Novel control system based in DSPs for 800 KW wind power station

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Abstract

Wind energy conversion is a very mature technology. Its applications are widely accepted all over the world. Consequently, a tendency to erect more wind turbines can be observed. Therefore, wind turbines may gradually start to replace the output of conventional generators in the future, specially during low load situations with much wind.

The wind power has a huge potential to supply electrical power without generating pollution. It has the potential to provide many countries with more of one-third of their electricity demand.

A novel control system for a variable speed wind turbine generator has been developed in order to improve the wind turbine behaviour, the hardware is based in two digital signals processors (DSPs) in parallel operation, first one is a TMS320VC33, which manages all the signal analysis, control strategies, the protection systems and mechanical behaviour, and second one is a TMS320LF2407, that controls the PC monitoring program communication, the chopper and inverter PWM devices, temperature measures, encoders velocity and the programmable logic controller communication.

The conjunction of the variable speed constant-frequency operation with the digital signal processors capacities improves cost and reliability, low Harmonic distortion (THD), stresses reduction in the drive train, turbine efficiency, audible noise minimization, mechanical design, active power production, reactive production or absorption (leading or lagging power factor) and control strategies (PWM, for example).

Key words

Wind energy, PWM control strategy, harmonic elimination, variable speed control, power system protection, digital signal processors.

1. Introduction

This report gives results of an application of DSP based system control to enhance the performance and control of a variable speed wind generation system.

The control hardware is based on two Texas Instruments digital signal processor (DSP) boards which are placed in a designed board. DSPs TMS320VC33 and TMS320LF2407A based hardware with C control software was built. The theoretical development was fully validated, and the system is actually successful working in a 800 KW power installation.

The purpose of this research and development was to develop a control system (hardware and software) which could be versatile, optimize efficiency and enhance performance for a variable speed wind turbine electrical generation system by using DSP based hardware. The project involved system analysis, control hardware and software development for digital signal processors and experimental study in the laboratory and the field to demonstrate performance. Mainly, all system performance goals have been successfully demonstrated.

2. Hardware Control System

Hardware of wind power station control is based in three boards, measuring, handling and control board. Each board has a specific function, and they all are interconnected between them through screened wires. After this, the different boards and its functionality will be described.

A. Measuring Hardware

To measure the performance characteristics and behaviour of the 800 KW wind power station the following measures were used.

1) Three AC voltage inputs to measure line voltage.
2) One DC voltage input to measure DC link voltage.
3) Three AC current input to measure line currents.
4) One DC current input to measure DC link current.
5) One encoder input to velocity measurement.
6) Nine temperature inputs to measure power electronic temperature, as inductances or rectifier temperatures.

In addition a PC-DSP intercommunication software is used to monitor this measures in real time.

1) Current measurement

Chopper current and line currents are measured employing Hall effect sensors. It is necessary implement an adaptation stage, as shows figure1. 15 Khz first order low pass filtering, with pole location at

$$f = \frac{1}{2\Pi RC}$$

, variable gain amplifier, 800 Hz first order low pass filter and test point circuit have been implemented.

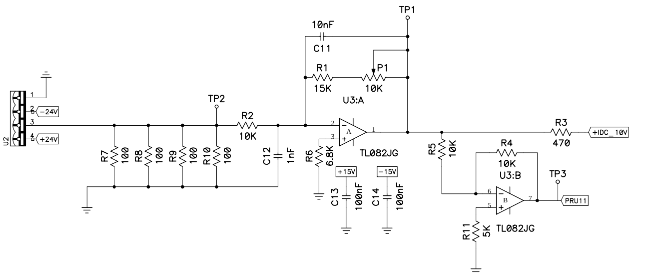

Fig. 1. Chopper measurement squematic

Line currents measurements are based in the following circuit:

