Modeling and Simulation of DFIG Against Disturbance Condition

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***Abstract*—This paper presents the detailed modeling and simulation of doubly-fed induction generator (DFIG) for variable speed operation whose stator circuit connected directly to the stiff grid and rotor circuit is connected through cascade coupled AC-DC DC-DC DC-AC (AC/DC/AC) power electronic circuits. With the help of these power electronic converters, we have implemented a fully functional Rotor side controller (RSC) and Grid side converter (GSC) by which we can control output power and DC-link voltage regulation of the DFIG. Doubly fed induction generator dynamic behavior is modeled in the Stator Flux Orientation (SFO) that is related to the RSC and GSC control strategies. Both active and reactive powers delivered from DFIG stator to the grid are separately controlled by RSC by controlling rotor currents, where GSC controls grid side currents to maintain proper DC-link voltage. The whole operational scheme is realized based on Conventional PI Controller based on SFO Vector control, which permits us to operate DFIG in super-synchronous mode. This method not only enhances the efficiency of DFIG but also makes it operates the machine at Unity power factor. If there are is a short time disturbance it absorbs reactive from grid stabilizes itself and operates with stability without losing synchronism and no dangerous speeds variations. The proposed control scheme is successfully simulated and observed for variations under small disturbance and during wind speed variations. The effectiveness of the proposed method is verified by developing the simulation model of 1.5 MW DFIG connected to a 120kV bus in MATLAB-SIMULINK-R2014b.**

Keywords*— *Doubly-fed Induction generator (DFIG), Rotor Side Converter (RSC), Grid Side Converter (GSC), Stator flux Oriented Control (SFO).

I. INTRODUCTION

Now-a-day's pollution ramping-up unpredictably, so the world is much concerned about the emission of greenhouse gases like CO_2. Everyone is eagerly searching for Clean energy sources to minimize global warming. So, people are looking at pollution-free renewable energy sources to save our mother earth. wind power playing a key role among the different non-conventional energy sources. From the past few decades, there is remarkable growth in wind turbine size and quantity of power generated. Wind turbine becomes larger and larger from 50kW to 7mW with respect to time [1]. Power generation capacity in India through has significantly increased in during recent years. Installed capacity of wind power in india upto 2020 February is 37GW and it is the fourth largest capacity in the world.

The overall system of Wind Energy Conversion System (WECS) consisting of electro-mechanical and aerodynamic components that convert wind energy to electrical energy. The major problem with this wind energy system is that the mechanical energy produced from it cannot be maintained constant. So, there are two types i.e. fixed speed and variable speed wind turbines. Previously Squirrel cage induction motor coupled fixed speed turbine is widely used. But with this outdated technology, we cannot extract maximum efficiency. Hence, we moved towards the Advanced variable speed era. These variable-speed turbines have not only improved efficiency but also wides operating speed ranges with reduced mechanical stress. Horizontal axis 3-blade variable speed wind turbines are the most common and popular configuration that widely used throughout the world [2,3]. These turbines coupled to Doubly fed induction generators have a lot of advantages compared to Direct drive synchronous generators. Hence DFIGs Widely used in wind power generation.

II. WORKING OF DFIG

Doubly fed induction generator is a standard wound rotor induction machine whose stator is directly connected to the grid system, and the connection of the rotor to the grid is happened via a back-to-back pulse width modulation (PWM) converter. Simplified diagram of a DFIG based WECS is shown in Figure 1. The wind rotates the Aerodynamic blades, which is coupled to DFIG through a gearbox. Gearbox steps up the speed to more than synchronous mode to operate the machine in super-synchronous mode. The stator is connected to the grid through a filter and a three-winding transformer. The Rotor side is accessed through slip rings and connected to the grid through SPWM power electronic converters.

