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Active Power Control in Doubly Fed Induction Generator by Using PID Control Technique

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Abstract – **This paper deals with control strategy of active power of Doubly Fed Induction Generator (DFIG) by using PID controller. The active power control of wind farms becomes major concern of stability and security of entire power system. Control over active power according to dispatch command means the wind farm should behave in some way more similar to the conventional power plants. Doubly Fed Induction Generators (DFIG) are generally used in power plants due to capability of decoupled active and reactive power control. This paper describes design and simulation of DFIG using back to back voltage source PWM converter, converter switches gets signal by PID controller attach to output of comparator circuit & rotor circuit using MATLAB Simulink environment. Vector control scheme for supply side PWM converter results in active and reactive power control.**

Keywords – **Doubly Fed Induction Generator (DFIG), Pulse Width Modulation (PWM), Rotor Side Converter (RSC), Grid Side Converter (GSC), Variable Speed Constant Frequency (VSCF), PID, MATLAB.**

I. INTRODUCTION

The renewable energy including solar, wind, tidal, geothermal etc are reusable, environmentally friendly and clean along with advantages of increasing storage in fossil fuels and contribution in reduction in pollution problems renewable energy has become an important source of energy. Recently generation of electricity using wind power has received much interest and considerable attention all over the world. One of the simplest methods of running a wind generation system is to use an induction generator connected directly to the power grid, because induction generators are the most cost-effective and robust machines for energy conversion. However, Induction generators have stability problems similar to the transient stability of synchronous machines [1-2]. Therefore, it is important to analyze the transient stability of power systems including wind power stations. Among these different renewable energy sources wind energy have great potential and scope to develop a system, which reduce dependency upon fossil fuel system at many numbers of points. 1 MW wind turbines reduce 2000 tons CO_2, 10 tons SO_2, and 6 tons of NO_2 emissions to the atmosphere each year [1]. Literature survey shows that Doubly Fed Induction Generators (DFIG) are the most common technology used in variable speed wind turbine, having 45% of the medium to large turbines installed in Europe [2]. DFIG is one of the most popular generator in wind forms due to availability of slip rings, there by partial scale power electronics converter are sufficient for power control power electronics converter encompasses back to back voltage source converters along with a dc link capacitor. The rotor side converter (RSC) connected to the rotor of DFIG via brushes, the grid side converter (GSC) connected to the grid. A capacitor connected in between the act as DC voltage source. The function of GSC is to regulate the dc bus voltage and to control power factor. The RSC has to control the active and reactive power on the stator side. These power converters only process slip power therefore the active and reactive power therefore they are designed in partial scale and just about 30% of generator rated power [3] which makes attractive from economical point of view. Many different technique and methods can be used for control of power converter. One of the most common controlling technique is sinusoidal pulse width modulation (PWM) in vector control (dq) reference frame by which active and reactive power control of DFIG can be achieve separately. The sinusoidal PWM compare a high frequency carrier wave with three sinusoidal reference signals, known as modulating signal, to generate the getting signals for the converters switches [4].

This paper presents an attempt to study and examine the role of variable speed based wind turbines (Doubly Fed Induction Generator) in active power control with different level of wind penetration into the system. In DFIG wind turbine, the stator is directly connected with grid while the rotor circuit is connected via power converter by mean of slip ring and brushes. The rotor current is regulated by the power converter to control the electromagnetic torque and field current and thus stator output either active power or reactive power. The DFIG can operate in either sub synchronous or super synchronous speed operation mode due to capability of converter to operate in bi directional operation power mode [4,5,6]

The wind turbine and the doubly-fed induction generator (WTDFIG) are shown in the figure called The Wind Turbine and the Doubly-Fed Induction Generator System. The AC/DC/AC converter is divided into two components: the rotor-side converter (C rotor) and the grid-side converter (C grid). C rotor and C grid are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source [7-10].

A coupling inductor L is used to connect C grid to the grid. The three-phase rotor winding is connected to C rotor by slip rings and brushes and the three-phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control

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system generates the pitch angle command and the voltage command signals V rand Vgc for C rotor and C grid respectively in order to control the power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid terminals[11-14].