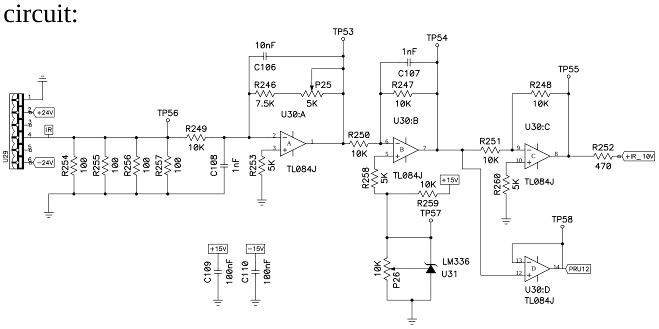

Fig. 2. Line currents measurement circuit

The input is low pass filtered,

$$f = \frac{1}{2\Pi RC}$$

the filtered signal is amplified and low pass filtered again using a first order filter of 1600 Hz. The signal has to be offset compensated and the output signal is:

$$V_{out} = -V_{in} + 5 \text{ Voltios}$$

2) Voltage measurement

Chopper voltage measure is implemented employing the following circuit:

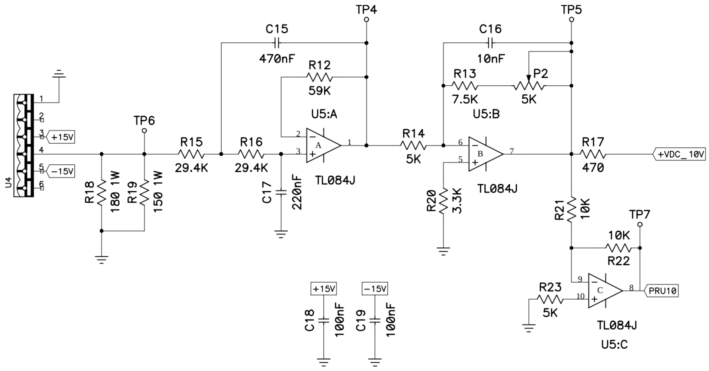

Fig. 3. Chopper voltage measurement circuit

The circuit is divided in the following stages:

1. 2nd order Butterwoth filter, $f = \dfrac{1}{2\Pi\sqrt{2}R15C17}$ =17

2. Variable gain amplifier and low pass filter, 1600 Hz.

$$A_v = \frac{R13 + P2}{R14}, \quad f = \frac{1}{2\Pi(R13 + P2/2)C16}$$

3. Output stage, overcurrent protection and test point circuit.

Line voltage measurement circuit is implemented as shows the following figure:

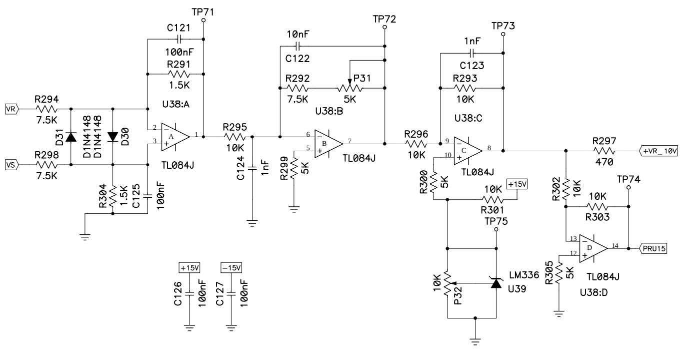

Fig. 4. Line voltage measurement circuit

Line voltage is filtered, amplified and offset compensated to obtain the adecuate output signal.

$$V_{out} = \frac{R291}{R294} \cdot (V_S - V_R) = -\frac{1}{5} \cdot V_{RS}$$

3) Temperature measurement

Temperature measure is a optical frecuency modulated input signal. It´s processed employing the following circuit.

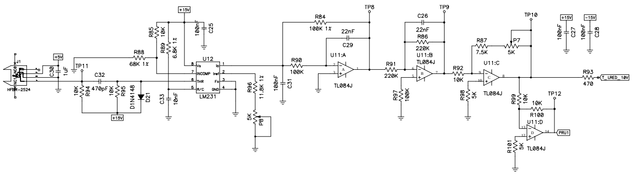

Fig. 5. Temperature measurement schematic

We can remark five different stages:

1. Voltaje-frecuency converter, LM331 based, voltaje output is proportional to frecuency input signal:

$$V = -F_{in} \cdot 2{,}09 \cdot \frac{R84}{R96 + P8} \cdot R89 \cdot C33$$

2. First order low pass filter

$$f = \frac{1}{2\Pi \cdot R86 \cdot C26}$$

4. Amplifier stage.
5. Output stage, overcurrent protection and test point circuit.

4) Encoder measurement

The encoder input signal is an analog voltage one, so an amplifier stage and low pass filtering, 1600, process is implemented.

