Simulation of Doubly-Fed Induction Generation based Wind Farm

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Abstract—The increasing concerns to environmental issues require the search for more sustainable electrical sources. Wind energy is one of the major available non-conventional sources to generate electrical energy. Wind turbine can be operated in constant speed or variable speed mode. DFIG Generator is used in variable speed wind turbine. A detailed model of wind power station including Doubly-Fed Induction Generator (DFIG) is presented in this paper. The model proposed in this paper is developed in simulation tool PSCAD/EMTDC.

Key words: Doubly Fed Induction Generator, Wind turbine, Modelling, Vector control.

I. INTRODUCTION

With the increasing in the demand of Electrical energy and reducing the conventional source of energy, it is necessary to increase the generation of electrical energy through the renewable source of energy like wind, solar etc. Also the drawback of generating electricity from fossil fuels and nuclear fission are the adverse environmental impacts, such as greenhouse effect and nuclear waste problem. From the renewable energy sources, the wind energy is very promising energy for the future. The major problem is the power quality problems due to installation of wind turbines. Wind is not consistence. Because of its variable nature, power delivered by wind turbine directly coupled to grid is not constant. This fluctuating power supply can lead to voltage variation in the grid and flickering occurs. Also, most of the induction machines utilized in wind turbine require the reactive power that changes with the wind speed and time. Because of this problem, DFIG receives more attention.

For the variable speed wind turbines, it is equipped with a Wound Rotor Induction Machine. They are controlled with electronic converters, which make it possible to control the speed of rotor and power. In the wound rotor induction machine, stator is directly connected to grid and rotor windings are connected by back to back connected converters. It is known as DFIG as it allows the flow of electrical energy in both the direction; into the grid when generator operating speed is super-synchronous and into the rotor if generator speed is sub-synchronous. The bidirectional AC/DC/AC converters, which are connected in between rotor circuit and grid, control the speed above the synchronous speed and the power is generated from both stator and rotor. Fig.1 shows variable speed wind turbine with DFIG.

The main advantages of DFIG are as follow:

1) Able to supply the power at constant voltage and frequency while the speed of rotor varies.
2) To improve the efficiency of wind generator, rotor speed may vary according to wind speed.
3) Power electronic converters require lower power ratings as it has to handle the fraction of total power.
4) Independent control of active and reactive power is possible and so the power factor can be controlled.

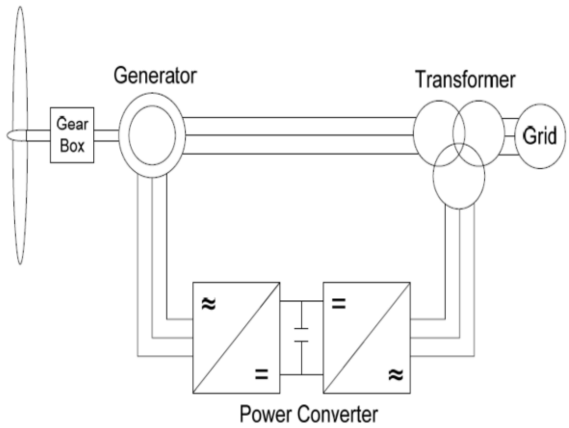

Fig. 1: Variable speed wind turbine with DFIG

As shown in Fig.1, the main power flows out of the stator and fed to the grid through the generator and transformer. The path from DFIG rotor to the transformer, through power converters, only has to transfer 20% to 30% of total power. The power converters in Fig.1 perform as an AC/DC/AC converter, which means that the AC power has to be converted to DC and then to be inverted back to AC in order to connect with the AC grid. This converter has to prevent the damage transmitted to the grid, which might come from the power variation or wind speed turbulence. The Rotor Side Converter controls the active and reactive power by controlling the rotor current components, while the Grid Side Converter controls the DC link voltage and DFIG terminal voltage or power factor of the overall DFIG system by controlling amount of reactive power exchanged with the power grid.

