A STRATEGY FOR DELIVERY OF CONSTANT ELECTRIC POWER IN DOUBLY FED INDUCTION GENERATORS

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Abstract **– This paper describes a strategy for maintenance of constant mean electric power delivered by the stator of a doubly fed induction generator (DFIG) with a variable speed wind turbine. The stator of DFIG is connected to the electric network, its rotor is connected to a voltage inverter, and its axis is mechanically coupled to a variable speed wind turbine that is subjected to turbulent torques. In order to developing the strategy, the equations of active and reactive power of the machine are used in the qd0 Park variables. It is also used the electric power reference signal that is a function of the mechanical power extracted from the wind. This information data set is used to calculate the reference voltage to be imposed in the rotor brushes by using a PWM voltage inverter. The strategy is applied in a test system and the simulation results are presented and commented.**

KEYWORDS

doubly fed induction generator, active and reactive power control, wind turbine.

I. INTRODUCTION

In the future, significant blocks of electric power can be generated in wind farms, adding the actual electric network supply [1,2,3,4]. This will implicate in generation scheduling for the wind farms. Because of random behavior of wind, with the effects of gusts and turbulences, the power of the wind varies continually. Therefore, the energy injected in the network should be controlled in a fast way in order to assure to the system a satisfactory electric power quality, with few low frequency transient effects. The double fed induction machines have been used in wind farms of high rated power due their superior performance when compared to the traditional generators with cage rotor [5,6,7,8]. The DFIG makes possible the reactive power control delivered to electric network, and allows generation of electric power in several different mechanical speeds. However, in the case of DFIG operation, there is need of converters circuits connected to the rotor as shown in the Figure 1.

Conventionally, all the energy that the wind can supply should flow to the electric network, because this maximizes the sold energy and minimizes the pay off time of the investment in the installed equipments. However, if a wind farm is forced to deliver a scheduled constant electric power, defined by supervisory action, it is necessary to control the power flow for the electric network and consequently there will be unbalance among the possible mechanical power and the necessary electric power. With this new restriction, rotor voltage can be controlled so that the unbalanced power can flow from or to an accumulator equipment of energy, when there is lack or excess of mechanical energy in the wind turbine. Therefore, based on the equation of power balance, for all the momentary excess of mechanical energy existing in the wind turbine, the electric power in the rotor should change according, that is, the power delivered by the rotor should vary of this same value.

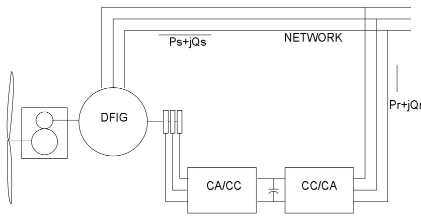

Figure 1 DFIG connected to network

THE STRATEGY:

The rotor of DFIG is connected to a three phase converter, as schematized in the Figure 2. The accumulator device is not discussed in this work, but it may be a chemical device, mechanical device (flywheel energy-storage system) or even another electric network with lower energy quality requirements.

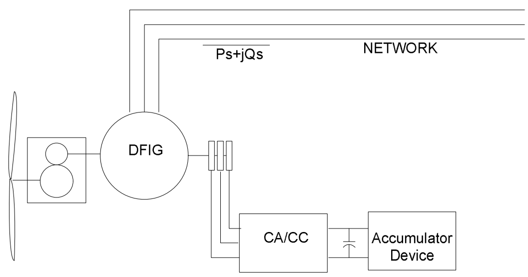

Figure 2 DFIG connections

The power delivered to the network by the stator is measured in a given sampling frequency. The mechanical speed of axis is also sampled and, this sample value corresponds to the maximum mechanical power that can be extracted from the turbine, according to a characteristic curve that is supplied by the manufacturer of the wind turbine; this curve has the aspect of the Figure 3. In a certain operating point of electric power, the wind turbine will have its mechanical adjustment

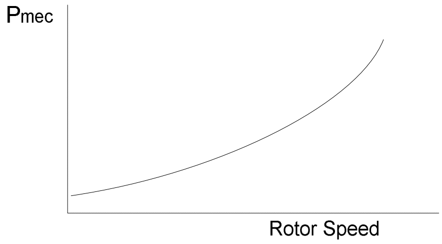

Figure 3 Optimal Power versus mecanical speed

corresponding to this point. Following the equation of power balance, this set point should be tracked by the action of the positioning of the blades of the turbine as well of the switches of the PWM converter connected to the rotor. It is supposed that the reactive power is also controlled in DFIG. As momentary variations of mechanical power cannot be measured accurately and quickly, the effects of these variations in power will be felt in the stator and rotor. By having available the measures of electric power of the stator, and considering that the rotor will absorb any deviation of this electric power, the PWM converter connected to the rotor may control the necessary power flow. The advantage of this compensation process is that the electric response is much faster than the mechanic response.

