A 75KW DOUBLY-FED INDUCTION GENERATOR IMPLEMENTATION FOR WIND ENEGY – POWER AND GRID CONNECTION CONTROL

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***Abstract* –The variable speed doubly-fed induction generator (DFIG) wind turbine is today the most widely used concept for high-power (over 1 MW) sites. The paper presents an overall control system of the variable speed 75 kW DFIG wind turbine, with focus on the control strategies and algorithms applied at each hierarchical control level of the wind turbine. The present control method is designed for normal continuous operations. The strongest feature of the implemented control method is that it allows the turbine to operate with the optimum power efficiency over a wide range of wind speeds. The variable speed wind turbine with doubly-fed induction generator is implemented using a 100 kW to emulate the wind turbine. Experimental results are performed and analyzed in different normal operating conditions.**

***Keywords* – The doubly-fed induction generator, variable speed wind turbine, power system, wind power.**

I. INTRODUCTION

As result of increasing environmental concern, the impact of conventional electricity generation on environment is being minimized and efforts are made to generate electricity from renewable sources. The main advantages of electricity generation from renewable sources are absence of harmful emissions. One way of generating electricity from renewable sources is to use wind turbines.

Evaluating the wind turbine market, there is a trend towards the configuration using a double fed induction generator (DFIG) with variable speed control by the most of manufacturers. It happens because of some reasons: (1) possibility to provide energy with constant frequency despite of rotor frequency variation; (2) Enable control of the whole generator output, using a power electronic converter rated at 20-30% of nominal generator power, Voltolini *et all* [6]; (3) Possibility to adjust the power factor, Costa *et all* [1].

Moreover, in wind power generation the input resource power varies considerably in function of the wind speed. According to Betz, within its effective region, the rotor of a wind turbine absorbs energy from the air stream, depending on rotor and air stream velocity. Using single fed systems, such as induction, synchronous, or reluctance drives, the maximum power point tracking sets the operating point of the electrical machine and, thus, the losses of the electrical generator associated with that operating point. As the power flow path is fixed at a given speed and magnetic flux level of the generator, losses and, thus, conversion efficiency are fixed. Varying the velocity in this single fed systems require a power electronic converter designed for the total power of the generator.

Because of this, variable speed generation is more attractive than fixed speed systems. In these systems, a maximum power point tracker (MPPT) adjusts a system to maximize turbine power output, depending on wind and rotor speed conditions. With a doubly fed system, a ±30% controllability through the rotor could be achieve with an electronic converter set in 30% of the power of the overall system.

In this work, a wind turbine is analyzed based on a 75 kW DFIG. It is controlled by the rotor with a back to back converter. The performance of the presented system is evaluated by presented experimental results in different conditions.

The following sections will analyze the different control algorithms that allow a wind turbine to individually influence system operations in terms of voltage and frequency control, where the wind turbine operates with speed and reactive power references.

II. DOUBLE FED INDUCTION GENERATOR CONTROL

A schematic diagram of the overall system is show in Figure 1. As it can be seen, the DFIG system is implemented using an IGBT´s based back-to-back converter between rotor side and power side. The DFIG is a 75 kW type, 60 Hz, 600 RPM, 8 pole, whose parameters is given in Table 1. Note that the system presents a squirrel cage induction motor. This machine is driven by a CFW 09 frequency converter, [7]. It is used to emulate the wind turbine. Moreover, a three phase power switch is used to connect the DFIG stator side to the power network.

To connect the DFIG to the network and to control it, three steps need to be followed. The first step is the regulation of the stator voltages with the network voltages as reference. The second step is connecting the stator to this network. Once this connection is achieved, the third step is the reactive power and rotor speed regulation, Morel *et all* [2]. The stator voltage regulation and the reactive power and velocity regulation are described as follows.

