DIGITAL SIGNAL PROCESSING COURSE INNOVATIONS FOR POWER ELECTRONICS PRACTICE

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Abstract *- This paper describes a new course on Digital Signal Processing for Power Electronics Practice for undergraduate students of Electronics Engineering at Federico Santa María University of Technology. A comprehensive program was designed to develop practical experience on power electronics by employing a low-cost complete DSP-based module, based on the Texas Instruments TMS320F241 digital signal processor, developed by two graduate students. This new program has been successfully applied in lab activities on power electronics equipment such as single-phase inverters, single-phase boost rectifier and others. Two applications are described with methods and tools. Strengths and weaknesses of the proposed approach are analyzed integrating teachers' perspectives and students' feedback.*

Index Terms – Digital signal processor, Laboratory innovation, MATLAB-based interface, Software interface.

INTRODUCTION

Due to enormous technological advances, Digital Signal Processors (DSP's) learning and applications have become a fundamental part of the engineering teaching process. Every day the digital world is growing and more complex technology is being developed. It is imperative, to face this challenge successfully, so that students acquire a solid base and skills dealing with real designs and applications. The education process in digital signal processing is carried out commonly at undergraduate level, where many Institutes and Universities offer several DSP learning programs with a common basis including topics like discrete systems, Fast Fourier Transform, Signal Generation and Digital Filters. However, the real world is more complex than that and students need broader multifaceted knowledge to face increasingly more challenging tasks.

To accomplish that, an innovating digital signal processing course at undergraduate level has been proposed and implemented. A DSP-based card with simple and necessary features was used to help develop more applied knowledge in power electronics matters and digital control theory. Main features of the developed module are the functionality and availability of:

- Full DSP operation
- All ADC converters availability
- RS-232 communication
- General I/O pins
- Low cost
- Incorporated analog filters

All of these features allow the student to take full advantage of the design card and develop the tasks of power electronics not only in the monitoring of signals but also in the control of a given system.

In the following sections, methodology to develop real applications, fundamental concepts, and the results obtained in a semester from July to November 2002, are discussed.

DIGITAL SIGNAL LABORATORY APPROACH

The laboratory for digital signal processing at Federico Santa María University of Technology has been structured in such a way that the students acquire a theoretic basis on the most relevant topics of digital signal processing. At the same time students experience the conventional hardware of power electronics, such as the single-phase cells or boost choppers. In this approach, special attention is given to common algorithms of signal generation, digital filters and the Fourier fast transform. The mentioned topics are necessary, especially those involved with signal processing. This allows applying techniques to improve the conditions for analog signal acquirement [5] and thus, improving the quality of the obtained results in control, estimation, etc. After these topics are covered, students begin to experience different areas. Some are related to power electronics. Students must choose experiences that make them study power electronics devices and, at the same time, enhance their recently acquired knowledge of digital signal processing. To undertake the chosen tasks, students have about a two-month period; which may include 8 lab (5 hours each) sessions and the same two months for research work. Hardware handling is permitted only as scheduled.

A fundamental tool during the laboratory sessions is the software MATLAB. There are many areas where this software is a powerful tool for simulations and understandings of the theory involved [1]-[4]. In the lab, MATLAB enables the student to try the algorithms that will later be used on the DSP. This work begins with a simple sinusoidal signal, the generation of an AM signal, to the

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implementation on DSP of a fast Fourier transform (FFT) algorithm.

In the second part of the lab, MATLAB continues helping with the simulation and implementation of control systems for power electronics devices. During the simulations, it is possible to implement the electronic systems and during this implementation, it is possible to use it with the GUIDE tool, as an interface that allows the student to read data from the DSP and send data to switch variables or commands through the computer.

DSP-BASED BOARD FEATURES DESCRIPTION

As a part of a graded project, two undergraduate students developed a DSP-based card for the control of a brushless DC motor [6]. From this project, a robust and generic card, with interesting features that make it ideal for use in teaching activities, was developed. As mentioned before, the developed card includes the use of A/D converters, serial port RS-232 and dedicated pins for its utilization as digital ports. These peripherals are of great importance, as the student learns the most important tasks, from handling them, that familiarize him/her with methods of digital control.

From the TMS320F241 processor-based module, of low cost and a series of advantages related to hardware, two kind of power electronics controls have been developed. Both systems require a minimum hardware for proper operation.

