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Modelling And Analysis of Faults In Wind Based Doubly-Fed Induction Generator

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ABSTRACT

Demand for wind power has increased considerably due to technological advances and favourable government policies. As a result, large wind farms with multi-megawatt capacity are connected to sub-transmission and transmission systems. With high penetrations of wind energy, performance of the overall system is affected by the technical impacts introduced by wind turbine generators (WTG). Fault current contributions from WTGs will have a significant impact on the protection and control of the wind farm as well as the interconnected system. This paper initially describes the modelling aspects of Doubly- Fed Induction Generator (DFIG) during steady state and faulty conditions. Vector decoupling control strategy has been adopted to establish the mathematical model of DFIG based wind generator. Further, a 9 MW wind farm with 6 units of 1.5 MW DFIG is modelled in Matlab/Simulink and, voltage and current waveforms are presented and discussed for symmetrical and asymmetrical faults created in the power system.

Keywords : Wind power, doubly-fed induction generator, dynamic performance, mathematical modeling, decoupled control

INTRODUCTION

AS per the projections made by Central Electricity Authority, the national electricity requirement in 2020 would be 1,643 billion units. Fifteen percent of that would be green power added to grid by 2020. 15% would mean addition of installed capacity of about 89,690 MW of renewable based power projects by 2020. It is estimated that the maximum contribution of about 48,240 MW will have to come from wind. Wind will remain dominant technology till 2020 because of following reasons:

- maturity of technology
- near commercial viability and grid parity
- well developed national market
- strong and indigenous manufacturing facilities
- high scalability
- short gestation period
- technology acceptable among corporates
- modularity

Experiences in countries with high penetration of wind power, such as Denmark, Spain, and Germany, have demonstrated that this scenario is technically and economically feasible. However, the rapid expansion of this energy has made it necessary to redesign the existing grid code requirements (GCR). As a result, large wind farms with multi-megawatt capacity are connected to sub-transmission and transmission systems.

In order to guarantee the safety and reliability for wind power integration operation, it is of great significance to establish an appropriate wind power generator system model and analyze electro-magnetic transient characteristics.

I. Basic concepts of DFIG

The layout of a WT that is based on DFIG technology is shown in Fig. 1.

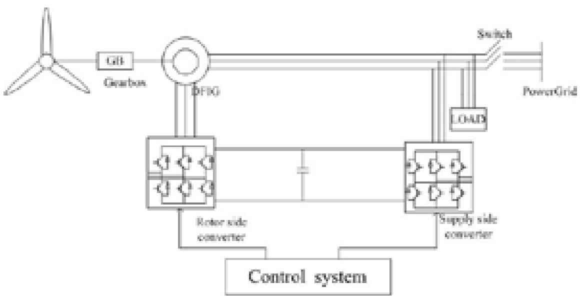


Fig. 1. DFIG connected to a grid

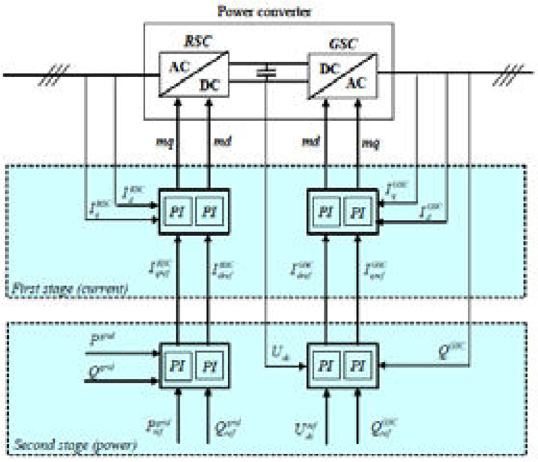
A doubly-fed induction generator is a standard wound rotor induction machine with its stator windings directly connected to grid and its rotor windings connected to the grid through an AC/DC/AC converter. AC/DC converter connected to rotor winding is called rotor side converter and another DC/AC is grid side converter. Doubly-fed induction generator (DFIG), is used extensively for high-power wind applications. DFIG's ability to control rotor currents allows for reactive power control and variable speed operation, so it can operate at maximum efficiency over a wide range of wind speeds. The aim of this paper is to develop a control method and analysis of dynamic performance of DFIG's rotor control capabilities for unbalanced stator voltages, grid disturbances and dynamic load condition.

