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Modeling of DFIG for Power System Stability Studies

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Abstract— **This cardboard explains the modelling of the doubly-fed consecration architect (DFIG), its ceaseless operation and it adherence operation if affiliated to the ability system. With added assimilation of wind ability into electrical grids, DFIG wind turbines are abundantly deployed due to their capricious acceleration affection and appropriately influencing arrangement dynamics. To accredit bigger result, a reduced-order DFIG archetypal is developed that reduces the adding locations to the axiological abundance component. This cardboard presents simulation after-effects of a Grid-connected DFIG. The proposed archetypal for acceleration and bend angle ascendancy can be acclimated if wind and rotor acceleration variations are significant.**

Index Terms— **back-to-back PWM converter, Doubly-Fed induction generator, fault analysis, Grid integration, Variable-speed wind turbine, Vector control.**

I. INTRODUCTION

Globally, wind energy has become a mainstream energy source and an important player in the world's energy markets at the end of 2010.The Global wind Energy Council (GWEC) has reported that 20,000 MW of wind power was installed in 2007, bringing worldwide installed capacity to 94,112 MW. This is an increase of 31% over the 2006 market and represents an overall increase of about 27% in global installed capacity. As per the current projections, the country will require an additional 150,000MW of installed power generation capacity by 2012, which would entail an annual addition of about 10,000 – 15,000MW every year. As traditional fossil fuels become scarcer and there is a growing concern over the environmental impacts of the conventional energy systems, power from non-conventional energy resources has assumed significance. Wind is one of the largest resources in country with a potential of about 45,000MW at 50m above the ground level.

With, added assimilation of wind ability into electrical grids, DFIG wind turbines are abundantly deployed due to their capricious acceleration affection and appropriately influencing arrangement dynamics. This has created an absorption in developing acceptable models for DFIG to be chip into ability arrangement studies. The affiliated trend of accepting top assimilation of wind power, in contempt years, has fabricated it all-important to acquaint new practices.

The assumption of the DFIG is that rotor windings are affiliated to the filigree via blooper rings and back-to-back voltage antecedent advocate that controls both the rotor and the filigree currents. Thus rotor abundance can advisedly alter from the filigree abundance (50 or 60 Hz).

By application the advocate to ascendancy the rotor currents, it is accessible to acclimatize the alive and acknowledging ability fed to the filigree from the stator apart of the generator's axis speed. The ascendancy assumption acclimated is either the two-axis accepted agent ascendancy or absolute torque ascendancy (DTC). [2] DTC has angry out to accept bigger adherence than accepted agent ascendancy abnormally if top acknowledging currents are appropriate from the generator.

In this chapter, the stabilization of the variable speed wind turbine driving DFIG is analyzed.

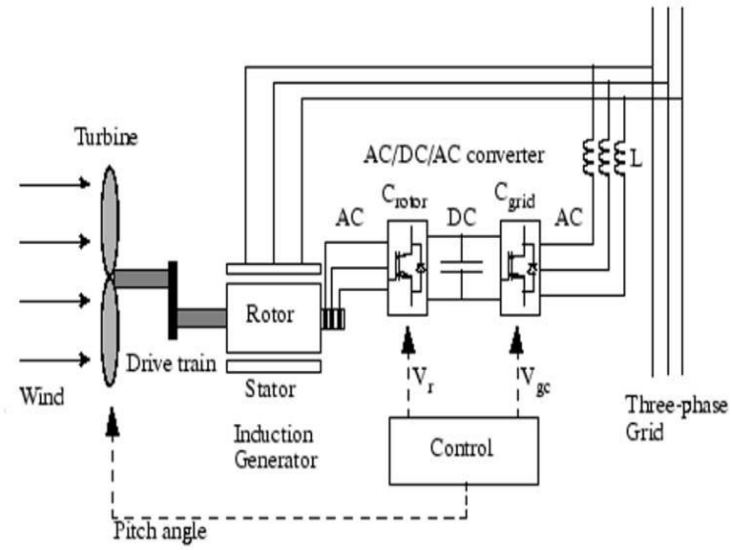

Fig. 1 Block representation of DFIG

II. Modelling of Wind Energy Conversion System

Wind turbines have to compete with many other energy sources. Therefore, it is important that they should be cost effective. They need to meet any load requirements and produce energy at a minimum cost per dollar of investment.