If we connect a wind turbine to the alternator, the output frequency cannot be maintained constant as rotational input speed is not constant. But with DFIG we can produce a constant frequency with the help of controllers. In an alternator, the rotor has a constant or stationary magnetic field which only rotates with rotor physical moment. But in DFIG Rotor has a rotating magnetic field which rotates in opposite direction to rotor rotation such that the relative speed with stator conductors always remains constant with respect to rotor magnetic field and it is irrespective of rotor physical rotational speed which is supplied by wind turbine whose source is the wind which is not constant with respect to time. Primarily we have to design a controller that adjusts the frequency of rotor currents with respect to variations in mechanical speed input to the machine.

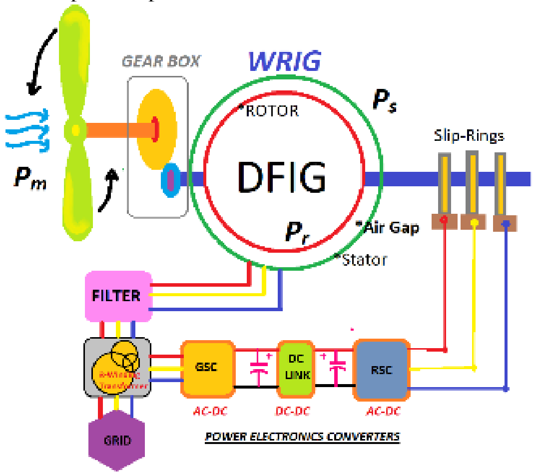

Fig. 1. Operation of DFIG connected to the Grid.

So, we need to change to frequency of current supplied to rotor, hence we can go for either cycloconverter or cascaded set of controlled rectifier and inverter can be used. But to control Active power, Reactive power, and DC link voltage we need to control other parameters also which is not possible with cycloconverter[5,6]. Hence, 2 four-quadrant Insulated Gate Bipolar Transistor (IGBT) PWM converter back-to-back of a DC -link capacitor is used[4,9]. Grid side converter converts grid side AC power to DC and by controlling to the Stator currents, GSC can able to control DC link voltage regulation makes it independent of magnitude and direction of rotor power, and reactive power exchanged with the electrical grid. DC-DC Converter is used to shift the voltage level to the required range. Rotor side converter which again converts the DC voltage to AC at a required frequency such that output frequency is constant. RSC controls the Active and Reactive power by controlling the Rotor currents.

III. MODELING OF DFIG AND OVERALL CONTROL SCHEME

The simulation diagram shown in figure 2 is developed based on the schematic shown in figure 1

The model consists of a wound rotor induction generator whose rotor terminals are accessible outside the machine through slip rings which are connected again to the grid through RSC and GSC. The Variable wind input[3] is given to the machine by constructing a small system which is given bellow whose wind speed is continuously changing

The single line diagram of DFIG demonstrated in figure 4, have two SPWM converters i.e. RSC and GSC. The control of DFIG can be attained by control the triggering to these power electronic converters[11]. The rotor currents transformed to dq-reference frame for 3 phase abc form i.e. I_{abcr} to id_{qr} (i_{dr} and i_{qr}). The obtained id_{qr} compared with the sensed values of rotor currents to generate voltage control vd_{qr}*(v_{dr}* and v_{qr}*) by using the PI controller. The dq-components of v_{dqr} * are sampled and transformed to three-phase rotor voltage (V_{abcr})[11]. These are used by the two-level SPWM converter to generate the six IGBT gate control signals to drive the RSC