II. DFIG wind turbine Modelling and Control

A. Overall control scheme

The overall structure of the DFIG based wind generator model can be divided into five parts: wind speed model, aerodynamic model, pitch angle control model, mechanical drive model and DFIG model with its control system.

The DFIG control structure, illustrated in Figure 2, contains the electrical control of the power converters, which is essential for the DFIG wind turbine behaviour both in normal operation and during fault conditions. The aim of the RSC is to control independently the active and reactive power on the grid, while the GSC has to keep the dc-link capacitor voltage at a set value regardless of the magnitude and the direction of the rotor power and to guarantee a converter operation with unity power factor (zero reactive power). As illustrated in Figure 2, both RSC and GSC are controlled by a two stage controller. The first stage consists of very fast current controllers regulating the rotor currents to reference values that are specified by a slower power controller.



In this paper Vector decoupling method is the core technology used. The electrical drive controls become more accurate in the sense that not only are the DC current and voltage controlled but also the three phase currents and voltages are managed by vector control. Control strategy can be divided into two stages: control of Grid Voltage Side Converter and Rotor Voltage Side Converter.

B. Control scheme of Grid side VSC

The equivalent circuit of grid connected inverter is shown in fig. 3.

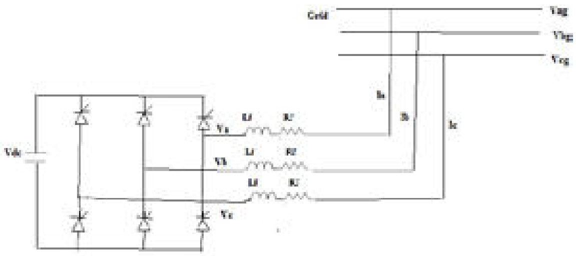


Fig. 3 Equivalent circuit of Grid side controller Upon mathematical simplifications, we get

$$v_{sd} = I_{sd}R_f + L_f\frac{dI_{sd}}{dt} - w_s L_f I_{sq} + v_{gd} \tag{1}$$

$$v_{sq} = I_{sq}R_f + L_f\frac{dI_{sq}}{dt} - w_s L_f I_{sd} + v_{gq} \tag{2}$$

Power exchange between Power Grid and Grid VSC is calculated as 3-phase power = 2 x line power in d-a axis frame

Active Power, $P_r = 1.5(e_d i_d + e_q i_q)$ (3)

Reactive power, $Q_r = 1.5(e_q i_d - e_d i_q)$ (4)

Modelling of grid VSC is based on power decoupling control strategy. Here in this case while converting from stationary frame to rotating frame the Grid voltage is considered as reference vector and d-axis is considered in the direction of Grid voltage.

So, v_{sd} =e and v_{sq} =0. (5)

Substituting the above in equations (3) and (4), we get

$$P_r = 1.5ei_d \tag{6}$$

$$Q_r = -1.5ei_q \tag{7}$$

We get power decoupling strategy i.e. active power is only dependent on d-axis current and reactive power is only dependent on q-axis current. Since current cannot be controlled, current should be transformed to voltage and the references voltages which are in synchronous frame are applied to Grid VSC Pulse width Modulation, which generates required pulses to fire the IGBT s.

Using the relation of eq. (5),

From eq. 1 we get

$$v_{sd} = I_{sd}R_f + L_f\frac{dI_{sd}}{dt} - w_s L_f I_{sq} + v_{gd} \tag{8}$$

or, $$v_d{*} = e + w_s L_f I_{sq} - (I_{sd}R_f + L_f\frac{dI_{sd}}{dt}) \tag{9}$$

And from eq. 3, we get

$$v_{sq} = 0 = I_{sq}R_f + L_f\frac{dI_{sq}}{dt} + w_1 L_f I_{sd} + v_{gq} \tag{10}$$

or, $$v_q{*} = -w_1 L_f I_{sd} - (I_{sq}R_f + L_f\frac{dI_{sq}}{dt}) \tag{11}$$

DFIG should be mathematically modelled first to apply the control scheme of Rotor VSC.

C. Mathematical modeling of DFIG

Modelling of Rotor Voltage Side Converter(VSC) is based on power decoupling control strategy. Stator flux oriented vector control scheme is adopted where the stator flux is considered as reference frame.

