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Simulation Based Study of Doubly Fed Induction Generators for Wind Electric Generation Using Matlab/Simulink

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Abstract: - The wind power plants continue its ever increasing penetration in the power production will be comparable to or even larger than the conventional power generation. Development in the Wind Energy segment has been steady over the 30 years period. In the initial years, the highest rating of wind energy turbine was 50 kW. Today it has touched about 3 MW and many companies are working round the clock to have one single unit delivering 5 MW. Doubly Fed Induction Generators are used widely for wind electric generation due to a range of advantages offered by it. The working principle, advantages of DFIG is discussed as opportunities and challenges arise in the Indian market.

Keywords: **- Doubly Fed Induction Generator (DFIG), Power Electronic Converters (PEC).**

I. INTRODUCTION

There has been a rapid increase in wind turbine connection to distribution and transmission networks in the recent years, and the increased penetration makes the power network more dependent on, and susceptible to, the wind energy production. Wind energy dominates India's renewable energy industry, accounting for 70% of installed capacity (14 GW) [1].In this paper an overview on the principle of working of DFIG used in wind farms and their advantages in integration with the power system are presented.

This paper is organized in six sections. Section 2 shows the penetration figures of wind power in Indian power industry. Then, in Section 3 a brief outline of common wind generation technologies is given and the technological advancements in wind power are presented. In Section 4 the working principle of DFIG is discussed. Simulation results the DFIG are presented in Section 5. Finally, in section 6 the paper conclusions are presented.

II. THE WIND POWER DEVELOPMENT

At present wind power is the fastest growing power generation technology in India and it accounts for around 70% of total grid-interactive renewable capacity in the country. From installed capacity of 41 MW in March 1992, the wind power capacity has reached to 14,157 MW by the end of March 2011 and has positioned fifth in global scenario. [1][2]

The country has become a most preferred destination for almost all the big names in wind power industry for investment in the wind power sector. As the regulatory framework is also favorable for the developers, companies like Suzlon, Enercon, Vestas etc has setup base in the country and since then is rapidly expanding their operations.

Turbine technologies used by these developers are mainly a SCIG, PMSG or DFIG. All these technologies differ in operation and related costs. The working principle of DFIG is explained in the preceding sections.

III. TECHNOLOGY DEVELOPMENT TRENDS

A variable- speed wind turbine generator runs in its own, decoupling electrical grid frequency and mechanical rotor frequency. There are different concepts for the variable-speed wind generators: a) wound rotor induction generator with dynamic slip control, connected through power electronics to a variable resistance. [3] b) direct driven (gearless) multiple-pole synchronous generator connected to the grid through full size PECs. [4] c) doubly fed induction generator, i.e. a slip-ring wound-rotor induction generator[3] .

The two most widely used variable-speed wind-generator concepts are doubly-fed induction generators (DFIG) and multi-pole synchronous generators. These wind turbines are equipped with a pitch control system that enables them to: improve the dynamic behavior of the turbine; reduce drive train stresses, partially dump the mechanical power variations and the resulting voltage variations; limit the mechanical power on the main shaft of the wind turbine generator controlling mechanical speed, and hence the active power delivered to the network, to the maximum active power the wind generator can withstand [3] .

IV. WORKING PRINCIPLE OF DFIG

In this case, mechanical power at the machine shaft is converted into electrical power supplied to the ac power network via both the stator and rotor windings. Furthermore, the machine operates like a synchronous generator whose synchronous speed (i.e., the speed at which the generator shaft must rotate to generate power at the ac power network frequency f Network) can be varied by adjusting the frequency of the ac currents fed into the rotor windings.

In a conventional three-phase synchronous generator, when an external source of mechanical power (i.e., a prime mover) makes the rotor of the generator rotate, the static magnetic field created by the dc current fed into the generator rotor winding rotates at the same speed (n Rotor) as the rotor. As a

$$f_{Stator} = \frac{n_{Rotor} \times N_{Poles}}{120} \qquad (1)$$

Where, fstator is the frequency of the ac voltages induced across the stator windings of the doubly- fed induction generator, expressed in hertz (Hz).

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nRotor is the speed of the doubly-fed induction generator rotor, expressed in rotations per minute (r/min).

Npoles is the number of poles in the doubly-fed induction generator per phase.