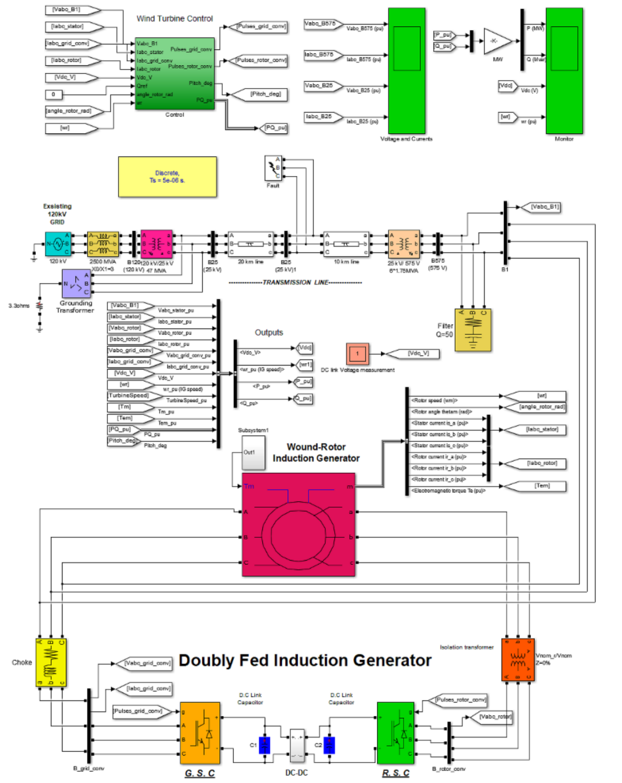

Fig. 2. Simulation diagram DFIG.

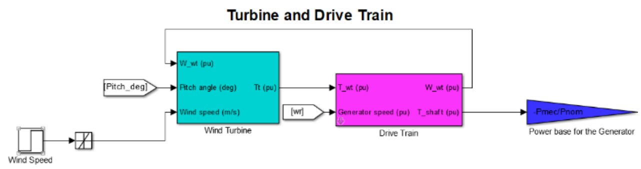

Fig. 3. Block Diagram for Turbine Drive Train.

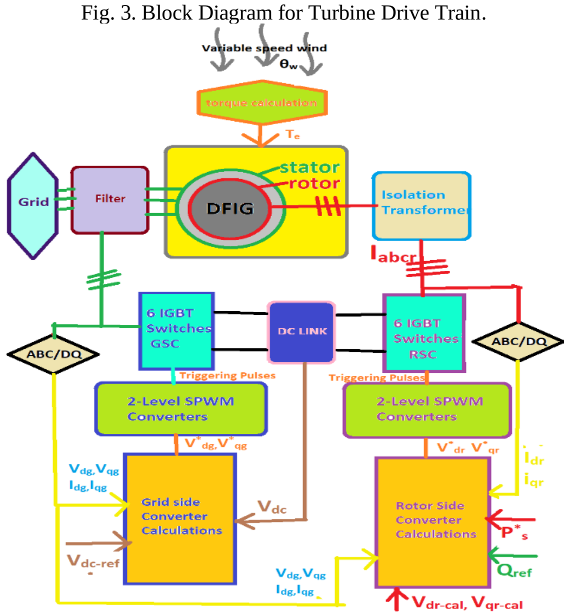

Fig. 4. the vector control[7] scheme for the DFIG wind turbine.

The same operation is possible on GSC with the suitable transformation of abc to dq and dq to abc for maintaining the DC voltage constant [8]. The grid voltage (v_{dg} *,v_{qg} *) and rotor voltage (v_{dr} *,v_{qr} *) are required to operate

DFIG at the reference active power set point (Ps *), reactive power setpoint (Qref) and DC-link voltage set point (V_{dc}ref) all this is obtained through a summation of the term obtained by PI controller and compensation term.

v_{drcal} and v_{qrcal} are the compensation term are required to minimize cross-coupling between current control loops and voltage control loops on RSC.

The block diagram for the rotor side voltage control in dq-reference frame is shown in Figure 5.

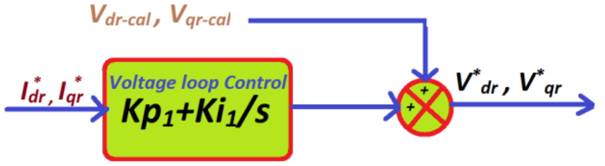

Fig. 5. PI controller tuner for RSC voltage control.

