DSP and FPGA Based System to Control a Wind Turbine Generator Implementing a Variable Speed Vectorial Control Method

M. Perales, F. Barrero, J.L. Mora, E. Galván, J.M. Carrasco 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: perales@gte.esi.us.es

Abstract— **The purpose of this paper is to describe a DSP and FPGA control system to implement a variable speed vectorial control . Two semi-systems, both of them consisting on a DSP, a FPGA and A/D, D/A & digital I/O's are used. Each one will control an inverter: The first inverter implements a variable speed vector control of the induction generator and the second one handle the power injected into the utility grid. Experimental results will be shown to confirm the validity of the proposed controller.**

I. 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 transmissions 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.

The paper describes a digital controller based on a DSP and a FPGA to implement these control policies. The controller has been evaluated using a the test rig including the power circuits and the control strategies, that will be described later. The paper has been organized in the following sections: section two describes test rig implementation and control algorithms applied to the induction generator. Next section describes the implementation of the proposed controller. Section four shows some experimental result confirming the performance of the prototype and finally, will be given some conclusions.

II. TEST-RIG DESCRIPTION

A. Power Circuits

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

1

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 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. Current controlled DC motor
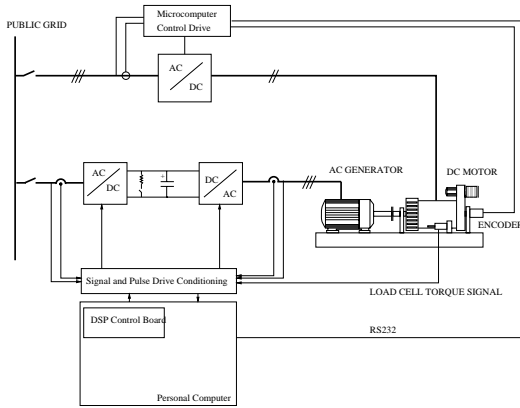

Figure 1: Power and Control Diagrams of the Test-Rig Variable Speed Wind Turbine
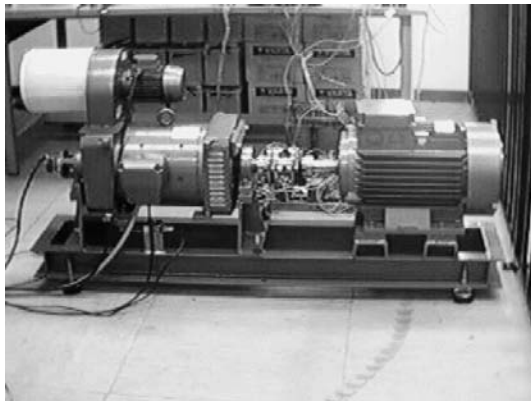

Figure 2: Photograph of the test–Rig.

is used to implement a Variable Speed and Pitch–angle Wind Turbine. In the wind turbine model 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.

B. Control Strategies

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 3. The rotor speed is added to slip speed to obtain the synchronous speed of the reference frames:

$$\omega_e = \frac{p}{2}\,\omega_r + KCV\,i_q \qquad (1)$$

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 4. A space vector
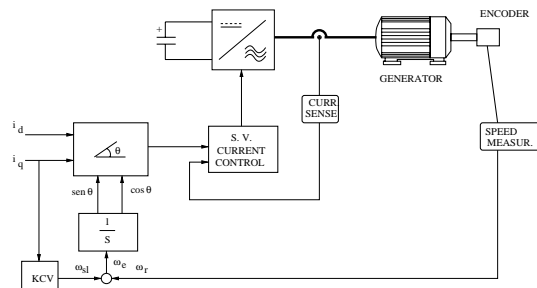

Figure 3: Indirect Vector Control Method Block Diagram.

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.
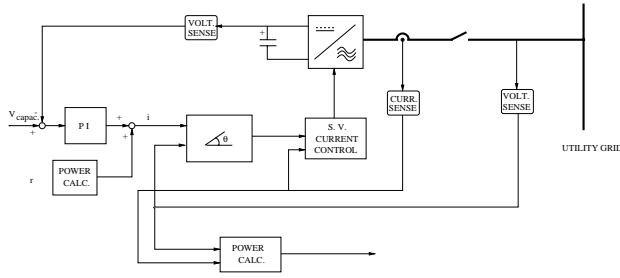
2

Figure 4: Public Grid current injection Block Diagram.

III. CONTROLLER IMPLEMENTATION

In this section it will describe the control system physically. The system itself is composed of two semi-systems, each one controlling a three-phase full-bridge inverter, linked together thru a Dual-Port Ram. in the Figure 5 we can see a global description of this system: In this figure, the main
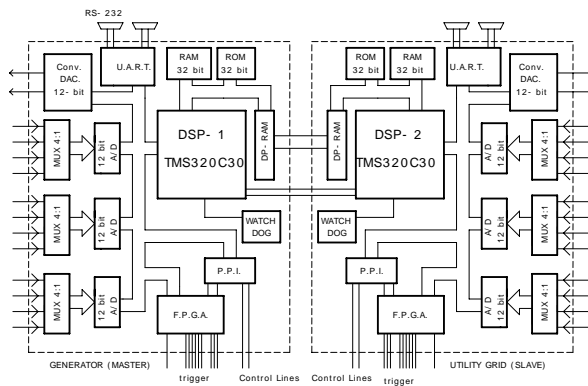

Figure 5: Overview of the control system implemented.

components are shown. They are: a TMS320C30, 40 MHz DSP, a FPGA as co-processor, a 8255 PPI, a 16552 DUART, a Watch Dog module, a Dual Port RAM to provide communication between subsystems, and 32 bit RAM and EPROM. Due to real time process requirements, and control two complex systems (two inverters) a floating point DSP was chosen. The FPGA used in the design was the TPC1020BFN-068C, and perform the following tasks: interrupt handling, address generation, speed encoder read, and managing triggers of the inverter.

