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An Overview on Modeling and Simulation of Brushless Doubly Fed Induction Generator Coupled with Wind Energy System using Matrix convertor

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Abstract-*This Paper represents An Overview on Modeling and Simulation of Brushless Doubly Fed Induction Generator Coupled with Wind Energy System using Matrix convertor. Some of important research and developments are overviewed in this paper. Because of the advantages of the BDFIG over other generators it is being used for most of the wind applications. Various researches have been done in modeling and simulation in field of DFIG. This paper summaries the researches in the area of study of DFIG, steady state and transient analysis, its modeling, simulation, reactive power control strategies and performance analysis of BDFIG coupled with wind turbine. The response of BDFIG wind turbine system to grid disturbances, which is simulated and verified experimentally, is overviewed here.*

I. Introduction

The wind energy industry is booming due to its capability of producing ecologically sustainable energy. China has the most installed wind energy capacity, followed by the United States, Germany, Spain and India. Wind energy is one of the fastest growing industries at present and it will continue to grow worldwide, as many countries have plans for future development. Rapid developments in science and technology have witnessed a disastrous effect on environment. This issue is raised since some decades and reflected as a major agenda in Kyoto protocol and many other climate change summits. The Indian wind energy sector has an installed capacity of 18.551 GW (up to 31.02.2013) [A]. In terms of wind power installed capacity, India is ranked 5th in the World [B]. Today India is a major player in the global wind energy market. The potential is far from exhausted. Indian Wind Energy Association has estimated that with the current level of technology, the 'on-shore' potential for utilization of wind energy for electricity generation is of the order of 102 GW [C]. According to the Centre for Wind Energy Technology, Government of India- Growing concern for the environmental degradation has led to the world's interest in renewable energy resources. Wind is Commercially and operationally the most viable renewable energy resource and accordingly, emerging as one of the largest source in terms of the renewable energy sector. Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land. The effects on the environment are generally less problematic than those from other power sources. As of 2011, Denmark is generating more than a quarter of its electricity from wind and 83 countries around the world are using wind power to supply the electricity grid. In 2010 wind energy production was over 2.5% of total worldwide electricity usage, and growing rapidly at more than 25% per annum.

Wind power is very consistent from year to year but has significant variation over shorter time scales. As the proportion of wind power in a region increases, a need to upgrade the grid, and a lowered ability to supplant conventional production can occur. Power management techniques such as having excess capacity storage, geographically distributed turbines, dispatch able backing sources, storage such as pumped-storage hydroelectricity, exporting and importing power to neighboring areas or reducing demand when wind production is low, can greatly mitigate these problems. In addition, weather forecasting permits the electricity network to be readied for the predictable variations in production that occur.

Brushless doubly fed induction electric machine is constructed by adjacently placing two multiphase winding sets with unlike pole-pairs on the stator body.With unlike pole-pairs between the two winding sets, low frequency magnetic induction is assured over the speed range. One of the stator winding sets (power winding) is connected to the grid and the other winding set (control winding) is supplied from a frequency converter. The shaft speed is adjusted by varying the frequency of the control winding. As a doubly fed electric machine, the rating of the frequency converter need only be fraction of the machine rating.

The brushless doubly-fed induction generator(BDFIG) as a variable-speed constant-frequency(VSCF) wind power generator not only inherits similar advantages of the doubly-fed induction generator(DFIG) in that variable speed operation is possible with a converter rated at only a fraction of the machine rating, but also promises significant superiority as it offers high reliability and low maintenance requirements by virtue of the absence of brush gear, this is particularly beneficial for wind turbines located off shore where maintenance costs are high. Furthermore, the cost of manufacturing a BDFIG is likely to be less than that of an equivalent DFIG due to the absence of the slip-ring system and to the simpler structure of the rotor winding [5]. Nowadays, there is a tendency to increase the size and capacity of wind turbines. For such high power applications, multilevel converters are preferred due to their significant advantages such as they can increase the output voltage magnitude, reduce the output voltage and current harmonics without increasing the switching frequency or decreasing the output power and presenting better efficiency as the converter losses are reduced [6].