A. Stator Voltage Regulation

Figure 2 shows control mode in this first step. To obtain the synchronism between generator stator and network, is necessary equalize frequency and amplitude of both sides of the switch *sw*. To obtain the network frequency, a phase locked loop (PLL) algorithm is used. The measured three phase network voltage is converted in synchronous frame axes obtaining V_{Dnet} and V_{Qnet}. By a PI controller G_{PLL}, the

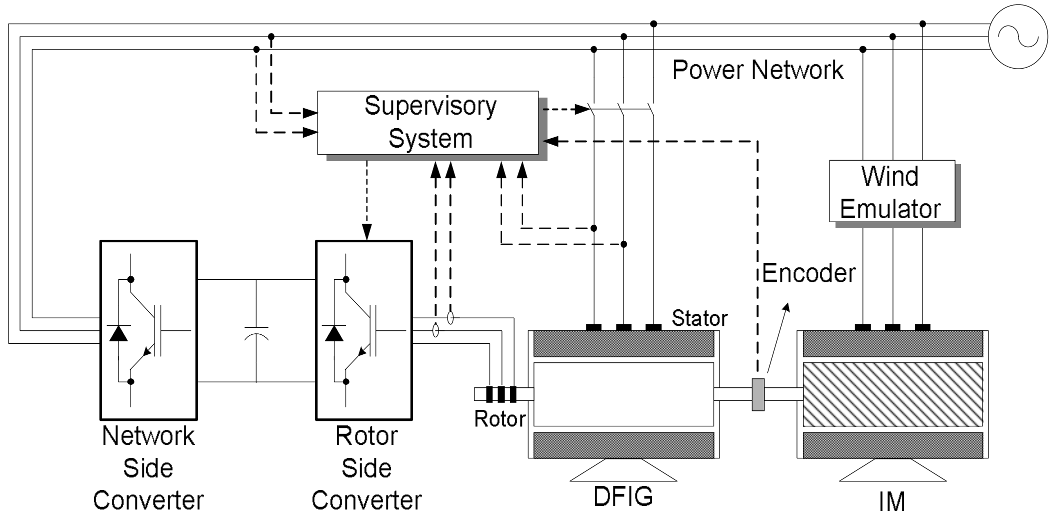

Figure 1- The structure of a wind turbine with a double fed induction generator

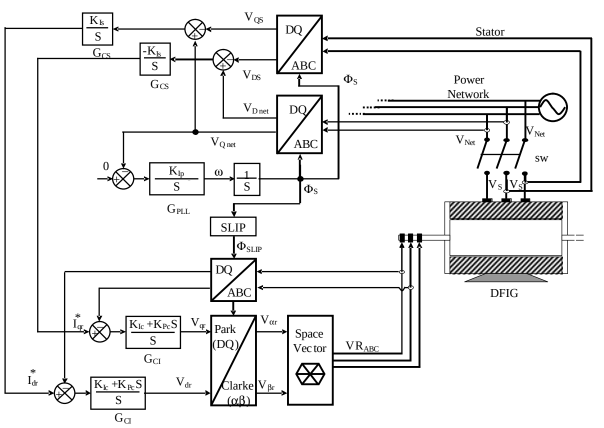

Figure 2- Control of DFIG before connection

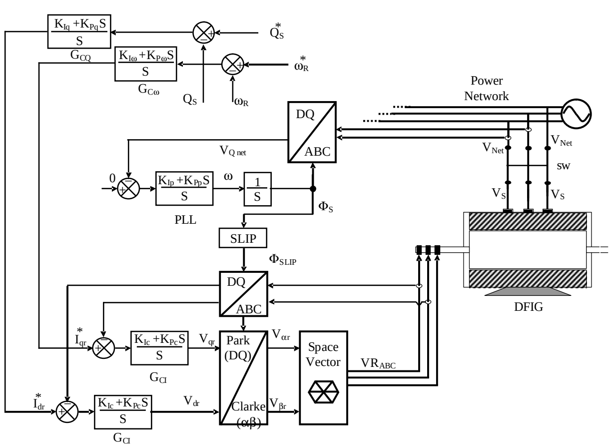

Figure 3- Control of DFIG after connection

park angle ϕ_S is modified until V_{Qnet} = 0. When this value is achieved, the synchronous frequency ω is obtained. To control the stator voltage V_S and equalize both sides of *sw*, rotor current controllers G_{CI} are used. They are responsible to impose the rotor currents I_{dr} and I_{qr} in synchronous frame axes. By them, it is possible to control the synchronous rotor (V_{dr} and V_{qr}) and stator (V_{ds} and V_{qs}) voltages. Comparing stator and net voltages, the reference rotor current (*) is defined to be imposed by estator controllers G_{CS}. When the voltages of the two devices are synchronized, the connection can be done closing *sw*.