Analog to Digital Converters

The A/D converter of the DSP has 8 multiplexed channels. These have been enabled on the card in a way that access is granted to each one of the eight channels. Since this module was conceived for the acquirement of thee-phase currents; a system of analog low-pass filters has been designed on the channels 0 and 1 of the converter to avoid aliasing. These have a quality that can be modified on their cut-off frequency only by modifying the values of few external resistance. The filters are based on the use of integrated circuits designed for that task [7]. The A/D converter of the DSP can only work with voltages in the range of (0:5)v. For that reason, an additional circuit has been provided. It applies an offset voltage of 2.5 v, which is used as a level for the digital zero that is internally subtracted for representing digitally negative voltages or currents as two-complement numbers. The remaining six channels have input buffers to limit the voltages and adapt the inputs impedance. Thus, any other variable to be measured (at channels 2 to 7) must consider the use of anti-aliasing filters with an adequate cut-off frequency for the application in progress.

RS-232 Communication

One of the most relevant features of the designed DSP module is the communication ability of the DSP with the computer (PC) through the serial port and the communication protocol RS-232.

The serial communication between the DSP and the PC allows the programming of the DSP using only this interface; it means that no additional hardware is required for programming. This represents the advantage of having a low cost card implemented in the classroom. Moreover, it represents the possibility of easy communication of variables and data between the computer and the DSP. The main disadvantage is the impossibility for on-line real-time communication when high sampling rate or a great amount of calculations must be done by the DSP. However, when an application such as a motor control is done with sampling less than 1 kilohertz, it is possible to have an exchange of data without any loss.

Digital Ports

An important feature of the DSP TMS320F241 is its capability as a DSP controller. Its manufacture contemplates special digital ports to be used as dedicated pins for the generation of PWM signals, which are chained to the inner timers and registers of the DSP. The designed module considers the use of these ports, leaving them in an easy access position on one side of the card.

Figure 1 represents the DSP board used for experiments.

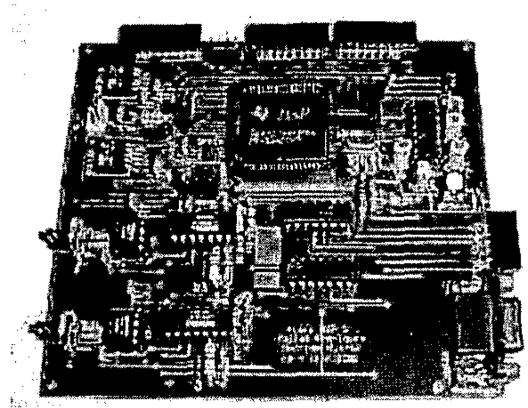

FIGURE 1
DSP BOARD USED FOR EXPERIMENTS

THEORETICAL BASES FOR DIGITAL CONTROL OF POWER ELECTRONICS DEVICES

The main objective for the use of a DSP module, is to give students a practical basis on the implementation of control systems for power electronics equipment. Based on that, two power systems are presented as alternatives for students to choose and to do the programming of a control system.

In the implementation of a control system, a series of concepts, related to the digital control, must be used besides the necessary understanding of the functions of the power equipment. Among the most important topics to be considered in order to have a robust and efficient implementation are:

- Data acquisition via the A/D converter
- Digital handling of the obtained data
- Binary representation in two-complement
- Anti-aliasing filtering
- Knowing the Nyquist theorem

The main objective of the DSP lab is to teach digital signal processing. That is why the power electronics topic is secondary, but not irrelevant. Based on the applications designed for the work of the students, there is consideration of both software and hardware. The hardware work consists on knowing and adequately configuring the necessary peripheries in order to complete the control tasks. This includes the instrumentation and the connection of the DSP to the power equipment. On the software side, the student must program the peripherics (timers, ADC, I/O ports) to be properly used.

On the following sections the equipment used for the practical experiences is described. The equipment is:

- Three-phase power cell
- Boost rectifier

Single-phase cell

The multi level converter applications use single-phase cells as integrating parts of a higher voltage system [8]. These cells generally have a three-phase source, although each cell can work in a single-phase configuration, handling a DC link-voltage that will be used to generate different voltage levels on the output of the inverter, see fig. 2.

