LOW COST VERSATILE POWER ELECTRONICS TEACHING PLATFORM

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***Abstract* – Despite the importance of power electronics devices and the growing number of applications in the market, there is still a lack of low cost teaching platforms, which can be used by teachers to improve the education of Power Electronics in universities. This would provide a meaningful "hands on" experience to students.**

This paper describes a Power Electronics Teaching Platform, which was elaborated, built and tested in the UNICAMP laboratories with the objective of becoming part of the curriculum for the undergraduate power electronics laboratory discipline.

The system has been used as an inverter to drive an induction motor, showing interdisciplinary principles of power electronics, electrical machine drives, control and programming.

With a few external connections and some software reprogramming the system can also be used in other experiences involving power electronics e.g. switching-mode power supplies.

***Keywords* – Power Electronics Education, Power Electronics Teaching, Computer Aided Learning.**

I. INTRODUCTION

The development of real applications in Power Electronics is a complex and challenging duty. It requires a link between the hardware resources and the control theory along with knowledge of digital signal processing, power electronics devices and electrical machines (if applicable) [1].

The computer can be used to aid in learning, not only with simulations, which are undoubtly important, but also integrated with real power electronics circuits, providing results in real time for the user as well as a unique learning experience. Yet, there are few experiments combining computer assisted learning (CAL) tools with real applications [2].

Nowadays, web-based virtual laboratories are attracting attention amongst the engineering community as being a valuable learning tool. They help students to verify actual results from experiments in power electronics, however, virtual laboratories don't provide real contact with the equipment and devices under study [5] [6]

This paper gives a detailed account of a teaching platform whose objective to introduce gradually the students from the initial theoretical learning to practical experiences in laboratory in a shortened cycle.

In a more advanced course the student could also develop their own control strategy, by creating new control routines or even programming a new application using their own software algorithms and hardware interfaces.

In the first phase we focused the driving of induction motors, because of its wide application in industry (many times it is driven by a frequency inverter).

The elaboration of the system was based on the idea that it would be used by undergraduate students for their first course on power electronics.

Our main objective in the designing of the system was to create an open-box approach, that is, to clearly exhibit to the end user how the system works, without hiding details of the project from the user. The system was designed, as much as possible, to be easily understood. We also looked for a user friendly interface and protection system against failures or misuse.

All the project and software are accessible to the student as well.

In addition, the embedded control systems used for educational purposes must be simple, interactive, and their functionality must be adapted to the student´s level as well as to its final application. Systems providing quick learning and effective experiences are highly desirable [3].

The control algorithm should be implemented on DSP or microcontroller due to their flexibility. Windows and Linux operational systems were not developed for real-time control applications. Thus, DSPs and microcontrollers have high software flexibility, real-time performance and require low development cycles [4]. They have A/D and D/A converters, PWM generators and other peripherals implemented onto their boards. It is important to note that computers are very useful to implement advanced graphical resources in order to design the appropriated controller for a specific plant. Additionally, they are essential for performing the simulations and the analysis and visualization of the results.

II. SYSTEM DESCRIPTION

A. Hardware

The system is comprised of two Printed Circuit Boards (PCBs), one with the processing and interface circuits and the other with the power and protection circuits.

Fig. 1 illustrates the implemented system. The PCB in the center of the picture is the Processing and Interface Board (A), where the microcontroller is located. It is possible to see the serial cable (which connects this board to a personal computer).

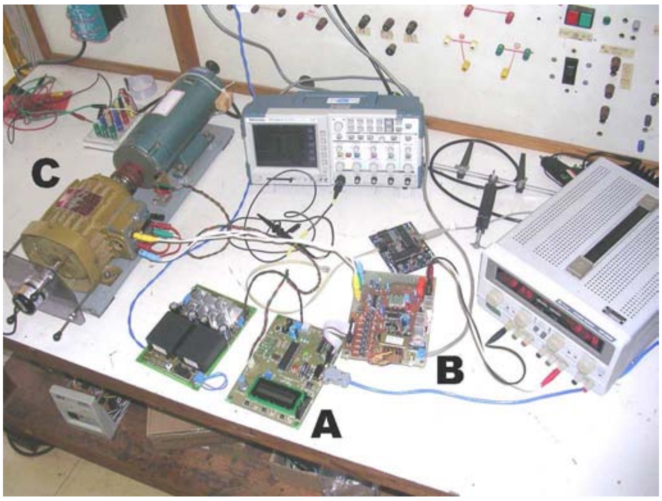

Fig. 1: Experimental prototype used to drive an induction motor.