The mathematical equations for the rotor side voltage control in dq-reference frame are given as

$V_{dr}^* = [K_{p1} + (K_{i1}/s)] (i_{dr}^*)$ (1)

$V_{qr}^* = [K_{p1} + (K_{i1}/s)] (i_{qr}^*)$ (2)

The v_{drcal} and v_{qrcal} calculated by

$V_{drcal} = -s\omega_s \sigma L_r i_{qr}$ (3)

$V_{qrcal} = s\omega_s (\sigma L_r i_{dr} + (L_m^2 L_s)$ (4)

Grid side voltage control block diagram in dq reference frame is shown in Figure 6.

Fig. 6. PI controller tuner for GSC voltage control.

The mathematical equations for the grid side voltage control in dq-reference frame are given as

$V_{dg}^* = [K_{p2} + (K_{i2}/s)] (i_{dg}^*)$ (5)

$V_{qg}^* = [K_{p2} + (K_{i2}/s)] (i_{qg}^*)$ (6)

Where i^*_{dr}, i^*_{qr}, i^*_{dg}, and i^*_{qg} are the error signal of dq-components of the rotor and grid currents K_{p1}, k_{i1}, k_{p2}, and k_{i2} are the propositional and integral constants of the rotor and grid side current regulator, respectively.

IV. SIMULATION RESULTS AND EXPLANATION

This Simulink model of DFIG is developed based on the following specifications. 1.5MW wind turbine connected to 575V DFIG operating at 60HZ frequency and disturbance created within the range of 0.25 to 0.3 sec

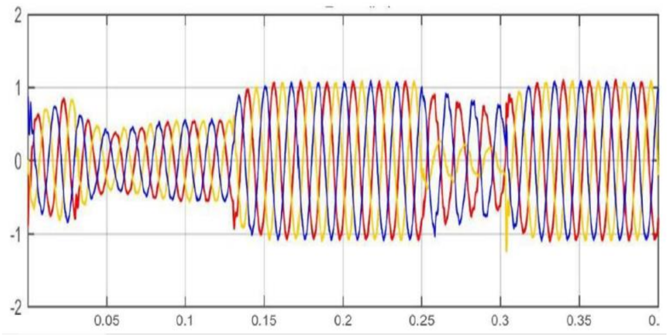

Fig. 7. Variations of three-phase voltages {Vabc B_575 (p.u.)} of DFIG with respect to time

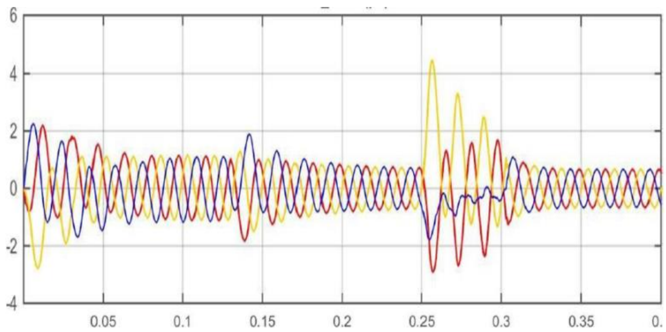

Fig. 8. Variations of three-phase currents {Iabc B_575 (p.u.)} of DFIG with respect to time.

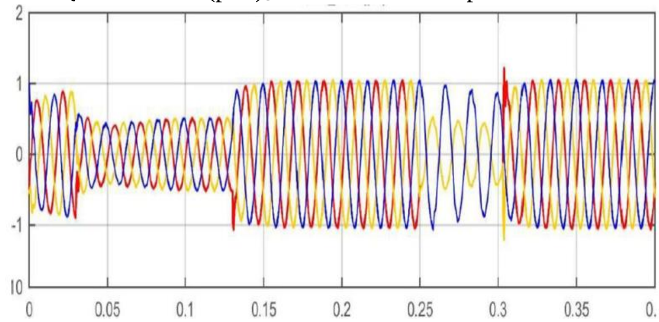

Fig. 9. Variations of three-phase Voltages {Vabc B_25kv(p.u.)}of the grid with respect to time.