II. Literature Review

Some of the important literature related to DFIG modeling, simulation and analysis is presented in this section. Satish Choudhury et al [1] presented performance analysis of DFIG. They are using 10 h.p. wound rotor induction machine whose parameters are given. Paper presents voltage fed current regulated rotor-side and grid-side control of doubly-fed induction generator (DFIG) under steady and transient conditions. The vector control of grid-side is made to control the active and reactive power flow from the utility grid to the grid side converter independently and also maintain the dc-link voltage constant. Machine-side control regulates the speed of the prime mover thus making the system suitable for variable speed application. The voltage control, current control and speed control loops use PI controllers. Fig.1 shows the simulation results under voltage sag. The generated stator voltages and currents, active power supplied to grid, VAR requirement for the DFIG are observed and it is concluded that with the implemented vector control strategy, the DFIG system under simulation study is suitable under sudden change in grid voltage.

Abdoulaye Mamadie Sylla et al [2] they represent maximum power control of doubly-fed induction generator (DFIG) based grid-connected wind energy system. The control system used a combination of MPPT method with pitch control to extract maximum power from the wind turbine. PWM hysteresis controller is used to control the back to back converter which output is connected to the utility grid through a multivariable filter.

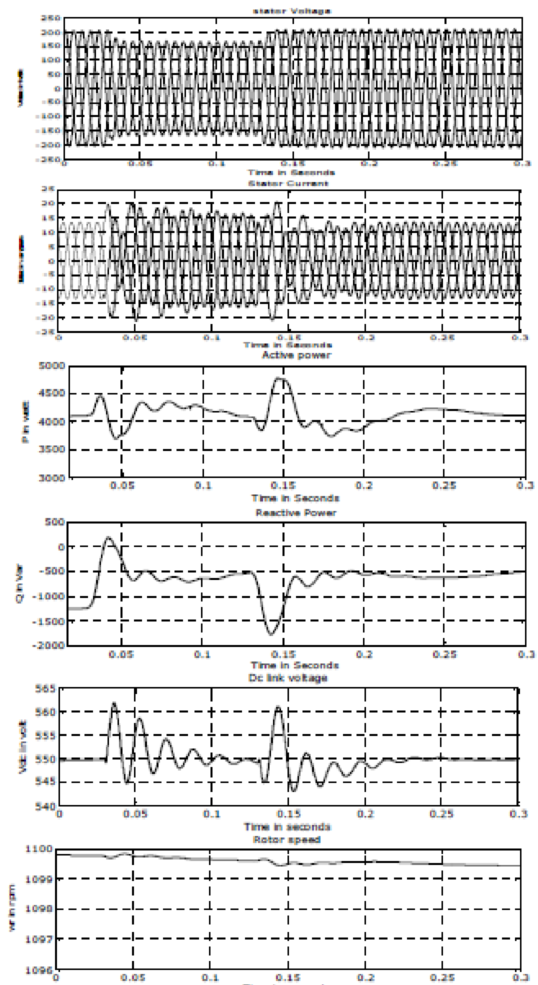

Fig. 1. simulation result under voltage sag

The overall wind system is theoretically analyzed and modeled in Matlab/ Simulink/ SimPowerSystems environment. The grid-connected wind system's

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performances are evaluated. This paper presents maximum power control of doubly-fed induction generator (DFIG) based grid-connected wind energy system. A MPPT method was implemented. PWM hysteresis controller is used to control the back to back converter which output is connected to the utility grid through a multivariable filter. The overall grid-connected wind system was modeled and its performances were evaluated. The system can fully control and inject high quality active and reactive power to the grid.

