

Field-oriented control of DFIG in Wind Turbine

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Abstract— the increasing size of wind farms requires power system stability analysis including dynamic models of the wind power generation. Doubly-fed induction machines allow active and reactive power control through a rotor-side converter, while the stator is directly connected to the grid. In this paper, a new control of doubly-fed induction machines of field oriented for multilevel inverter is advanced and based on imaginary coordinate. The additional control could be implemented easily with this method, so that the inverter performance could be improved.

Keywords- Wind turbine, Doubly Fed Induction Generator, field oriented, Power System.

I. INTRODUCTION

Due to clean and economical energy generation, a huge number of wind farms are going to be connected with the existing network in the near future. Doubly-fed Induction generator (DFIG) is widely used as wind generator. But as it has some stability problems [1], it is necessary to investigate the stability aspect of Doubly-fed induction generator when connected to the power grid.

Several authors have studied the impact of various wind generators on power system using different tools and softwares. These figures clearly show that there is a strong need for power system stability analysis, including dynamic models of on- and off-shore wind farms. For dynamic power system analysis, different models, from fully detailed to highly reduced order models are proposed in the literature [2],[3], but standard doubly-fed induction machine models for modeling large power systems are still under investigation [4].

Most DFIG wind turbine models that are used in transient analyses represent the generator by means of a two-axis model with constant lumped parameters [5], [6], [7]. A model of DFIG that takes into account the equivalent circuit parameter variation was presented in [8].

Multilevel converters are increasingly studied widely recently thanks to their much approximately sinusoidal output waveform [9][10]. Multilevel converters can leave out the bulky, heavy transformers or reactors. This advantage is much of utility since the size and cost of the transformers and reactors is the main embarrassment for

improving the capability of converters. Presently, there are four types of circuit topology in multilevel converters. In this paper, a new control of flux oriented for multilevel inverter is advanced; the additional control could be implemented. Simulations are performed using the Matlab-Simulink environment.

II. VARIABLE SPEED WIND TURBINE CONCEPT

The typical DFIG configuration, illustrated in Fig.1 consists of a wound rotor induction generator (WRIG) with the stator windings directly connected to the three-phase grid and with the rotor windings connected to a back-to-back partial scale power converter. [11] The back-to-back converter is a bi-directional power converter consisting of two conventional pulse width modulation (PWM) voltage source converters (rotor side/grid side converter) and a common dc-bus. The transformer connecting the system to the grid has two secondaries; one winding connecting the stator and the other connecting the rotor. The voltage reduction on the rotor side makes possible to operate at a lower DC bus voltage.

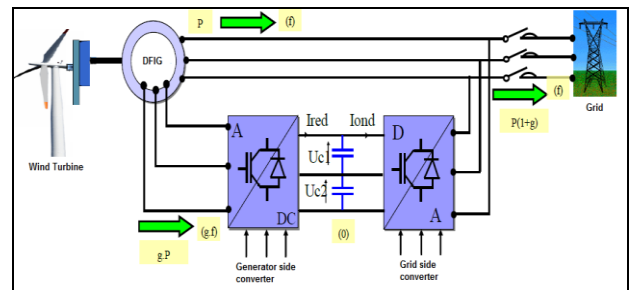


Figure. 1. The Wind Turbine with DFIG

III. WIND TURBINE ROTOR MODEL

The aerodynamic model of the wind turbine rotor is based on the torque coefficient C_Q or the power coefficient C_P . The torque coefficient C_Q is used to determine the aerodynamic torque directly by using:

$$T_{wr} = 0.5\pi\rho R^3 V_\infty C_Q \quad (1)$$

Where:

ρ Is the air density
 R Is the blade radius
 V_∞ Is the wind speed

C_Q Is the torque coefficient.

