The Control System Simulation of Variable-Speed Constant-Frequency Wind Turbine

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Abstract—In general, Variable-Speed Constant Frequency (VSCF) Wind generation system is controlled by stator voltage orientation method which based on the mathematic model of VSCF Wind generation system and discussed the control strategy. Present the whole dynamic control model of variable-speed wind generator system in MATLAB/ Simulink, and the simulation results confirm the validity and effectiveness of the proposed control strategy.

Keywords*—*Variable-Speed constant-frequency; model; wind turbines ; control system; vector control

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1 Introduction

In Wind turbine generator system (WTGS), one of the operational problems is the changeability and discontinuity of wind. In most cases, wind speed can fluctuate rapidly. Hence, Improving the quality of output power, torque regulation and the operation efficiency of wind power generation depend on the changes in wind speed is the key technologies of WTGS.

According to the operating characteristics and control technology, the wind power technology can be divided into constant speed constant frequency and variable speed constant frequency [1] .The VSCF wind generation system with Doubly-Fed Induction Generator (DFIG) that can capture the maximum wind energy is becoming the hot point of study.

The simulation model of VSCF wind generation system is developed in this paper, with the analysis and compares of the different control strategies. The simulation modules are made in MATLAB and the simulation results are analysed. The control strategy can get the biggest power coefficient at various wind speed.

2 Characteristics of VSCF

The VSCF wind power generation system is comprised of wind turbine, gear boxes, DFIG, AC excitation convertor, the back-to-back PWM converter is often used in the system. As see the figure 1. When the rotor speed varies with wind varying, the frequency of stator current can be maintained by regulating the frequency of rotor AC excitation current. Comparison with the general wind energy generation system, because of equipped transducer of VSCF AC excitation doubly fed wind energy generation system located at rotor loop, it not only possesses the characteristics of small cubage、light weight and low cost but also realizes flexible connection of mechanical-electric system, which only deals with slip power in double direction.

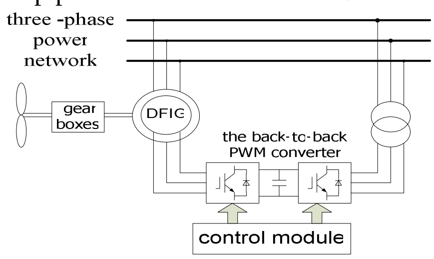

Fig 1 double-fed variable speed wind turbines

Output power of a wind turbine is expressed by the following formula, which determines the power-speed characteristic of a wind turbine

$$P_M = \frac{1}{2} C_p(\lambda, \beta) \cdot \rho_{AIR} \cdot A \cdot v^3$$

Where C_p the performance coefficient determined by the aerodynamic laws, ρ_{AIR} is the air density, A is the swept area of the turbine blades and v is the wind speed (m/s).

The performance coefficient depends on both the pitch angle (β) and the tip speed ratio (λ). The tip speed ratio is calculated by using blade tip speed and wind speed upstream of the rotor, as in the following formula:

$$\lambda = \frac{\omega_M R}{V}$$

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where R is the blade radius, ω_M is the rotational speed and k is the tip speed ratio.

3 The mathematics of DFIG

The mathematics model of DFIG can be given as the following equations under the synchronization reference frame.

Voltage equations

$$\begin{cases} u_{ds} = -R_s i_{ds} - p\psi_{ds} + \omega_1 \psi_{qs} \\ u_{qs} = -R_s i_{qs} - p\psi_{qs} - \omega_1 \psi_{ds} \\ u_{dr} = R_r i_{dr} + p\psi_{dr} - \omega_s \psi_{qr} \\ u_{qr} = R_r i_{qr} + p\psi_{qr} + \omega_s \psi_{dr} \end{cases}$$