Fig. 2 and Fig. 3 represent respectively the profile of wind's speed and turbine's speed.The reference value of the reactive power is set to zero to obtain unity power factor. Fig. 4 and 5 display respectively the rotor's current and voltage. Fast transient variation in wind's speed can impact the rotor's current and voltage waveforms (time from 4 to 4.2sec)

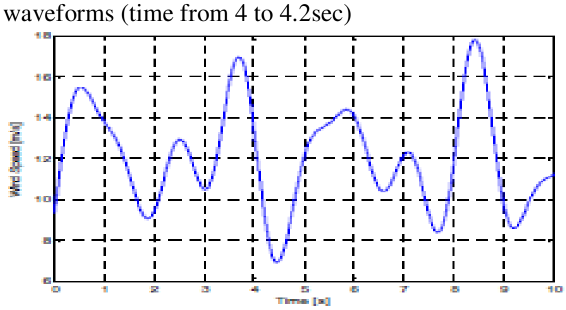

Fig. 2. wind speed profile

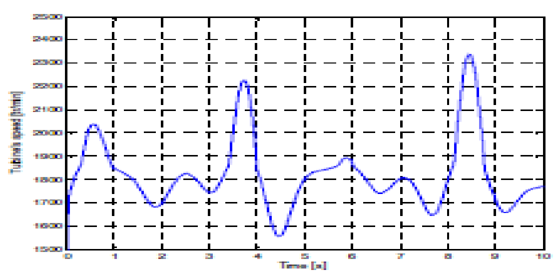

Fig. 3. Turbine's speed.

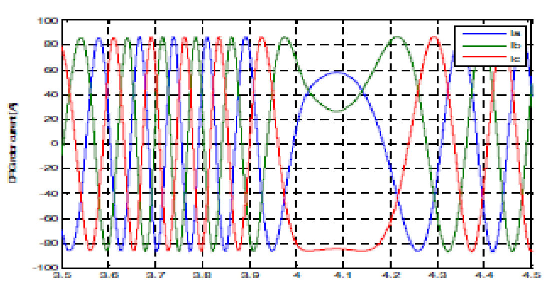

Fig.4 DFIG rotor current

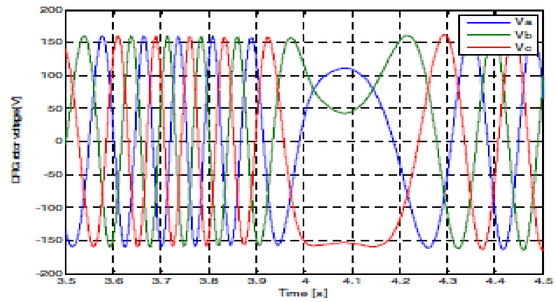

Fig. 5. DFIG rotor voltage.

Roberto Cardenas et al [3] represent in this paper, the performance of a grid-connected wind energy conversion system (WECS), based on a doubly fed induction generator (DFIG) fed by a matrix converter (MC), is presented. The MC replaces the back-to-back converters conventionally used to control a DFIG. The MC is operated with close- to-unity power factor at the grid side. Stability issues related to the operation of the MC in the proposed WECS are discussed. Experimental results, obtained with a 4-kW prototype, are presented and fully discussed in this paper. The performance of the system for variable speed generation is verified using the emulation of a variable speed wind turbine implemented with a digitally controlled dc machine. Fig.6 shows the DFIG powers and currents corresponding to the test in Fig. 6(a) shows the total power Pm supplied to the grid and the rotor power Pr fed to the rotor by the MC. In Fig. 6(b), the DFIG currents and the MC input current are shown. Fig. 7 shows the system operating with a low damping coefficient and a super synchronous operation. For this test, ωr ≈ 1300 r/min, and fbw ≈ 700 Hz.

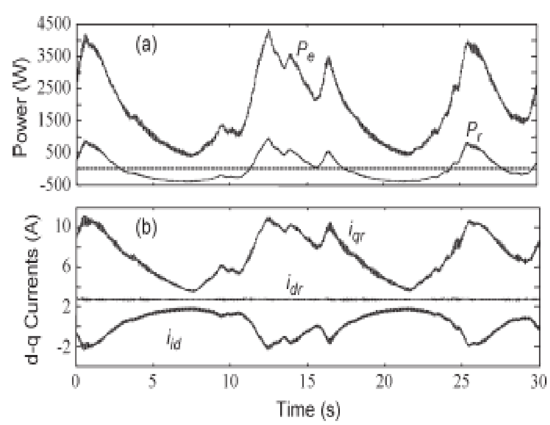

Fig. 6. Genrator powers and circuit,(a) DFIG output power Pm and rotor power Pr.(b) DFIG rotor current and MC current