The kinetic energy in a parcel of air of mass, m, flowing at speed, vw in the x direction is,

$$U = \frac{1}{2} m v_w^{\ 2} = \frac{1}{2} (\rho A X) v_w^{\ 2} \quad \rightarrow (1)$$

The power in the wind, $P_{w,\ is}$ the time derivative of the kinetic energy:

$$P_w = \frac{dU}{dt} = \frac{1}{2} \rho A v_w^{\ 2} \frac{dx}{dt} = \frac{1}{2} \rho A v_w^{\ 3} \quad \rightarrow (2)$$

The fraction of power extracted from the power in the wind by a practical wind turbine is usually given by the symbol C_p, power coefficient.

$$P_m = C_p(\frac{1}{2}\rho A v_w{}^3) = \frac{1}{2}\rho \Pi R^2 v_w{}^3 C_p(\lambda, \beta) \rightarrow (3)$$

Where

Cp: Power coefficient
A: Area swept by rotor blades in m^2
ρ: Air density in kg/m^3
V: Velocity of wind in m/s
λ: Tip speed ratio
β: Blade pitch angle (deg)

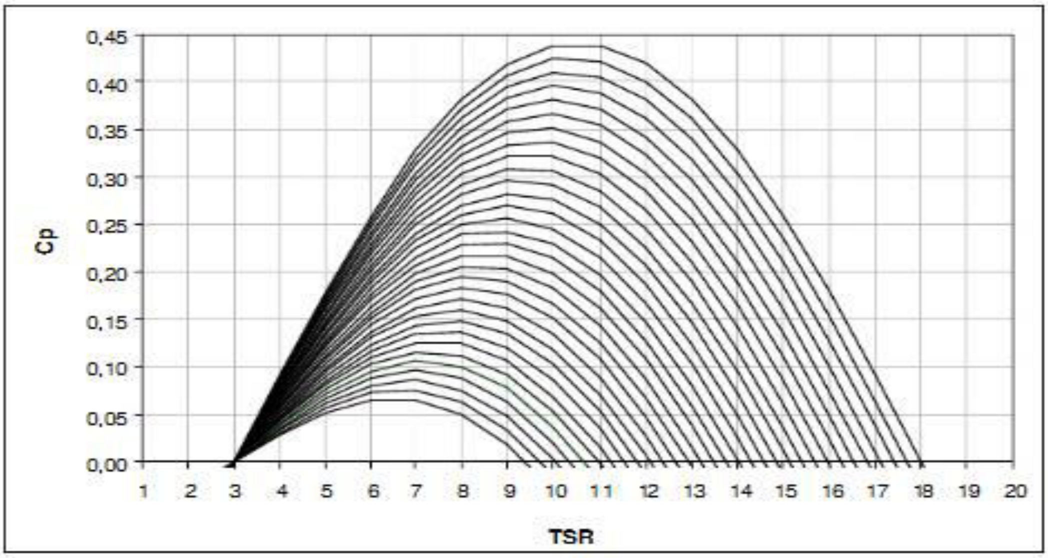

Fig. 2 Power coefficient vs Tip speed ratio

III. Wind Turbine Generation System (WTGS)

A wind turbine generator system (WTGS) transforms the energy present in the blowing wind into electrical energy. As wind is highly variable resource that cannot be stored, operation of a WTGS must be done according to this feature. The general scheme of a WTGS is shown as below,

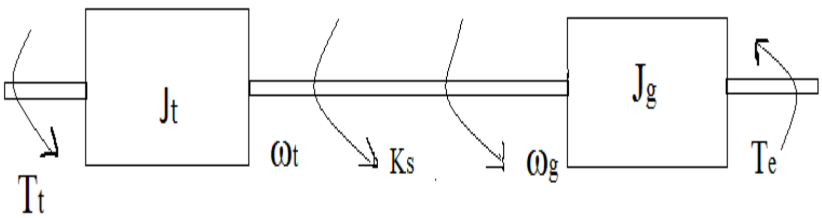

Fig. 3 Mechanical shaft system model

Where,

Tt = Mechanical torque referred to generator side in Nm
Te = Electromagnetic torque in Nm