Under assumption of linear magnetic circuits and balanced operating conditions, the equivalent two-phase model of the symmetrical DFIG, represented in an arbitrary rotating (d-q) reference frame is:

$$v_{sd} = i_{sd}R_S + \frac{d\psi_{sd}}{dt} - \omega_1\psi_{sq} \tag{12}$$

$$v_{sq} = i_{sq}R_S + \frac{d\psi_{sq}}{dt} + \omega_1\psi_{sd} \tag{13}$$

$$v_{rd} = i_{rd}R_r + \frac{d\psi_{rd}}{dt} - (\omega_1 - \omega)\psi_{rq} \tag{14}$$

$$v_{rq} = i_{rq}R_r + \frac{d\psi_{rq}}{dt} + (\omega_1 - \omega)\psi_{rd} \tag{15}$$

Stator Power equations are:

$$P_s = v_{sd}i_{sd} + v_{sq}i_{sq} \tag{16}$$

$$Q_s = v_{sq}i_{sd} - v_{sd}i_{sq} \tag{17}$$

D. Control scheme of Rotor side VSC

In rotor control scheme the stator flux is assumed as reference and d-axis is set along stator flux and stator voltage which is perpendicular to the flux becomes equal to zero .i.e.,

$$\psi_{sd} = \psi_s, \psi_{sq} = 0, v_{sd} = v_s \;\&\; v_{sq} = 0 \tag{18}$$

$$Q_s = v_s \left(\frac{\psi_s - L_m i_{rd}}{L_s}\right) \tag{19}$$

Using (18), (19) in (16), (17), we get stator power equations as:

$$P_s = -v_s \frac{L_m i_{rq}}{L_s} \tag{20}$$

$$Q_s = v_s \left(\frac{\psi_s - L_m i_{rd}}{L_s}\right) \tag{21}$$

From the above equations it can be observed that the power decoupling control is possible in rotor scheme and active power is dependent on q-axis current and Reactive power is dependent on d-axis rotor current respectively. Since currents cannot be controlled, the currents are converted to respective reference voltages in synchronous frame of reference.

Let

$$\sigma = \left(\frac{L_s L_r - L_m^{\,2}}{L_s}\right) \tag{22}$$

Combining (15), (18), (20), we get

$$v_{rd}{}^* = i_{rd} R_r + \sigma \frac{d}{dt} i_{rd} - \sigma s w_1 i_{rq} + \frac{L_s}{L_s} \psi_s \tag{23}$$

$$v_{rq}{}^* = i_{rq} R_r + \sigma \frac{d}{dt} i_{rq} - \sigma s w_1 i_{rd} + \frac{L_m}{L_s} s w_1 \psi_s \tag{24}$$

The above inputs are applied to rotor VSC PWM Modulation which generates pulses for firing the IGBTs in rotor VSC circuit.

III. Case study

The purpose of this study is to understand the behaviour of a wind farm with DFIGs, under different faulty conditions. A 9 MW wind farm with six DFIG based wind turbine generators, each having a capacity of 1.5 MW has been considered in this study. A 3-phase fault and a phase to phase fault have been created in the power system. Time domain voltage and current waveforms at generator terminal is observed for 0.02 seconds. Simulations start at t=0 sec and faults are created at t=0.04sec. Faults are cleared after 0.02 sec at t=0.06 sec. Fault resistance has been kept constant at 0.001Ω.

A. Three Phase fault

A three phase fault is created at the generator terminal at t=0.04s and cleared at t=0.06s.Fig.4 and Fig.5 show the voltage and current waveforms respectively at the generator terminal. During the fault, voltages of all three phases reach very low values as shown in Fig.4. Ideally this should reach to zero, but in practice, there will be some fault resistance and hence will have a very small magnitude voltage values. Generator terminal current will suddenly increase at the instant of fault initiation as shown in Fig.5, followed by a rapid decay as determined by the transient impedance of the generator.