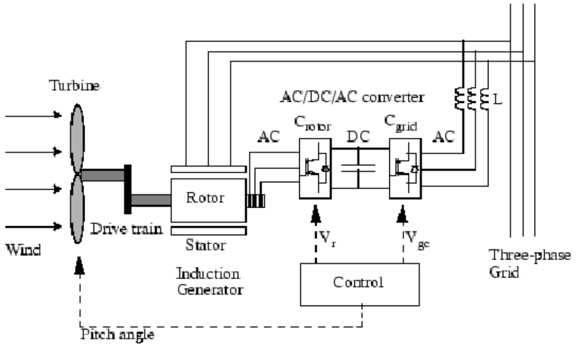

Fig.1. The Wind Turbine and the Doubly-Fed Induction Generator System

II. OPERATING PRINCIPLE OF THE WIND TURBINE DOUBLY-FED INDUCTION GENERATOR

The mechanical power and the stator electric power output are computed as follows:

$$P_m = T_m \omega_r$$
$$P_s = T_{em} \omega_s \quad (1)$$

For a loss less generator the mechanical equation is:

$$J\frac{d\omega_r}{dt} = T_m - T_{em} \quad (2)$$

In steady-state at fixed speed for a loss less generator $T_m = T_{em}$ and $P_m = P_s + P_r$

It follows that:

$$P_r = P_m - P_s = T_m\omega_r - T_{em}\omega_s = -T_m\left(\frac{\omega_s - \omega_r}{\omega_s}\right)\omega_s = -sT_m\omega_s = -sP_s \quad (3)$$

where s is defined as the slip of the generator:

$$s = \frac{\omega_s - \omega_r}{\omega_s} \quad (4)$$

The Power Flow

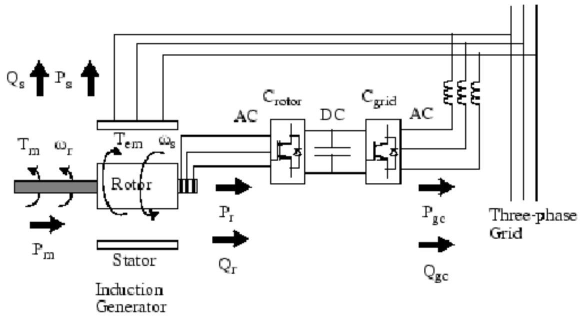

Fig.2. Control System of DFIG

Generally the absolute value of slip is much lower than 1 and, consequently, Pr is only a fraction of Ps. Since Tm is positive for power generation and since ωs is positive and constant for a constant frequency grid voltage, the sign of Pr is a function of the slip sign. Pr is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed).For super-synchronous speed operation, Pr is transmitted to DC bus capacitor and tends to rise the DC voltage. For sub-synchronous speed operation, Pr is taken out of DC bus capacitor and tends to decrease the DC voltage. C grid is used to generate or absorb the power Pgc in order to keep the DC voltage constant. In steady-state for a loss less AC/DC/AC converter Pgc is equal to Pr and the speed of the wind turbine is determined by the power Pr absorbed or generated by C rotor. The power control will be explained below. The phase-sequence of the AC voltage generated by C rotor is positive for sub-synchronous speed and negative for super-synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip [15, 16, 17].

III. REQUIREMENT FOR ACTIVE POWER CONTROL THROUGH DFIG

The need for continuous contribution to frequency control is achieve by compensating sudden change in active power demand by load side of grid. The quick fluctuations of the wind power are compensated by the system primary frequency control. If these fluctuations exceed the primary reserve it should be possible that the generation load balance could not be obtain. Furthermore if the wind generations on small scale differ from the forecasted values non spinning reserves could not be in time to compensate this discrepancy [5]. When needed the active power control capability of wind farm could improve the safe operation of the power system by controlling the generation of all wind turbines at a reduced level instead of stopping some of them.

According to the requirements presented in enterprise standard of SGCC (Q/GDW392-2009 Technical Rule for Connecting Wind farm into Power Grid)[6].Wind farm should possess the active power regulatory ability and control the active power output according to the dispatch unit of power system. It should rapidly control the active power output according to the dispatch unit of power system under the condition of power system emergency situations. Meanwhile, the wind farm should ensure the rapidity and reliability of the active power control system [7].

On the basis of requirements above we can conclude that to fulfill the active power control, the wind farm should be equipped with active power controller which could receive the signal from active remote dispatch units and keep the active power of wind farm tracing the signal.

