bus voltage of the system is fed to the controller of the convertor and compared with voltage reference, then output the modulated signal after a PI regulation, and generate the PWM pulses after the SVPWM unit, and drive the IGBT power module.

When the isolated system shift into grid-connected mode, the time for phase synchronization will be very long if the frequency difference of the two systems is small[13-14]. The phase synchronization control strategy based on frequency disturbance is applied in this paper to achieve rapid phase synchronization. Before the connection, the phase angle of the grid voltage θ_g is measured and compared with the phase angle of the bus voltage of the isolated system θ_u . The difference is regard as the frequency disturbance after a PI regulation to disturb the bus frequency of the isolated system. As a result of the disturbance, θ_u changes relevantly until it is in-phase with the phase angle of the grid voltage. The strategy is capable to achieve rapid phase synchronization between the isolated system and the grid.

III.SIMULATION AND ANALYSIS

The simulation model is developed using Matlab/Simulink. The step is 1×10^{-5} s, simulate time is 10s, the rating power of DFIG is 2MW, the rating wind speed is 12m/s, the bus frequency of the system is 50.2Hz, the rating output voltage is 690V, and transformed to 10kV to connect to the load. Four situations are considered to verify this strategy.

A. Situation 1 – Load Jump

The load jumps from 1MW to 2MW at $t=4$ s while the wind speed is 9m/s. Fig .4 shows the power which the system provides to the load and which DFIG generates. It can be observed from Fig .4 P&Q_load that the active power from the system to the load jumps from 1MW to 2MW while the reac-tive power rarely change. It can be seen from Fig .4 P&Q_Dfig that the jump of the load have

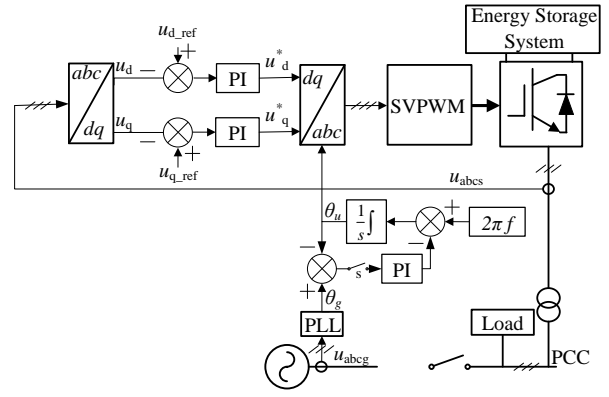


Figure 3. Control strategy of the load-side converter

no distinct effect on the power DFIG generates. The bus voltage and current of the isolated system is shown in Fig .5. It can be seen that the bus voltage slightly fluctuates at $t=4$ s and rapidly recovers to the rating value, while the bus current increases to double as before. The rotor angular velocity of DFIG and the bus frequency of the system is shown in Fig .6. The simulation results of situation 1 shows that the jump of the load have no significant effect on the stability of the isolated system, the power supply of the sys-tem meet the requirement.

B. Situation 2 – Wind Speed Jump

The wind speed jumps from 9m/s to 12m/s at $t=4$ s while the load is 2MW. Fig .7 shows the power which the system provides to the load and which DFIG generates. It can

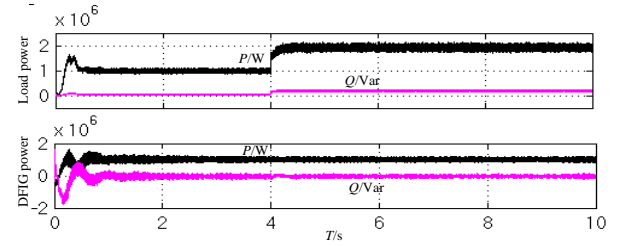


Figure 4. Real and reactive power of load and DFIG

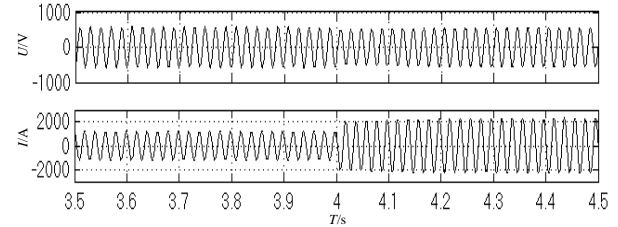


Figure 5. Bus voltage and current

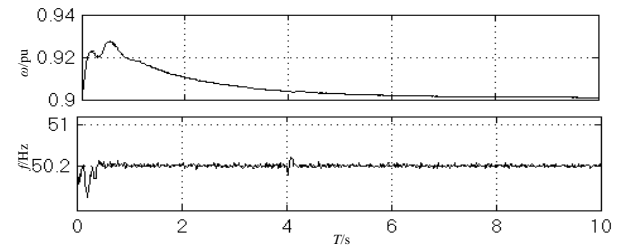


Figure 6. Rotor angular velocity of DFIG and Bus frequency

been observed from Fig .7 P&Q_Dfig that the active power DFIG generates jumps from 1MW to 2MW. The bus voltage and current of the isolated system is shown in Fig .8, and it can be seen that they have no marked fluctuates when the wind speed jumps. The rotor angular velocity of DFIG and the bus frequency of the system is shown in Fig .9. The simulation results of this situation shows that the jump of the wind speed have no significant effect on the stability of the isolated system. The shortage of power is supported by the power storage module, and the power supply of the system meet the requirement.

C. Situation 3 – Earthing Fault Disturbance

An earthing fault occurs during $t = 3.8s$ to $t = 4.1s$ while wind speed is 12m/s and the load is 2MW. Fig .10 shows the power which the system provides to the load and which DFIG generates. The bus voltage and current of the isolated system is shown in Fig .11.