There are many possible applications of this configuration [8], [9], [10], which is why we believe that its study gives the student a modern and applied perspective of equipment used nowadays.

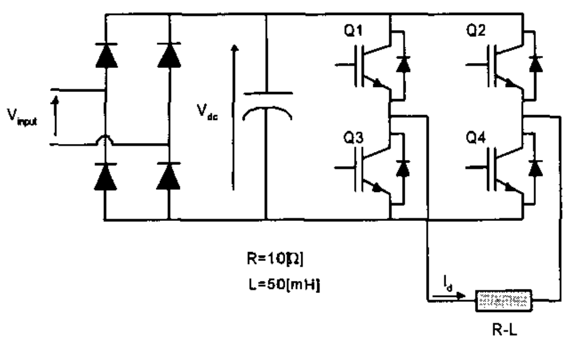

FIGURE 2
MONO-PHASE CELL

Due to its simplicity and easy construction, this cell has been chosen for the student to take advantage of the DSP potential. To achieve the objective planned for the lab, it is necessary that the student uses ADC converters, digital PWM ports and the serial communication interface RS-232. This work implies that the student must know the architecture of the DSP in order to adequately configure the peripherics, timers and interrupts, that must be handled in a joint way for generate the sample frequency and the commutation frequency of the cell semiconductors.

The scheme required for the student to be implemented in the lab is detailed in fig 3.

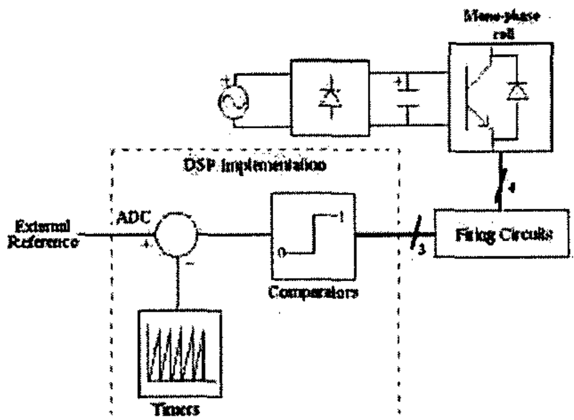

FIGURE 3
DSP AND POWER SYSTEM

From the circuit in fig. 3, the student is expected to be able to generate a continues current and a sinusoidal current of any frequency (as the external signal of reference) on the load. The expected results for full development of the experience are:

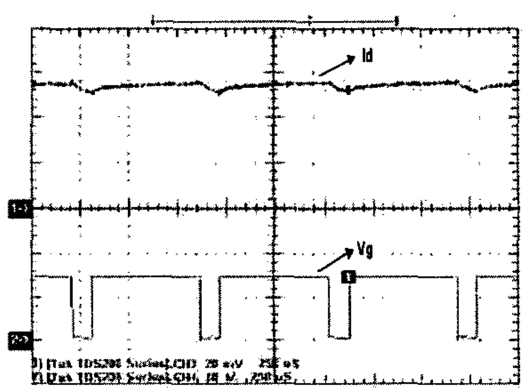

FIGURE 4
CURRENT AND VOLTAGE. CURRENT SCALE: 4 AMP/DIV, VOLTAGE SCALE: 10 V/DIV.

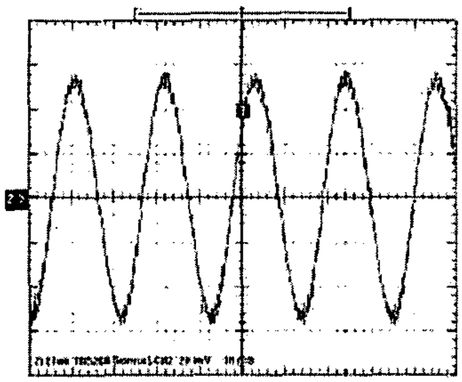

FIGURE 5
SINUSOIDAL CURRENT. CURRENT SCALE: 4 AMP/DIV

Due to the configuration used to trigger the power semiconductors, it is necessary to configure a dead time on each commutation. This time must be correctly set on the DSP inner dead time generator. These are applied internally to the DSP digital outputs.

Boost Rectifier

For a second circuit to work on the lab, a boost rectifier has been chosen. The main advantage of a boost rectifier is that it has a power factor very close to 0.99 and a low harmonic distortion (< 5%), this means that there is no disturbance on the feeding line.

