JPE 10-6-7

Distance Education in Soft-Switching Inverters

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Abstract

The paper describes aspects regarding an E-learning approach of resonant ac inverters. The learning process is based on "Learning by Doing" paradigm supported by several learning tools: electronic course materials, interactive simulation, laboratory plants and real experiments accessed by Web Publishing Tools under LabVIEW. Built on LabVIEW and accompanied by a robust, flexible and versatile hardware, the experiment allows a comprehensive study by remote controlling and performing real measurements on the inverters. The study is offered in a gradual manner, according to the Leonardo da Vinci project EDIPE (E-learning Distance Interactive Practical Education) philosophy: theoretical aspects followed by simulations, while in the end the real experiments are investigated. Studying and experimenting access is opened for 24 hours a day, 7 days a week under the Moodle booking system.

Key Words: Engineering education, Remote controlled experiments, Internet-based distance measurement, Courseware, Resonant inverters.

I. Introduction

The rapid changes in society and technology have also generated a demand for more flexible engineers having more qualifications than just a high level of technical or scientific specialization. Distance learning has been promoted across the entire education sector due to the increasing number of people that educate themselves as part of their professional development. The drawback of a pure theoretical approach in a curriculum is that less attention is paid to the phenomena looming around laboratory experiments and real components. The results of this, corroborated with the rapid development of computer simulations, were that hands-on laboratory experience was vanishing and that computer simulations gained more and more attention. However, it is of crucial importance for the student to gain practical experience. Physical experiments help the students in practical testing and allow them to see the influence of second and higher order effects or parasitics that are often difficult to simulate as in reality. Hence it is of great importance to make the student familiar with the real world experience. Although classical hands-on laboratories are very useful, they may have limitations regarding space, time and staff costs. These problems can be significantly alleviated by using remote experiments and remote laboratories, when the students operate with real systems, although they are not present in the laboratory. For engineering related distance education the use of a web-based delivery mechanism is the only realistic method for providing hands-on experience, allowing remotely located students to complete laboratory assignments unconstrained by time or geographical considerations. They can change parameters, perform experiments, observe results in graphical or numerical form and download them [1], [2]. Modern education shifts emphasis from *teaching* to *learning*, assuming that knowledge is not transferred, but the learner himself constructs knowledge on the basis of prior knowledge and additionally acquired information. While in the teaching-oriented approach the student is rather passive, in the vision of learning-oriented the student plays an active role, constructing knowledge on the basis of prior knowledge and additionally acquired information, with teaching as a facilitating precondition. This approach is referred to as constructivism and neo-constructivism [3], [4]. In this spirit, in order for the "Learning by doing" or "Learning by experimenting" approaches to be successful, clear learning objectives have to be formulated. The course module "Resonant AC Circuits" presented in the paper is integrated in the Leonardo da Vinci EDIPE program framework. It is dedicated to bachelor students, particularly to the students in Politehnica Univesity Timişoara enrolled in Telecommunications Systems and Technologies studies but also to anyone interested in understanding resonant inverters operation.

II. Leonardo da Vinci Project and Its Philosophy

The Leonardo da Vinci project EDIPE was approved to create a full set of distance experiments called PEMCWebLab in an integrated learning platform, providing the user with a practical experience in Power Electronics and Electrical Drives

Manuscript received May 3, 2010; revised Aug. 19, 2010
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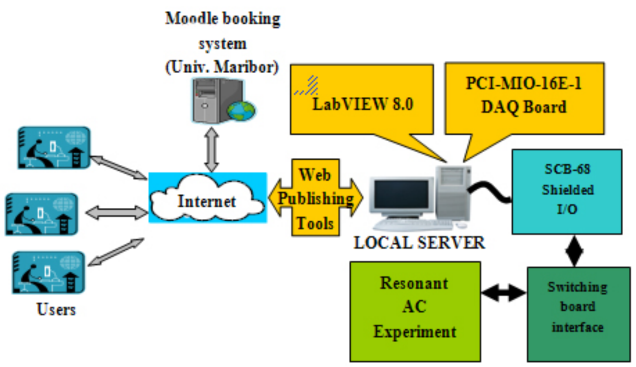

Fig. 1. Structure of the distance laboratory for E-learning. practical teaching of resonant inverters.