II. MODELLING OF DFIG

The DFIG consists of stator winding and the rotor winding. It is equipped with slip rings. The stator is provided with three-phase insulated windings and it is connected to the grid through a three-phase transformer. Similar to the stator, the rotor is also constructed of three-phase insulated windings. The rotor windings are connected to an external stationary circuit via a set of slip rings and brushes. By means of these components, the controlled rotor current can be either injected to or absorbed from the rotor windings.

A. Mathematical Model

The equivalent circuit diagram of an induction machine is shown in fig.2.

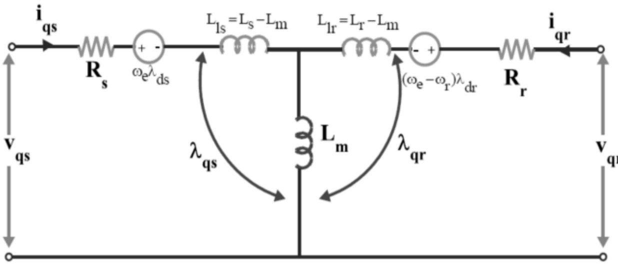

Fig. 2: Dynamic d-q equivalent circuit of DFIG (q axis circuit)

Stator and rotor circuit equations in terms of d-q frame can be written as,

$$V_{qs} = R_s\, i_{qs} + \frac{d}{dt}\lambda_{qs} + (\omega e\, \lambda_{ds})$$

$$V_{ds} = R_s\, i_{ds} + \frac{d}{dt}\lambda_{ds} - (\omega e\, \lambda_{qs})$$

$$V_{qr} = R_r\, i_{qr} + \frac{d}{dt}\lambda_{qr} + (\omega e\, \lambda_{dr})$$

$$V_{dr} = R_r\, i_{dr} + \frac{d}{dt}\lambda_{dr} - (\omega e\, \lambda_{qr})$$

The flux linkage equations in terms of current can be,

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr}$$

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr}$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs}$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds}$$

The torque expression can be written in terms of flux linkage and current as,

$$T_e = \frac{3}{2}\frac{P}{2}\,(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds})$$

$$T_e = \frac{3}{2}\frac{P}{2}\,L_m\,(i_{dr} i_{qs} - i_{qr} i_{ds})$$

III. CONTROL CIRCUIT

Fig. 3 represents the model of DFIG in PSCAD. The main controller of the DFIG is a back to back connected converters placed in rotor circuit.

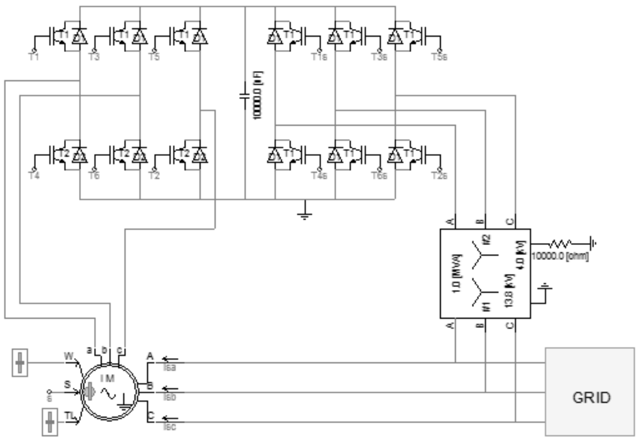

Fig. 3: Model of DFIG

A. Rotor side Converter control

For the rotor side converter control, the rotor currents I_{ra}, I_{rb} and I_{rc} are resolved into i_{dr} and i_{qr}. The estimation of stator flux linkage in stationary reference frame is given by,

$$\lambda_s = \int (V_s - I_s R_s)\,dt$$

From the above equation, correct values of i_{dr} and i_{qr} are obtained and then, by using, Current Reference Pulse Width Modulation (CRPWM) forces the current into rotor.

