Trondheim

A Test–Rig to evaluate a Wind Turbine Generation Control System based on DSP

F.Barrero, J. L. Mora, M. Perales, A. Marchante, E. Galván, J. M. Carrasco, A.Torralba, and L.G.Franquelo
Dpto de Ingeniería Electrónica, Univ. de Sevilla,
Avda Reina Mercedes s/n, 41012-Sevilla (SPAIN)
phone: +34-5-4556873 ; fax: +34-5-4556849 ; e-mail: fbarrero@gte.esi.us.es

Abstract. The purpose of this paper is to describe a test–rig used to evaluate some control policies for wind-energy conversion systems. A current controlled DC motor is used to implement a model of Variable Speed and Pitch-angle Wind Turbine. This DC motor drives an induction generator. Two inverters are used to control the power delivered from the induction generator. The first inverter implement a variable speed vector control of the induction generator and the second one handle the power injected into the utility grid. At this moment, this system is under experimentation and some experimental results are shown in this paper.

Keywords. DSP control, Variable speed Wind Turbine.

INTRODUCTION

Many horizontal axes, grid-connected, medium to large scale wind turbines are regulated by pitch control and most of wind turbines so far built have practically constant speed, since they use an AC generator, directly connected to the distribution grid, which determines its speed of rotation.

In the last years, variable speed control is been added to pitch–angle controlled design ([1]–[4]) in order to improve the performance of the system. Variable speed operation of a wind turbine has a number of advantages: the reduction of electric power fluctuations by changes in kinetic energy of the rotor, the potential reduction of stress loads on the blades and the mechanical trasmisions and the possibility to tune the turbine to local conditions by adjusting the control parameters.

The objectives for variable speed control system are summarized by the following general goals:

1. To regulate and smooth the power generated.
2. To maximize the energy capture.
3. To alleviate the transient loads throughout the wind turbine.
4. Unity power factor in the line side with no harmonics current injection.
5. To reduce the machine rotor flux at light load reducing core losses.

Objectives for the pitch–angle control are:

1. To permit the starting blades angle to differ from the operation blade pitch angle, hence allowing easier starting and optimum running.
2. Overpower and overspeed can be dissipated through rotor pitch regulation.

A wind turbine can operate in four regions ([3], [4]):

1. Below cut-in wind speed.
2. Below rated wind speed.
3. Above rated wind speed.
4. Above cut-out wind speed.

The purpose of this paper will be to describe the test-rig used to evaluate some control policies for wind-energy conversion systems. These control policies were listed before. In section two, the DC motor emulation of the wind turbine will be detailed. Then, in section three, the vector control algorithms of induction generator will be shown. Also, it will be described the overall control of the induction generator. Finally, experimental result will shoun.

TEST–RIG DESCRIPTION

Figure 1 shows the power and control systems of the test-rig. In that figure, two subsystems can be found: the DC motor and the AC generator control.

The DC motor is controlled by a commercial thyristor full bridge rectifier with its control system based on a microcomputer.

In order to control the induction generator, two inverter connected by a DC–Link capacitor have been used. The first one works as a controlled rectifier and the second one handles the power injected into the utility grid. The control board is based on a 32 bits floating point DPS (TMS320C30) due to the real time calculations required in speed variable vector control.

The overall systems is controlled using a personal computer were the wind turbine model was implemented by software.

In figure 2 is shown the Test–Rig general view.