Alternatively the aerodynamic torque can be determined using the power coefficient C_p based on:

$$T_{wr} = 0.5\pi\rho R^2 V_\infty^3 C_p \quad (2)$$

Important to underline that both coefficients C_p and C_Q can be function of the tip speed ratio λ for passive-stall wind turbines or function of tip speed ratio λ and pitch angle θ for active stall and variable pitch/speed wind turbines. The parameters for this model are: blade radius, air density, cut-in and cut-out wind speeds. Using a reduced look-up table in respect with the variation of the torque coefficient/power coefficient with the pitch angle ($-10^\circ \leq \theta \leq 10^\circ$) the model for the active-stall wind turbine is obtained

IV. DOUBLY-FED INDUCTION MODEL

Some of the machine inductances are functions of the rotor speed, whereupon the coefficients of the state-space equations (voltage equations), which describe the behavior of the induction machine, are time-varying (except when the rotor is at stand-still). A change of variables is often used to reduce the complexity of these state-space equations. There are several changes of variables, which are used but there is just one general transformation [12]. This general transformation refers the machine variable to a frame of reference, which rotates at an arbitrary angular velocity ω_g . In this reference frame the machine windings are replaced with some equivalent windings as shown in Fig. 2.

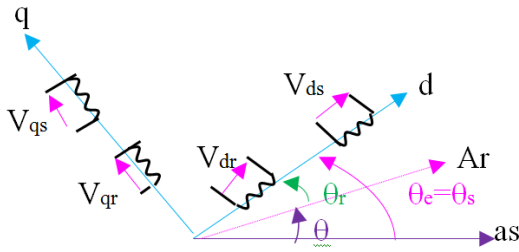


Figure.2. Induction machine windings in the dq arbitrary reference frame.

The six coils obey to the following electric equations:

For the rotor:

$$v_r = \begin{bmatrix} v_{ra} \\ v_{rb} \\ v_{rc} \end{bmatrix} = \frac{d\varphi_r}{dt} + R_r i_r = \frac{d}{dt} \begin{bmatrix} \varphi_{ra} \\ \varphi_{rb} \\ \varphi_{rc} \end{bmatrix} + \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix} \begin{bmatrix} i_{ra} \\ i_{rb} \\ i_{rc} \end{bmatrix} \quad (3)$$

For the stator:

$$v_s = \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \frac{d\varphi_s}{dt} + R_s i_s = \frac{d}{dt} \begin{bmatrix} \varphi_{sa} \\ \varphi_{sb} \\ \varphi_{sc} \end{bmatrix} + \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \quad (4)$$

The transformation of Park is often defined by the P matrix normalized. [6].The transformation of inverse

Park is defined by the P^{-1} matrix. The coefficient $\sqrt{\frac{2}{3}}$ is chosen to give an invariant expression of the electromagnetic torque from the property: $P^{-1} = P^T$

The system of PARK that constitutes a dynamic electric model thus for the coil two-phase model:

$$v_d = R_s i_d + \frac{d\varphi_d}{dt} - \frac{d\theta}{dt} \cdot \varphi_q \quad (5)$$

$$v_q = R_s i_q + \frac{d\varphi_q}{dt} + \frac{d\theta}{dt} \cdot \varphi_d$$

$$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \begin{bmatrix} R_s & 0 \\ 0 & R_s \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_{sd} \\ \varphi_{sq} \end{bmatrix} - \begin{bmatrix} 0 & -\frac{d\theta_s}{dt} \\ \frac{d\theta_s}{dt} & 0 \end{bmatrix} \cdot \begin{bmatrix} \varphi_{sd} \\ \varphi_{sq} \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} v_{rd} \\ v_{rq} \end{bmatrix} = \begin{bmatrix} R_r & 0 \\ 0 & R_r \end{bmatrix} \begin{bmatrix} i_{rd} \\ i_{rq} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_{rd} \\ \varphi_{rq} \end{bmatrix} - \begin{bmatrix} 0 & -\frac{d\theta_r}{dt} \\ \frac{d\theta_r}{dt} & 0 \end{bmatrix} \cdot \begin{bmatrix} \varphi_{rd} \\ \varphi_{rq} \end{bmatrix}$$

$$\begin{bmatrix} \varphi_{sq} \\ \varphi_{rq} \end{bmatrix} = \begin{bmatrix} L_s & M \\ M & L_r \end{bmatrix} \cdot \begin{bmatrix} i_{sq} \\ i_{rq} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} \varphi_{sd} \\ \varphi_{rd} \end{bmatrix} = \begin{bmatrix} L_s & M \\ M & L_r \end{bmatrix} \cdot \begin{bmatrix} i_{sd} \\ i_{rd} \end{bmatrix}$$

Where:

R_s, R_r, L_s, L_r are the resistances and inductances of the stator and rotor windings, M is the main inductance.

