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Grid Connected Doubly Fed Induction Generator for Wind Power Applications

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***Abstract*—This paper describes about grid connected doubly fed induction generator that can be used for wind power applications. The sources of most of our power, natural gas and coal, produce large quantities of greenhouse gases, but wind energy is pollution free and negligible greenhouse Gases. Among all the available technologies for wind energy conversion systems (WECS), the doubly fed induction generator (DFIG) is most acceptable one, because it has got advantages like efficient power capture due to the variable speed operation, improved system efficiency and, most importantly, reduced converter rating. The main problem which is found in wind energy conversion system (WECS) is the power fluctuations in the grid due to varying nature and uncertainty of wind speed. For reducing these power fluctuations a topology of doubly fed induction generator with battery energy storage system has explained in this paper. The system mainly consist of a doubly fed induction generator, rotor side converter and a grid side converter. Control of these converters is done for controlling the power in the grid constant irrespective of the wind speed. To verify the validity of the discussed system for wind power applications Matlab/Simulink Software is applied and the results are discussed in this paper.**

***Keywords*—Wind energy conversion systems(WECS), Doubly Fed Induction Generator(DFIG), AC/DC/AC Converter.**

I. INTRODUCTION

Wind energy offers many advantages, which explains why it's one of the fastest-growing energy sources in the world. Research efforts are aimed at addressing the challenges to greater use of wind energy.

Now-a-days global warming is the most burning issue found in many of the climate summit. Many researchers, scientists are working their own relevant areas to reduce the effective mitigation of climate effect due to global warming by using different techniques. Change will require deep reductions in greenhouse gas emissions. The electricity system is viewed as being easier to transfer to low-carbon energy sources than more challenging sectors of the economy such as surface and air transport and domestic heating. Hence the use of cost-effective and reliable low carbon electricity generation sources is becoming an important objective of energy policy in many countries. This is only possible by utilizing renewable sources as the key sources for the generation of electricity. Main renewable energy sources are solar, wind, geothermal etc. Wind energy is one of the most promising form of renewable source of energy. Wind energy is a clean, renewable form of energy that uses virtually no water and pumps billions of dollars into our economy every year. Since 2008, the U.S. wind industry has generated more than 100 billion in private investment. Furthermore, wind energy is a drought-resistant cash crop in many parts of the country, providing economic investment to rural communities through lease payments to landowners. Wind energy helps avoid a variety of environmental impacts due to its low impact emitting zero greenhouse gas emissions or conventional pollutants and consuming virtually no water. The main components of a wind energy conversion system are a turbine rotor, a gearbox, a generator, a power electronic system, and a transformer for grid connection. Wind turbines capture the power from wind by means of turbine blades and convert it to mechanical power. It is important to be able to control and limit the converted mechanical power during higher wind speeds. It can be seen that the power may be smoothly limited by rotating the blades either by pitch or active stall control while the power from a stall-controlled turbine shows a small overshoot and a lower power output for higher wind speed. The common way to convert the low-speed, high-torque mechanical power to electrical power is using a gearbox and a generator with standard speed. The gearbox adapts the low speed of the turbine rotor to the high speed of the generator, though the gearbox may not be necessary for multi pole generator systems. The generator converts the mechanical power into electrical power, which being fed into a grid possibly through power electronic converters, and a transformer with circuit breakers and electricity meters. The two most common types of electrical

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machines used in wind turbines are induction generators and synchronous generators.

This paper is organized as follows. The variable speed system using doubly fed induction generator (DFIG) is briefly reviewed in section II. Section III and IV discuss the dynamic modeling of DFIG in terms of D-Q winding and mathematical modeling in synchronous reference frame. Section V describes the converter control scheme. Section VI discusses about the simulation study and results. Finally conclusion is given in section VII.

II. VARIABLE SPEED SYSTEM USING DOUBLYFED INDUCTION GENERATOR (DFIG)

Variable speed wind energy conversion system using a wound rotor induction machine is explained in the following fig. 1. In this system, the rotor circuit is capable of bidirectional.