The PCB on the far right (B) is the Power and Protection Board to which the induction motor is connected. The DC link must be connected externally from an isolated power supply (for user protection).

The motor used in our tests (C) is a three phase induction motor, 0.5 hp, 220V.

The Power and Protection board is based on the IRAMS10UP60A, a low cost power integrated circuit (we bought it for R$ 85.00) containing 6 IGBTs (in a three-phase inverter bridge configuration, as show in Fig. 2), their drives and a thermal protection. The IGBTs are rated 600V, 5 A_{rms} @ 100 °C.

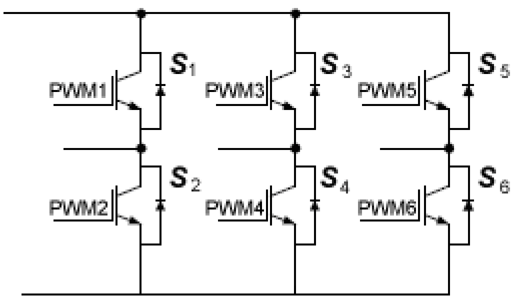

Fig. 2. Three Phase Inverter Bridge.

Although the DC-link must be externally connected, the board has its own power supply for logical circuits. It must be connected to a 127V or 220V (-10% +5%) AC power source.

The Built-In thermal protection is based on a NTC and shuts down the system if the temperature measured exceeds a defined range.

The input and output signals are optically isolated, providing additional security to the user.

During our experiments we found that if the logical circuits of IRAMS10UP60A are fed with a voltage lower than its datasheet recommendation, it can result in an erroneous switch turn on. To avoid this, we provided an under-voltage protection to safely turn off the inverter if the voltage is too low.

There is also an over-current protection designed to act quickly (within a few microseconds) whenever the current in any switch goes beyond an adjustable level (implemented with fast comparator integrated circuits). It can protect the system in the event the user tries to start the motor at full speed (resulting in a current too high for the IGBTs). This protection is not designed however to act in a situation of prolonged periods of small overload (this situation prompts the thermal protection to act).

The Control and Interface PCB is built with a low cost 8-bit PIC18f4431 microcontroller (bought for R$35.00), which can run at a maximum of 40MHz (we are using it at 20MHz).

The board has a RS232 serial port, used with the serial PC connection.

It has an output buffer for the signals to the power board, which protects the microcontroller in case of an external failure or inappropriate connection. There is an input for the tachometer and an additional input for an encoder (if more precision is required).

B. Microcontroller Software

The microcontroller was programmed in C language, with critical routines in assembly code and compiled using the PIC-C CCS® compiler. The microcontroller software is responsible for executing all the control routines in the system, providing a basic interface thru an LCD display and communicating with the PC software using a dedicated protocol.

C. PC Software (Graphical User Interface)

The code was written in C++ and the data transfer is carried out by Windows® API functions for serial communication. The Windows Driver Model (or device drivers) can optimize the managing of data exchange between GUI and the control unit. Additionally, this tool enables USB communication.

Due the relatively slow speed of the serial communication when compared with the sampling rate of the signals in the microcontroller, a sub-sampled strategy was used. This strategy doesn't generate any limitation to the system because all the control routines are running in the microcontroller and, due to slow response of the system, the communication speedy is enough to provide good graphical results.

III. APPLICATION

The system can work in two modes: stand alone and PC-connected.