Considering that electric currents leave the stator and the rotor, in qd0 variables, the active and reactive power delivered by the generator, are given by:

$$P = \frac{3}{2}(v_{ds}i_{ds} + v_{qs}i_{qs} + v_{dr}i_{dr} + v_{qr}i_{qr})$$
$$Q = \frac{3}{2}(v_{qs}i_{ds} - v_{ds}i_{qs} + v_{qr}i_{dr} - v_{dr}i_{qr}) \quad (1)$$

At any moment, the stator voltages, stator currents and the speed of the rotor are known. Due to random variations around Pmec (set point) all the time there is the generation of an error signal, as can be seen in Figure 4, and given by:

$$P = P_{ref} - \frac{3}{2}(v_{ds}i_{ds} + v_{qs}i_{qs}) \quad (2)$$

Similarly the error signal generated for the reactive power is given by:

$$Q = Q_{ref} - \frac{3}{2}(v_{qs}i_{ds} - v_{ds}i_{qs}) \quad (3)$$

Making the errors signals to be zero in the equations (2) and (3), and substituting in equation (1), the two equations relating the rotor voltages and currents are given by:

$$v_{dr}i_{dr} + v_{qr}i_{qr} = \frac{2}{3} P$$
$$v_{qr}i_{dr} - v_{dr}i_{qr} = \frac{2}{3} Q \quad (4)$$

There are four variables (vqr, vdr, iqr, idr), and only two equations. By using the sampling routine, the currents in the rings of the rotor may be obtained and consequently idr and iqr, by using the transformation of variables. By substituting these actual values of currents in the equation (4), it is obtained a linear system for vdr and vqr. Once the linear system is solved, a transformation from qd0 variables to abc variables must be performed in order to generate the reference values of voltages of rotor brushes. These references signals will be supplied to the PWM inverter after being treated by a linear controller. These values are given by:

$$v_{dr} = \frac{2}{3}\left(\frac{i_{dr} \times P - i_{qr} \times Q}{i_{qr}^2 + i_{dr}^2}\right)$$
$$v_{qr} = \frac{2}{3}\left(\frac{i_{qr} \times P + i_{idr} \times Q}{i_{qr}^2 + i_{dr}^2}\right) \quad (5)$$

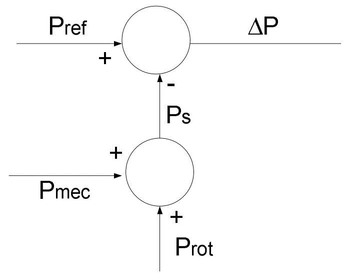

Figure 4 - Schematic of error generation

RESULTS OF SIMULATION

The simulation of the strategy described in the previous section was accomplished in a small electric machine coupled to a wind turbine. The electric model for this machine uses flux linkages as state variables.

The data of the electric machine are given in the Appendix A. The turbine was adjusted to produce a constant torque. This reference torque is added to a random disturbance that simulates gusts and turbulences, as schematized in the Figure 5. Figure 6 depicts the mechanical torque applied to the DFIG axis.

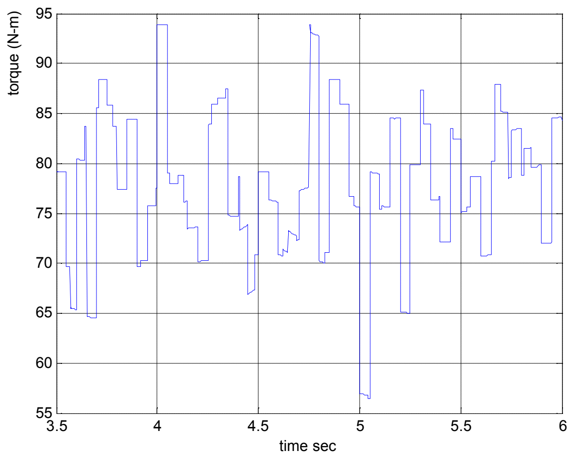

Figure 6 Mechanical Torque seen by DFIG axis

During 3.5 to 4.5 sec interval, it is considered the machine as an induction generator with cage rotor. The electric power delivered to the grid varied in low frequency swings. In 4.5