The circuit used is shown in fig. 6

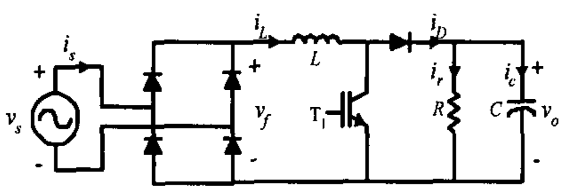

FIGURE 6
BOOST RECTIFIER DIAGRAM

The objective of this circuit is to generate a voltage V_o towards a higher charge of rectified voltage V_s. The current i_s can be controlled to be in phase with V_s, and in that way obtain a power factor close to 1. As shown in fig 6, this circuit has only one semiconductor, which operates as an interrupter to charge or discharge the inductance *L*.

As well as in the single-phase cell, the requirements of the control system demand that the ADC circuits, digital port, timers and interrupts be properly configured to achieve the correct control of the system. In fig 7 a diagram of the used control is shown:

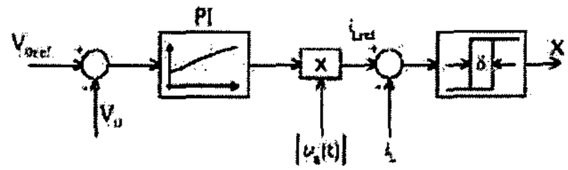

FIGURE 7
DSP AND POWER SYSTEM

The objective of this experience for the student is to close a voltage and a current control loop. Three variables must be measured. Clearly, this control scheme is more demanding and harder than the single-phase rectifier. For its implementation additional concepts related to the digital handling of signals are required.

From this circuit and its control, the student is expected to first do a simulation to verify the theory and make sure that he/she knows the behavior of the variables. Since the system is conceptually simple, it is easy to program as block diagram and simulate it on MATLAB-SIMULINK. The typical waves to be observed are shown in figs 8 and 9:

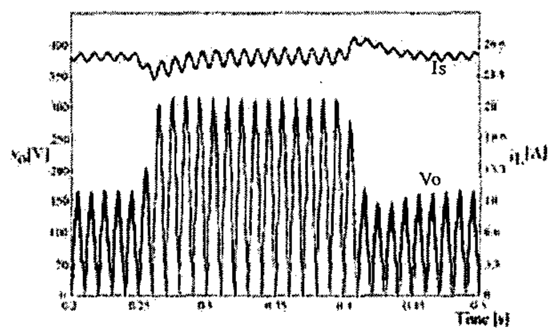

FIGURE 8
INDUCTOR CURRENT AND OUTPUT VOLTAGE

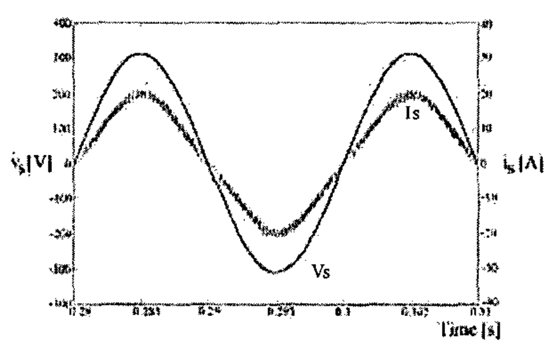

FIGURE 9
VOLTAGE AND CURRENT ON THE SOURCE

MATLAB INTERFACE

As an important part of the power electronic practice in the lab, it is considered necessary for students to interact with the DSP. For this purpose, a graphic interface has been created with the help of the tool GUIDE of MATLAB. This interface allows the student to read and write data from and to the DSP. The interface can be easily used and is very versatile. By changing only one line of code on the DSP program, it is possible to change the instruction or data that the computer, through the GUIDE-based application, can send or receive. The next figure shows the interface created for lab use.

