DYNAMIC REACTIVE POWER COMPENSATION FOR WIND FARMS

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Abstract: Whenever there is a grid fault, the DFIG unit absorbs certain amount of reactive power from the grid, which causes the grid voltage to drop further and effect the normal gird integration. Hence a facts device is necessary for the compensation of reactive power in the system and also for the maintenance of system voltage within the range. This paper analyses the grid integrated doubly fed induction generation (DFIG) and the feasibility to improve its dynamic voltage level by using reactive power compensation device during fault conditions. In this paper the reactive power variation during fault condition for wind farms with wind turbine protections are analyzed and the reactive power is compensated using a facts device. With the compensation of reactive power, the reactive power transmission from the grid to the wind farm can be reduced and the terminal voltage at the wind turbine can be improved. This paper is simulated using MATLAB simulink.

Keywords: SVC, DFIG, Wind turbine protection, Dynamic reactive power compensation.

I. INTRODUCTION

Now-a-days there is more demand for the power as the consumption of power is increasing drastically in all the areas of the world. But the conventional resources are not sufficient to meet this demand. So the world is aiming to meet the demand with the help of renewable resources. As a source of renewable and clean energy, wind power has drawn more people attention, and currently it possesses the largest development potential in the world. Wind turbine integration to the grid is an important aspect for the large-scale utilization of wind energy. Wind turbine mainly consists of two types. One is induction generator (IG) and the other is doubly fed induction generator (DFIG). In these DFIG is one of the main types of wind turbine. DFIG can adjust the frequency, amplitude and phase of the rotor voltage through the rotor-side converter with four quadrants to control its operating conditions, so that DFIG can run with high efficiency of wind energy conversion within a wide range of wind speeds[1]-[5].

The increasing penetration of wind energy, with its characteristics of high intermittency and uncertainty, into traditional power grid, has brought a huge challenge to the operation and dispatching of power grids[6]. In order to handle this difficulty, many countries have developed standards for large-scale wind power integration, and required that wind turbines should have been equipped with Low Voltage Ride Through (LVRT) capability[7][8]. Reactive power plays an important role in the power system stability. In order to maintain the voltage within the limits reactive power compensation is necessary. Whenever there is a grid fault the wind turbine draws reactive power from the grid. In order to maintain the system stable, the wind turbine needs to be tripped. The frequent occurrence of wind turbine tripping not only brings a lot of troubles to wind power companies, but also poses a threat to the security of the power grid [9]. During severe grid fault, the wind turbines must be able to remain grid connected within a predefined time period, so that the instability status of power grids cannot be exacerbated.

Upon the grid's requirement, wind turbines can quickly supply reactive power to the grid to assist the regulation and stabilization of grid voltage according to the magnitude of grid voltage sag, when the grid voltage disturbance has been eliminated, the rapid recovery of its active power to the grid is required [10]&[11]. In order to compensate the reactive power a facts device is connected to the system. SVC can dynamically change values of the shunt capacitors and reactance. In another words, it can dynamically change the SVC's output of reactive power [12]. It also can control voltage of the bus connected to SVC and even that of buses which need remote control. Simulation results in this paper show that SVC plays an important role in supporting reactive power and voltage of wind turbine during fault conditions.

II. CHARACTERISTIC ANALYSIS OF DFIG

DFIG consists of wind turbine, mechanical transmission system, induction generator, converter and its control system; pitch angle control system, etc. The basic structure is shown in Fig1.