Using Equation (1), it is possible to determine that, when the speed nRotor of the generator rotor is equal to the generator synchronous speed ns, the frequency fstator of the ac voltages induced across the stator windings of the generator is equal to the frequency fNetwork of the ac power network [5]. The same operating principles apply in a DFIG as in a conventional (singly-fed) induction generator. The only difference is that the magnetic field created in the rotor is not static (as it is created using three-phase ac current instead of dc current), but rather rotates at a speed n0,rotor proportional to the frequency of the ac currents fed into the generator rotor windings. This means that the rotating magnetic field passing through the generator stator windings not only rotates due to the rotation of the generator rotor, but also due to the rotational effect produced by the ac currents fed into the generator rotor windings. Therefore, in a DFIG, both the rotation speed nRotor of the rotor and the frequency f rotor of the ac currents fed into the rotor windings determine the speed n0, stator of the rotating magnetic field passing through the stator windings, and thus, the frequency fstator of the alternating voltage induced across the stator windings. Taking into account the principles of operation of doubly-fed induction generators, it can thus be determined that, when the magnetic field at the rotor rotates in the same direction as the generator rotor, the rotor speed nRotor and the speed n0,rotor of the rotor magnetic field (proportional to frotor) add up. Conversely, when the magnetic field at the rotor rotates in the direction opposite to that of the generator rotor, the rotor speed nRotor and the speed n0, rotor of the rotor magnetic field subtract from each other.

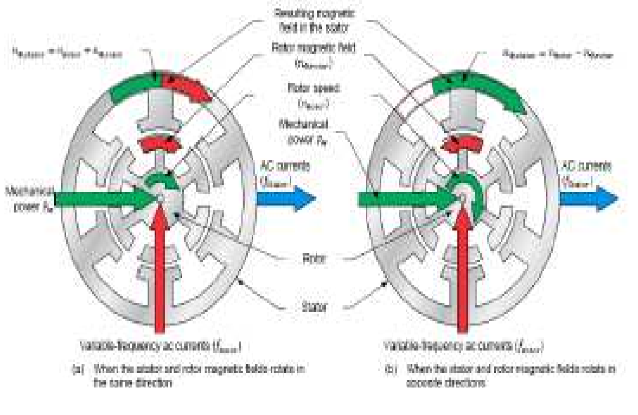

Fig .1. (a) Flow Diagram

In other words, the frequency fstator of the ac voltages produced at the stator of a DFIG is proportional to the speed n0, stator of the rotating magnetic field at the stator. The speed n0, stator of the stator rotating magnetic field itself depends on the rotor speed nRotor (resulting from the mechanical power at the rotor shaft) and the frequency f rotor of the ac currents fed into the machine rotor [5].

V. Simulation Results

Where Vr is the rotor voltage and Vgc is grid side voltage. The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system.