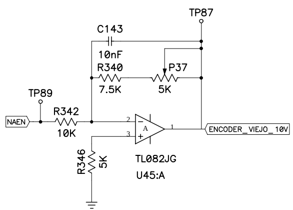

Fig. 6. Encoder measurement circuit

5) Chopper IGCT driver control

Chopper driver control signal is wired from the handling board and in the measurement board the error signal is analogic processed to avoid via hardware the chopper operation. Error signal is wired to control board to inform to the DSP about this event.

B. Handling Hardware

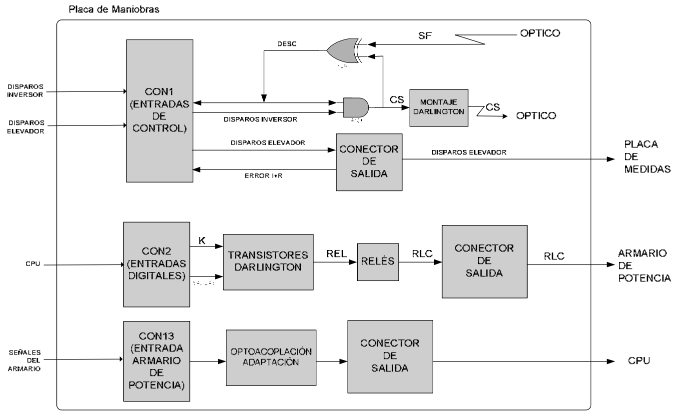

Fig. 7. Handling board squematic

Handling board is the control interface with the power electronic system. High power switches, IGCTs control, power electronic handling are mainly the functions of this board.

Inverter and Chopper IGCTs control is implemented employing optical fiber to avoid system noise and the consequent driver errors.

Optocoupled signals are wired to the control board and control board manages digital output to drive the power electronic hardware.

C. Control Hardware

Hardware control board is based in two digital signals processors (DSPs) in parallel operation, first one is a TMS320VC33, which manages all the signal analysis, control strategies, the protection systems and mechanical behaviour, and second one is a TMS320LF2407, control co-processor, that controls the PC monitoring program communication, the chopper and inverter PWM devices, temperature measures, encoder velocity and the programmable logic controller communication.

TMS320VC33 implements all control system of the chopper and inverter power system, and TMS320LF2407A is a co-processor that release of control task to VC33. The parallel operation requires the inter-communication beetwen both of DSPs. Two intercommunication implementations have been designed, one serial communication protocol based in synchronous serial port (SPI) and parallel communication protocol based in dual port ram.

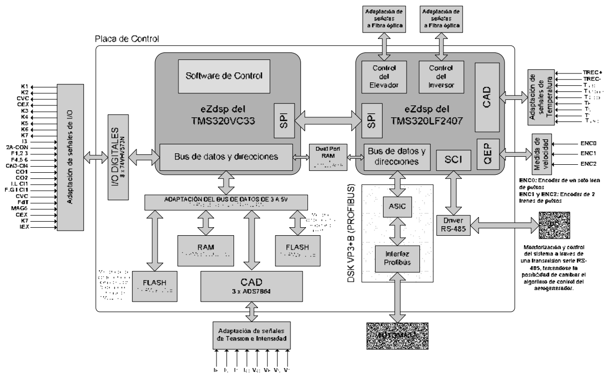

Fig. 8. Control board squematic

Hardware control board requires some additional components in order to implement system functionality and measurement and handling board interconnections.

Some of the most important elements employed in the system are the following:

1) EZDSP 2407
2) EZDSP VC33
3) 1 RAM memory
4) 2 Flash memories
5) 1 Dual Port RAM
6) 3 A/D converter
7) 8 Latches

1) EZDSP VC33

SpectrumDigital® eZdsps are been employed to interface DSPs and control hardware board.