In <Stand Alone> mode the interface with the user is made using an LCD display of 2x16 characters, a potentiometer, and three push buttons, as illustrated below (Fig. 3):

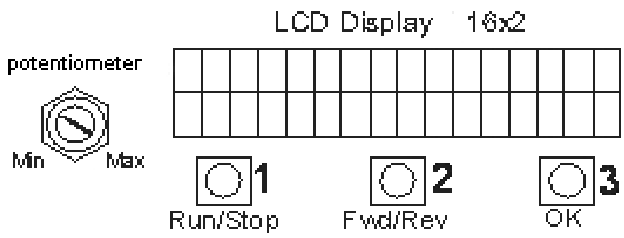

Fig. 3. Schematic view of LCD Display.

In this mode, the student turns on the device, he is then asked to configure the system. First the user can adjust the type of modulation (to change independently the voltage or frequency) or change both voltage and frequency simultaneously in the V/f method.

The user then needs to adjust the control to open loop or closed-loop (this is not yet implemented in the software). After setting this, the user can start or stop the motor by pressing the Run/Stop button, change its direction with Fwd/Rev, and adjust its speed using the potentiometer.

The LCD indicates:

- The synchronous frequency,
- The peak output voltage of modulated sinusoid with respect to DC-link voltage (that is, the maximum duty cycle)
- The measured velocity
- The reference velocity (if in closed loop mode).

In <PC-connected> mode the student uses a GUI, shown in Fig. 4. Using the sliding bar on the left, the user can adjust in real time the synchronous speed of the motor. The resulting graph appears to the right, showing velocity.

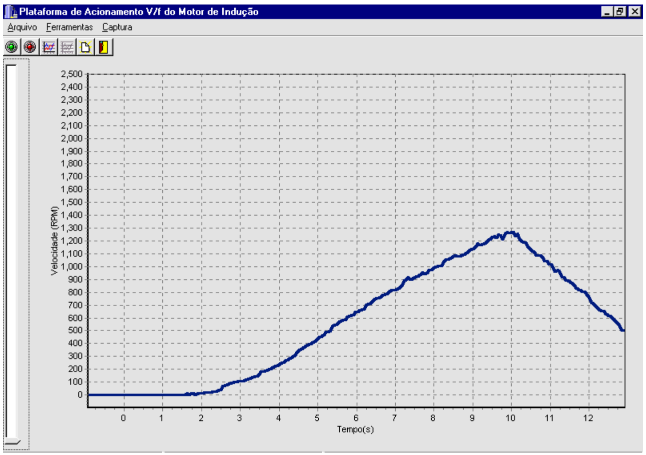

Fig. 4. Graphical User Interface.

When selecting the go button (far left side), the parameters are sent to the microcontroller. Even if the process is running, the control unit can modify on-line the parameters.

The results are shown on the computer screen, similar to an oscilloscope.

IV. EXAMPLE OF EXPERIMENTS

The experimental results in this section were obtained from voltage/frequency (*V/f*) open-loop control of a three-phase induction motor, 0,5 hp, 220 V.

Several measuring points are available in both PCBs so the student can observe a set of electrical signals with the aid of an oscilloscope. The teacher can guide the experiment, suggesting signals to be observed and asking the student to explain some of the devices functions.

We will explain some experiments could be done in an Power Electronics Laboratory Class. Of course many others are possible.

In the first contact with the system the student will notice that the system can measure the velocity of the motor.

But how it is done? That’s an opportunity for the student to explore the generation of the signal in the tachometer phototransistor, which uses a disc with holes to modulate the light produced by an LED.

Fig. 4 shows this signal (which goes to an input of the microcontroller and is used to calculate the rotational speed of the motor).

