Study on Var coordinated control strategy of DFIG

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ABSTRACT: The paper has built a wind farm ground on Doubly Fed Induction Generator (DFIG). It pro-posed a novel strategy of DFIG, which can be as active power source to supply active power to network, and as reactive power source to provide Var compensation (reactive power absorbed or generated) or stabilize voltage, in order to supply sufficient reactive power to sustain system stability. The control strategy is realized by DigSILENT/PowerFactory, with correlation and compensation. The eigenvalue analysis method is used to verify its impact on small signal stability of power system integrated with wind farm and low-frequency oscillation modes . The results from eigenvalue analysis certify the effectiveness of Var coordinated control in wind farm system.

INTRODUCTION

The installed capacity of wind generation is increasing worldwide at a fast-paced rate. And with capacities ranging in thousands of megawatts are being built and are coming online. By far, the larger number of wind farms is still equipped with the DFIGs, therefore, this paper centers on this type of generator.

The modeling of DFIG and its control system is dealt with in numerous papers and textbooks. Some researchers focused on the super and sub synchronous operation of the DFIG system. And it presented the coordinated tuning of controller to enhance the damping of oscillatory modes by bacteria foraging technique. It was discovered that large wind power integration can generate positive or negative impacts on power system damping depending on the position of the wind farm, a large number of conventional generation replaced by wind farm and the stress level of power system. Some researchers discussed the effects of wind power penetration in power system oscillation damping. Both electro-mechanical and Var oscillatory modes were discussed. And the general trend is to increase oscillation damping and tuning of DFIG reactive power control can enhance damping. With the optimized controller parameters, the stability was improved under small or large disturbances.

The impact of wind farm generation on oscillation modes and small signal stability is studied in this paper. The Var coordinated control is carried out in DigSILENT/PowerFactory. A large wind farm is built based on DFIG using the proposed control strategy. Simulations are performed on Two-area Four-machine (TAFM) system and the results demonstrate the damping performance of system with Var coordinated control.

DFIG MODELING

DFIG is different from other conventional induction generator. It employs a series voltage converter to feed rotor side. The principle of wind turbine contains two main processes, Rotor Side Controller (RSC) and Grid Side Controller (GSC). The basic theory including its control models is shown in Fig.1.

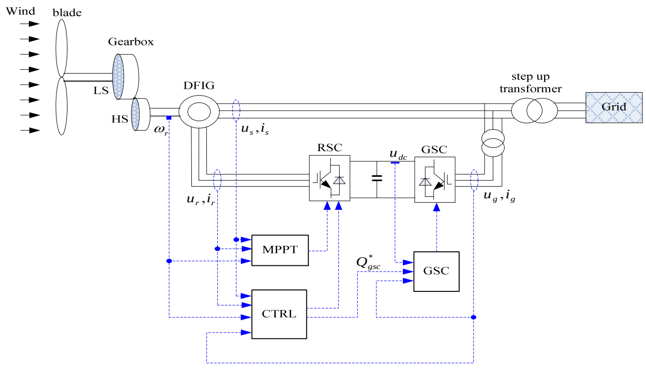

Figure 1. A schematic diagram of DFIG

Beside the main mechanical and electrical components, the realistic response of DFIG requires other controlling models, including turbine, gearbox, generator, shaft, and back-to-back converter.

Mechanical Model

Wind turbine collects power from wind and converts it into mechanical power. Therefore, wind speed plays a vital role in aerodynamic model. Because the wind is complex, including shear, tower shadow, turbulence and so on. A simplified aerodynamic model is used when the electrical behavior is main interest of study. So this paper reads practical wind text to drive wind turbine, as shown in Fig.2.