The eZdsp VC33 is a stand-alone card that lets evaluators examine certain characteristics of the VC33 digital signal processor (DSP) to determine if this DSP meets their application requirements. This module has an on board JTAG Interface. Therefore, the module can be operated without additional development tools, such as an emulator. This module provides two expansion connectors for any necessary evaluation circuitry not provided in the as shipped configuration. This debugger provides assembly language and 'C' high level language debug capability through the integrated on board JTAG logic, or optional JTAG emulators.

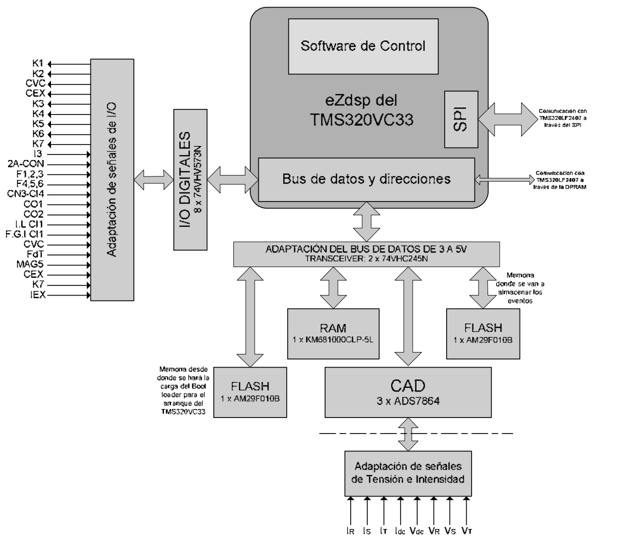

Fig. 9. EZDSP VC33 Block diagram

2) EZDSP LF2407A

The eZdspTM LF2407 is a stand-alone card--allowing evaluators to examine the TMS320LF2407 digital signal processor (DSP) to determine if it meets their application requirements. The eZdspTM LF2407 allows full speed verification of LF2407 code. Three expansion connectors are provided for any necessary evaluation circuitry not provided on the as shipped configuration.

To simplify the development of the code and shorten debugging time, a C2000 Tools Code Composer driver is provided. In addition, an onboard JTAG connector provides interface to emulators, operating with other debuggers to provide assembly language and 'C' high level language debug.

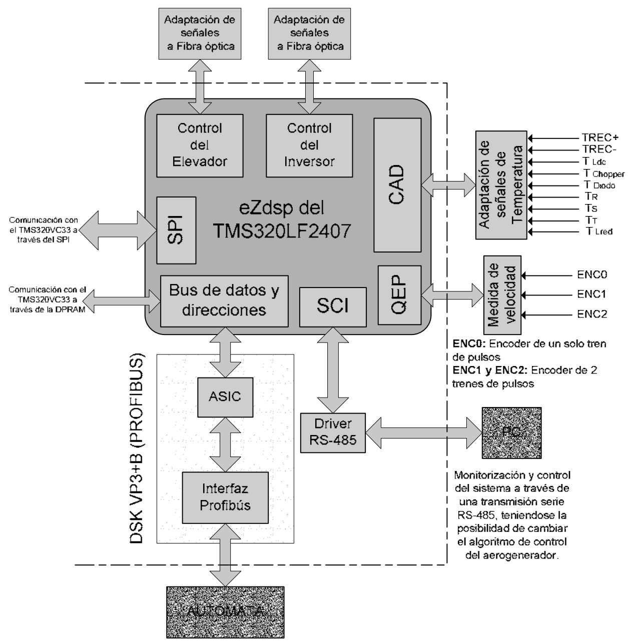

Fig. 10. EZDSP LF2407A Block diagram

3) AM29F010B Flash memory

Flash memories employed are AM29F010B based, with 70 ns of access time and 128k x 8 bits.

- Data Flash Memory: It stores different system events.

- Program control Memory: It stores TMS320VC33 control software. This software will be loaded in the DSP VC33 internal RAM memory. This allows that VC33 software control can be replace employing the designed PC monitor program.

4) Latch 74VHC573N

The VHC573 is an advanced high speed CMOS octal latch with 3-STATE output. This 8-bit D-type latch is controlled by a latch enable input (LE) and an Output Enable input. When OE input is HIGH, the eight outputs are in a high impedance state.