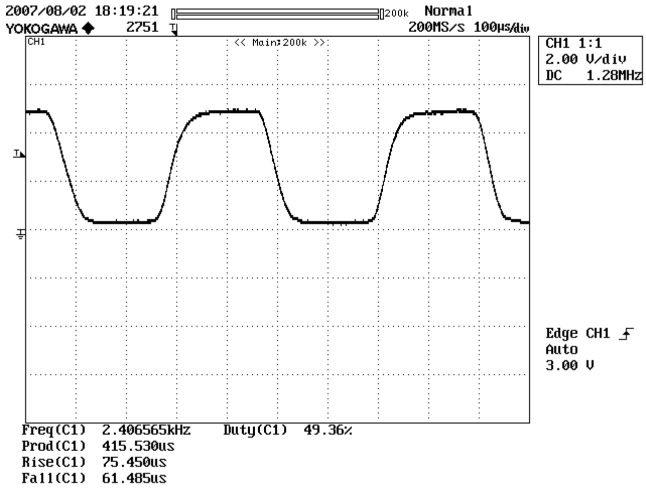

Fig. 5. Example of digital signal tachometer.

Observing this signal, the student can conclude that the frequency is speed proportional. He or she can even calculate the speed based on the number of holes in the disc.

The heart of this inverter is the generation of PWM signals in the microcontroller, which can be compared to the power switching voltage, as shown Fig. 6. The microcontroller was programmed to create an 1.5 µs dead-time, as can be seen in the top part of Fig. 6. This figure shows the delay in the turn-on of the switch as 0.5µs.

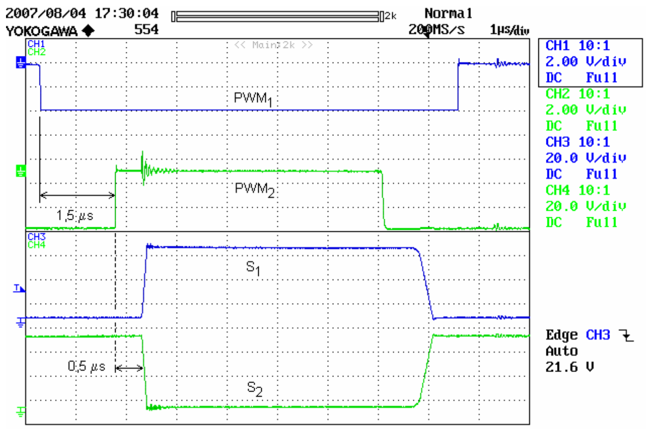

Fig. 6. Drive signals generated in the microcontroller (top graph) and power switch voltage (bottom graph).

We can also see in Fig 6 that the voltages applied to the motor’s terminals are a pulsed waveform (PWM technique) and not a sinusoid, as one might expect before being introduced to power electronics. Interestingly, the current waveform in the motor really resembles a sinusoid, as shown in Fig 7.

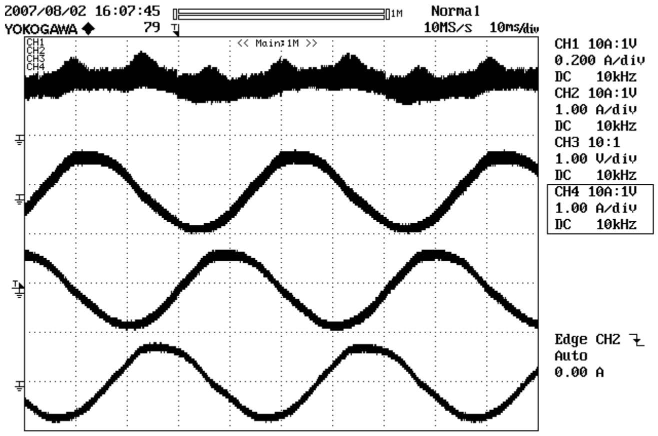

Fig. 7. DC-Link current (CH1, in the top of the figure) and currents in the motor (CH2, CH3, CH4)

At first this may be strange to the student, but looking in detail to the current waveform (Fig. 8) it can be seen that sinusoidal format is made by a switched pattern, explained in time domain by the limitation in the derivative of the current by the inductance of the motor. In frequency domain this is called filtering.