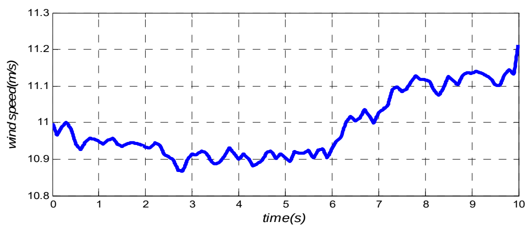

Figure 2. The wind speed of turbine

The generator rotor is connected to turbine shaft flexibly by gearbox and coupling. Thus, a two-mass model is used. The pitch angle applies active stall control strategy for controlling output power of wind turbine. The pitch angle can be adjusted to obtain optimal power at a given wind speed.

Converter Control Model

A complete model of DFIG includes active power and reactive power control together with pitch angle and speed control. The structures of GSC and RSC are shown in Fig.3 and Fig.4. The two models summarize the core functionalities of the DFIG.

Grid side converter control

The objective of the control of GSC is to maintain the DC-link voltage in a series value, ignoring the direction and magnitude of rotor power and to ensure a converter operation with unity power factor (zero reactive power). It can be responsible for controlling reactive power from GSC to the grid. The GSC contains two PI control loops in cascade.

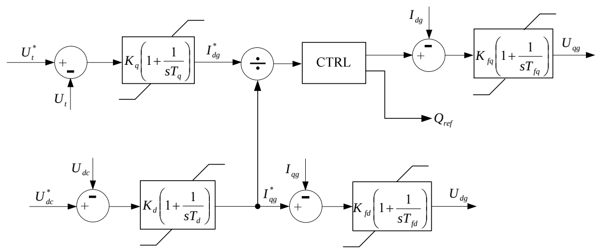

Figure 3. The control model of grid side converter

The strategy enables independent control of active and reactive exchange. With respect to the converter control operates oriented reference frame (u_{qt}=U_{tm}， u_{dt}=0). In such reference frame the *q*-axis is utilized to control DC voltage, then d-axis regulates the terminal voltage or reactive power.

I_{qg}^{*} and I_{dg}^{*} acquired from $\triangle U_{dc}$ and $\triangle U_{T}$ by PI controller. Therefore, the CTRL block checks available capacity for I_{dg} respect to I_{qg} and the rating of GSC is 25% of DFIG. The relationship for GSC between active power and reactive power is as follow:

$$\vec{I}_g = \frac{\vec{U}_g - \vec{U}_t}{jX_t} \Rightarrow \begin{cases} P_g = \frac{3}{2}u_{qt} \cdot i_{qg} = \frac{3}{2}u_{qt} \cdot \frac{u_{dg}}{X_t} \\ Q_g = \frac{3}{2}u_{qt} \cdot i_{dg} = \frac{3}{2}u_{qt} \cdot \frac{u_{qt} - u_{qg}}{X_t} \end{cases} \quad (1)$$

Where subscripts 'q' and 'd' refer to q-axis and d-axis respectively, subscripts 'g' and 't' refer to GSC and terminal side respectively, and X_t is the inductance of GSC transformer.

Rotor side converter control

As mentioned other literatures, the rotor windings are connected to main grid by power converter allowing slip ring voltage of the generator in phase angle and magnitude. The RSC also contains two PI control loops in cascade.

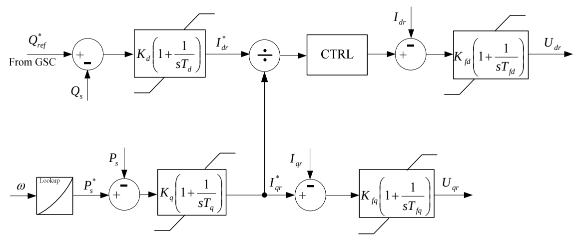

Figure 4. The control model of rotor side converter

In the synchronous reference frame fixed to the stator voltage. In such a reference frame, the q-component of rotor current is utilized to control the active power, and d-component of rotor current regulates the reactive power. The relationship between stator reactive power and active power, and rotor current components are as follow:

$$\begin{cases} P_s = -k\omega_s \lambda_{ds} \lambda_{qr} \\ Q_s = k\omega_s \lambda_{ds} (\lambda_{dr} - \frac{L_{lr} + L_m}{L_m} \lambda_{ds}) \\ k = \frac{3}{2} \frac{L_m}{(L_{ls} + L_m)(L_{lr} + L_m P) - L_m^2} \end{cases} \quad (2)$$