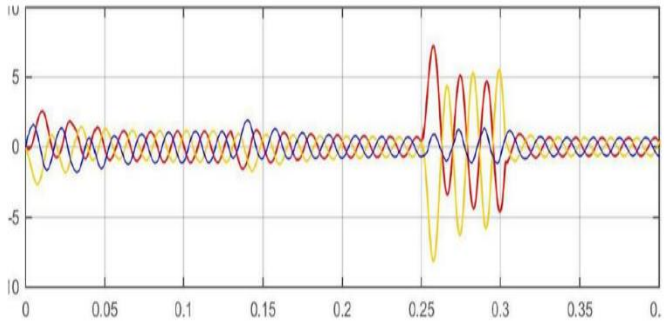

Fig. 10. Variations of three-phase currents {Iabc B_25kv (p.u.) of the Grid with respect to time.

The above four figures (7,8,9,10) show the variations of output currents and voltages from the DFIG with respect to time. Up to the time 0.175sec the system undergo transient state and the proposed PI control strategies are confirmed with better power control, and accurate regulation. Constant 3phase voltage obtained and the output current depends on wind input.

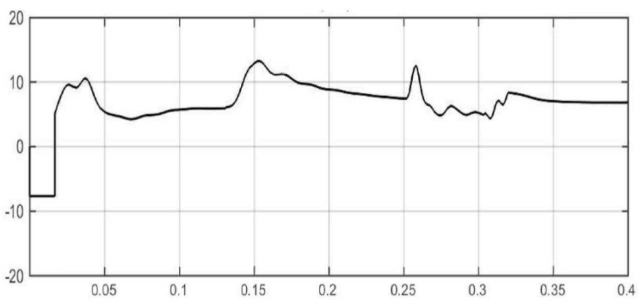

Fig. 11. Variations of Active power of DFIG with respect to time.

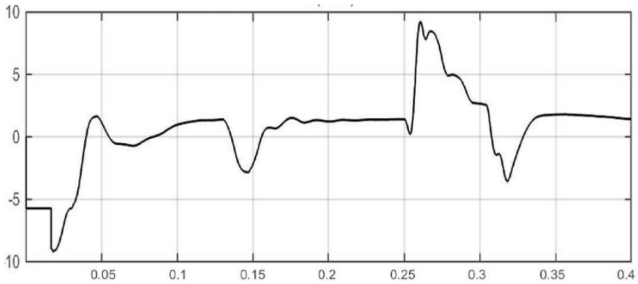

Fig. 12. Variations of reactive power of DFIG with respect to time.

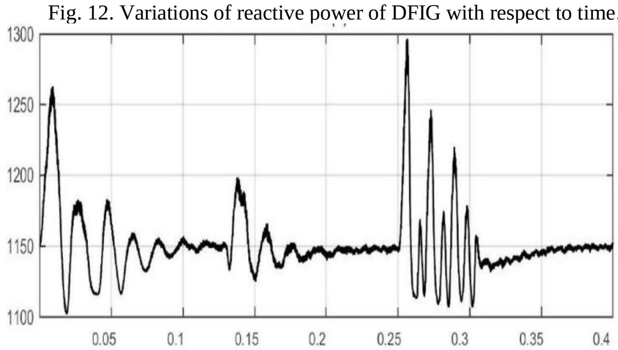

Fig. 13. Variations of DC link voltage of DFIG controlled by GSC with respect to time.

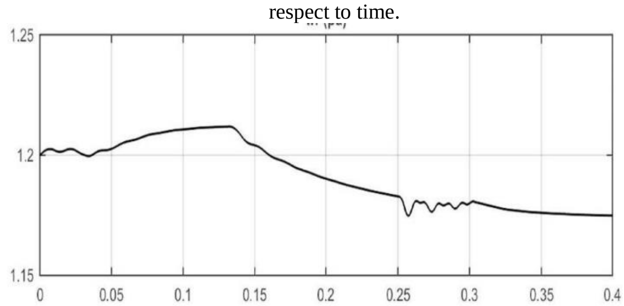

Fig. 14. Variations of wind speed in p.u. with respect to time.