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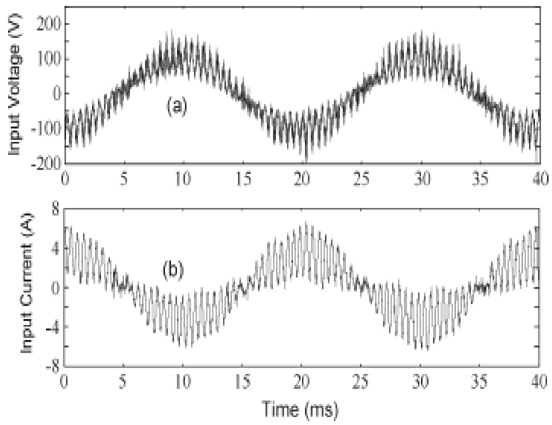

Fig 7. MC input current waveform for a low damping coefficient and a subsystem operation.
(a) line to neutral input voltage.(b) MC line input current.

Kai ji et al [4] et al represent in this paper, a novel variable-speed constant- frequency brushless doubly-fed induction generator (BDFIG) system using back-to-back multilevel converter for high power wind turbine is described. Based on analysis of power stator flux oriented vector control theory of BDFIG, an improved maximum power point tracking control strategy is explored. The paper specialty discusses the feasibility and advantage of a novel technique which should soft and fast synchronizing of BDFIG to the grid by using power stator voltage control method and disconnecting from the grid. Simulation results prove the feasibility and validity of the proposed model, theoretical analysis and excellent performance of the proposed control scheme.

III. Wind energy conversion system

A wind turbine catches the wind through its rotor blades and transfers it to the rotor hub. The rotor hub is attached to a low speed shaft through a gear box. The high speed shaft drives an electric generator which converts the mechanical energy to electric energy and delivers it to the grid. As the wind speed varies, the power captured, converted and transmitted to the grid also varies[7]. The output power of the turbine is given by the following equation

$$Pm = Cp\ (\lambda, \beta)(\rho A/2)V^3\ wind$$

Where, Pm is Mechanical output power of the turbine (W), Cp is performance coefficient of the turbine, ρ is the air density (kg/m3), A is the turbine swept area (m2), V wind is wind speed (m/s), λ is tip speed ratio of the rotor blade tip speed to wind speed and β is the blade pitch angle (deg).

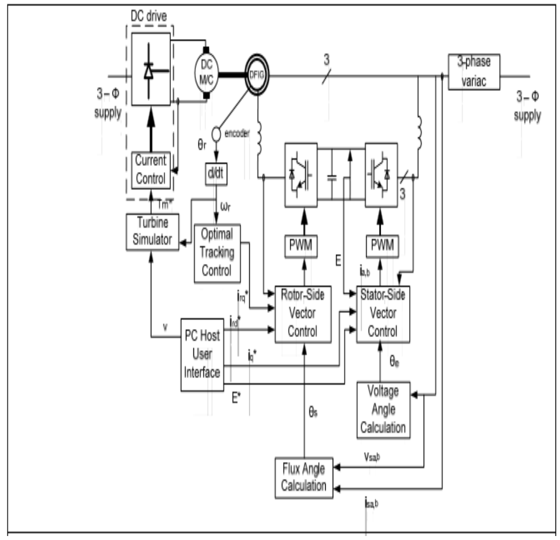

Fig. 8 Wind energy conversion system

The DFIG has windings on both the stator and the rotor. The stator is connected to the 3 phase supply - the mains. To match the stator voltages with the ones of the mains a 3 phase transformer could be used. [8]The shaft of the generator receives mechanical power through a coupling. For the practical case of wind application, the mechanical power originates from the wind powered blades of the turbine. To emulate the mechanical input, in laboratory testing, an electrical machine may be used in motoring regime [9]. Often DC machines are used as their speed may be controlled by controlling the voltage. Torque received from DC machine emulates the wind speed transmitted through the blades of the wind turbine. In order feed the DC machine a rectifier and current control are used. The rotor is connected through an inductance to the rotor side inverter. The back to back inverter system is commonly used in such systems. Both inverters are PWM driven and vector controlled. [10][11]. Measurement blocks are needed to acquire elements needed for the control. An encoder is needed to obtain the position of the rotor. From this, the speed of the shaft is obtained. [12][13]