When the stator flux holds constant, the active power and reactive power change in a period of time are given by:

$$\begin{cases} \Delta P_s = -k\omega_s \lambda_{ds} \Delta \lambda_{qr} \\ \Delta Q_s = k\omega_s \lambda_{ds} \Delta \lambda_{dr} \end{cases} \quad (3)$$

The reference value of active power (P_s^*) is obtained by looking up table for a given DFIG wind speed, which enables the maximum energy capturing from the wind.

As DFIG can be responsible for reactive power flow, a PI control loop obtains I_{dr}^{*} from the difference between expected and real reactive power. The same as GSC control theory, the priority belongs to active power. Therefore, the CTRL checks available capacity for d-component respect to q-component. Finally two PI control loops adjust rotor voltage components.

TEST SYSTEM TOPOLOGY

Simulation system is based on the classic two-area four-machine system. The system represents two areas and a wind farm is added to bus7. The transfer level along the tie line of the two areas varies from zero to four hundred MW depend on the variation of load levels in the two areas.

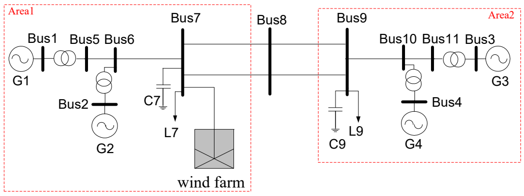

Figure 5. Two-area Four-machine system integrated with a wind farm

A typical arrangement for wind farm is equipped with the DFIGs. The wind farm produces 100MW, contains fifty 2MW parallel DFIGs. These DFIGs are interconnected by a complex collector system, five rows and every row parallel ten sets. A time series wind speed stored in a file is used to drive the wind turbines, to simulate the wind speed on each DFIG. It is assumed that the rows of wind turbines are lined up along the direction of the prevailing wind speed as shown in Fig.2.

Table 1. The parameters of wind farm

Single DFIG	P_N=2MW,V_N=690V,f=50Hz,R_s=0.00488pu,X_s=0.09241pu,R_r=0.00549 pu,X_r=0.09955pu,X_m=3.95279pu,p=2,J=200kg • m^2
Wind Turbine	H_{tur}=3.5s,H_{gen}=0.5s,K=10,D=3.14, R=45m,V_w=11m/s, ,V_{in}=3m/s, ,V_{out}=25m/s, T_{servo}=0.5s, J=6.3×10^{6}kg • m^2
Transmission Line	35kVLine: R=0.36Ω/km，X=0.4005Ω/km; 110kVLine: R=0.047Ω/km，X=0.1382Ω/km;
DC-link Capacitor	C=14000μF,U=1.2kV

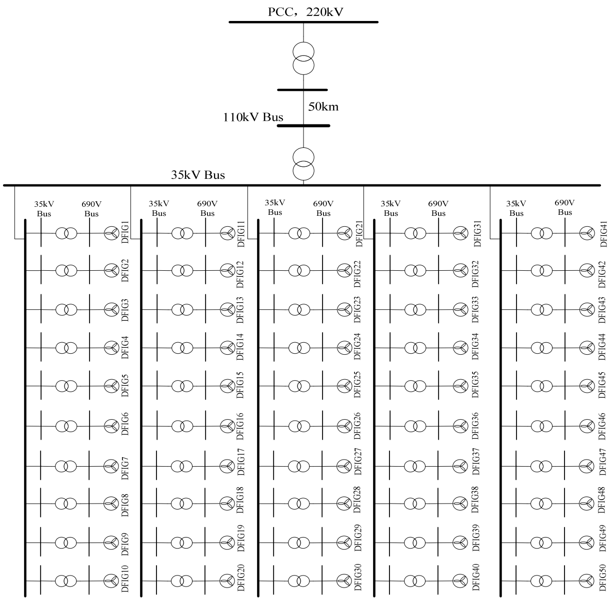

Figure 6. Typical connection diagram of a wind farm

Each DFIG has its own independent control system, and can achieve the maximum power tracking under variable speed constant frequency operation, and can regulate active power and reactive power independently.