Jt = Equivalent turbine –blade inertia referred to the generator side (kg m^2)

ωt = Turbine rotational speed(rad/s)

ωg = Generator rotational speed(rad/s)

Ks = Shaft stiffness (Nm/rad)

θs = Angular displacement between the ends of the shaft(rad)

If shaft, turbine and generator damping are neglected, the two mass models is described by the following equations

$$Tt = Jt\,(d\omega t/dt) + Ks\,\theta s \quad \rightarrow (4)$$

$$Te = Jg\,(d\omega t/dt) - Ks\,\theta s \quad \rightarrow (5)$$

$$d\theta/dt = \omega t - \omega g$$

IV. DFIG MODELLING

The arbitrary reference frame is used to present the general equations. ωe can be replaced with the speed of the considered coordinate system.

Using Kirchhoff's law for Generator convention for stator windings.

$$V = Ri - p\psi$$

Effecting the transformation for the above equation.

Taking d-q-o co-ordinates for DFIG

d axis - the axis in which the current in the rotor windings generates a flux.

q axis - an axis perpendicular to d axis.

o axis - to make the system complete, a third component zero sequence is defined.

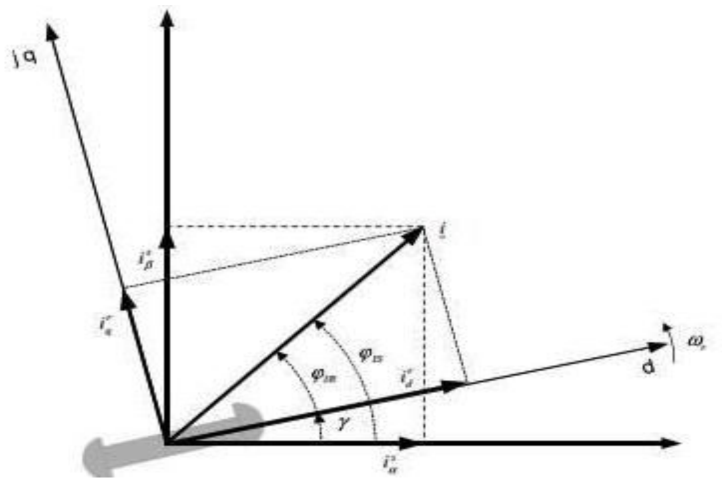

Fig. 4 Park's Transformation

The dq equations of the electric system, referred to a reference frame dq rotating at speed ωa. In order to decouple and further simplify the system, typically the synchronous angular speed ωa is chosen equal to the angular speed of the grid voltage ωs, and the d axis of the rotating frame is aligned with the grid voltage space vector as shown in above Figure 4.

Voltage equations:

Stator Voltage Equations:

$$V_{ds} = p\lambda_{ds} - \omega\lambda_{qs} + r_s i_{ds} \quad \rightarrow(6)$$

$$V_{qs} = p\lambda_{qs} + \omega\lambda_{ds} + r_s i_{qs} \quad \rightarrow(7)$$

Rotor Voltage Equations:

$$V_{qr} = p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} + r_r i_{qr} \quad \rightarrow(8)$$

$$V_{dr} = p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} + r_r i_{dr} \quad \rightarrow(9)$$

Power Equations:

$$P_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs}) \quad \rightarrow(10)$$

$$Q_s = \frac{3}{2}(V_{qs} i_{ds} - V_{ds} i_{qs}) \quad \rightarrow(11)$$

Torque Equations:

$$T_e = -\frac{3}{2}\frac{p}{2}(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad \rightarrow(12)$$

Flux Linkage Equation:

Stator Flux Equations:

$$\lambda_{qs} = (L_{1s} + L_m) i_{qs} + L_m i_{qr} \quad \rightarrow(13)$$

$$\lambda_{ds} = (L_{1s} + L_m) i_{ds} + L_m i_{dr} \quad \rightarrow(14)$$

Rotor Flux Equations:

$$\lambda_{qs} = (L_{1s} + L_m) i_{qs} + L_m i_{qr} \quad \rightarrow(15)$$

$$\lambda_{dr} = (L_{1r} + L_m) i_{dr} + L_m i_{ds} \quad \rightarrow(16)$$

From the above equations the equivalent circuit of DFIG is shown below,

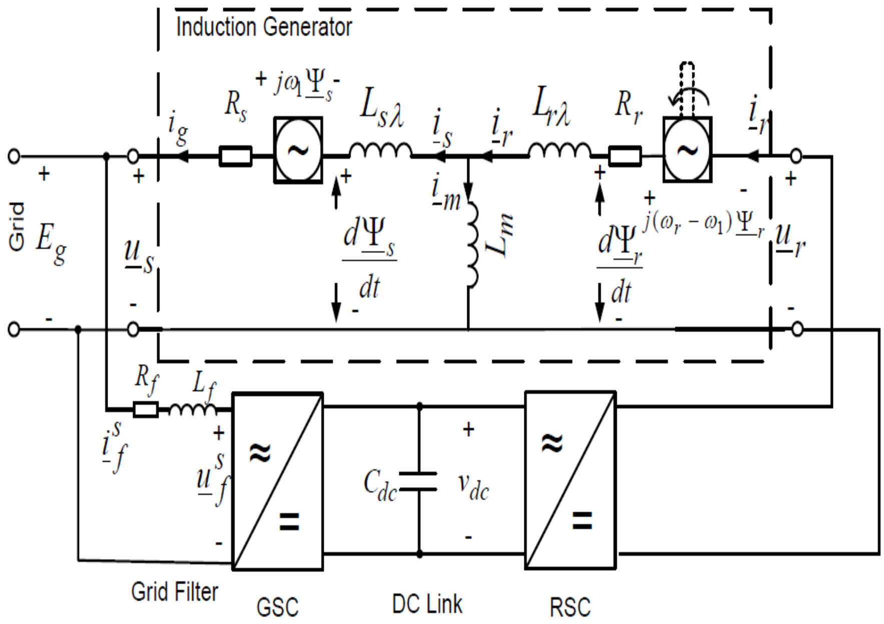

Fig. 5 Equivalent Circuit of DFIG

The grid side converter is in charge of controlling part of the power flow of the DFIM. The power generated by the wind turbine is partially delivered though the rotor of the DFIM as advanced in the previous chapter. This power flow that goes through the rotor flows also through the DC link and finally is transmitted by the grid side converter to the grid.

V. Integrating DFIG with Grid

Simulation is carried out using PSCAD/EMTDC simulation tool. The performance of a 2.2 MVA, 690 V, 50 Hz, 4- pole DFIG is investigated before, during and after fault by applying a constant -1 p.u mechanical torque. Mechanical damping is set to 0.02 p.u to compensate for friction and windage losses. Reference values are set in such a way that Sub synchronous generating mode with +0.28 slip is realized. For sake of the simplicity, shaft is represented as a single-mass model using the swing equation. In order to limit fault currents/voltages, stator-to-rotor turn ratio is set to 0.4333.

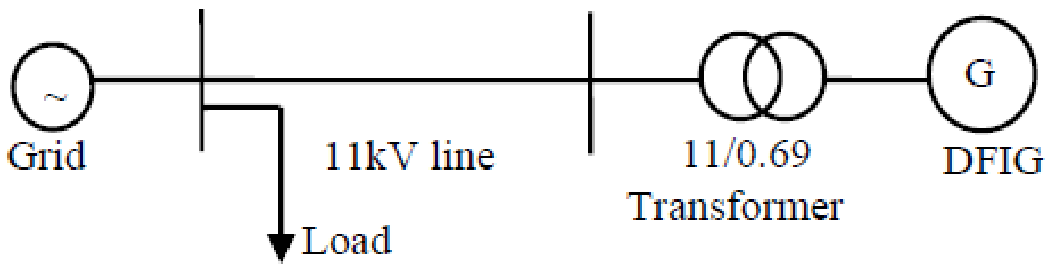

Fig. 6 Test system

The above figure shows the power system used to investigate the performance of the DFIG under fault condition. A boost-up 0.69/11 kV, 2.5 MVA transformer with leakage inductance of 0.06 p.u connects the generating system through the distribution cables to the consumers and the rest of the network, where the latter is represented as a three-phase voltage source with a short circuit level of 100 MVA and X to R ratio of 10. A 3LG short-circuit fault with a fault resistance of 0.01 Ω is applied to the network at t=7 sec for 470 msec. As can be seen in Fig.7, the dip in the stator voltage is about 85 % representing one of the most severe fault conditions under which DFIG should withstand.