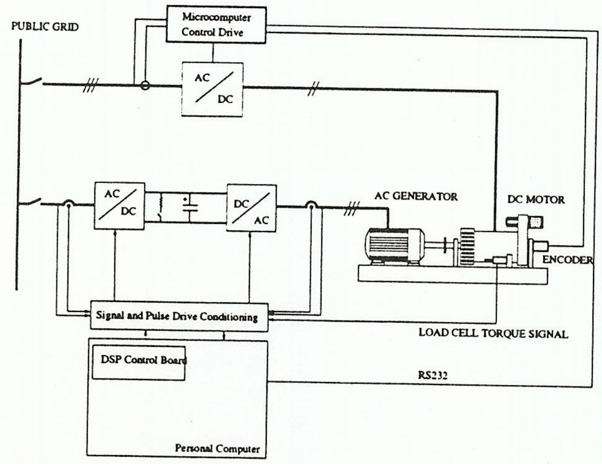

Figure 1: Power and Control Diagrams of the Test-Rig Variable Speed Wind Turbine

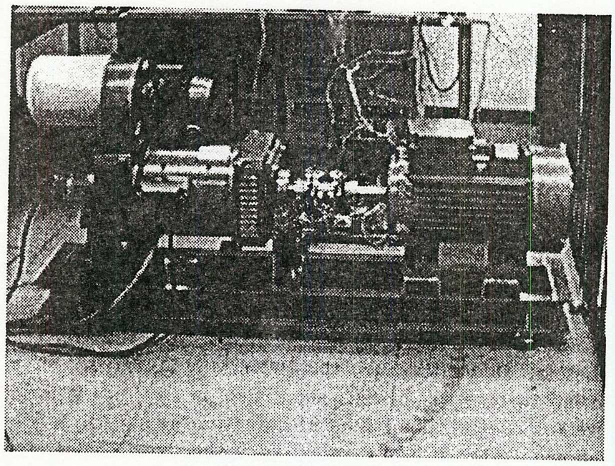

Figure 2: Photograph of the test–Rig.

WIND TURBINE MODEL

Current controlled DC motor is used to implement a Variable Speed and Pitch-angle Wind Turbine.

The block diagram of the wind turbine model is shown in figure 3. The reference torque is compounded of three components: aerodynamic, oscillatory and dynamic torque which are calculated on the PC. The reference torque is sent to the DC motor microcontroller from the PC by a RS232 serial communication. It should be noted in figure 3, the rotor speed is necessary in wind turbine model. Thus, the rotor speed has been acquired from the DC motor microcontroller.

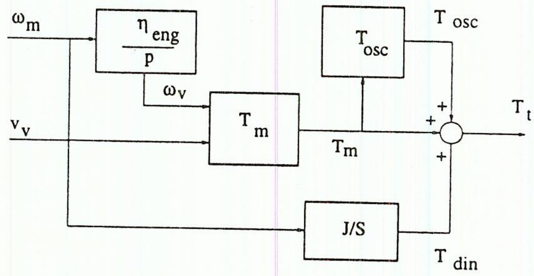

Figure 3: Block diagram of the wind turbine model.

INDUCTION GENERATOR CONTROL BASED ON DSP

The control of the induction generator can be divided in three parts: Power control, induction generator control and power injected into the utility grid control.

Power Control Block

The power control block implements different control policies depending on the wind speed and pitch–angle position. The control policies are torque, rotor speed or power constant reference.

Induction Generator Control Block

This control is based on an indirect vector method ([5]). The well known block diagram of this control system is shown in figure 4. The rotor speed is added to slip speed to obtain the synchronous speed of the reference frames:

$$\omega_e = \frac{p}{2}\,\omega_r + KCV\,i_q \tag{1}$$

ω_e is the synchronous frequency.

p is the pole number.

ω_r is the mechanical frequency.

KCV is a vector control constant.

In that reference frame, the torque and flux control is performed.

A Space Vector technique is used to control the induction generator current. This current control has been implemented in a synchronous reference frame.

Fuzzy logic techniques ([6]) are been implemented in order to improve speed control. In a future, fuzzy selftuning control system for Induction generator will be used ([7]).

Control of the Power Injected to the Public Grid

The DC–link capacitors voltage must be controlled to maintain a constant reference voltage. This is performed, injecting the active power delivered of the induction generator. The control block diagram is represented in figure 5.

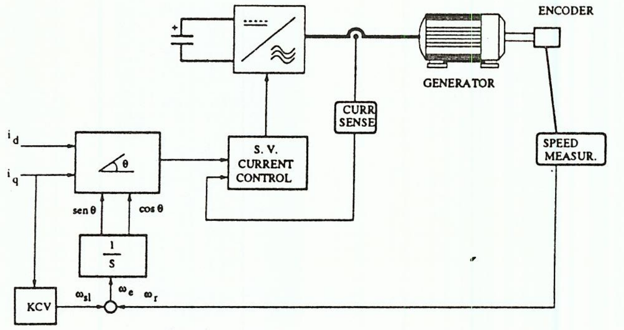

Figure 4: Indirect Vector Control Method Block Diagram.