IV. EXPERIMENTAL RESULTS

In this section experimental results obtained of the test-rig prototype are analyzed to evaluate the performance of the proposed controller based on a DSP and FPGA. Fig. 6 show oscillograms of the

injected current in the public grid in nominal conditions using the proposed control board, and the motor current. Fig 7 show oscillograms of the dc link capacitor voltage ripple, and the current injected in the public grid. 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 show oscillograms of the generator current and the rotor speed for a step load change from 5 kW to 2 kW of the wind power. The final offset, due to an unadjusted constant on the PI, is being corrected. Fig 9 show oscillograms of the generator current and its speed, when accelerating from 0 to 1500 rpm.
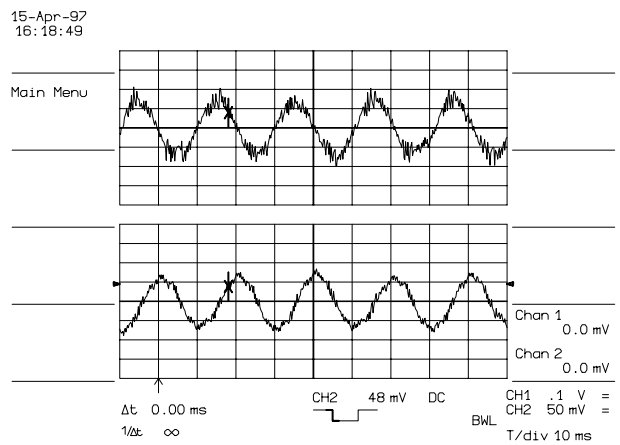

Figure 6: Oscillograms of the injected current in the public grid (channel 1) and the generator current (channel 2) in nominal conditions (1500 rpm 380 V). Channel 1 10A/div, channel 2 5A/div and 10ms/div.
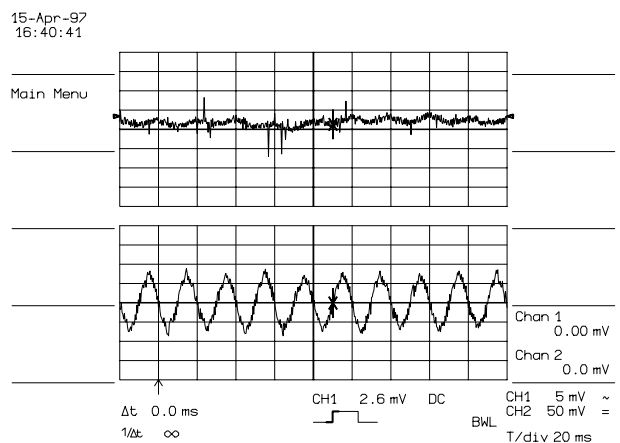

Figure 7: Oscillograms of the dc link capacitor voltage ripple (channel 1), and the current injected in the public grid (channel 2) in nominal conditions (1500 rpm 380 V). Channel 1 10V/div, channel 2 10A/div and 20ms/div.

V. Conclusions

A control board based on a DSP and FPGA is proposed in this paper in order to evaluate some control policies for wind-energy conversion systems. To confirm the validity of the propose control board and the control strategies a test rig prototype has been built in the laboratory. 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. The control of the generator has been implemented using vector control method and space vector current control. Preliminary experimental results confirming the validity of the control method proposed in the test–rig have been shown.
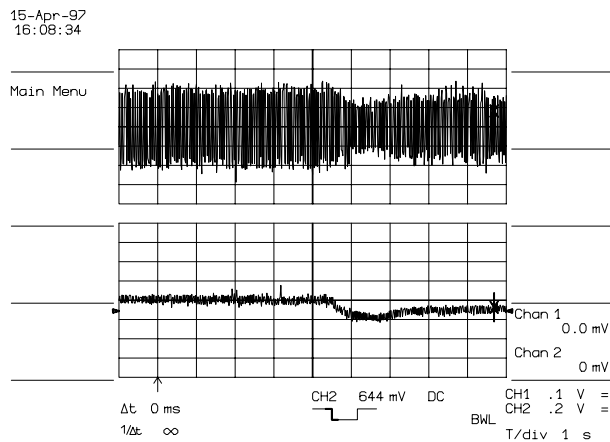
ACKNOWLEDGMENT

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.

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*, pp 2055–2058, Toronto 1993.

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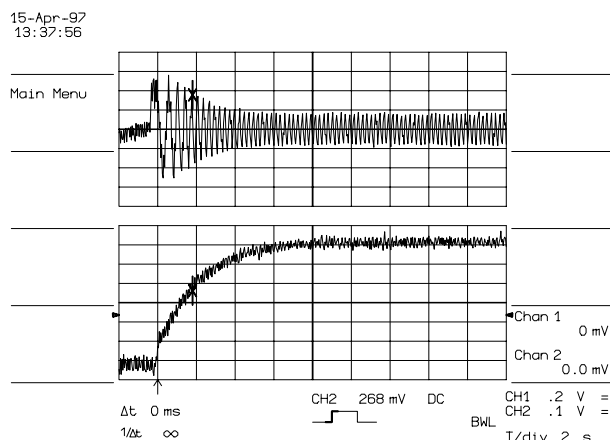EPE'95*, Seville, Spain, September 1995.