Flux linkage Equations:

$$\begin{cases} \psi_{ds} = L_{ls} i_{ds} + L_m \left(i_{ds} - i_{dr} \right) = L_s i_{ds} - L_m i_{dr} \\ \psi_{qs} = L_{ls} i_{qs} + L_m \left(i_{qs} - i_{qr} \right) = L_s i_{qs} - L_m i_{qr} \end{cases}$$

$$\begin{cases} \psi_{dr} = L_{lr} i_{dr} + L_m \left(i_{dr} - i_{ds} \right) = L_r i_{dr} - L_m i_{ds} \\ \psi_{qr} = L_{lr} i_{qr} + L_m \left(i_{qr} - i_{qs} \right) = L_r i_{qr} - L_m i_{qs} \end{cases}$$

The power equation of rotor and stato:r

$$\begin{cases} P_s = u_{ds} \cdot i_{ds} + u_{qs} \cdot i_{qs} \\ Q_s = u_{qs} \cdot i_{ds} - u_{ds} \cdot i_{qs} \end{cases}$$

$$\begin{cases} P_r = u_{dr} \cdot i_{dr} + u_{qr} \cdot i_{qr} \\ Q_r = u_{qr} \cdot i_{dr} - u_{dr} \cdot i_{qr} \end{cases}$$

4 The model and control method of VSCF

The control system of VSCF wind generation system is a high order, nonlinear, time-varying system, In order to simplify the controller, the system adopts vector control scheme. The vector control in common use is divided into the stator field-oriented and stator voltage-oriented vector control. The stator flux linkage observer can be omitted in stator voltage-oriented vector control, the angel of coordinate transformation can be calculated by measured Grid voltage. Hence, This paper adopts stator voltage-oriented vector control.

4.1 The model and control method of the grid-side converter

The Model of the grid-side converter as follows:

The mathematical model of the grid-side converter is established under the synchronization reference frame.

$$\begin{cases} L * di_d / dt = -Ri_d + \omega L i_q - S_d u_{dc} + u_d \\ L * di_q / dt = -Ri_d + \omega L i_d - S_q u_{dc} + u_q \end{cases}$$

$$C * du_{dc} / dt = \frac{3}{2} S_d i_d + \frac{3}{2} S_q i_q - i_L$$

In two phase synchronized rotation coordinates (d、q system)，fixed the d-axis on the direction of grid voltage vector direction. From this we get the expression: $u_d = u_s$； $u_q = 0$；

So the input current is:

$$\begin{cases} L * di_d / dt = -Ri_d + \omega L i_q - v_d + u_s \\ L * di_q / dt = -Ri_q + \omega L i_d - v_q \end{cases}$$

Where $v_d = S_d V_{dc}$； $v_q = S_q V_{dc}$

As DC-bus voltage is significant for AC-DC-AC converter system operation. So the dominant control object was to get the stability of DC voltage.

Type makes clear on，the grid-side converter can be controlled by voltage feed-forward decoupling schemes. The control strategy is shown in Figure 2.

The system adopts the speed and current central double-loop control structure. In the outer-loop controller, DC voltage is compared with the given, and regulated by the PI controller using active command current i_d^*, in order to unity input power factor, it made $i_q^* = 0$ [5], the control voltage can be obtained by PI controller after compared i_d^* and i_q^* with the reality current in the inner current loop control system. The output voltage produce SPWM wave through coordinate transformation after cross-coupling compensation.

4.2 The control of the rotor-side convector and DFIG

In order to make full use of the wind energy and achieve decoupled control between active power and reactive power at stator port, the target of VSCF wind generation control system is realizes the control of the excitation current of the rotor. So, the controlled member is DFIG, the performer of control command is the rotor-side PWM convector[9].

The model as follows:

In order to simplify control, the stator voltage is orientated the d-axis of rotating coordinates. Ignore the stator resistor, we can get:

$$\begin{cases} u_{ds} = U_s \\ u_{qs} = 0 \end{cases} ; \quad \begin{cases} \psi_{ds} \approx U_s / \omega_1 = \psi_s \\ \psi_{qs} = 0 \end{cases}$$

The equation thus becomes

$$\begin{cases} u_{dr} = (R_r + bp) i_{dr} + \omega_s (a\psi_s - b i_{qr}) \\ u_{qr} = (R_r + bp) i_{qr} + \omega_s b i_{dr} \end{cases}$$

$$\begin{cases} P_s = 3/2 U_s i_{ds} \\ Q_s = 3/2 U_s i_{qs} \end{cases}$$

Where $b = L_r \left(1 - L_m^2 / L_s L_r\right)$; $\omega_s = \omega_1 - \omega_r$; $a = L_m / L_s$

Starting from this expression, show that stator real and reactive power is in proportion to the d and q components of the stator current. The d and q components of the stator current is influenced by the control voltage (u_{dr} 、 u_{qr}) and coupling voltage. Hence, the controllers need to add the feed forward compensation.