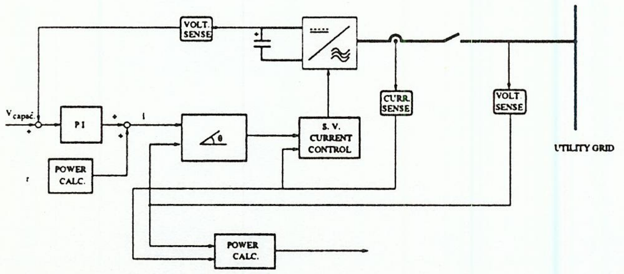

Figure 5: Public Grid current injection Block Diagram.

A space vector technique is used to control the current injected into the utility grid. In this case, current control has been implemented in a stationary reference frame.

EXPERIMENTAL RESULTS

Actually, the current control is been implemented by a bang-bang method. The sample time is $150\mu S$ and then a hight current ripple is observed. In this section some experimental results, obtained of the test-rig prototype, are analyzed to evaluate the performance of the system. Fig. 6 shows oscillograms of the injected current in the public grid (bottom) in nominal conditions using the proposed control system, and the generator current (top). Fig 7 shows oscillograms of the dc link capacitor voltage ripple (top), and the current injected in the public grid (bottom). It should be noted that the oscillogram of the dc voltage has been magnified in order to observe its ripple (600 V DC level against 15 V pp). Fig 8 shows oscillograms of the generator current and the rotor speed for a step load change from 5 kW to 2 kW of the wind power. Fig 9 shows oscillograms of the generator current and its speed, when accelerating from 0 to 1500 rpm.

CONCLUSIONS

A test–rig to evaluate some control policies for wind-energy conversion systems has been built. A current controlled DC motor has been used to implement a model of variable speed and pitch-angle wind turbine. The DC motor has been used to drive an induction generator.

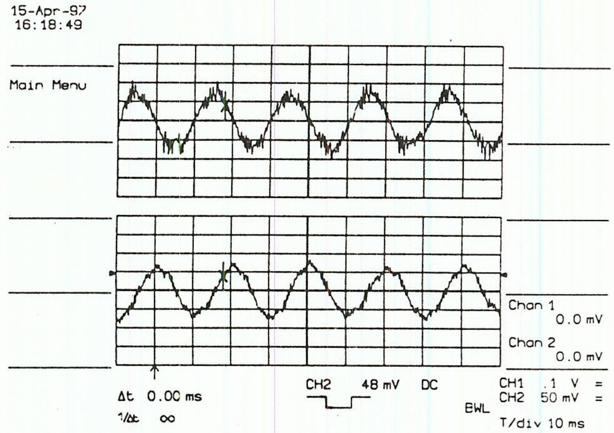

Figure 6: Oscillograms of the injected current in the public grid (channel 2, bottom) and the generator current (channel 1, top) in nominal conditions (1500 rpm 380 V). Channel 1 10A/div, channel 2 5A/div and 10ms/div.

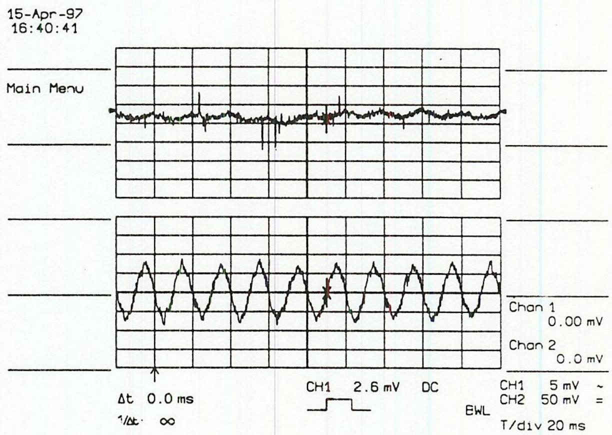

Figure 7: Oscillograms of the dc link capacitor voltage ripple (channel 1), and the current injected in the public grid (channel 2) in nominal conditions (1500 rpm 380 V). Channel 1 10V/div, channel 2 10A/div and 20ms/div.

Actually, the control of the generator has been implemented using vector control method and bang-bang current control.