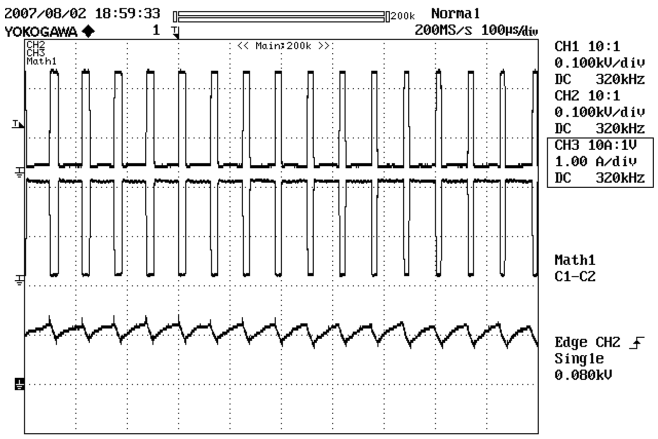

Fig. 8. Detail of voltages in one leg of the inverter (top and middle) and current in the motor.

Another experiment that enriches the conceptual understanding of the student is the measurement of the power loss in a switch, which plays an important role in the efficiency of the system.

Fig. 9 shows the voltage, current and power in a switch while the system is used to drive the motor.

It is possible to observe the switching (turn-on and turn-off) power losses and the conduction power loss.

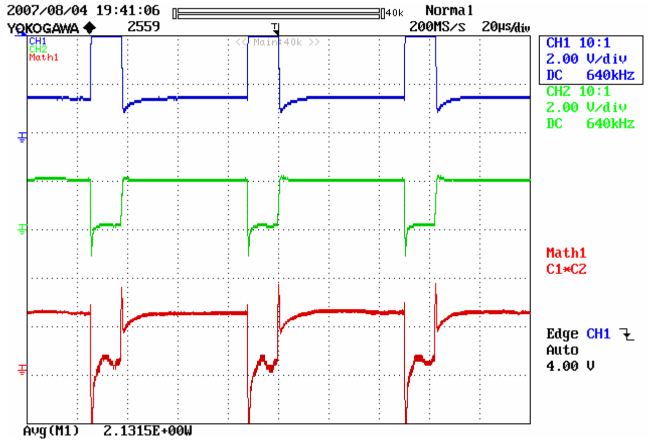

Fig. 9. Voltage (top), current (middle) and power (bottom) in a switch.

In more advanced courses, the user can change the software and add external components to build new devices. The disposition of the switches makes the system highly flexible. Examples include: switching-mode power supplies, power conditioning for alternative sources of energy, grid-connected inverters, class D switching subwoofer power amplifier, amongst many others possibilities.

V. COST

The cost of building the system is mainly the cost of the IRAM integrated power circuit, the PIC, and the PCB fabrication (we spent R$50 on each for 10 units). The system can be made for less than R$ 250.00.

VI. FUTURE IMPROVEMENTS

Further improvements include:

* Closed-loop control;
* Vector modulation option;
* Isolation and conditioning of the current signal (which is already measured) that could be used by the microcontroller in a current control loop;
* Voltage measure to the DC link that (together with the current measure) would make it possible to display the current, voltage and power information to the user in real time;
* The next version of the PC software will include a load file for profile speed generation. It will allow for driving cycle emulations (necessary to evaluate the performance of an electric vehicle system).
* We plan to organize all the material about this project and make it accessible in the internet so anybody interested in using the system can copy or improve our design.

VII. CONCLUSIONS

Besides the many possibilities of improvements the system is already working with characteristics that make it useful to be used in undergraduate Power Electronics classes at Unicamp.

The system was presented to high school students in a projects exposition hosted by this university. The students could interact freely with the system, and listen to explanations of how it works and its applications. A picture of this is show below in the Fig. 10.

In this event we had a very good feedback from the students, and many of them became curious about how it worked.

Currently a batch of boards are being assembled and tested in order to implement the system in power electronics laboratory classes during the second semester of 2007.

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Fig. 10. Experimental demonstration of the implemented system.

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