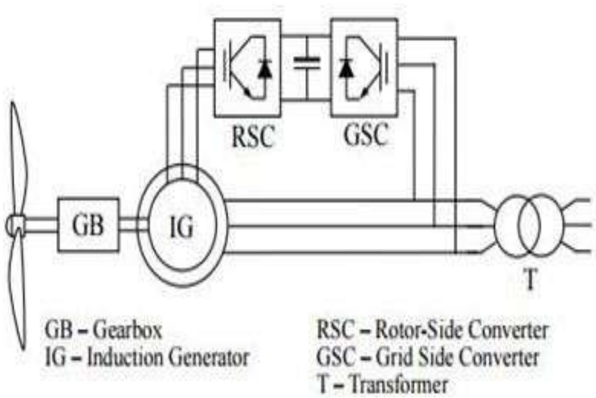

Fig. 1: Variable speed system using doubly fed induction machine (DFIG)

power flow allowing sub synchronous and super synchronous modes of operation[1]-[5]. During sub synchronous generation, the rotor circuit absorbs a fraction of the power generated by the stator, whereas under a super synchronous condition, both the stator and the rotor feed in power to the grid. Thus if the stator generates 1 PU at a slip of s PU the total generated output is (1+s) PU. The stator of a doubly fed induction generator (DFIG) is connected to the grid directly, while the rotor of the generator is connected to the grid by electronic converters through slip rings, as shown in Fig. 2.The generator can deliver energy to the grid at both super synchronous and sub synchronous speeds. The slip is varied with the power flowing through the power electronic circuit. The advantage is that only a part of the power production is fed through the power electronic converter[6]-[9]. Hence, the nominal power of the power electronic converter system can be less than the nominal power of the wind turbine. In general, the nominal power of the converter may be about 30% of the wind turbine power, enabling a rotor speed variation in the range of about 30% of the nominal speed. By controlling the active power of the converter, it is possible to vary the rotational speed of the generator, and thus the speed of the rotor of the wind turbine. The DFIG system also enables the application of special operation strategies and provides the high-quality power to the grid. The control system of a variable-speed wind turbine with DFIG mainly functions to:

- Adjust the power drawn from the wind turbine in order to track the optimum operation point.
- Limit the power in the case of high wind speeds.
- Regulate the reactive power exchanged between the wind turbine and the grid.

III. DYNAMIC MODELING OF DFIG IN TERMS OFD-Q WINDING

The general model for wound rotor induction machine is similar to any fixed-speed induction generator as follows

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$$V_{qs} = p\lambda_{qs} + \omega\lambda_{ds} + r_s I_{qs} \quad (1)$$

$$V_{ds} = p\lambda_{ds} + \omega\lambda_{qs} + r_s I_{ds} \quad (2)$$

Rotor voltage equations:

$$V_{qr} = p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} + r_r I_{qr} \quad (3)$$

$$V_{dr} = p\lambda_{dr} + (\omega - \omega_r)\lambda_{qr} + r_r I_{dr} \quad (4)$$

2.Power equations:

$$P_s = \frac{3}{2}(V_{ds} I_{ds} + V_{qs} I_{qs}) \quad (5)$$

$$Q_s = \frac{3}{2}(V_{qs} I_{ds} - V_{ds} I_{ds}) \quad (6)$$

3.Torque equations:

$$T = \frac{3}{4}P(\lambda_{ds} I_{qs} - \lambda_{qs} I_{ds}) \quad (7)$$

4.Flux linkage equations:
Stator flux equations

$$\lambda_{qs} = (L_{ls} + L_m)i_{qs} + L_m i_{qr} \quad (8)$$

$$\lambda_{ds} = (L_{ls} + L_m)i_{ds} + L_m i_{dr} \quad (9)$$

Rotor flux equations

$$\lambda_{qr} = (L_{lr} + L_m)i_{qr} + L_m i_{qs} \quad (10)$$

$$\lambda_{dr} = (L_{lr} + L_m)i_{dr} + L_m i_{ds} \quad (11)$$

IV. MATHEMATICAL MODELING IN SYNCHRONOUS REFERENCE FRAME

Efficient analysis of behavior of any complex system, under different operating conditions and control strategies becomes easier with mathematical modeling. For DFIG, model is derived in terms of direct and quadrature axes quantities.