B. Reactive Power and Velocity Regulation

Once this connection is achieved, other mode control is authorized, step three. To achieve a stator power and rotor speed control, as show in Figure 3, *dq* reference frame is synchronized with the stator flux [3]. By setting the stator flux vector ψ_S aligned with *d*-axis, it possible define that

$$\psi_{ds} = \psi_S \text{ and } \psi_{qs} = 0 \qquad (1)$$

In this condition, the electromagnetic torque only depend on the *q*-axis rotor current I_{qr}. So, comparing the measured rotor speed ω_R and the desired rotor speed ω_R^*, a rotor speed controller $G_{C\omega}$ is capable to define the reference *q*-axis rotor current I_{qr}^* responsible to control the generator rotor speed, Figure 3.

Similarly, because of this alignment, the stator reactive power Q_S only depend on the *d*-axis rotor current I_{dr}. So, comparing the measured Q_S and the desired reactive power Q_S^*, a reactive power controller G_{CQ} is capable to define the reference *d*-axis rotor current I_{dr}^* responsible to control the generator power factor, Figure 3.

However, note that the *PLL* algorithm used to determinate the stator voltage vector position. So, to obtain ψ_S vector position, let consider the per phase stator resistance R_S very small. Consequently, the stator voltage of the *n* phase can be defined as

$$V_{Sn} \cong \dot{\psi}_{Sn} \qquad (2)$$

where n can be the phases a, b or c. Because of this, the stator voltage vector is in 90° advanced in comparison with the stator flux vector.

In order to elaborate transformation angles for rotor variables, the stator flux and rotor positions must be considered. So, a block *SLIP* is used to convert rotor three-phase variables into two-phase *dq* variables in rotate reference frame and reciprocally, Figure 2 and Figure 3. More details of *SLIP* block can be seen in Figure 4.

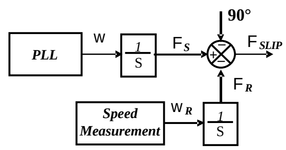

Figure 4- Diagram block of the slip position determination

III. EXPERIMENTAL RESULTS

For validation, the supervisory system described in section II was developed and implemented in DSP-based platform (Hitachi SH7047), developed by WEG®. The DFIG is supplied by 160 A type frequency inverter, operating at 5 kHz switching frequency. The developed controllers are applied in a DFIG whose parameters are given in Table 1. As it was sad previously, a 100 kW squirrel age induction motor is used to emulate the wind turbine. Its parameters are given by Table 2.

Table 1
DFIG Parameters

DFIG Characteristic	Value
Number Poles	12
Nominal Speed	600 RPM
Mutual Inductance	52.1 mH
Stator Self Inductance	54.0 mH
Rotor Self Inductance	54.8 mH
Stator Resistance	0.2006 Ω
Rotor Resistance	0.3559 Ω

Table 2
IM Parameters

IM Characteristic	Value
Number Poles	8
Nominal Speed	900 RPM
Mutual Inductance	29.9mH
Stator Self Inductance	31.1mH
Rotor Self Inductance	32.4 mH
Stator Resistance	0.0420 Ω
Rotor Resistance	0.0622 Ω

The following experimental results are obtained using a Digital Storage Oscilloscope TPS 2014, Voltage Probes P2220 and P5110, and AC current probes A621, all Tektronix® types.

Figure 5 presents stator and network voltages before supervisory system initialize and stator circuits are open. When it starts, the voltage regulation mode is habilitated (Figure 2), and the stator voltages are controlled (Figure 6) until stator and network voltage vector become synchronous (Figure 7). When this control goal is reached, the switch *sw* is closed.