Eight latches are been employed, four input latches and four output latches, this is necessary to implement general purpose inputs and outputs signals for TMS320VC33 DSP. It provides of 32 digital outputs and 32 digital inputs for the VC33. These signals are connected to the handling board, which is the interface with the power electronic elements, and it enables the power switches control and monitor external signals.

5) ADS7864 converter

A/D conveter ADS7864 is a 12 bits converter with six channels and 2µs of channel sample.

6) Transceiver 74VHC245N

74VHC245 transceivers are employed to adapt external elements level signals and DSP bus.

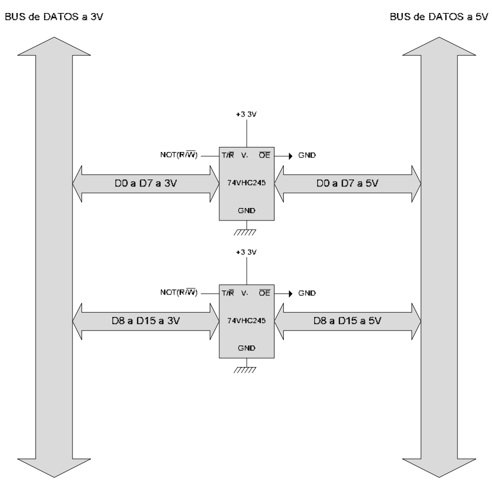

Fig. 11. 3.3V to 5 V data bus adaptation

7) KM681000CLP-5L RAM memory

128K x8 bit Low Power CMOS Static RAM is used to implement a store protection device. It stores important system information that could be useful in case of hardware control power supply transient absence that could unstable hardware control system of the wind power station. External power supply is implemented using two batteries that enables the permanent power supply of the RAM memory.

8) DSPs Inter-communication

Two methods of communication have been designed:

- Sinchronous serial port.
- Dual Port RAM.

Sinchronous serial port communication is based in serial lines availables in two DSPs, VC33 and LF2407. Connection circuit is shown in figure 12

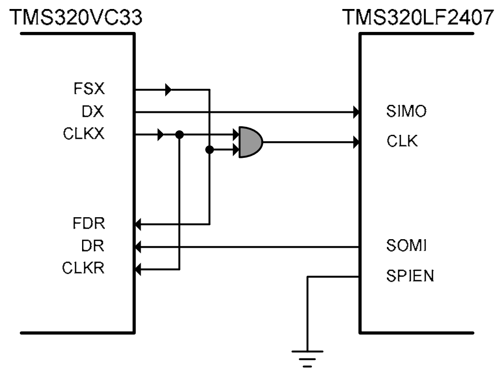

Fig. 12. SPI interface connection

Second inter-communication implementation is based in dual port RAM interchange of information. This Dual Port Ram is accessible to both DSPs.

9) PROFIBUS Communication

DSK VP3+B (PROFIBUS) is employed to manage control board and PLC communications.

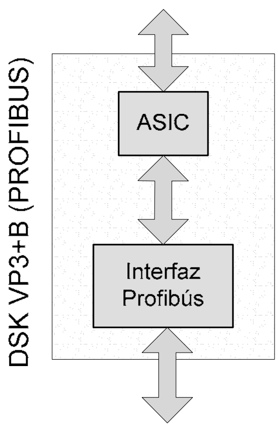

Fig. 13. DSK VP3+B block diagram

We can distinguish two blocks, ASIC VP3+B, where the PROFIBUS-DP protocol slots are implemented and the BUS adaptation circuit, RS485 or optical.

The VPC3+B is a pre-processing communication circuit with a processor interface for intelligent PROFIBUS-DP/DP-V1/DP-V2 slave access according EN 50170. VPC3+B handles levels 1 and 2 of the ISO/OSI-reference-model excluding the analog RS485 drivers. As the protocol handling is carried out completely in hardware, this ASIC is suited for time critical applications, even at high data transmission rates, up to 12 Mbit/s.