$$v_{qds} = r_s i_{qds} + j\omega_e \psi_{qds} + \frac{d}{dt}\psi_{qds} \quad (12)$$

$$v_{qdr} = r_s i_{qdr} + j\omega_e \psi_{qdr} + \frac{d}{dt}\psi_{qdr} \quad (13)$$

$$\psi_{qds} = L_s i_{qds} + L_m i_{qdr} \quad (14)$$

$$\psi_{qdr} = L_r i_{qdr} + L_m i_{qds} \quad (15)$$

$$T_e = \frac{3}{2}\frac{P}{2} R_e(j\psi_{qds}(i_{qds})^*) \quad (16)$$

$$= \frac{3}{2}\frac{P}{2} R_e(j\psi_{qdr}(i_{qdr})^*) \quad (17)$$

Stator and rotor inductances are defined as

$$L_s = L_{ls} + L_m \quad (18)$$

$$L_r = L_{lr} + L_m \quad (19)$$

The torque equation can be resolved in reference d-q leading to

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) = \frac{3}{2}\frac{P}{2}(\psi_{dr} i_{qr} - \psi_{qr} i_{dr}) \quad (20)$$

The stator side active and reactive powers are given as

$$P_s = \frac{3}{2} Re(v_{qds}(i_{qds})^*) \quad (21)$$

$$= \frac{3}{2}(v_{qs} i_{qs} + v_{ds} i_{ds}) \quad (22)$$

$$Q_s = \frac{3}{2} I_m(v_{qds}(i_{qds})^*) = \frac{3}{2}(v_{qs} i_{ds} - v_{ds} i_{qs}) \quad (23)$$

$$P_s = \frac{3}{2}[\frac{1}{L_s}(v_{qs}\psi_{qs} - v_{ds}\psi_{ds}) - \frac{L_m}{L_s}(v_{qs} i_{qr} - v_{ds} i_{dr})] \quad (24)$$

$$Q_s = \frac{3}{2}[\frac{1}{L_s}(v_{qs}\psi_{qs} + v_{ds}\psi_{ds}) - \frac{L_m}{L_s}(v_{qs} i_{dr} - v_{ds} i_{qr})] \quad (25)$$

The magnitudes of stator currents govern the active and reactive powers of stator, and these currents depend on the rotor currents. Thus the active and reactive powers can be controlled by appropriately controlling the rotor currents (iqrand idr) in WECS.