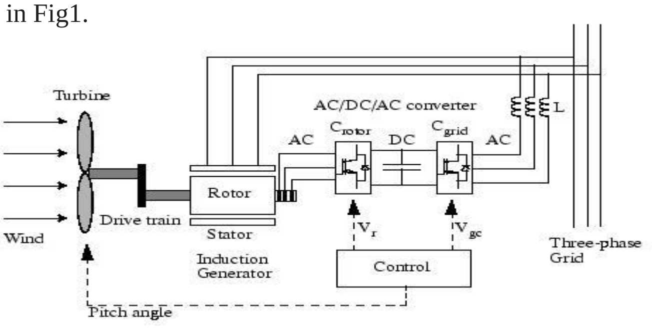

Fig1. Structure of DFIG

The mathematical model of the DFIG system under synchronous rotating coordinate system can be established. Where $u_{sd}, u_{sq}, u_{rd}, u_{rq}$ represent the d, q axis components of stator and rotor voltage, respectively, $i_{sd}, i_{sq}, i_{rd}, i_{rq}$ the d, q axis components of stator and rotor current L_s, L_r, L_m are self and mutual inductances of stator and rotor, R_s, R_r are the resistance of stator and rotor, ω_1 is the synchronous reference frame rotating speed ω_r, is the electrical angular velocity of rotor and p is the differential operator.

$$\begin{bmatrix} u_{sd} \\ u_{sq} \\ u_{rd} \\ u_{rq} \end{bmatrix} = \begin{bmatrix} pL_s + R_s & -\omega_1 L_s & pL_m & -\omega_1 L_m \\ \omega_1 L_s & pL_s + R_s & \omega_1 L_m & pL_m \\ pL_m & -(\omega_1 - \omega_r)L_m & pL_r + R_r & -(\omega_1 - \omega_r)L_r \\ (\omega_1 - \omega_r)L_m & pL_m & (\omega_1 - \omega_r)L_r & pL_r + R_r \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} \quad \ldots\ldots (1)$$

According to the definition of motor flux:

$$\psi_{sd} = L_s i_{sd} + L_m i_{rd} \quad \ldots\ldots (2)$$

$$\psi_{sq} = L_s i_{sq} + L_m i_{rq} \quad \ldots\ldots (3)$$

Through the derivation of equation (1) and by defining the stator flux as d-axis of rotating reference frame, that is, set $\psi_{sq} = 0$ and $\omega_s = \omega_1 - \omega_r$ then substitute equations (2) & (3) into equation (1) to get:

$$u_{rd} = (L_{sd} - \frac{L_m^2}{L_s}) p i_{rd} + r_r i_{rd} - \omega_s (L_{sd} - \frac{L_m^2}{L_s})\, i_{rq} + \frac{L_m}{L_s} p \psi_{ds} \quad \ldots\ldots (4)$$

$$u_{rq} = (L_{sd} - \frac{L_m^2}{L_s}) p i_{rq} + r_r i_{rq} + \omega_s (L_{sd} - \frac{L_m^2}{L_s})\, i_{rd} + \omega_s \frac{L_m}{L_s} \psi_{ds} \quad \ldots\ldots (5)$$

Equations (4) and (5) shows that feed forward compensation of rotor voltage can realize the decoupling control of the generator. The model of feed forward compensation e_{rd} and e_{rq} is shown as follows:

$$e_{rd} = \omega_s (L_r - \frac{L_m^2}{L_s})\, i_{rq} - \frac{L_m}{L_s} p \psi_{ds} \quad \ldots\ldots (6)$$

$$e_{rq} = -\omega_s (L_r - \frac{L_m^2}{L_s})\, i_{rd} - \omega_s \frac{L_m}{L_s} \psi_{ds} \quad \ldots\ldots (7)$$

From equations (4), (5), (6) and (7), the relationship of voltage and current can be derived as:

$$\omega_s (L_r - \frac{L_m^2}{L_s})\, i_{rd} - \frac{L_m}{L_s} p \psi_{ds} = -r_r i_{rd} + u_{rd}^* \quad \ldots\ldots (8)$$

$$\omega_s (L_r - \frac{L_m^2}{L_s})\, i_{rq} - \frac{L_m}{L_s} p \psi_{ds} = -r_r i_{rq} + u_{rq}^* \quad \ldots\ldots (9)$$

The derivation of the steady-state mathematical model of the DFIG system shows that the inner current control performance of the DFIG system can be improved by the PI controller and feed forward compensation of voltage.

When the grid fault occurs, the system voltage drops, then the DFIG unit needs to absorb a certain amount of reactive power from the grid, which causes the grid voltage to decline further and affect the normal grid integration. Therefore, the requirement on the LVRT capability of DFIG is much higher. SVC, a static reactive power compensation device, has good dynamic characteristics, and can quickly provide reactive power support to the system to meet the demand and also to maintain the voltage of system within a certain range.