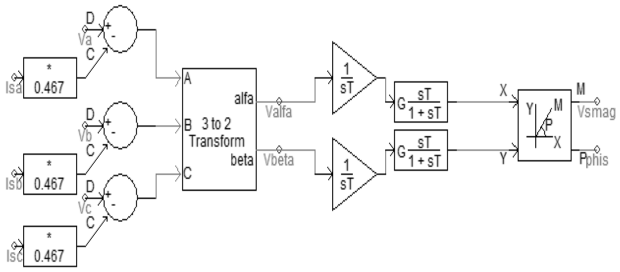

Fig. 4: Determining the present location of rotating stator flux

Subtracting the actual rotor angle from this angle will give the slip angle (slpang). It is used to determine the actual difference between stator flux and rotor position. With the help of these reference currents, the switching signals for IGBT are generated using CRPWM.

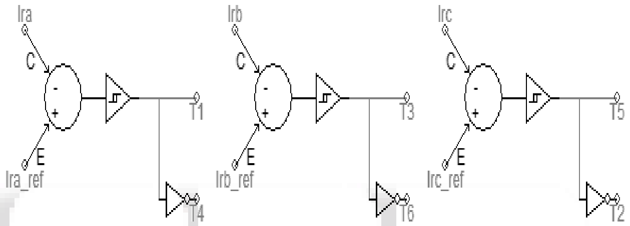

Fig. 5: CRPWM Controller for rotor current

B. Stator side converter control

For the stator side converter control, the stator voltage equation V_a, V_b and V_c are transformed into V_d and V_q. It can be expressed as,

$$\left.\begin{aligned} v_d &= Ri_d + L\frac{di_d}{dt} - \omega L i_q + e_d \\ v_q &= Ri_q + L\frac{diq}{dt} + \omega L i_d + e_q \end{aligned}\right\}$$

Converting above equations in terms of e_d and e_q, it will be,

$$ed = -LX1 + vd + \omega Liq$$

$$eq = -LX2 - \omega id$$

$$\text{Where, } X1 = \frac{vd - ed}{L} + \omega iq$$

$$X2 = -\frac{eq}{L} - \omega id$$

In the above equation, e_d and e_q are the d-q component of the generated VSC voltage. The current idref, which keeps the DC capacitor voltage at its rated value, is generated by comparing actual capacitor voltage with reference voltage. The transformer we use is of 4KV, 1MVA having 10% leakage, so impedance will be 1.6 ohm.

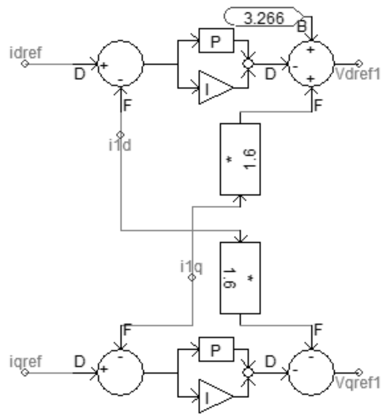

Fig. 6: Decoupled voltage controller

The generation of grid reference voltage angle phi is again by transforming and by using inverse transformation the reference for phase voltage is generated.

By using SPWM the required firing angle are generated. It is shown in Fig.7.

IV. SIMULATION RESULTS

The control scheme of the PSCAD/EMTDC simulated for wind turbine using DFIG was shown in the previous section. The simulation of Doubly Fed Induction Generator is shown in this section. Fig. 7 shows the circuit to generate the pulses to control the operation of the convertors. The simulation results of stator and rotor current waveform are shown in Fig. 8 and Fig.9.