According to different wind conditions, the operation of variable speed Wind turbine generator system can be divided into four stages: the starting stage, constant C_P region, constant rotate speed outputs and constant power outputs.

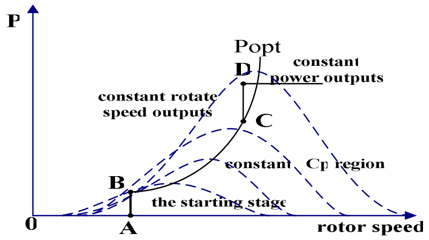

Fig 3 The relationship between rotor speed and power of wind turbine generator in different wind-speed

The control system can divided into power control mode and velocity control mode.

The power control system included the stator active power and current central double-loop control structure. Inner current controller responses quickly to power change, the stator can rapidly obtain expected power, then end the current adjust. But it doesn't mean that the system is stable. In dynamic process, the difference between wind turbine input mechanical power and stator output real power can be resolved into accelerating power of shafting and rotor active power. With the changes of the rotational speed, accelerating power decrease, rotor active power increase until balance. This transient process included electromagnetic energy and mechanical energy is depended on the dynamical characteristic. Hence, the equilibrium process of shaft torque is not controllable, especially torque inertia of generator is big. Work in revolving speed control mode, the speed is outer loop velocity feedback. The velocity feedback velocity feedback velocity feedback make dynamical characteristic involved in the closed loop control system, the equilibrium process of the active power and torque is controllable.

The velocity control mode has the advantage of capturing maximal wind energy and constant velocity control, but power control mode is preferable to constant power control. Thus, the control strategy of DFIG in this paper: At below rated wind speed, the controller adopts velocity control mode to capture maximum wind energy; the system uses power control mode to keep the rated output power above rated wind speed. As see the picture 5.

5 Simulation

According to the analysis above, the simulation modules of VSCF Wind generation system are made in MATLAB as shown in picture 6. The key parameters of system are set as:

Power system is three phase, frequency is 50Hz; the peak voltage of the high-voltage side is 3.5KV; the peak voltage of the low-voltage side is 575×10^{-3} kV; Rated Wind Speed is 13m/s; the rated voltage of DFIG is 575×10^{-3} kV; Rated power is 1500KW; DC voltage is 1200V.

Based on the finished model, the VSCF Wind generation is simulated under different wind speed, and the curves of output power, DC-voltage and rotor velocity are obtained seen in Figure 4, 7. The results of simulations show that the model is reliable and this control method has good control effectiveness.

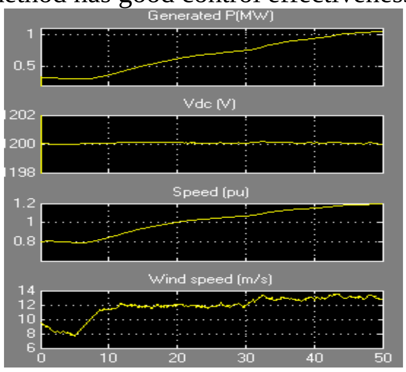

Fig 4 low-Rated wind speed

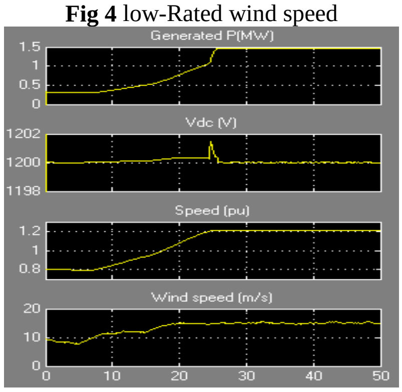

Fig 7 from low-wind speed to high-wind speed

6 Conclusions

It is demonstrated by simulation results that the control system can capture the maximum wind energy, provides the steady DC voltage, as well as rotor velocity has good following. The minor wind changes have a little effect on output power. Simulation results verify the validity and feasibility of the novel control strategy. This control strategy could satisfy the demand of the VSCF Wind generation, which is the base for its application in practice.