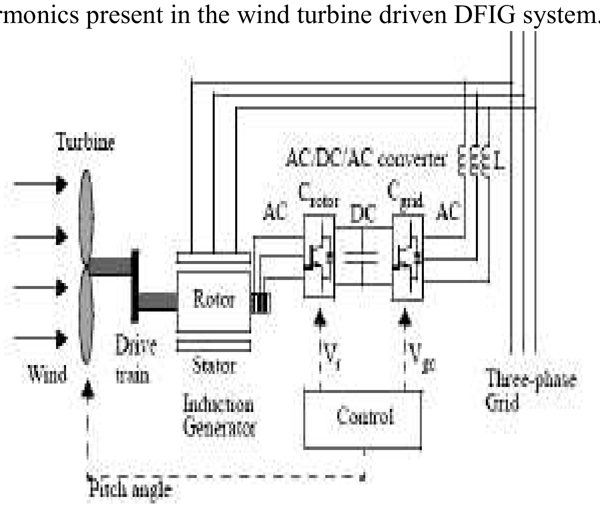

Fig.1 (b): - DFIG Model

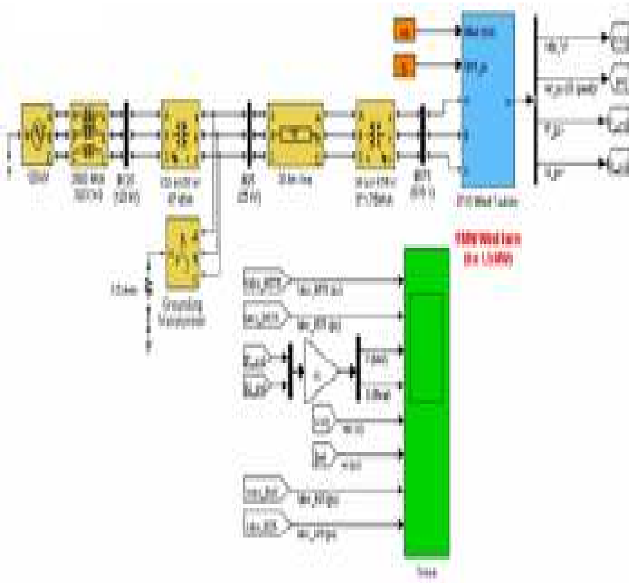

Fig.2: Simulink model of DFIG

Here Crotor is rotor side converter and Cgrid is grid side converter. To control the speed of wind turbine gear boxes or electronic control can be used [6].

The 6-wind-turbine farm is simulated by a single wind-turbine block by multiplying the following three parameters by six, as follows: the nominal wind turbine mechanical output: 6*1.5e6 watts, specified in the Turbine data menu the generator rated power: 6*1.5/0.9 MVA (6*1.5 MW at 0.9 PF), specified in the Generator data menu the nominal DC bus capacitor: 6*10000 microfarads, specified in the Converters data menu Also, notice in the Control parameters menu that the "Mode of operation" is set to " Voltage regulation". The terminal voltage will be controlled to a value imposed by the reference voltage (Vref = 1 PU) and the voltage droop (Xs = 0.02 PU).

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A. Turbine response to a change in wind speed

Initially, wind speed is set at 8 m/s, then at t = 5s, wind speed increases suddenly at 14 m/s.

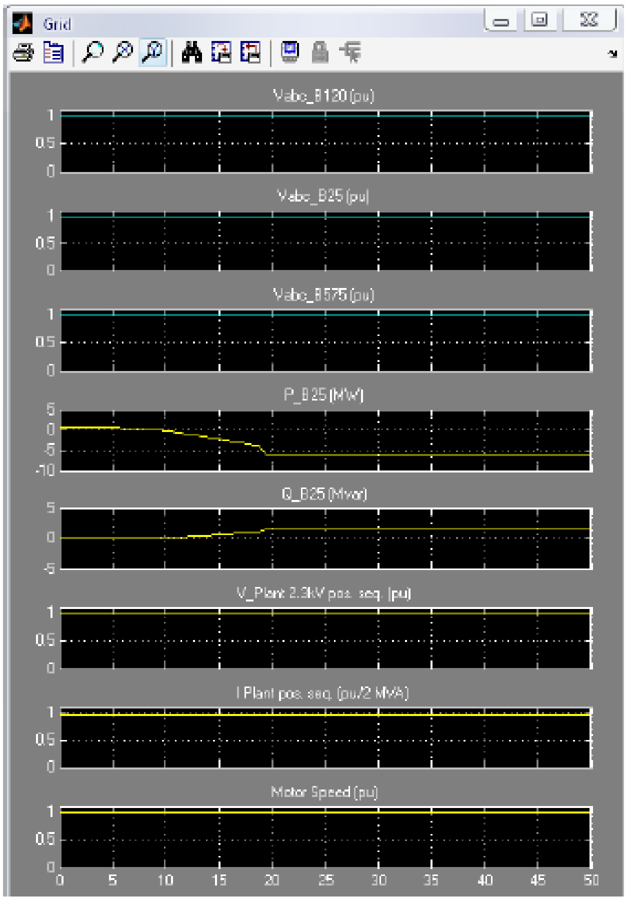

Fig.3 (a): GUI of Output's

At t = 5 s, the generated active power starts increasing smoothly (together with the turbine speed) to reach its rated value of 9 MW in approximately 20 s. Over that time frame the turbine speed will have increased from 0.8 PU to 1.21 PU. Initially, the pitch angle of the turbine blades is zero degree and the turbine operating point follows the red curve of the turbine power characteristics up to point D. Then the pitch angle is increased from 0 deg to 0.76 deg in order to limit the mechanical power. We also observed the voltage and the generated reactive power. The reactive power is controlled to maintain a 1 PU voltage. At nominal power, the wind turbine absorbs 0.68 Mvar (generated Q = -0.68 Mvar) to control voltage at 1PU.

If we change the mode of operation to "Var regulation" with the "Generated reactive power Qref" set to zero, we will observe that voltage increases to 1.021 PU when the wind turbine generates its nominal power at unity power factor.