VI. Simulation and Results

It can be observed that immediately after fault, stator flux and consequently stator voltage will drop, depending on several factors such as fault type, fault location, fault impedance, short circuit level etc.

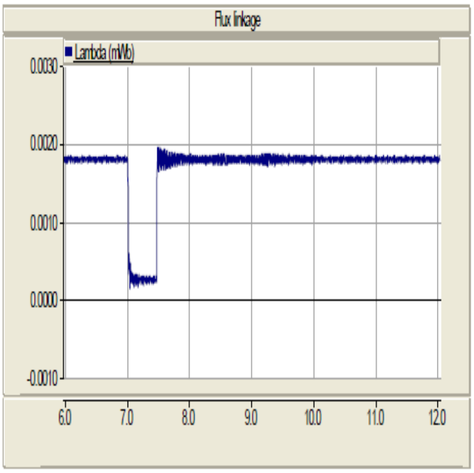

Fig. 7 Stator Flux

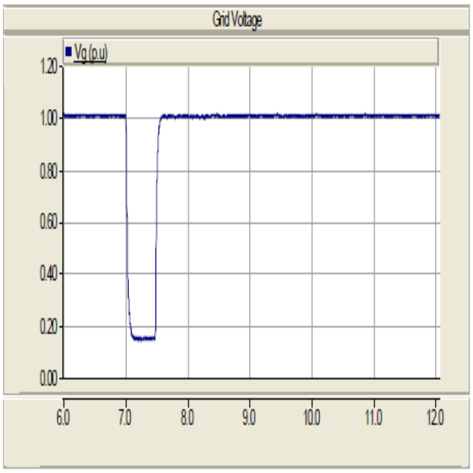

Fig. 8 Stator Voltage

Fig.6, an increase in electromagnetic torque, shortly after fault occurrence, is expected to observe. This characteristic can be confirmed by Fig.9. This increase in electromagnetic torque will result in the acceleration of the rotor based on the swing equation, as mechanical torque is assumed to be fairly constant. As depicted in Fig.10, upon fault clearance, rotor speed starts decreasing indicating appropriate action of the control system. However, in contrast to the electromagnetic torque, rotor speed does not immediately restore its pre-fault value, but decelerating for a few seconds until being stable. The main reason is that current control loops are designed to be much faster than speed control loop, e.g. 100 times faster, as fast speed control loops are susceptible to the noise.

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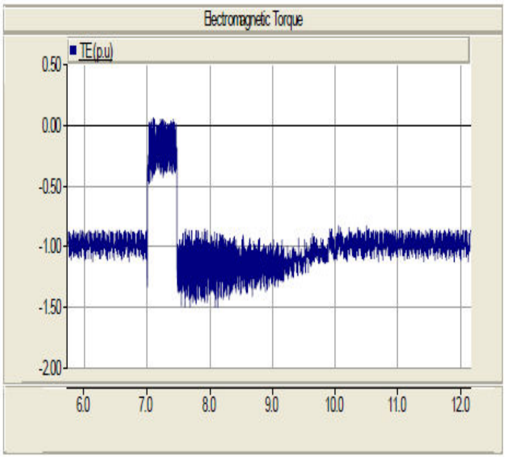