Policies of maximization of line power are been implemented at this moment. The experimental results are confirming the validity of the control method proposed in the test–rig.

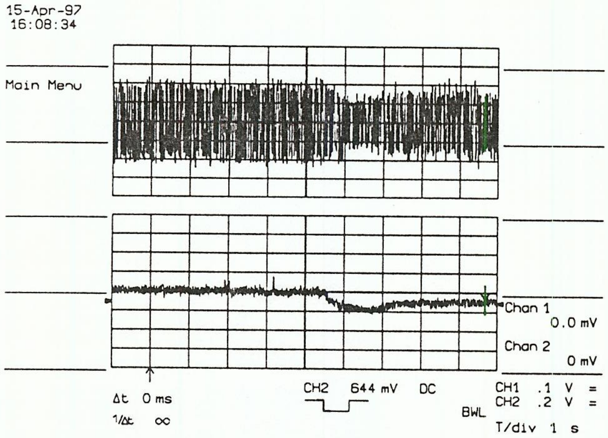

Figure 8: Oscillograms of the generator current and the rotor speed for a step load change from 5 kW to 2 kW of the wind power. Channel 1 10A/div, channel 2 500 rpm/div and 1s/div.

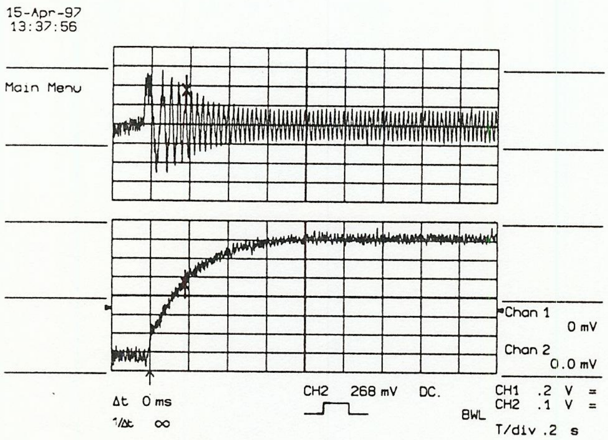

Figure 9: Oscillograms of the generator current (channel 1) and its speed (channel 2), when accelerating from 0 to 1500 rpm. Channel 1 20A/div, channel 2 250 rpm/div and .2 s/div.

Acknowledgment

This work has been partially supported by the Spanish *Comisión Interministerial de Ciencia y Tecnología* under project TAP–950371 and Desarrollos Eólicos S. A.

Appendix

$L_m(\Omega)$	74.91	$R_s(\Omega)$	1.0
$L_{\sigma s}(\Omega)$	4.03	$R_r(\Omega)$	1.12
$L_{\sigma r}(\Omega)$	3.51	p	2

Table 1: P. U. Induction Generator nominal parameters.

References

1. R. David Richardson and Gerald M. McNerney, "Wind Energy Systems", Proceeding of IEEE, VOL. 81, NO. 3, March 1993.

2. M. Godoy Simoes, Bimal K. Bose, "Fuzzy Logic Based Intelligent control of a Variable Speed Cage Machine Wind Generation System". IEEE, 1995.

3. Torbjonrn Thiringer and Jan Linders, "Control by Rotor Speed of a Foxed–Pitch Wind Turbine Operating in a Wide Speed Range". IEEE/PES Summer Meeting, Seattle, 1992.

4. A. D. Simmons, L.L. Freris and J. A. M. Bleijs, "Comparison of Energy Capture and Structural Implementations of Various Policies of Controlling Wind Turbines", Wind Energy: Technology and Implementation (Amsterdam EWEC'91).

5. B. K. Bose, *Power Electronic and AC Drives*. Prentice-Hall Englewood Cliffs, N. J., 1987.

6. E. Galván, F. Barrero, M. A. Aguirre, A. Torralba, L. G. Franquelo, "A Robust Speed Control of AC Motor Drives based on Fuzzy Reasoning", IAS–93 Annual Meeting, Toronto 1993, pp 2055–2058.

7. F. Barrero, E. Galván, A. Torralba, L. G. Franquelo, "Fuzzy Selftuning System for Induction Motor controllers", European Power Electronics EPE'95, Seville, Spain, September 1995.