A. Modeling of wind turbine

Wind turbine is first step energy conversion component of this system. It absorbs wind power by wind blades which convert wind power into rotational mechanical power for turbine of Doubly Fed Induction Generator. The wind turbine input power usually is [8]:

$$P_v = \frac{1}{2}\rho s_w v^3 \quad (5)$$

Where ρ is air density; s_w is wind blade swept area; *v* is wind speed. The output mechanical power of wind turbine is

$$Po = \frac{1}{2} c_p \rho s_w v^3 \quad (6)$$

Where c_p represent the wind turbine power conversion efficiency. It is function of the tip speed ratio λ and blade pitch angle β in a pitch controlled wind turbine.

$$\lambda = \frac{R.\Omega t}{v} \quad (7)$$

Where R is blade radius, Ωt is angular speed of the turbine. c_p can be describe as [9]

$$C(\beta,\lambda)=(0.5 - 0.0167(\beta-2))\left(\sin\frac{\Pi(\lambda+0.1)}{18.5-0.3(\beta-2)}\right) - 0.00184(\lambda-3)(\beta-2) \quad (8)$$

B. Modeling of DFIG

Proper controlling the output active power can be achieve by pitch control system and the rotor side converter of the DFIG based wind turbine vector control method, the three phase rotor quantities and stator quantities are modeled into two phase quantities one is along the direct axis and quadrature axis known as direct axis quantities and quadrature axis quantities respectively. Basically it contain some parts as Wind Turbine, Pitch Controller, Induction Generator, Drive train and a back to back converters known as rotor side converter if that converter connect to the rotor side and grid side converter if it connected to the grid side of the DFIG, these two converters are connect with each other with help of DC Link capacitor to provide energy at extreme conditions of operation. Two pulse generators are connected to provide pulse to the gate of connected power converter IGBTs. The pulse generating signals is provide by controller circuit which generate signal according to output of comparator of reference values and actual values of power system network according to the reference of direct axis and quadrature axis. The general block diagram for controlling power transfer by wind turbine is shown as bellow [10].

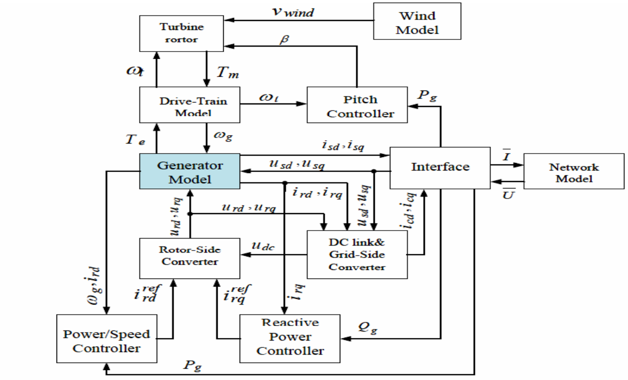

Fig.3. Block diagram representation of DFIG

The equation for stator and rotor voltage using three to two transformation method [11] are given bellow

$$V_{sd} = R_s i_{sd} + \frac{d\Phi sd}{dt} - \omega s \Phi sq \quad (9)$$

$$V_{sq} = R_s i_{sq} + \frac{d\Phi sq}{dt} + \omega s \Phi sd \quad (10)$$

$$V_{rd} = R_r i_{rd} + \frac{d\Phi rd}{dt} - (\omega s - \omega)\Phi rq \quad (11)$$

$$V_{sq} = R_r i_{rd} + \frac{d\Phi rd}{dt} + (\omega s - \omega)\Phi rd \quad (12)$$

Stator and rotor fluxes are as follows:

$$\Phi_{sd} = L_s i_{sd} + M i_{rd} \quad (13)$$

$$\Phi_{sq} = L_s i_{sq} + M i_{rq} \quad (14)$$

$$\Phi_{rd} = L_r i_{rd} + M i_{sd} \quad (15)$$

$$\Phi_{sd} = L_r i_{rq} + M i_{sq} \quad (16)$$

IV. CONTROLLING SYSTEM OF DFIG BASED WIND TURBINE

Two converters (RSC & GSC) connected in DFIG are use to control the operation of DFIG by controlled switching action of power switches connected in the network. The controlled signal is generated by PID controller connected in the network. The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor side converter or stator side converter in both super and sub-synchronous speed ranges. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes [12].