The change in wind speed waveform in the range of 8 to 14 m/s is shown in Figure 14. The change in mechanical torque (Tm) w.r.t waveform in Per Unit (pu) in the range up to 2 pu is as shown in Figure 15. The variations of DC-link voltage which is almost maintained constant by Grid side controller and that is shown in figure 13. Every induction generator must start as a motor. To obtain the generating action it must run in super synchronous mode i.e. running more than synchronous speed by an external prime mover. In Figure 11 initially, the active power is negative because it is running as the motor. after that, we shifted operation to the super synchronous mode where it started delivering active power. In figure 12 as initially runs as motor, it absorbs reactive power from the grid. Later RSC controls the reactive power and makes it nearly zero as our reference value is zero. During the disturbance only it is absorbing reactive power from the grid to stabilize but later on due to controller action, it again becomes zero so that the system runs at the Unity power factor. Even the effect of disturbance is high on DC link voltage, GSC gradually brings the voltage to 1150 volts and mechanical variation of speed is very low. Hence the mechanical system is safe.

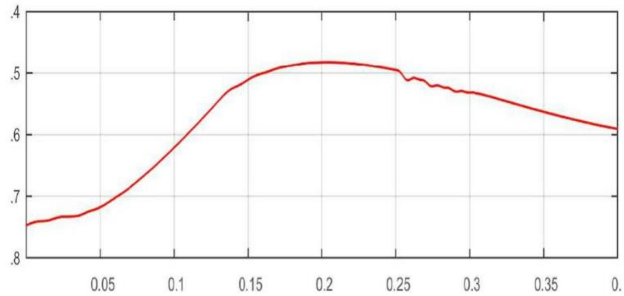

Fig. 15. Variations of Mechanical input Torque with respect to time

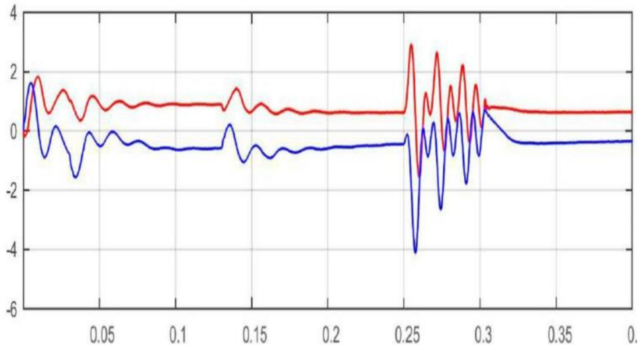

Fig. 16. The d-axis and q-axis of the rotor currents with respect to time.

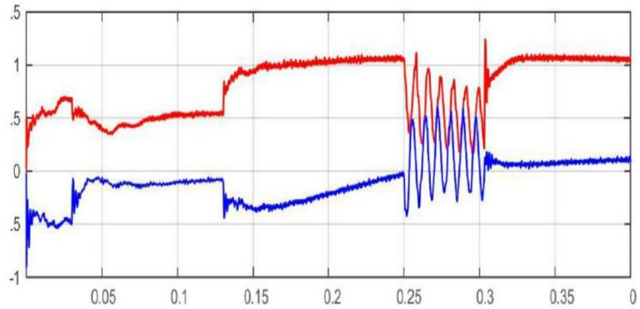

Fig. 17. The d-axis and q-axis of the Stator voltage with respect to time.

V. CONCLUSION

In this paper, the designing, modeling, simulating, and analysing the DFIG works for variable speed wind turbine is implemented successfully and results are satisfactory. The system is simulated by operating the machine at super synchronous mode. Operation is considered during variable speed wind input and during a small disturbance. DC link voltage is almost maintained constant as GSC implemented successfully. Reactive power drawn during normal conditions is almost zero. Hence it is operating at unity power factor. It is possible by proper implementation of RSC and controlling rotor currents. So, finally, it is observed from the results of the simulation that the dynamic behavior of DFIG has been significantly controlled by controlling voltage and current control loops over a wide range of wind speed variations.

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