sec the strategy of stator constant power was switched on, and the supply of electric power to electric system began to be controlled for a value of reference of P=14.2 Kw and Q=0. Figure 7 depicts the simulated power supplied to the network by the DFIG. It can be seen in Figure 8 the electric current before and after the control strategy to enter in action in t=4.5 sec. Figure 9 depicts the actual speed of the machine along the simulation time.

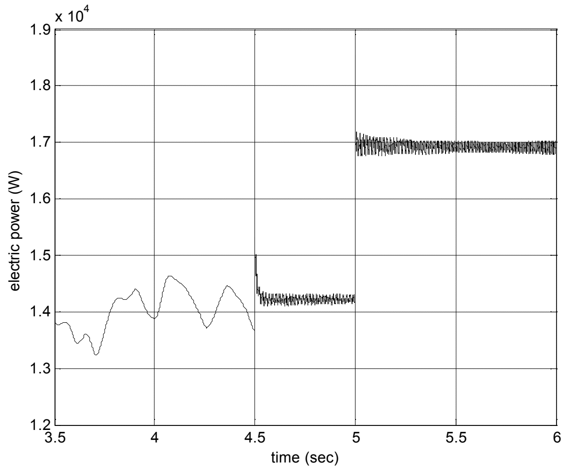

Figure 7 Instantaneous electric Power delivered to the grid

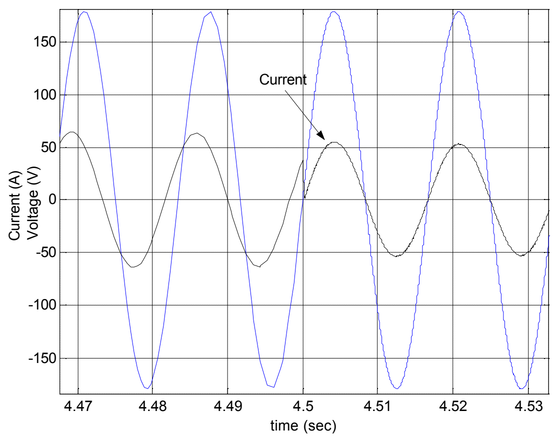

Figure 8 Voltage and Current before and after Control

In the instant t=5 sec the reference of active power was changed to 17 Kw and the reference of reactive power was changed to -10 kVAr (negative signal indicates capacitor operation). It can be seen in Figure 10 the electric current before and after the change of the reference values. The instantaneous power delivered by the rotor is shown in the Figure 11. In the Figure 12 it is shown the electric energy supplied from rotor circuit. During the 4.5 to 5 sec and 5 to 6 sec intervals the mean values of electric power in the rotor are 120 W and 920 W respectively.