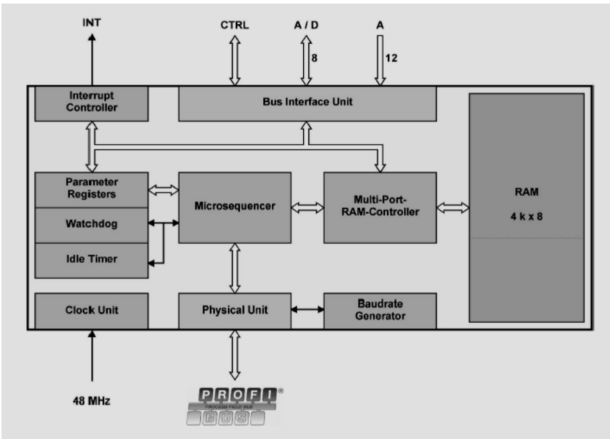

Fig. 14. ASIC block diagram

10) PC monitor programm communications

To comunicate control board with PC monitor program an optocoupled interface is going to be used.

RS-485 protocol has been employed for PC communication, RS-485 involves sending an inverted or out o phase copy of the signal simultaneously on a second wire. This is called a balanced transmission. Any outside electrical noise adds coherently to both signal copies. The receiver subtracts electrically this two signals to reproduce the original signal. The advantage in this substraction is that only the intended signal gets reproduced since they are out-of-phase. The in-phase noise on the two wires are also subtracted from each other to produce a net zero noise component in the reproduced signal. This noise immunity allows the RS-RS-485 interface to transmit digital signals at faster rates over longer distances than the RS-232/ SDI-12 interface does. The RS-232/SDI-12 interface does not use balanced transmission, therefore is susceptible to noise interference, which considerably limits the transmission distance and speed.

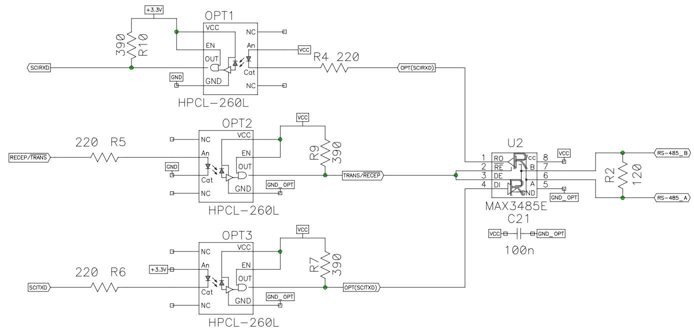

Fig. 15. RS-485 interface block diagram

6. Software Control System

A. *Development Tool*

Code Composer Studio™ Development Tool is employed due to its deeper visibility for a quick and precise problem resolution. It simplifies tedious guess work and enables a better management for real-time applications.

Code Composer Studio Debugger has DSP-specific capabilities and breakpoints to simplify development. Conditional or hardware breakpoints are based on full C-expressions, local variables or CPU register symbols. A General Extension Language (GEL) script file can also be executed when a particular breakpoint hits. Global breakpoints are also available for multiprocessor systems.

Code Composer Studio is one of the key components of the eXpressDSP Real-Time Software Technology that slashes development and integration time for DSP software, provides more choices for system ready software, and gets you to market faster.

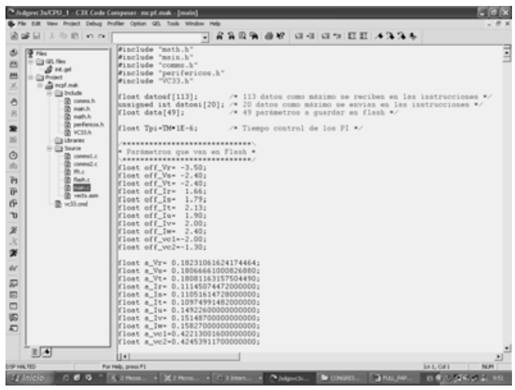

Fig. 16. Code Composer Interface

B. *TMS320VC33 Control Software*

TMS320VC33 software manages all the signal analysis, control strategies, the protection systems and mechanical behaviour

TMS320VC33 DSP has been programmed employing the Code Componer Tool in C language, the tool compiles this software and generates the assambler code. The state machine philosophy of control is an advantageous idea, in spite of the fact it implies a high programming effort. However, this philosophy improves the debugger task. A structured programming also improves the code compression.