The phase sequence of the AC voltage generated by the rotor side converter is positive for sub synchronous speed and negative for super synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. The rotor side and the grid side converter have the capability of generating or absorbing reactive power or active power and could be used to control the reactive power and active power or the voltage and frequency at the grid terminals. The rotor side converter is used to control the wind turbine output powers and the voltage (reactive power) and frequency (active power) measured at the grid terminals. The grid side converter is used to regulate the voltage of the DC bus capacitor which supply power to the RSC and GSC at the extreme condition for DFIG operation ie. faults or transients conditions [13].

To control the active power flow in DFIG, rotor side converters are use. Hence in other worlds drop in frequency can be compensated by controlled operation of rotor side converter. The controlling technique apply for active power controlling of DFIG based wind farms makes operation of these wind farms somewhat similar to the conventional power plant in this reference. The reference active power (P_{ref}) obtain by power speed curve as shown in Fig.3.The refer value of active power (P_{ref}) grid is compare with actual value of active power (P_a) in power system and output of this comparison (P_{er}) is fed to the PID controller circuit which generate signal to give pulse generator to give gate signals for IGBTs or other power switches connected to the rotor side converters. Similarly IGBTs connected to the Grid Side Converter also controlled to give controlling over reactive power flow through DFIG.

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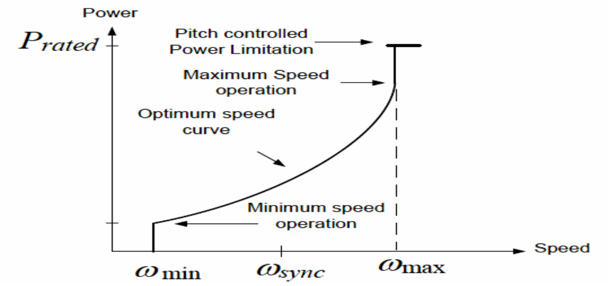

Fig.4. Power Speed characteristic

V. SIMULATION AND RESULT

The DFIG used 7500 VA 440V, nominal parameters are indicated in appendix. The response of doubly fed Induction Generator for rotor current in three phase quantities (i_a, i_b, i_c) is shown in Fig.5 and in dq refinance frame is shown in Fig.6 for per unit taking random speed of wind with mean of 12 m/m. The response of settling time is plotted at X axis and Magnitude of current (perunit) is plotted at Y axis.

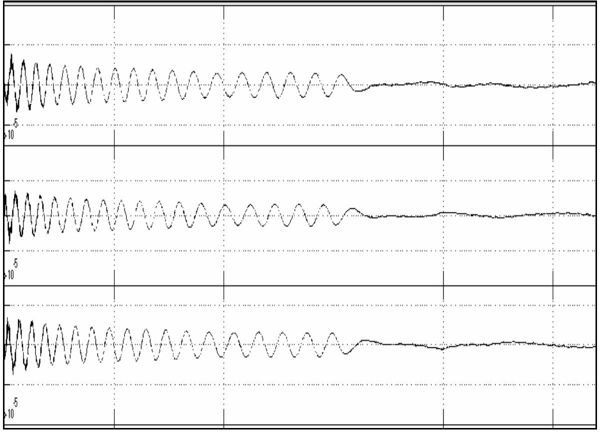

Fig.5. Wave form of three phase rotor current ($i_{a,}$ $i_{b,}$ i_c)

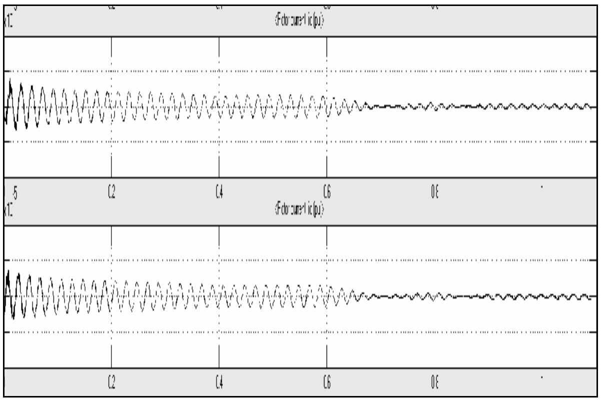

Fig.6. Wave form of three phase rotor current in dq refinance frame (i_d,i_q) X-axis -Time, Y-axis - Magnitude of current (per unit).

As the rotor current shown in above figures is injected to rotor circuit of the DFIG and thus the flux generated by rotor circuit is controllable as the command provide to rotor side converter by controller circuit. Similarly the three phase stator current ($I_{a,}I_{b,}I_c$) is shown in Fig.7 in per unit.