$v_{sd}, v_{sq}, v_{rd}, v_{rq}, i_{sd}, i_{sq}, i_{rd}, i_{rq}, \varphi_{sd}, \varphi_{sq}, \varphi_{rd}, \varphi_{rq}$ are the d and q-components of the space phasors, φ_{rd} of the stator and rotor voltages, currents, and flux.

V. METHOD OF CONTROL FOR FLUX-ORIENTED

The objective of this type of control is to achieve a simple model of the DFIG likely to separate the control flux and current flow. The Vector control of induction motor is to direct current vectors and to make the flow behavior of this latter similar to that of a machine DC separately excited (MCC) fig 3.

The electromagnetic torque of DC generator is:

$$C_{em} = K\varphi_f i_a \quad (8)$$

Where K is the constant of DC generator

The torque electromagnetic of DFIG is given by this expression:

$$C_{em} = p \frac{M}{L_s} (i_{sq} i_{rd} - i_{sd} i_{rq}) \quad (9)$$

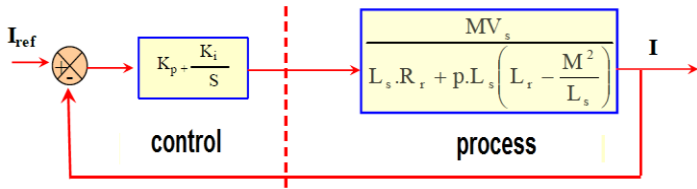


Figure. 4. Block diagram of the current control

VII. CASE STUDY AND SIMULATIONS

For validating the presented models, the results of simulating a heavy in the system shown in Fig.5 are described.



Figure. 5. Block diagram of the current control

The system consists of a wind turbine consisting of doubly-fed induction generator with a rating of 2MW is connected to infinite bus. Each doubly-fed induction generator is modeled according to Fig.1, including the three winding transformer, the induction generator, the grid-side and the rotor-side converter and the intermediate DC circuit Fig.1.

Figure 6 illustrates the simulation results of synchronous machine; the voltage terminal, the current of generator and the torque electromagnetic oscillations during the integration of wind turbine. As can be noted, after integration the system lost its stability but after a certain time the synchronous machine returned to its not initial operation.

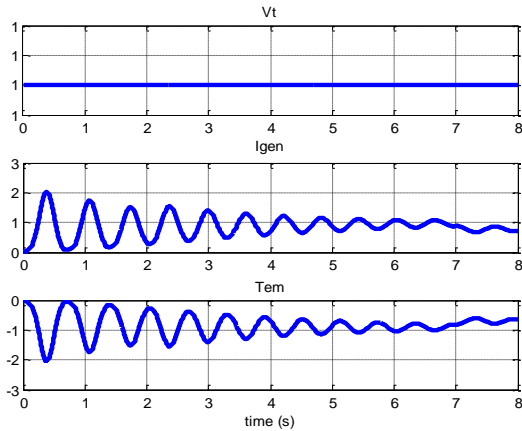


Figure.6. Simulation results of synchronous machine

The above figures show the performance of the vector control and reactive power in the stator applied to a doubly fed induction machine.

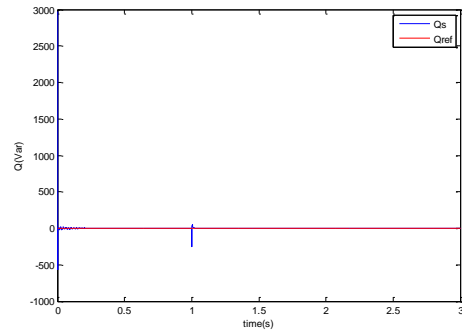


Figure. 7. Reactive power

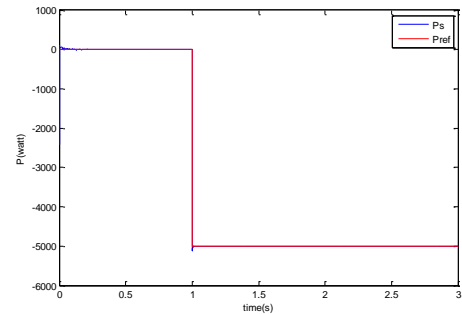


Figure. 8. Active power

Note that the active and reactive and current (i_{rd} , i_{rq}) are identified with their references powers.