III. CHARACTERISTIC ANALYSIS OF SVC

The dialog box settings of the programmable voltage source module parameters are shown as follows: at 0.1 second, the voltage amplitude changes from 1.0pu to 0.97pu; at 0.4 second, from 0.97pu to 1.03pu, at 0.7 second, the voltage amplitude recovers from 1.03, to 1.0pu. The rated capacity of SVC is 200MVA, and the adjustment of reactive power ranges from -100Mvar to 200Mvar, while the control mode of SVC is voltage regulation, where Vref=1.0pu, Xs=0.03, Kp=0, Ki=300. The studied system used in the simulation is shown in fig 2.

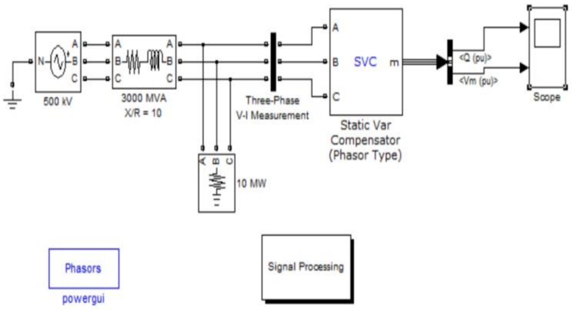

Fig2. Characteristics simulation of SVC

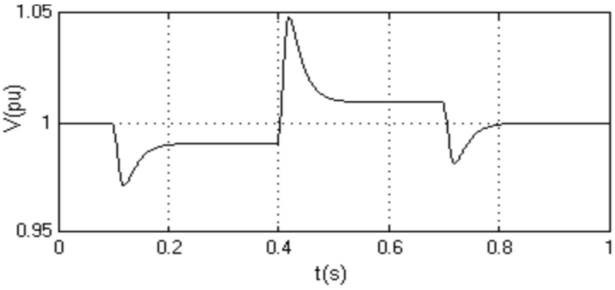

Fig.3 Voltage of SVC during fault condition

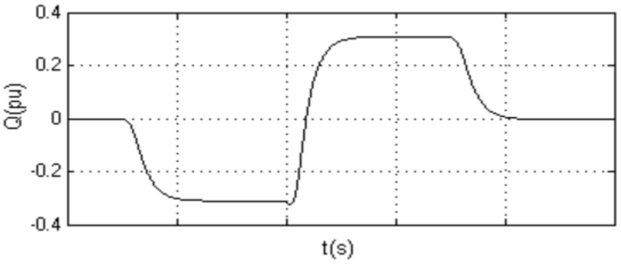

Fig.4 Reactive power output of SVC during fault condition

The voltage and reactive power curve of SVC from the oscilloscope after the completion of the simulation are shown in Fig3 and Fig4. At 0.1 second, the supply voltage drops to 0.97pu suddenly and the port voltage of SVC correspondingly declines to 0.97pu around, then SVC sends reactive power (about 0.31*200Mvar=62 MVAR) to the system, so that the voltage is restored to 0.99pu. At this moment one TSC has been put into operation, but because TSC only has two operation modes, on and off, the capacitive reactive input is discrete. If the capacity of a TSC is more than 62 MVAR, the TCR is on to absorb some of the capacitive reactive power. At 0.4 second, the supply voltage suddenly rises to 1.03pu, the port voltage of SVC correspondingly rises to 1.03pu around, SVC absorbs reactive power from the system (about 0.31*200Mvar=62Mvar), so that the voltage is down to 1.01pu, while TCR is on and TCS is off. At 0.7 second, the voltage is restored to 1.0pu. The simulation results show that SVC can achieve the best compensation effect within 100ms whether the system voltage is low or high.

IV. SIMULATION MODEL AND SYSTEM PARAMETERS

A wind farm with the capacity of 63MW, 42 sets of 1.5MW units, is connected to a 330kV power grid, by 35/110kV and 110/330kV step-up transformer. The system frequency is 50Hz, and the wind turbine terminal voltage is 690V.