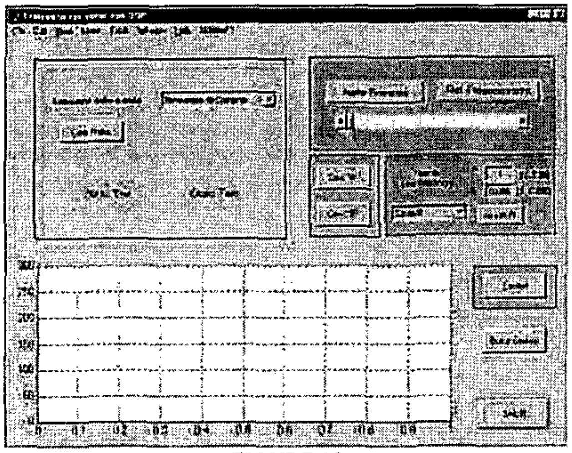

FIGURE 10
MATLAB INTERFACE FOR COMMUNICATION PC-DSP

As shown in the figure 10, the possibility of showing the signals readings from the DSP allows a diagnosis of the written code and allows making a semi-debbuging. It is possible to choose more than one variable to graph, which has to be previously programmed on the DSP in order to visualize it.

As shown with the boost rectifier control, there is a PI controller whose constants can be changed (integral time constant and proportional gain). The interface considers the possibility of changing this data on-line for new ones. Due to the existence of the characteristic of reading analog data over the 0 and 1 channels, a routine has been added (programmed on the DSP) to eliminate the offset of the measuring systems, that generally are signals from current sensors. The elimination of the offsets is achieved by the acquisition of successive data. These are averaged to obtain an offset fixed value, that later is subtracted from the rest of the acquisitions.

Due to the simplicity of the DSP computer interface, a few directives on how to change the value of the data are given to the students in order to enlace the GUIDE to the DSP. Next, a table is shown with some of the required codes to establish communication for the transmission and reception of data:

TABLE I
CODES FOR DSP-PC COMMUNICATION

ASCII HEX Code	Command	Data Direction
41	Channel 0 reception	DSP TO PC
42	Channel 1 reception	DSP TO PC
43	-1 * (Channel 0 + Channel 1)	DSP TO PC
50	Reception	DSP TO PC
49	Controller proportional gain	DSP TO PC
20	Adjust	PC TO DSP
21	Controller integral gain adjust	DSP TO PC
58	PI controller start/stop	DSP TO PC
59	PI controller result	DSP TO PC
5A	Reeds a DSP internal variable*	DSP TO PC
22	Reeds a DSP internal variable*	DSP TO PC
23	Reeds a DSP internal variable*	DSP TO PC
	Channel 0 offset adjust	DSP internal
	Channel 1 offset adjust	DSP internal
	*Configurable as needed	

As seen, the transmission and reception of the data can be done with the simple communication of codes to the DSP. These codes are interpreted by the DSP as data to change the configuration or as instructions to send required content of one or more inner registries of the DSP to the computer. This allows, as previously mentioned, the students to perform an on-line semi debugging and judge if the results are the expected or not.

COMMENTS AND CONCLUSIONS

A new course on Digital Signal Processing for Power Electronics Practice for undergraduate students was presented.

The systematic work developed by the students was described, where students must not only work with DSP technology, but also with power electronics devices and the necessary theory for understanding digital processing, data acquisition and power electronics devices, among others.

Feedback from the students was considered a key issue in the beginning when the laboratory was implemented.

The teams concerned with the work with single-phase cells gave good comments and were satisfied with the results and their gained experience.

On the other hand, the teams working with the boost-rectifier found that the work was harder than expected and their schedule was not met. The main reason for this situation was the complexity of the work. In addition to digital processing concepts, PI controller tuning, efficient C-code, conditioning circuits (instrumentation) for A/D conversion were aspects whose solutions demanded more than the assigned weekly laboratory hours. Therefore, this experience must be improved with better hardware modules and an improved prepared strategy.

We believe that students must concentrate their efforts on the Gcoding, the digital processing and the power electronics concepts. Hence, all the necessary conditioning circuitry will be given with the condition that they must tune the low-pass filters, and generate the proper signals to the firing circuit of the power semiconductors.

A major conclusion is that this work has provided the necessary conditions for creating a novel approach to the digital signal processing laboratory, based on the students experience and feedback. This laboratory integrates concepts in the domain of digital systems and power electronics.

We are sure that the main objective, which is the hardware hands-on experience, was achieved despite the observed difficulties.

The proposed laboratory has provided students with practical activities for better handling and integration of concepts related to:

- Analog to Digital conversion.
- Nyquist theorem knowledge
- Two-complement digital numbers representation.
- Work with modern DSP's.
- Digital filter theory
- Power electronics experience

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