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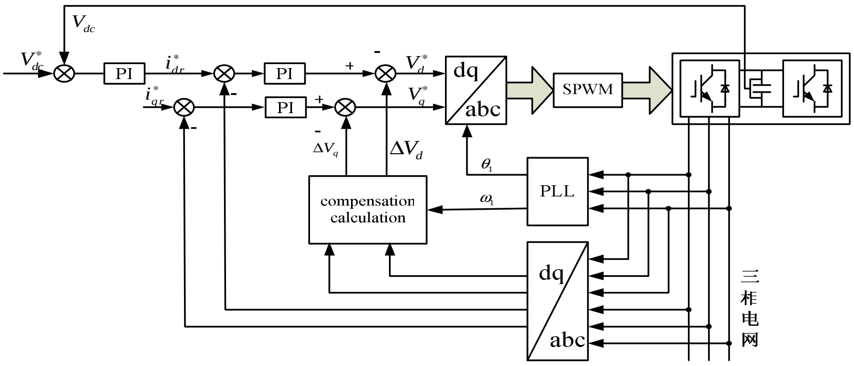

Fig 2 the vector control system block diagram of grid-side converter.

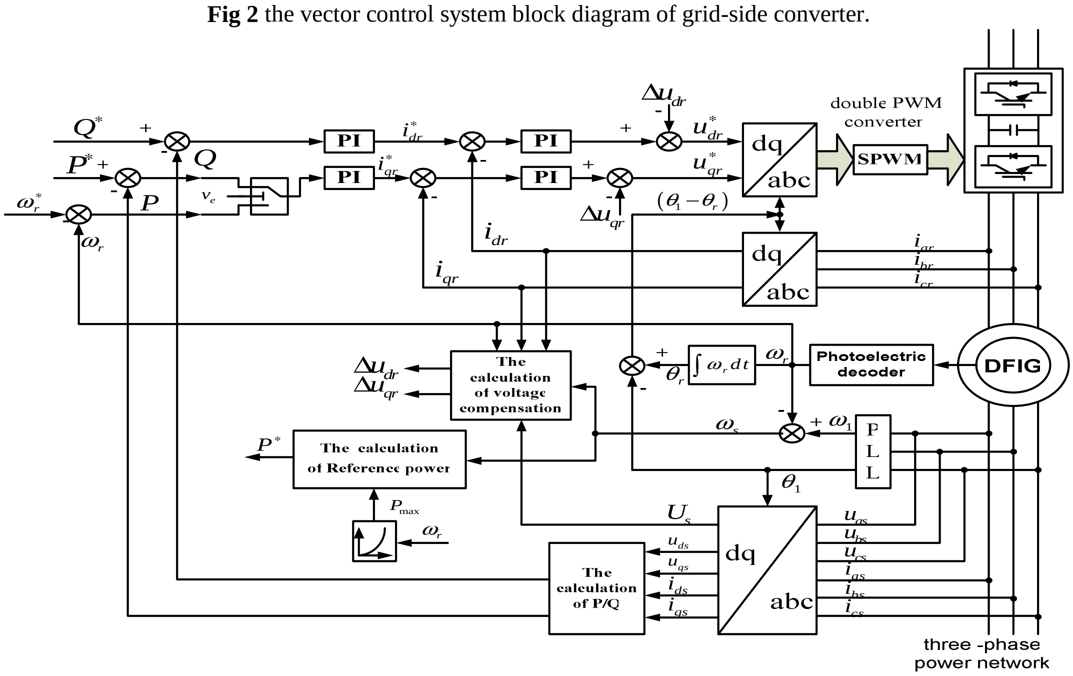

Fig 5 after grid-connection, the vector control system block diagram of double-fed variable speed wind turbines