In the wind turbine model in MATLAB, the following protections are considered:

1) AC under voltage protection: positive sequence voltage reaches 0.75pu, delay 0.1 second, wind turbine trips.
2) AC over voltage protection: positive sequence voltage reaches 1.1pu, delay 0.1 second, wind turbine trips.
3) DC over voltage protection: DC voltage reaches 2500V, delay 0.001 second, wind turbine trips.
4) Under Speed protection: speed reaches 0.3pu, delay 5 seconds, wind turbine trips.
5) Over Speed protection: speed reaches 1.5pu, delay 5 seconds, wind turbine trips.
6) AC over current protection: positive sequence current reaches 1.1pu, delay 5 seconds, wind turbine trips.

The curve of normal operation without failure shows the system start-up is complete in about 45 seconds. At 45 second, the units operate stably, and a 60% voltage sag is applied to the 330kV system during 45~45.1 second. The simulation model of system is shown in Fig5.

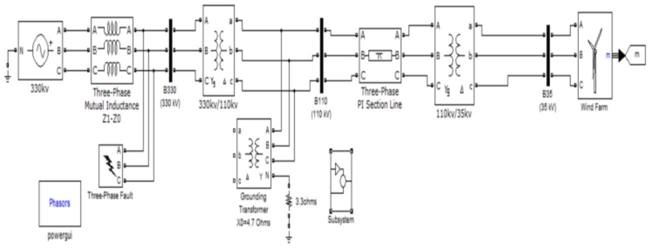

Fig5. Simulation model of system

Two scenarios have been used to verify the role of SVC to support reactive power on the power grid.

Scenario 1: 60% voltage sag occurs to the grid 330kV system.

Scenario 2: 60% voltage sag occurs to the grid 330kV system and SVC is connected to 35kV bus.

V. ANALYSIS OF DYNAMIC REACTIVE POWER COMPENSATION DURING FAULT CONDITION FOR THE WIND FARM

A. Simulation results of scenario 1: During 45 ~ 45.1 second, the terminal voltage, current, active power, reactive power and other curves of DFIG units are shown in Fig6(a) – Fig6(g).