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V. CONTROL STRATEGY OF DFIG

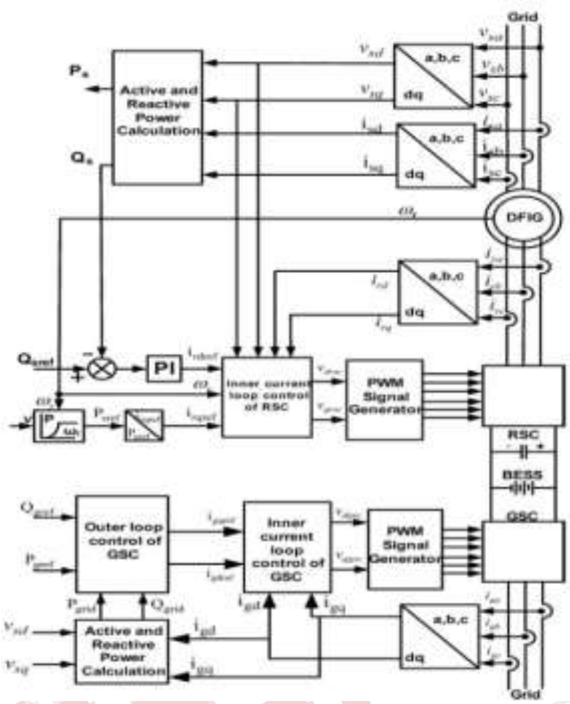

Fig. 2: Control of DFIG with RSC and GSC

The control strategy of the rotor side converter (RSC) and grid side converter (GSC) consists of an active and reactive power controlling outer loop and the current control inner loop. The unique control feature of the DFIG is that simultaneous and decoupled regulations can be done for active variables such as speed, active power, or torque and reactive variables such as voltage, reactive power, or power factor[10]-[12]. The line side controller has to control the active power supplied to the grid, Control of the reactive power between inverter and grid in order to satisfy someimposed reference, Control of the DC link voltage. Use of a PWM control method is used to reduce the current harmonic distortion. The energy stored in the DC link capacitor is proportional to the square of the DC voltage value. Therefore use of the voltage squares linearizes the system improving the use of a PI controller. The generator side controller has to control the induction generator speed to impose the generated power. For an optimal use of the wind power, it is useful to drive the generator with a variable speed. This mode can be accomplished by a superposed speed controller that determines the power delivered, Psref . The voltage rating of the generator side converter limits the maximum speed . RSC controls the rotor power flow in accordance with the available wind power. The reactive power in the rotor circuit is being controlled thus. Use of a PWM control method reduces thecurrent harmonic distortion here also.

The grid power is regulated to be a fixed value (determined by the average power as calculated earlier) and this is given as the reference active power. This is then compared with the actual grid power at any instant and the error is processed using a proportional-integral (PI) controller to generate the axis component of the reference grid current. For the reactive power outer-loop control of the GSC, the controlled variable can be the stator reactive power. When it is controlled, the reactive powerset point can be obtained in different ways depending on the power sharing strategy with the GSC. The d and q components of the reference grid currents to be given to the PWM controller of the GSC are obtained from the reference active and reactive powers components. The reference d-axis grid current is chosen according to the reactive power sharing between the stator and the GSC, and it can be chosen to be zero, for a unity power factor operation. These reference currents are then compared with the sensed grid side currents and the obtained error signal is processed with a PI controller to generate the control voltages for the PWM generator on the grid side.

B) Control of RSC

The RSC is a controller for the machine and therefore the active and reactive power outer loops are chosen to extract the maximum power from the wind and to maintain a unity power operation of the stator. The active power set point can be obtained from the instantaneous value of the rotor speed and the rotor current irq is controlled in the stator flux-oriented reference frame to obtain the desired active power according to the optimum torque speed characteristics. The set point for the reactive power can be calculated from the active power set point and a desired power factor. In the stator flux-oriented reference frame, the d -axis rotor current is used to control the required reference reactive power (Qref). The reference rotor currents ie.d and q components respectively are generated

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from the reference active and reactive power set. These reference values of rotor currents are compared with the sensed values of rotor currents. then the obtained error signal is processed with a PI controller to generate the control voltages for the PWM generator on the rotor side to produce pulses.

VI. SIMULATION STUDY

MATLAB model of the doubly fed induction generator of 3.7kW, 415V, 50Hz is developed. MATLAB simulation model is as shown in the figure below.