RESULTS ANALYSIS

Small signal stability analysis can identify the reasons for weakly damped or unstable oscillations, and also help to determine the effective means for damping oscillations control. But this type of information is very difficult to be obtained from time domain simulations.

The two main types of low frequency oscillations, namely inter-area and intra-area are analyzed.

1) Inter-area oscillations, i.e. oscillations of generators (groups of coherent) in a certain area of the network against generators (groups of coherent) in another area of the network.

2) Intra-area oscillations, i.e. oscillations of generators (groups of coherent) in a certain area of the network against each other.

In this paper, inter-area and intra-area oscillations are studied, and the results shown in Tab.2.

Table 2. The oscillation modes of simulation system

Case	NO.	Eigenvalues	Damping ζ (%)	f (Hz)	mode
without wind farm	mode1	-0.654±j8.658	7.530	1.378	intra-area1
	mode2	-0.520±j8.671	5.983	1.380	intra-area2
	mode3	-0.035±j4.567	0.760	0.727	inter-area
with conventional control	mode1	-0.620±j8.658	7.145	1.378	intra-area1
	mode2	-0.519±j8.670	5.979	1.380	intra-area2
	mode3	-0.879±j6.923	12.601	1.102	inter-area
with Var coordinated control	mode1	-0.665±j8.671	7.642	1.380	intra-area1
	mode2	-0.519±j8.670	5.979	1.380	intra-area2
	mode3	-0.448±j7.001	6.385	1.114	inter-area

In this way, it can be investigated whether the effect of wind farm on oscillations due to the way in which wind power is spread through out the swing node. Mode1 and mode2 belong to intra-area oscillations, while mode3 belongs to inter-area oscillation. The schematic diagram is shown as Fig.8. Mode1 shift right with conventional control, so the small signal stability becomes weak. But when using Var coordinated control, Mode1 shift left, the small signal stability is enhanced. Because the wind farm integrated in area1, the effect on area1 is larger than area2. Mode2 keeps invariant nearly because it caused by G3 and G4 in area2. Mode3 varies largely, shifting left. Both conventional control and Var coordinated control can supply positive damping. Mode3 from -0.035 shift to -0.879 with conventional control, the small signal stability is enhanced largely. And Mode3 from -0.035 shift to -0.448 with Var coordinated control; the small signal stability is enhanced less than conventional control.

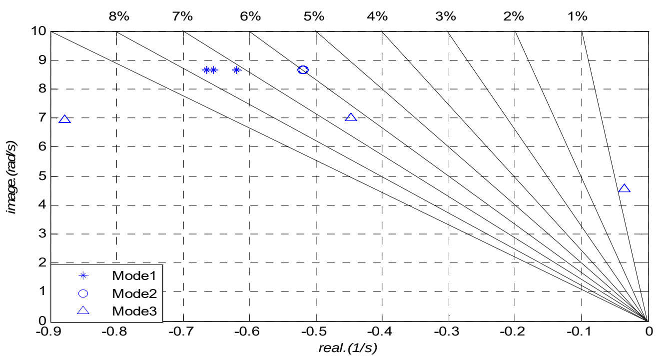

Figure 7. The distribution graph of eigenvalues

CONCLUSION

The impact of wind farm on low frequency oscillations is investigated by observing the movement of eigenvalues by complex plane. The results of simulation further reveal that the wind farm can supply positive damping with suitable control strategy and parameters. DFIG with conventional control and with Var coordinated control have been carried out. It has been found that the Var coordinated control is suitable for stability. Tuning DFIG reactive power can improve system stability during voltage sag or voltage swell. In addition, using proposed Var coordinated control, the dynamic performance of wind power system can be increased. The results of eigenvalue analysis have demonstrated the Var coordinated control can damp oscillations in multi-machine system.

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