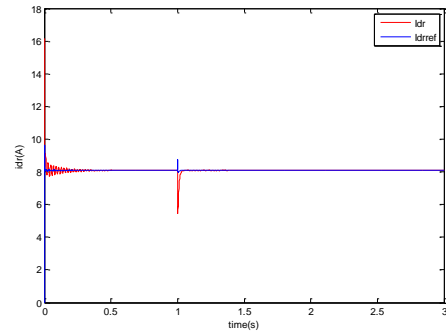


Figure. 9. Direct current of the rotor

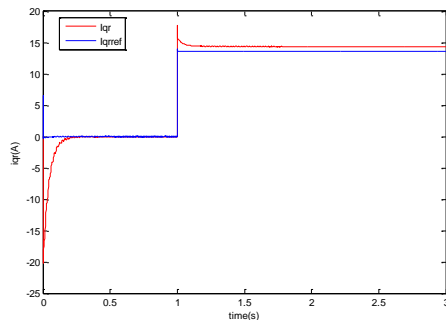


Figure. 10. Quadrature current of the rotor

Proportionality appears between the rotor current quadrature I_{qr} and active power, and between direct current I_{dr} and reactive power.

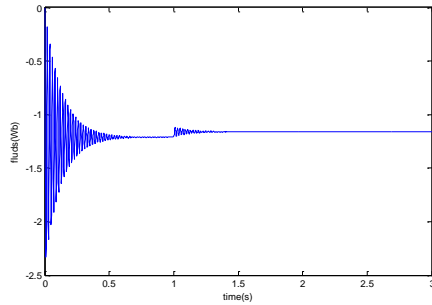


Figure.11. Direct flux of the stator

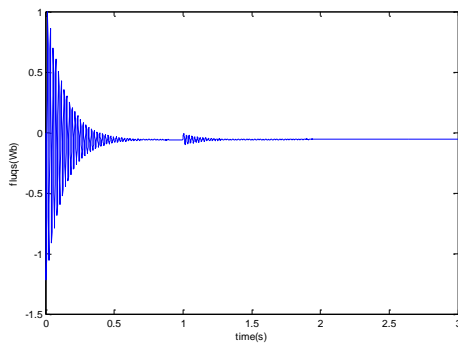


Figure. 12. Quadrature flux of the stator

The quadrature component of flux is almost zero in steady state, which confirms the hypothesis of the vector control. Note the effect of coupling between the two powers P and Q , because that P_{ref} pass (0 to -800) to ($t = 1s$) there is a small oscillation in the graph of the power Q .

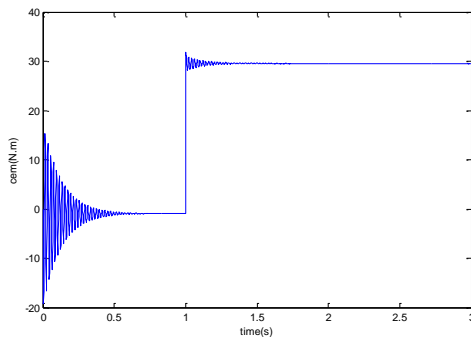


Figure. 13. Electromagnetic torque

Note that the electromagnetic torque reacts spontaneously when there is a demand for active power, reactive power independent.

VIII. CONCLUSION

This paper presents a study of variation of integration with a variable speed wind turbine connected in the grid.

In order to investigate the models and methods for the wind turbines system with DFIG, some methods to improve the control of field oriented are presented.

Using simulations under Matlab-Simulink environment, it has been found that, with the DFIG. The application of the proposed model demonstrates the effect of the control on the grid. Using this model, it is possible to estimate the dynamic characteristics of power system stability. All these observations underline the importance of tool for integration of the wind turbine in power system.

Moreover, for future work, the transient stability of the multi-machine power system including wind farms combined with this model to improve the power system stability should be studied.

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