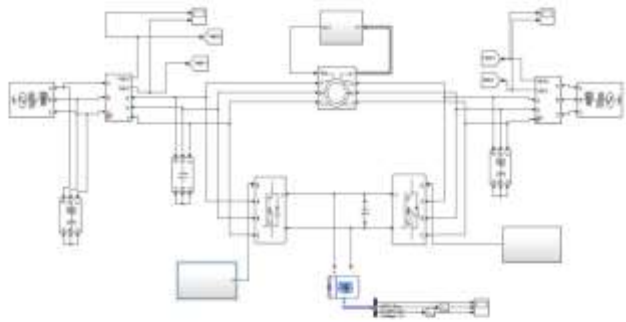

Fig. 3: MATLAB simulation model of DFIG

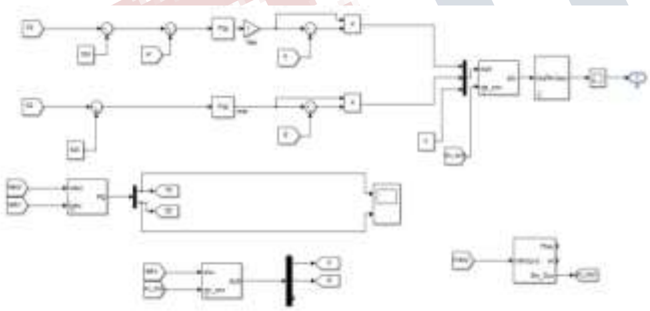

Fig. 4: Control of GSC

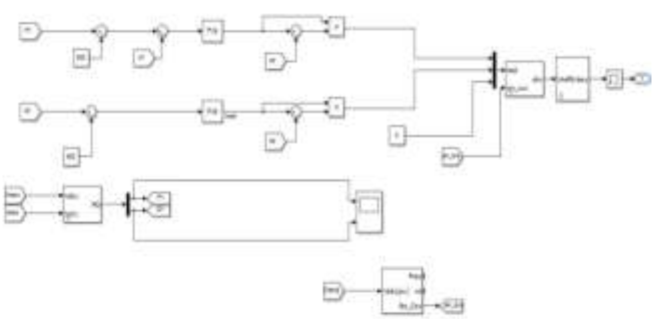

Fig. 5: Control of RSC

The doubly fed induction generator has simulated in MAT- LAB. Obtained waveforms are shown above. Fig.6 to Fig. 10 demonstrate the performance under super synchronous speed. Very similar results were obtained for sub synchronous speed also. The machine is working in syncronous mode of operation corresponding to varying wind speed. A purticular amount of active power is generated and given to the grid. A DC link voltage of around 1200 was observed as in Fig.7 and rotor speed was also regulated irrespective of wind speed as shownin Fig.10.

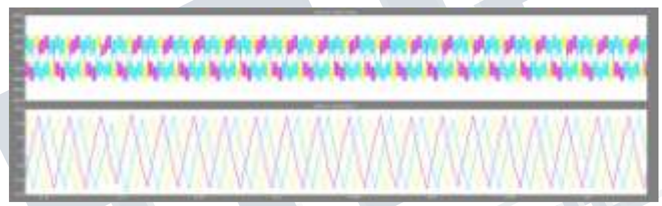

Fig. 6: stator side voltage and current

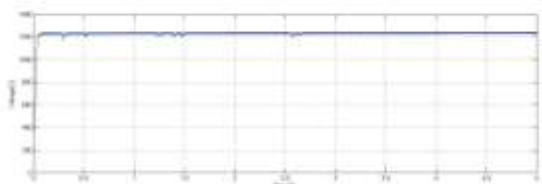

Fig. 7: DC link voltage

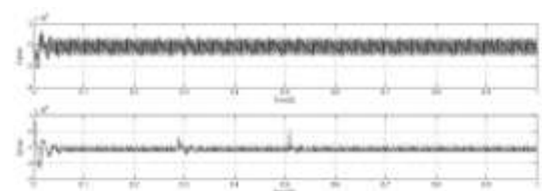

Fig. 8: Real and reactive power at grid

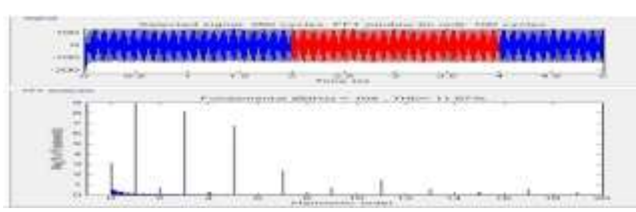

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Fig. 9: THD analysis of stator current

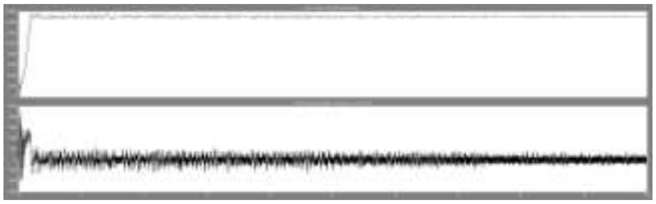

Fig. 10: Rotor Speed and Electromagnetic Torque

CONCLUSSION

This paper mainlydemonstrates DFIG for wind energy conversion systems. Configuration of DFIG-based WECS with a DClink capacitor and BESS has been discussed with a control strategy to maintain the grid power constant. A simulation study has been carried out to verify the performance. It has been observed that DFIG based WECS demonstratessatisfactory performance under different wind speed conditions.

The power was found to be constant for super synchronous speed and sub synchronous speed. THD of stator current was obtained as 11.67%.

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