IV. DFIG Equivalent Circuit and Equations

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

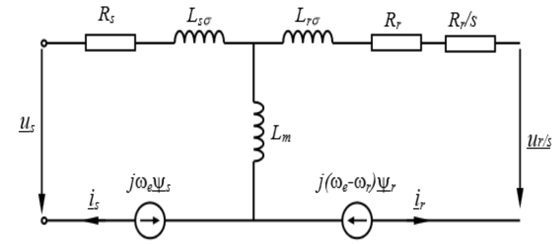

Fig. 9. DFIG Equivalent Circuit

The stator equation is presented below:

$$\underline{u}_s = R_s \underline{i}_s + \frac{d\underline{\psi}_s}{dt} + j\omega_e \underline{\psi}_s$$

Where

us - the stator voltage space vector,
is - the stator current space vector,
Rs - The stator resistance,
ψ s – stator flux, ωe - the reference frame speed (arbitrary),
j – Complex operator.

The stator voltage may be expressed as a sum of the stator d and q voltage components:

$$\underline{u}_s = u_{sd} + ju_{sq}$$

is, ir the stator and rotor current space vectors are also expressed in d and q components:

$$\underline{i}_s = i_{sd} + ji_{sq} \qquad \underline{i}_r = i_{rd} + ji_{rq}$$

Ψ s, Ψ r the stator and rotor flux space vectors,

$$\underline{\psi}_s = L_s \underline{i}_s + L_m \underline{i}_r \qquad \underline{\psi}_r = L_r \underline{i}_r + L_m \underline{i}_s$$

ur is the rotor voltage space vector equation is written for the rotor circuit.

$$\underline{u}_r = R'_r \underline{i}_r + \frac{d\underline{\psi}_r}{dt} + j(\omega_e - \omega_r)\underline{\psi}_r$$

R'r is the rotor equivalent resistor and ωr is the rotor speed,

$$\underline{u}_r = u_{rd} + ju_{rq}$$

$$\underline{\psi}_s = \psi_{sd} + j\psi_{sq} \qquad \underline{\psi}_r = \psi_{rd} + j\psi_{rq}$$

Where

R'r is the rotor equivalent resistor and ωr is the rotor speed,

$$L_s = L_m + L_{s\sigma} \qquad L_r = L_m + L_{r\sigma}$$

Where

sσL is the stator leakage inductance and
rσ L is the rotor leakage inductance

The mechanical equation comprising the rotor inertia J, load torque TL, electromagnetic torque Te and the rotor speed ωr is written as

$$J\frac{d\omega_r}{dt} = T_e - T_L$$

The electromagnetic torque is a function of the machine pole pairs (p) and stator currents and fluxes

$$T_e = \frac{3}{2}p(\psi_{sd}i_{sq} - \psi_{sq}i_{sd})$$

V. Control of DFIG

In this section, different aspects of designing and implementing control systems of DFIG are named. Controlling of DFIG depends upon the requirement, type of study and method to be used. The literatures reviewed have described some controlling techniques, which are: space vectors, power and reactive power in terms of space vectors, phase- locked loop (PLL)-type estimator, modified PLL- type estimator, internal model control (IMC), active damping, saturation and integration anti-windup, discretization. On the basis of these techniques controlling of DFIG can be done.

VI. Conclusion

The main objective of this paper is to give an overview of research and development in the field of Modeling and Simulation of DFIG coupled with WT. Wind energy conversion system, DFIG equivalent circuit, modeling of different parts and control of DFIG is discussed. So that the reader should be familiarized with the DFIG WT systems. This paper also discussed the different type of characteristics simulated for DFIG. This paper familiarized the reader about the work which has been done such as: the transient behavior, steady state behavior, load flow analysis, comparison in the real and reactive power control using stator-voltage and stator-flux oriented frames, experimental verification of the dynamic response to voltage sags, small signal stability analysis, comparison between rotor flux oriented reference frame and stator flux oriented vector control.

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