After connection, the speed and reactive power control is habilitated. At this moment, the stator current vector is delayed in comparison with stator voltage vector, Figure 8. Follow the grid code requirements concerning connection of wind turbines in Germany, [8], the connectee shall adhere a power factor of 0.95 to 1 on the network connection point. So, the goal of reactive power controller

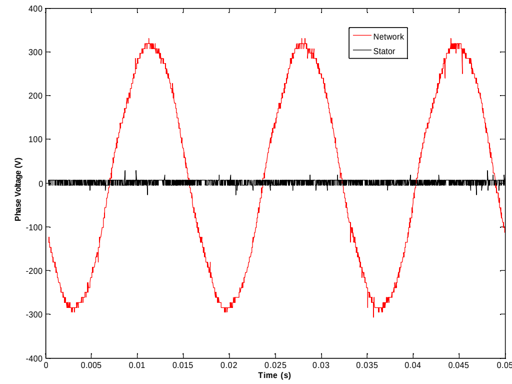

Figure 5- Comparison between stator and network phase voltage with supervisory system disabled

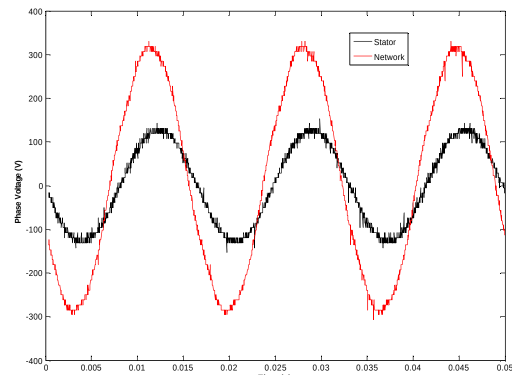

Figure 6- Comparison between stator and network phase voltage during voltage control action

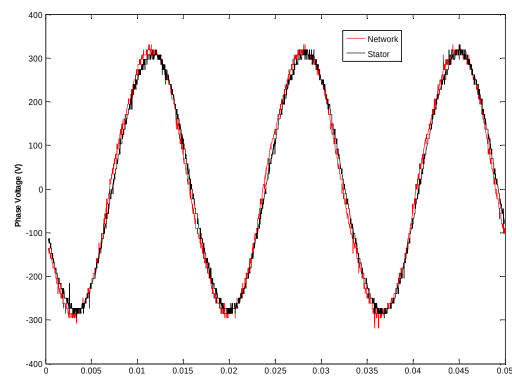

Figure 7- Comparison between stator and network phase voltage before connection

is reduce and Q_S near 0, as shown in Figure 9. Figure 10 presents a comparison between stator currents and voltage in a phase with Q_S controlled.