The rotor angular velocity of DFIG and the bus frequency of the system is shown in Fig .12. The system is unstable during the fault but recovers to origin state by self-adjustment after the fault. The simulation results of this situation shows that the isolated system is capable to recover after the fault is cleared, the system is of good steady and transient stability.

D. Situation 4 – Initialize the grid-connection strategy

The isolated system operates with the frequency of 50.2Hz while the wind speed is 9m/s and the load is

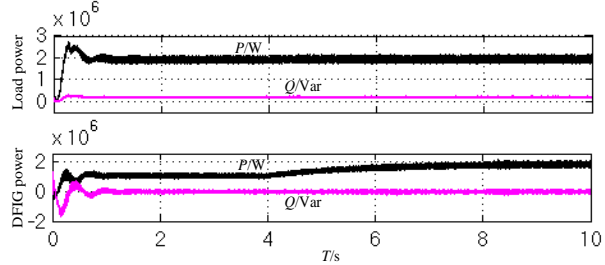


Figure 7. Real and reactive power of load and DFIG

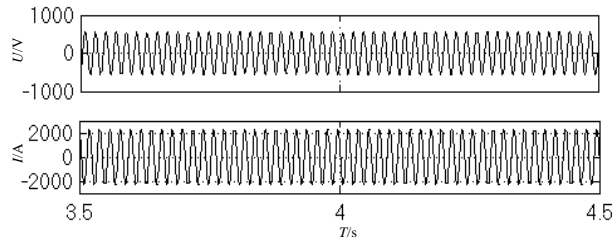


Figure 8. Bus voltage and current

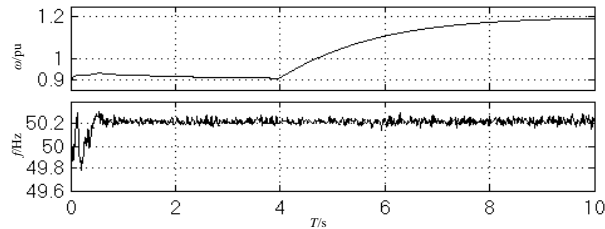


Figure 9. Rotor angular velocity of DFIG and Bus frequency

1MW, and the grid frequency is 49.8Hz. The phase synchronization control strategy based on frequency disturbance initializes at $t = 5.5s$. The phase A voltage of the system and the grid after the initialization of the strategy is shown in Fig .13. The phase A voltage of the system and the grid without the initialization of the strategy is shown in Fig .14. The simulation results of this situation shows that this strategy is capable to achieve rapid phase synchronization between the isolated system and the grid and accelerate the connecting process.

IV. CONCLUSION

In this paper the system structure and control strategy of DFIG operating in isolated system is studied. According to the simulation results, the proposed strategy is capable to achieve the stable operation of the system under the jump of load and wind speed and the earthing fault. Also, the initialization of the phase synchronization control strategy based on frequency disturbance can accelerate

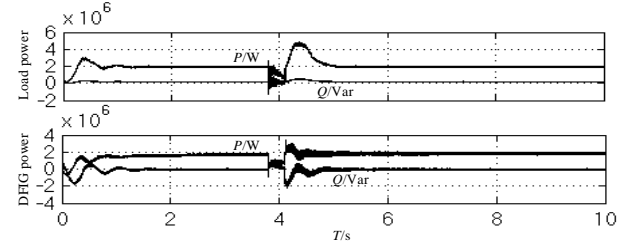


Figure 10. Real and reactive power of load and DFIG

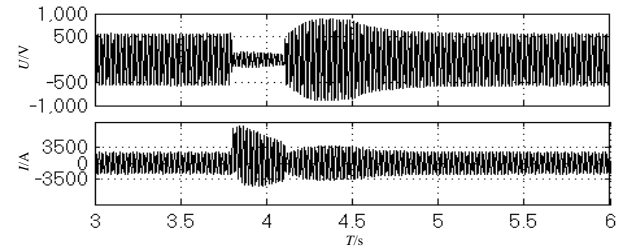


Figure 11. Bus voltage and current

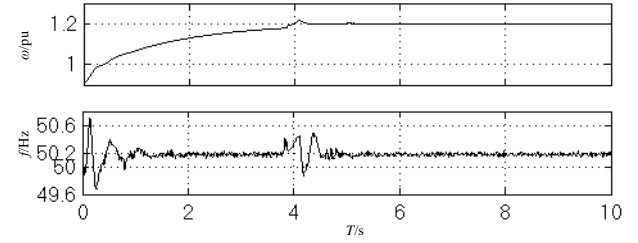


Figure 12. Rotor angular velocity of DFIG and Bus frequency

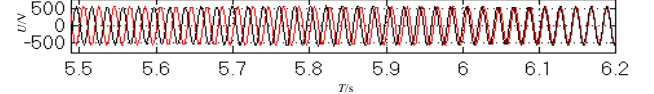


Figure 13. Phase A voltage with strategy

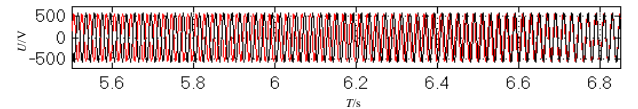


Figure 14. Phase A voltage without strategy

process of phase synchronization between the isolated system and the grid, effectively improves the electric power quality of isolated power supply system.

V. ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of the National Natural Science Fund of China (51467003) and the Introduce Talents Research Fund of Guizhou University, China(2014-07) and the Social Development Research Project of Guizhou Province, China (SY[2011]3081).

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