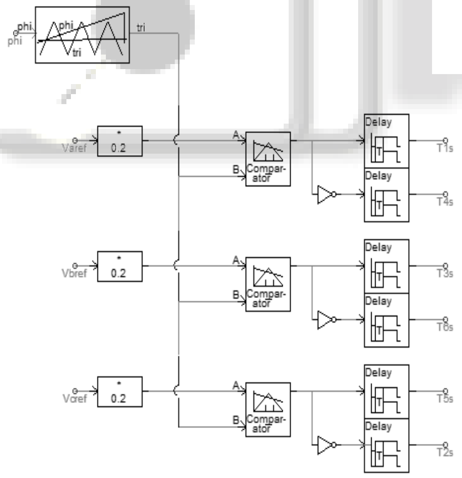

Fig. 7: SPWM Pulse generator

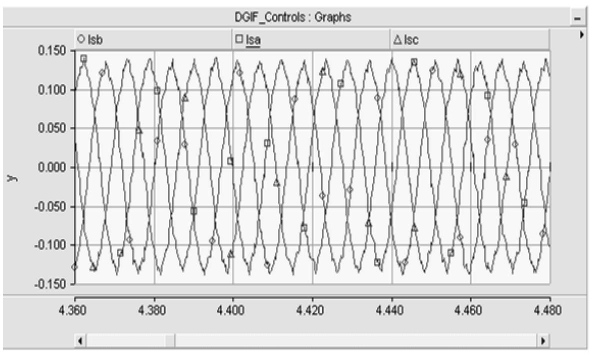

Fig. 8: Stator current waveform

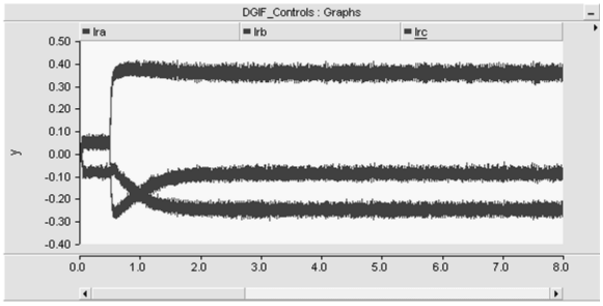

Fig. 9: Rotor current waveform

The simulation result to control the active power generated is shown in Fig. 10.

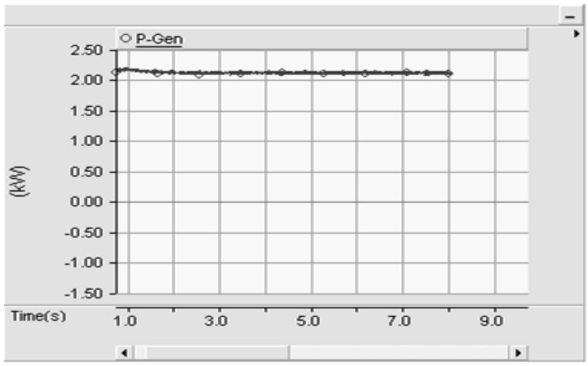

Fig. 10: Active power output of DFIG

Also, the waveform of DC link voltage between two PWM converters is shown in Fig.11.

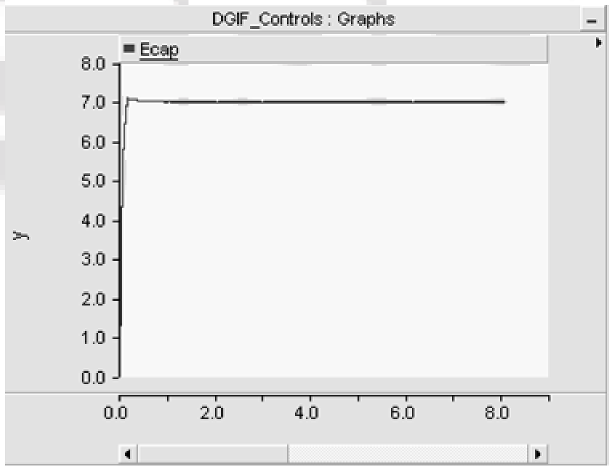

Fig. 11: DC link voltage waveform

V. CONCLUSION

In this paper, a Doubly Fed Induction Generator in wind turbine is simulated. The system model is developed in Simulation tool, PSCAD/EMTDC. The DFIG offer active and reactive power capabilities and reduced power loss. Simulation results show that DFIG model works satisfactorily.

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