In order to avoid aerogenerator structure and power conversion electronic damages the control software includes multiple software protections thanks to the sensor monitoring of the system, mainly with temperatures, voltages and currents measurements.

Inter-communications between both DSPs enable parallel information processing.

The control chopper and inverter strategies are easily interchangeable thanks to the DSPs digital control.

C. *TMS320LF2407A Control Software*

TMS320LF2407 controls the PC monitoring program communication, the chopper and inverter PWM devices, temperature measures, encoder velocity and the programmable logic controller communication.

D. *PC monitor interface*

A real time PC monitor software has been developed to monitorize system measures, implement a local control, plot important signals as PWM signals, intensities, indicate the system status, monitoring measures, manage alarm events, control errors, and save important results of the system. An historic file and an oscilloscope file are also generated to save in a directory of the computer. Communications between PC and control hardware are RS-485 protocol based.

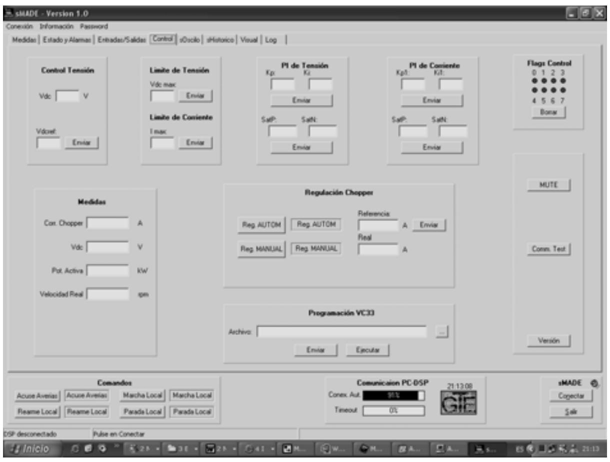

Fig. 17. PC monitor program interface (control section)

7. Conclusions and Results

The purpose of this research and development was to implement a control system (hardware and software) which could be versatile and optimize the time development and test of a variable speed wind turbine electrical generation system. In figure 18 we can observed the hardware implementation of the system. On the top we can observed the control board. VC33 and LF2407A eZdsps and profibus ASIC are connected to this board. Down, on the left, the adaptation board and on the right is mounted the handling board.

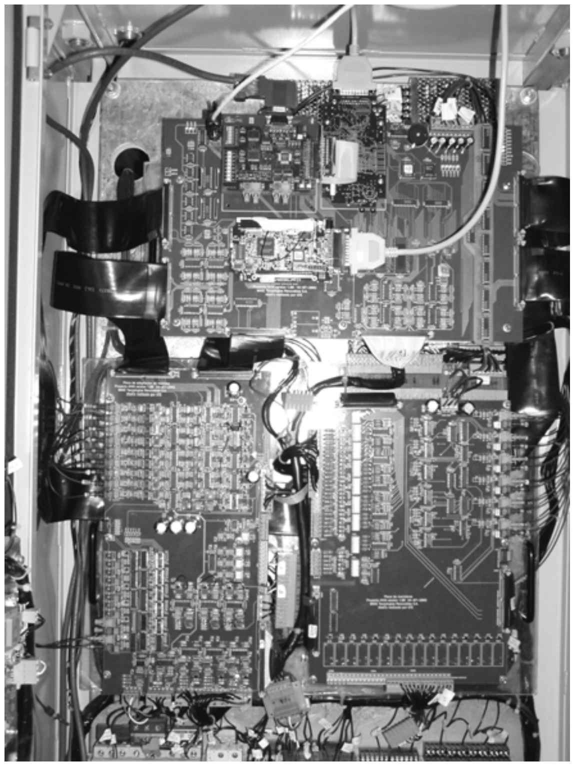

Fig. 18. Hardware implementation system

The software and hardware are been implemented successfully and have been tested on laboratory conditions.

Fig. 19. Power and control hardware system rig

Actually, control system is being tested in a variable speed wind turbine aerogenerator. The results of an efficiency and enhance performance of the implemented system for a variable speed wind turbine electrical generation system by using DSP based hardware is being waited and are optimist.

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