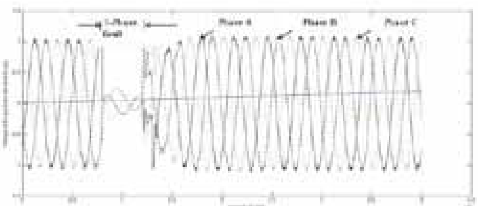


Fig. 4. Voltage at the generator terminal for a 3-phase fault

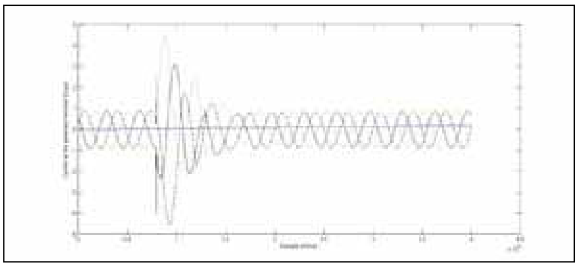


Fig. 5. Current at the generator terminal for a 3-phase fault

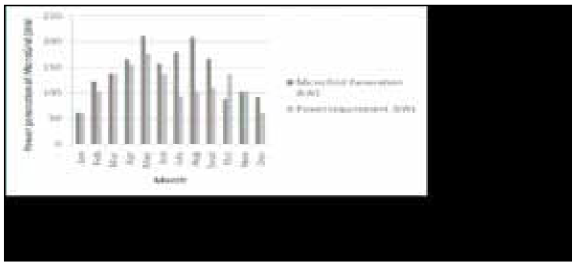


Fig. 6. Rotor current for a 3-phase fault

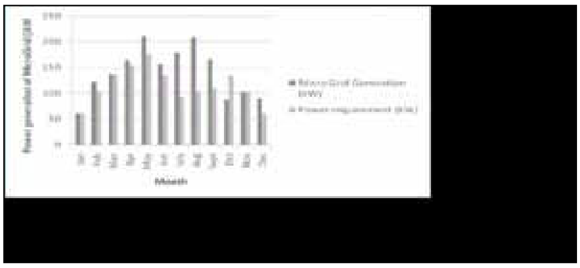


Fig. 7. Active power

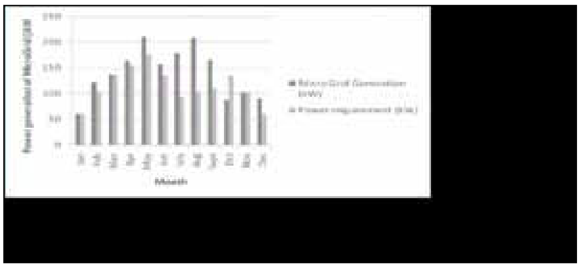


Fig. 8. Reactive power

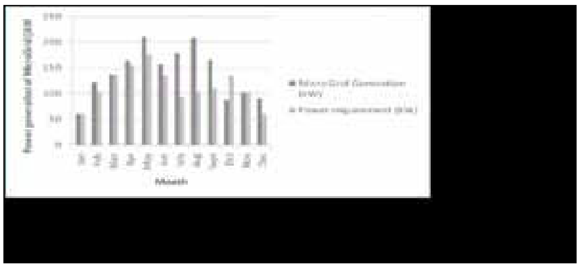


Fig. 9. DC link voltage during a 3-phase fault

In the fault moment, as the stator voltage decreases significantly, high current transients appear in the stator and rotor windings. As a demonstration the rotor current is plotted in fig. 6. In order to compensate for the increasing rotor current, the rotor side converter increases the rotor voltage reference, which implies a “rush” of power from the rotor terminals through the converter, as shown in fig.8.

On the other side, as the grid voltage has dropped immediately after the fault, the grid side converter is not able to transfer the whole power from the rotor through the converter further to the grid. Thus the control of the dc-voltage by grid side controller reaches quickly its limitation. As a result, the additional energy goes into charging the dc-bus capacitor and the dc-voltage rises rapidly as shown in fig. 9.

IV. Conclusion

This paper presents a study of the dynamic performance of variable speed DFIG coupled with wind turbine and the power system is subjected three phase fault and phase-to-phase fault. The dynamic behaviour of DFIG under power system disturbance was simulated using MATLAB/ SIMULINK platform using vector control concept. Accurate transient simulations are required to investigate the influence of the wind power on the power system stability.

The DFIG considered in this analysis is a wound rotor induction generator with slip rings. The stator is directly connected to the grid and the rotor is interface via a back to back partial scale power converter (VSC). Power converter are usually controlled utilizing vector control techniques which allow the decoupled control of both active and reactive power flow to the grid.

In this paper, a 9 MW wind farm is modelled and simulated for symmetrical and asymmetrical faults at generator terminal in the power system. Voltage and current waveforms are presented and compared with those under ideal fault conditions. Authors conclude that understanding fault current behaviour will help in selecting proper instrument transformers, switchgear and control gear, and in designing effective protection systems.

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