VI. CONCLUSION

By adjusting the amplitude and frequency of the ac currents fed into the generator rotor windings, it is possible to keep the amplitude and frequency of the voltages (at stator) produced by the generator constant, despite variations in the wind turbine rotor speed (and, consequently, in the generator rotation speed) caused by fluctuations in wind speed. By doing so, this also allows operation without sudden torque variations at the wind turbine rotor, thereby decreasing the stress imposed on the mechanical components of the wind turbine and smoothing variations in the amount of electrical

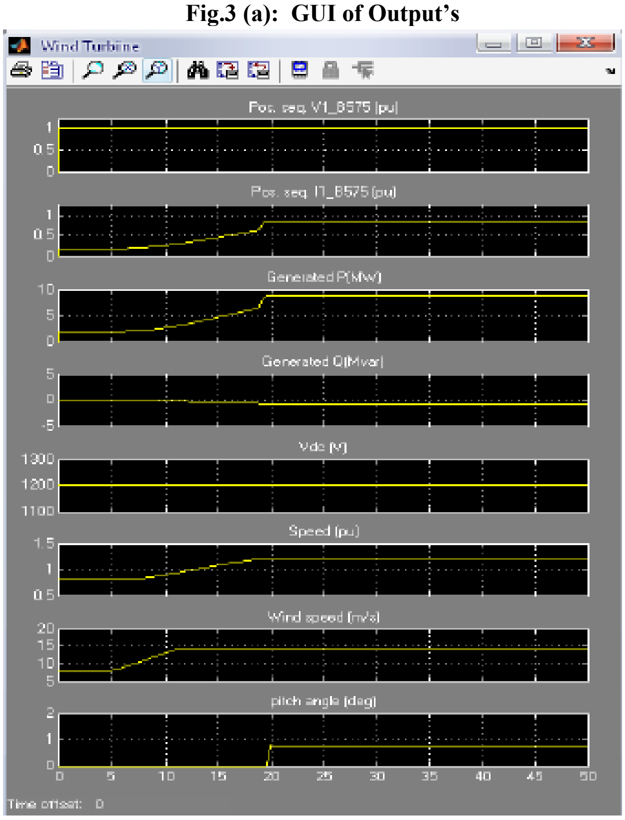

Fig.3 (b): GUI of Output's

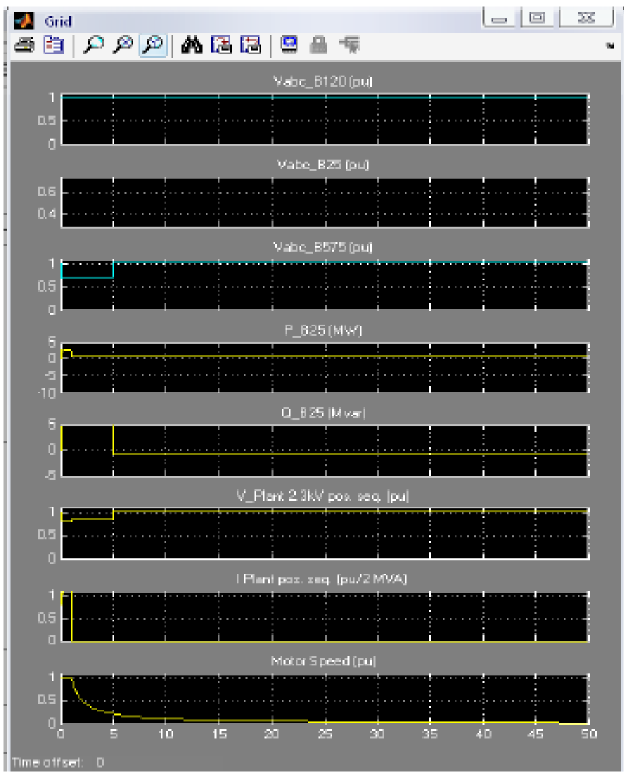

Fig.3 (c): GUI of Output's

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Finally, using a DFIG in variable-speed wind turbines allows electrical power generation at lower wind speeds than with fixed-speed wind turbines using an asynchronous generator. The power electronics devices used in DFIG, on the other hand, need only to process a fraction of the generator output power, i.e., the power that is supplied to or from the generator rotor windings, which is typically about 30% of the generator rated power. Consequently, the power electronics devices in variable-speed wind turbines using DFIG typically need only to be about 30% of the size of the power electronics devices used for comparatively sized three-phase synchronous generator. This reduces the cost of the power electronic devices as well as power losses in these devices.

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