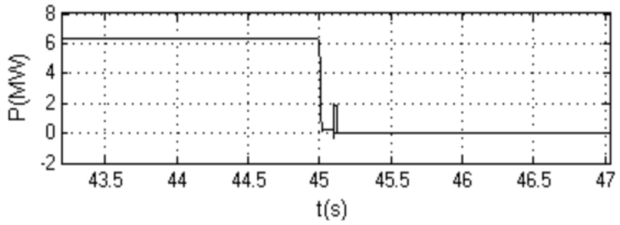

Fig.6(a) Active power output of DFIG

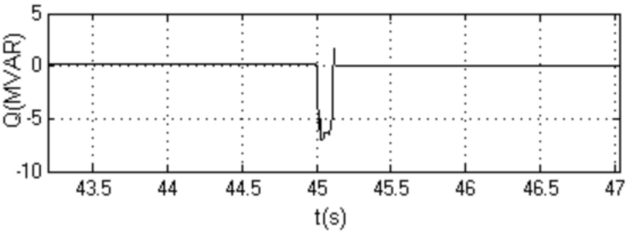

Fig.6(b) Reactive power output of DFIG

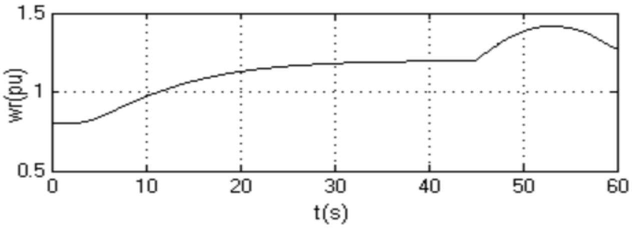

Fig.6(c) Angular velocity of DFIG

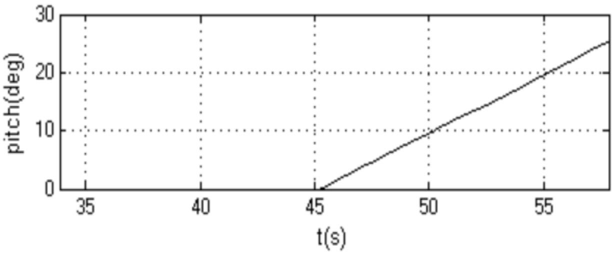

Fig.6(d) Pitch angle of DFIG

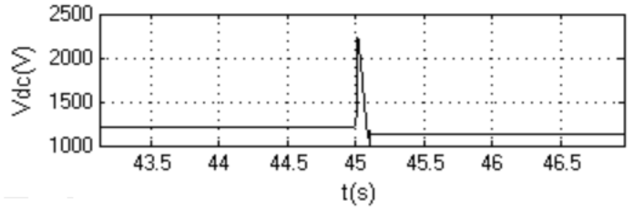

Fig.6(e) DC voltage of DFIG

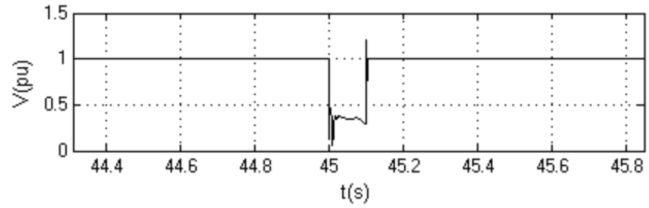

Fig.6(f) Voltage of 690V bus

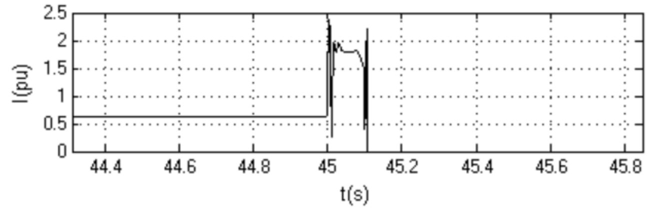

Fig.6(g) Current of 690V bus

At 45.11 second, the DFIG unit trip due to under voltage protection action, as shown in Fig.6(a), and the active power of the units is 0. During the voltage sag, the units absorb certain amount of reactive power from the grid, as shown in Fig.6(b) and the maximum of DC voltage reaches 2200V, as shown Fig.6(e). Fig.6(c) shows the relationship between electromagnetic torque and speed of the wind turbine. The absolute value of electromagnetic torque decreases with the voltage sag, because the flux decreases with the voltage sag, the electromagnetic torque is reduced. But the input mechanical torque of the wind turbine is constant, which cause the speed of the wind turbine to increase. As the wind increases the pitch angle is adjusted to control the turbine as shown in Fig.6(d). The voltage of 690V bus drops to 0.38pu, and the current increases to 3~4 times of rated value during the voltage sag, as shown in Fig.6(f) and Fig.6(g) resp.

B. Simulation results of scenario 2: With SVC connecting to the 35kV bus, under voltage protection of the wind turbine is not activated, so the wind turbine can remain grid integration during the voltage sag.