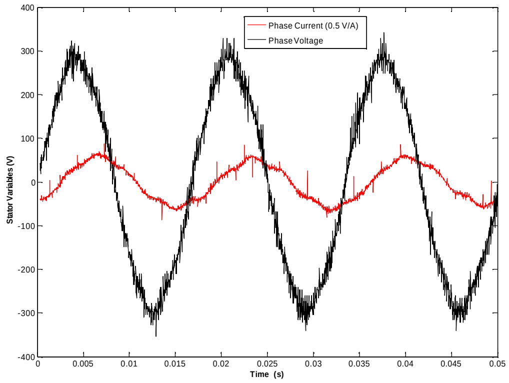

Figure 8- Comparison between stator current and voltage after connection

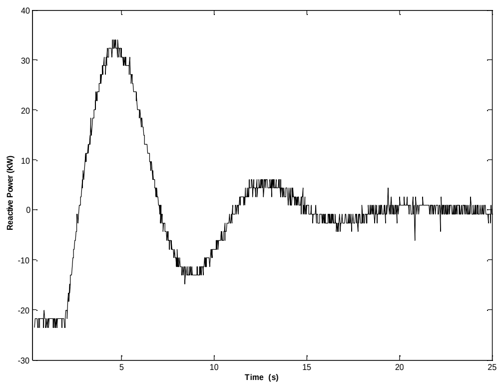

Figure 9- Stator reactive power during the test

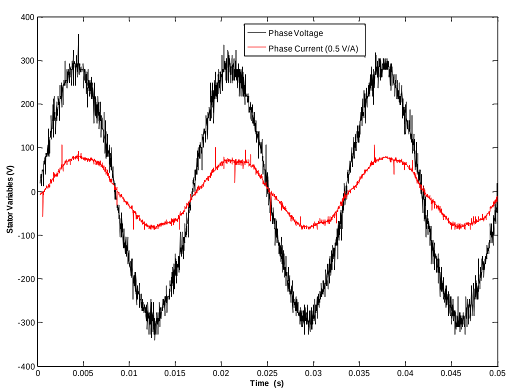

Figure 10- Comparison between current and voltage stator with controlled reactive power

During supervisory system action, the generator rotor speed has been controlled. By this way is possible to control the power extract from the wind [5]. To emulate this, consider the maximum power coefficient is obtained with generator rotor speed in 549 RPM. However, mechanical speed of wind turbine is in 580 RPM. Figure 11 presents the controller speed performance. It can be noted that rotor speed is reduced until 549 RPM and it kept near this condition.

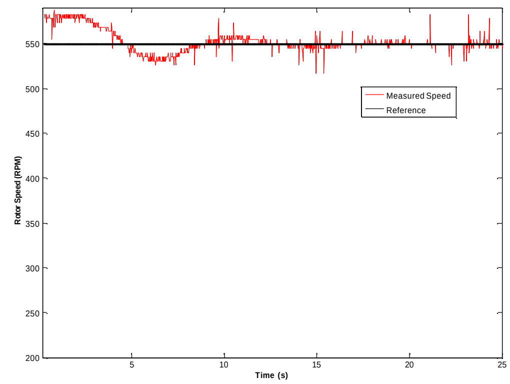

Figure 11- Rotor speed during the test

Another test was realized to verify the performance in different rotor speed conditions. In this case, the speed controller of primary machine and ω_R^* were fixed in 720RPM. When the switch *sw* was closed, ω_R^* was reduced progressively until 450 RPM. Figure 12 presents the measured rotor speed during this reference speed variation test. Figures 13, 14 and 15 are the stator voltage (blue) and rotor current (green) from a phase in 720, 600 and 450 RPM rotor speed condition, respectively.

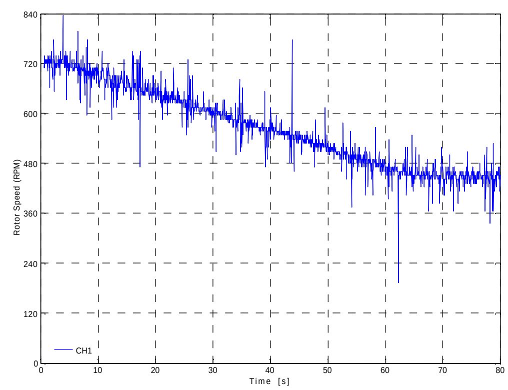

Figure 12- Measured rotor speed during the reference speed variation test

Figure 16 presents the 75 kW DFIG used during these tests and the 100 kW induction motor responsible to emulate the wind turbine. Finally, Figure 17 presents the drivers used to control both machines.