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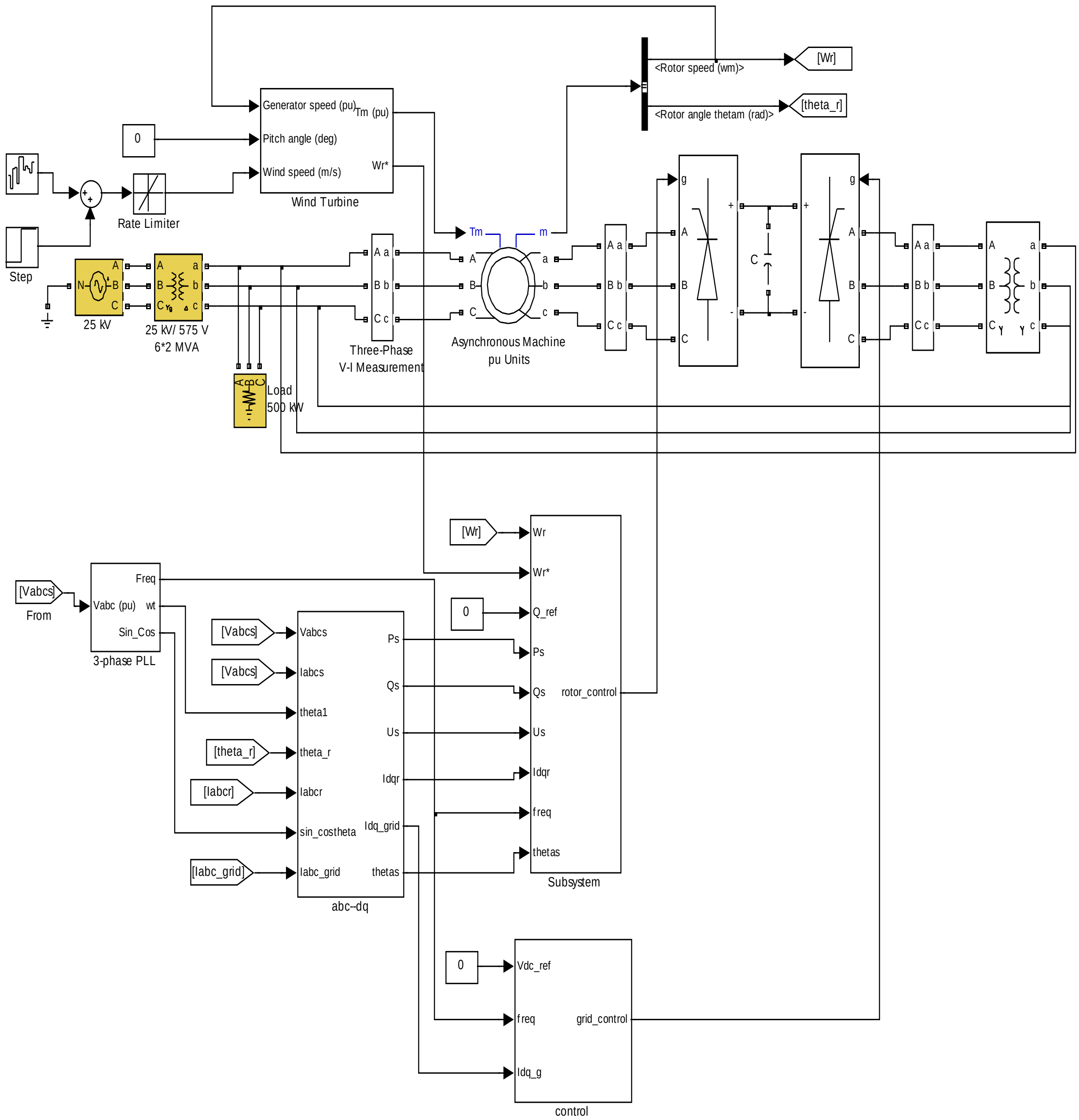

Fig 6 the simulation model double-fed variable speed wind turbine