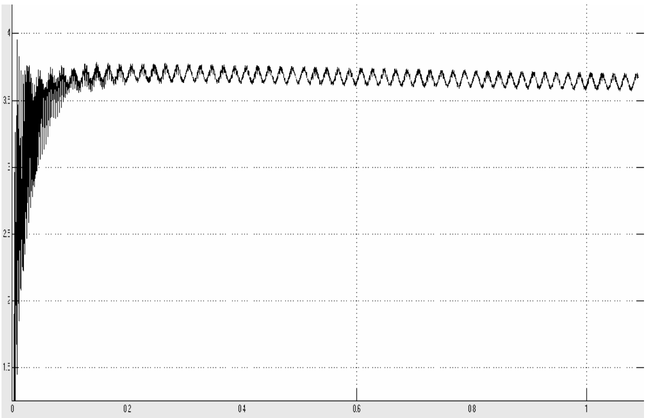

Fig.7. Response of Electromagnetic Torque (Te), X-axis - Time, Y-axis -Torque (per unit)

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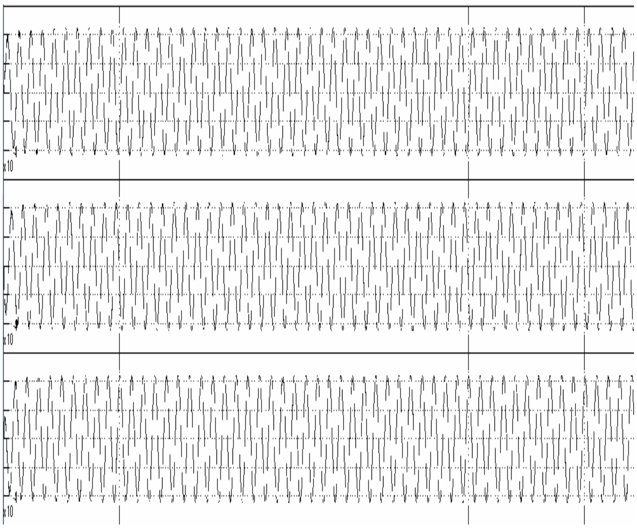

Fig.8. Waveform of three phase stator current (I_a,I_b,I_c) , X-axis Time Y-axis Magnitude of current

The responses of three phase rotor current become stable, the settling time is also reduced by using PID controller and the oscillations are also damped out. The electromagnetic torque is also become constant after a specific marginal time.

VI. CONCLUSION

As the different figures of responses obtained above by simulation using MATLAB software shows stator circuit three phase currents ($I_{a,}I_{b,}I_c$) are ac and thus the flux produce by these currents will be rotating so by the reaction of rotor circuit controlled flux (which is controlled due to injecting current controlling through rotor side converter) and rotating flux of stator circuit operation of DFIG depend, so active power flow through DFIG is also controlled as the waveform shows the three phase rotor current goes to stable after marginal time of disturbance occur in the power system and thus compensation for frequency through DFIG.

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VII. APPENDIX

Table 1: Parameters used in Simulation of DFIG

Sn.	Symbol	Parameter	Value
1.	ω_s	Synchronous speed	1 pu
2.	L_m	Mutual inductance	0.5 pu
3.	R_s	Stator Resistance	0.7 pu
4.	R_r	Rotor Resistance	0.8 pu
5.	L_s	Stator inductance	0.6pu
6.	L_r	Rotor inductance	0.4 pu
7.	P	No. of Poles Pairs	2
8.	J	Inertia constant	0.06
9.	ω_w	Mean wind speed	12 m/min
10.	θ_p	Pitch Angle	15.7degree

Nomenclature

DFIG : Doubly fed induction generator
PWM : Pulse width modulation
β : Blade pitch angle
λ : Tip Speed Ratio
C_p : Turbine power conversion efficiency
P_o : Output mechanical power of wind turbine
ρ : Air density
v : Wind speed
R_s : Resistance of Stator circuit
R_r : Resistance of rotor circuit
i_{sq} : Qudeture axis current of stator
i_{sd} : Direct axis current of stator
i_{rq} : Quadeture axis current of rotor circuit
i_{rd} : Direct axis current of rotor circuit
L_s : Inductance of stator
L_r : Inductance of rotor
M : Mutual inductance of rotor and stator
Ǿ$_{sq}$: Quadeture axis flux of stator circuit
Ǿ$_{sd}$: Direct axis flux of rotor circuit

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