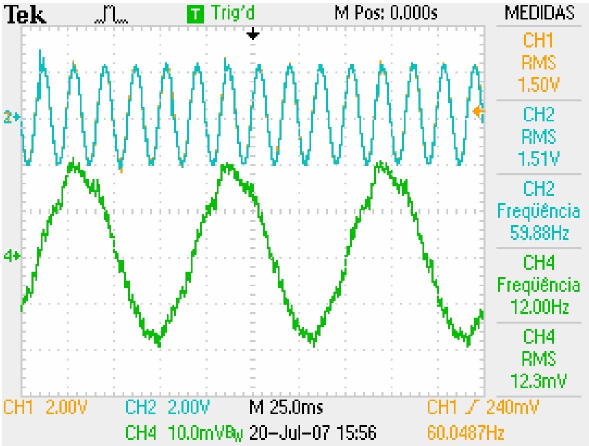

Figure 13- Stator Voltage (2 00V/V) and rotor current (20A/10mV) at 720 RPM

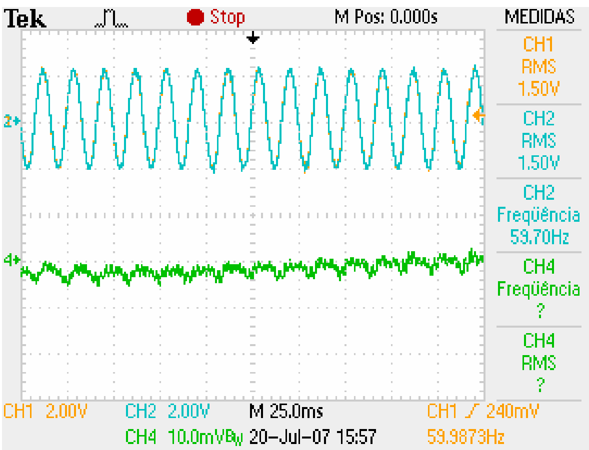

Figure 14- Stator Voltage (2 00V/V) and rotor current (20A/10mV) at 600 RPM

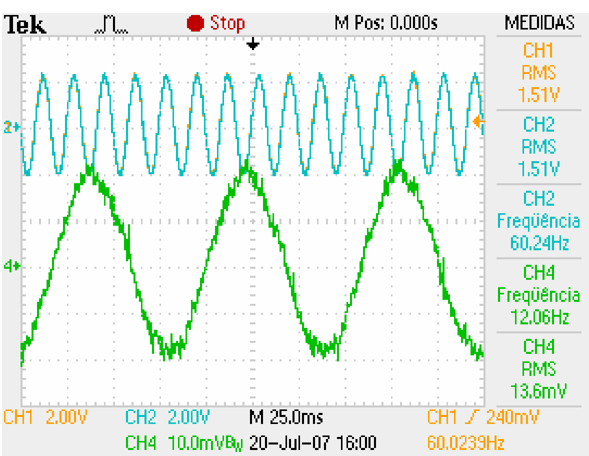

Figure 15- Stator Voltage (Blue_200V/V) and rotor current (Green_20A/10mV) at 450 RPM

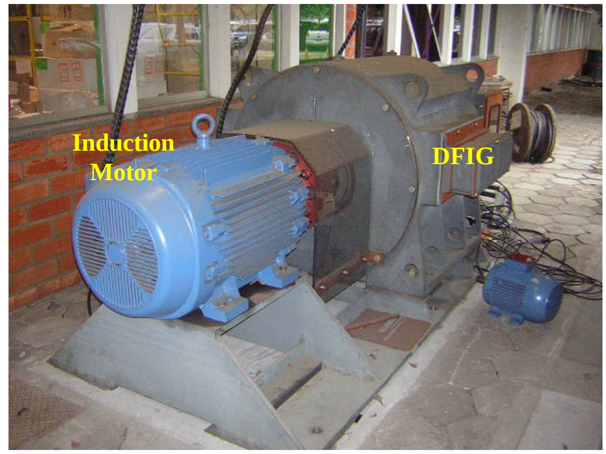

Figure 16- Motor and Generator complex used

Figure 17- Drivers used in the Motor and Generator complex

IV. CONCLUSION

This paper has presented a wind turbine under experimental analysis based on a 75 kW DFIG. After a description of this device and its connection procedure , a vector control approach is adopted for control of the DFIG. Speed and reactive power control was developed and implemented. These controllers have as goal to track the wind turbine optimum operation point, to limit the power in the case of high wind speeds and to control the reactive power interchanged between the wind turbine generator and the grid.

The performed implementations show that the evaluated control method is able to control efficiently the variable speed DFIG wind turbine at different normal operation conditions.

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