Fig. 9 Electromagnetic Torque

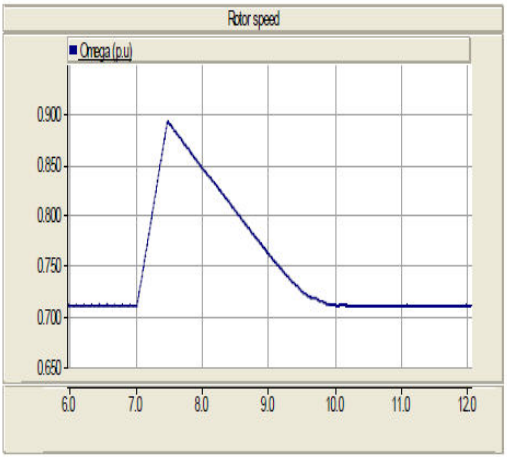

Fig. 10 Rotor Speed

Immediately after the occurrence of fault condition rotor current and hence DC-link current increase. However, due to low voltages of DFIG terminals, stator-side converter cannot exchange this extra current to the network and therefore active power falls toward zero (Fig.11). This can, in turn, cause the accumulation of the fees and therefore DC-hyperlink voltage will upward thrust. Shortly after fault clearance, rotor and stator cutting-edge will restore their pre-fault values and so does DC-hyperlink voltage making sure solid performance of the DFIG under brief situations as shown in Fig.12.

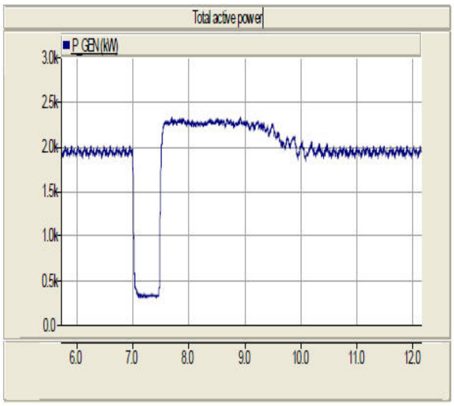

Fig. 11 Total Active Power

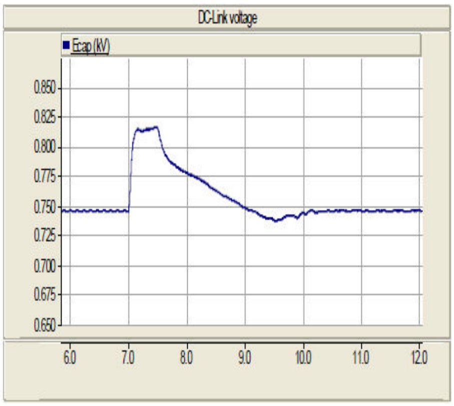

Fig. 12 DC Link Voltage

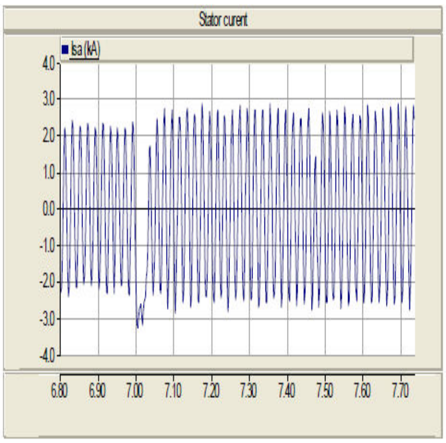

Fig.13 Stator Current

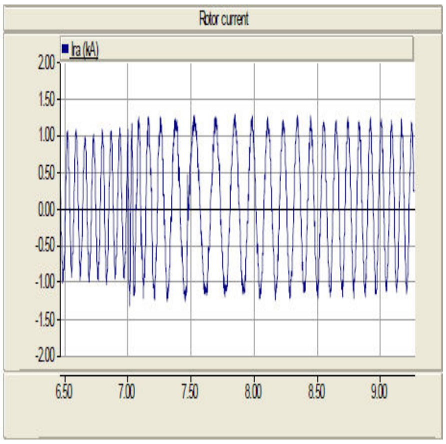

Fig.14 Rotor Current

VII. CONCLUSION

With increased penetration of wind energy and moving toward active networks, grid codes are being revised to reflect the new requirements. This has created an interest in developing more detailed models particularly with respect to fault analysis. Owing to the fact that DFIG controls have a significant influence on the system dynamics, vector control is applied for both stator- and rotor-side converters to increase the degree of controllability, where fixed-frequency Internal Model Controller approach is adopted to design the controllers precisely. In this way, a fairly robust fault-tolerant system is achieved ensuring transient stability of the system.

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