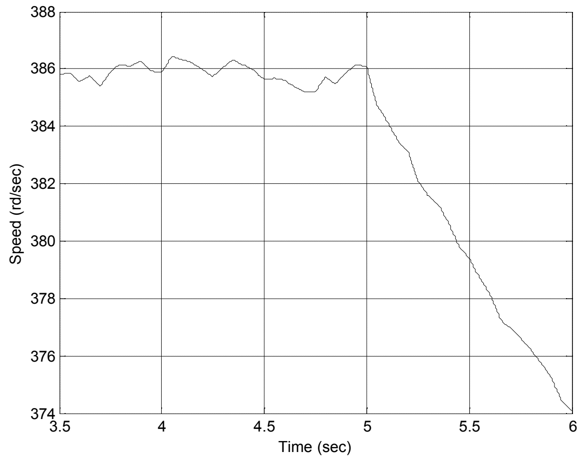

Figure 9 Rotor Electric Speed

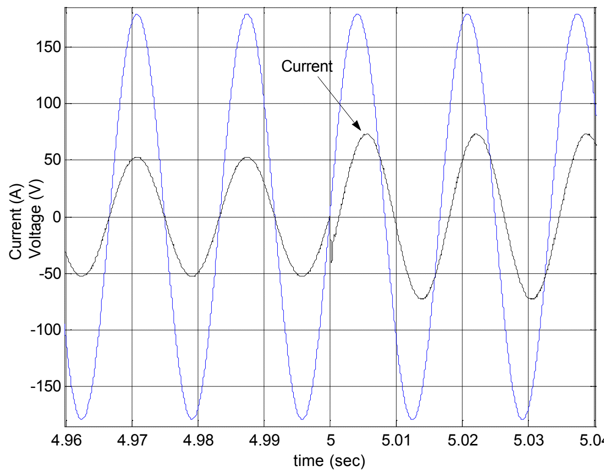

Figure 10 Voltage and Current for lead power factor operation

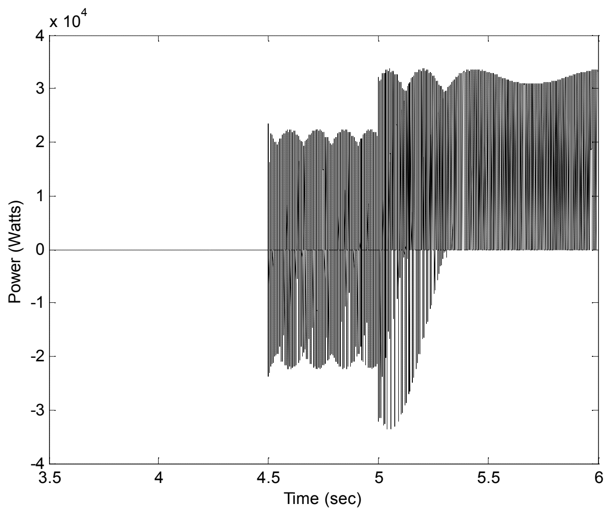

Figure 11 Instantaneous electric power delivered by rotor

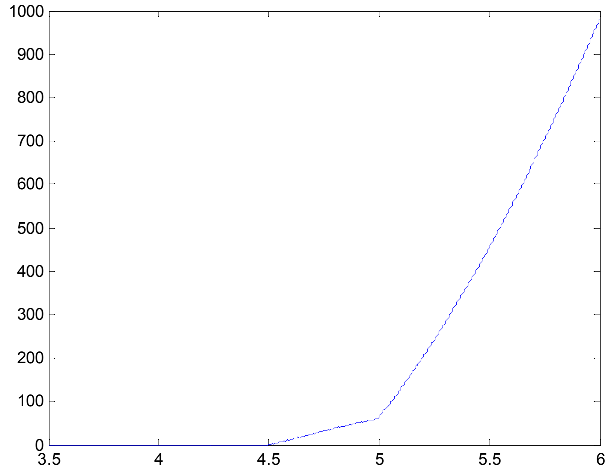

Figure 12 Energy supplied from rotor circuit

COMMENTS

It is noted that the control strategy of stator power has fast response and is capable of maintaining the constant mean power during many cycles. No filtering was introduced in order to prevent the high frequencies transients. During simulation it was not introduced any speed control, thus kinetic energy of wind turbine was transferred to electric form and delivered to network. If the mechanical speed of the axis varies beyond limits, the mechanical action of readjustment of the power of the turbine will be carried out through the pitch angle of the blades. It can be used slower and cheaper controls for this controller equipment because continuous action is avoided. In other words, it can be imposed larger hysteresis bands in the control of pitch angles.

CONCLUSIONS

This work described a strategy for control of electric power delivered by the stator of a DFIG to the network. It uses the information of electric power of the stator of the induction generator and it is insensitive to torque variations in the axis of the machine. The electric response is fast and this fact increases the electric power quality and it helps to relieve the mechanical controllers' performance in the blades of the turbine. Due to the several cycles that the constant electric power can be delivered by a DFIG, wider bands of hysteresis can be introduced in the tracking of power versus axis speed of turbine. This contributes with the durability of the mechanical system.

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APPENDIX A

DFIG data

Power	20HP
Vrated	220 V
Number of poles	4
Rated frequency	60 Hz
Rated rms phase current	49.68 A
Stator resistance	0.1062 ohms
Stator leakage reactance	0.2145 ohms
Rotor referred inertia	2.8 kg m2
Referred rotor resistance	0.0764 ohms
Magnetizing reactance	5.8339 ohms
Rotor leakage reactance	0.2145 ohms