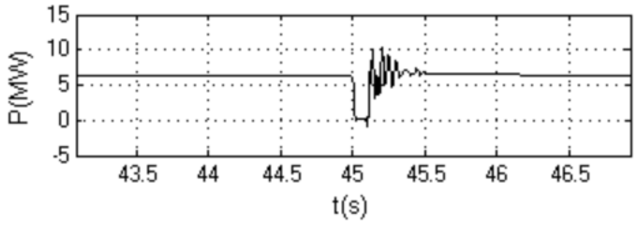

Fig.7(a) Active power output of DFIG

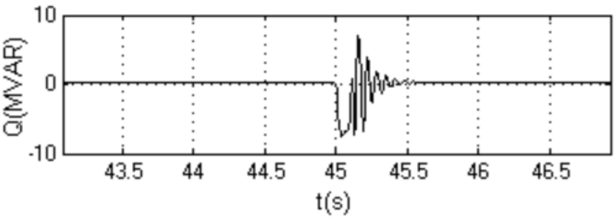

Fig.7(b) Reactive power output of DFIG

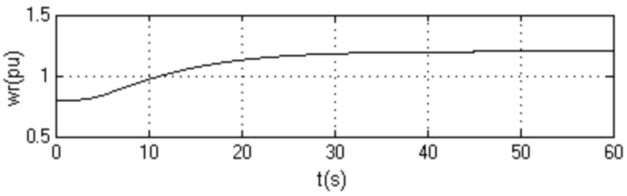

Fig.7(c) Angular velocity of DFIG

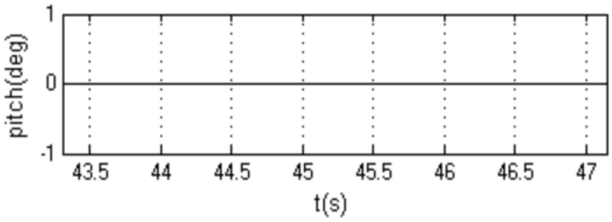

Fig.7(d) Pitch angle of DFIG

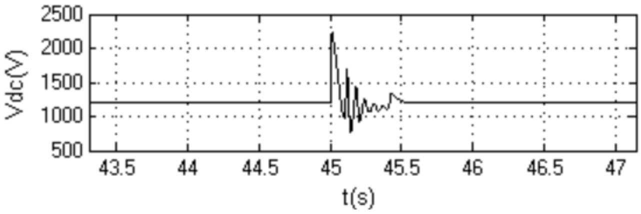

Fig.7(e) DC voltage of DFIG

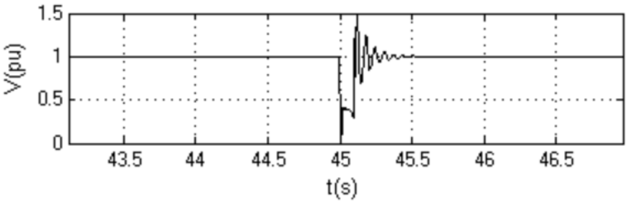

Fig.7(f) Voltage of 690V bus

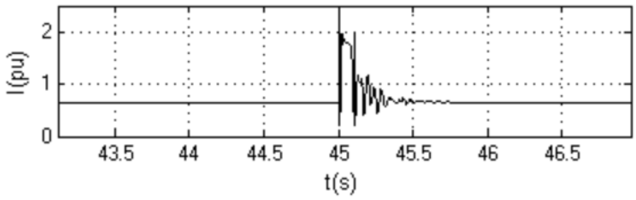

Fig.7(g) Current of 690V bus

The active power of the units recovers rapidly after the recovery of grid voltage, as shown in Fig.7(a) and the reactive power is shown in Fig.7(b). The angular velocity is a smooth curve, as shown in Fig.7(c) and the pitch angle remains constant as there is no change in wind speed as shown in Fig.7(d). The voltage of 690V bus drops to 0.415pu, improved 0.035pu compared to scenario 1, as shown in Fig.7(f). The current recovers to be normal after fluctuations, as shown in Fig.7(g). Each variable can restore stability after 0.5 second of fluctuations. SVC provides reactive power to the system during 45~45.1 second, and plays an important role for supporting grid voltage.

V. CONCLUSION

This paper analyses the dynamic reactive power compensation during fault condition for wind farms with wind turbine protections. Based on the analysis of dynamic characteristics of SVC and the establishment of a 63MW wind farm system model, this paper shows that SVC has good dynamic characteristics. When a SVC is connected to a wind farm, it can supply reactive power commensurate with the capacity of SVC for the wind farm, so that the reactive power transmission from the grid to the wind farm can be reduced. When severe voltage sag occurs in the grid side, SVC is able to adjust the output reactive power dynamically to help rebuilding the terminal voltage of wind turbine and plays an important role in supporting grid voltage. To certain extent, it is also able to improve the fault ride through capability of wind turbine.

On the other hand, it should be noted that, there are certain restrictions for the supporting role played by SVC: If the voltage sag of the system is too severe, then the reactive power compensation of SVC will be insufficient to let the wind turbine remain grid integration.

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