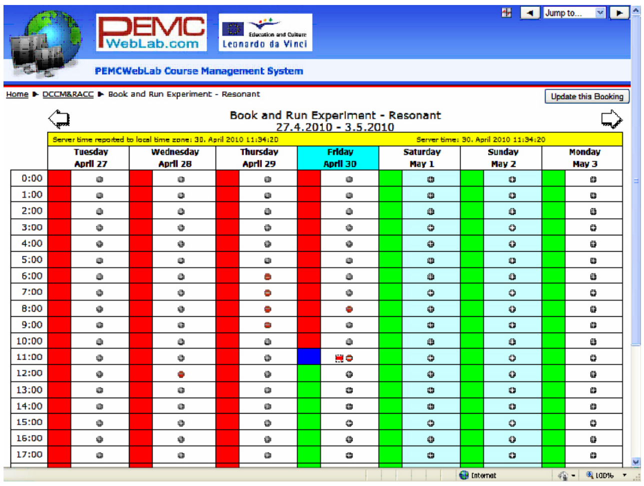

Fig. 2. The booking window

education. The participants are twelve universities with the span across the EU. The results were:

- Elaboration of clear learning objectives for distance experimental education,
- Guidelines for project oriented measurements,
- Synthesis oriented experimental work,
- Technology and technical documentation for distance practical education and measurements via Internet,
- Different experiments, each with its own specificity.

The learning issues addressed in the PEMCWebLab integrated learning platform are:

- Learning objectives;
- Education;
- Animation and Simulation;
- Experiment.

The order of these issues is important. For safety reasons no student will be allowed to perform any experiment until he or she has proofed adequate knowledge regarding the requested experiment. First the learning objectives are defined, while a theoretical background of each individual experiment is given in part Education. For the “Resonant AC Circuits” module the learning objectives are summarized below:

1. Prerequisites: Minimum knowledge on sinusoidal circuits analysis, including phasors. Elementary transfer functions calculation and interpretation.

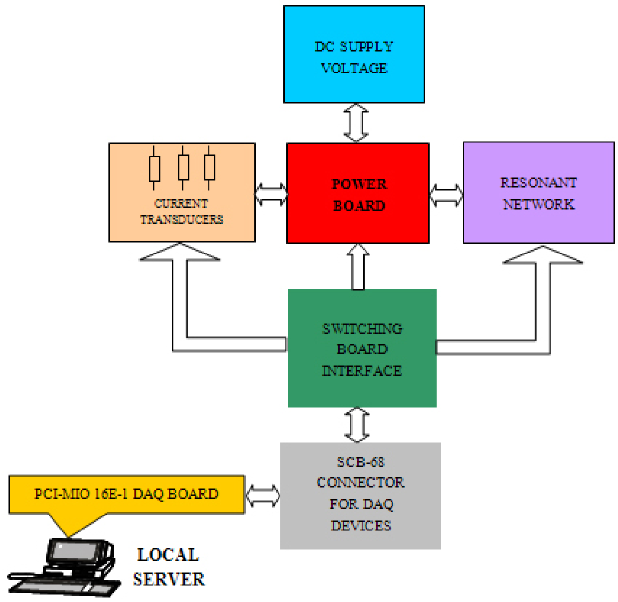

Fig. 3. Hardware architecture of the “Resonant AC Circuits” module.

2. Series resonant inverter (SRC) behavior. Resonant frequency, characteristic impedance and quality factor definitions and significance.
3. Understanding switch implementation in a SRC loaded bridge topology. Applying and handling with sinusoidal approximations in high quality factor resonant circuits. Elementary zero current and zero voltage switching phenomenon understanding.
4. LCC resonant inverter behavior. Resonant frequency, and quality factor definitions and significance. Open circuit output voltage and short circuit current values. Elliptical nature of the output characteristic of a resonant circuit.
5. Other resonant inverters: parallel resonant inverter (PRC), LLC inverter and dual of the SRC.

Interactive animation and/or Simulation are the steps preceding the real Experiment.

After completion of the real experiment the students are given a questionnaire and they have to submit their report for the final evaluation. All learning procedures are recorded for future reference and analysis.

Studying and experimenting access is opened for 24 hours a day, 7 days a week.

III. SYSTEM CONFIGURATION

Each experiment has its own server because it is located in a different location, as Fig.1 shows. Remote users first log onto a main booking server, located at the University of Maribor, after which they will be directed to the specific server for actually performing the experiment into a separate individual page. The booking system is based on the Moodle course management system [5]. In addition to the original booking system, some modifications have been made [6], enabling easy booking creation for those remote experiments that were developed under the LabVIEW Web Publishing Tools. The layout of Moodle pages for all experiments is uniform. The Moodle window for booking the experiment is presented in

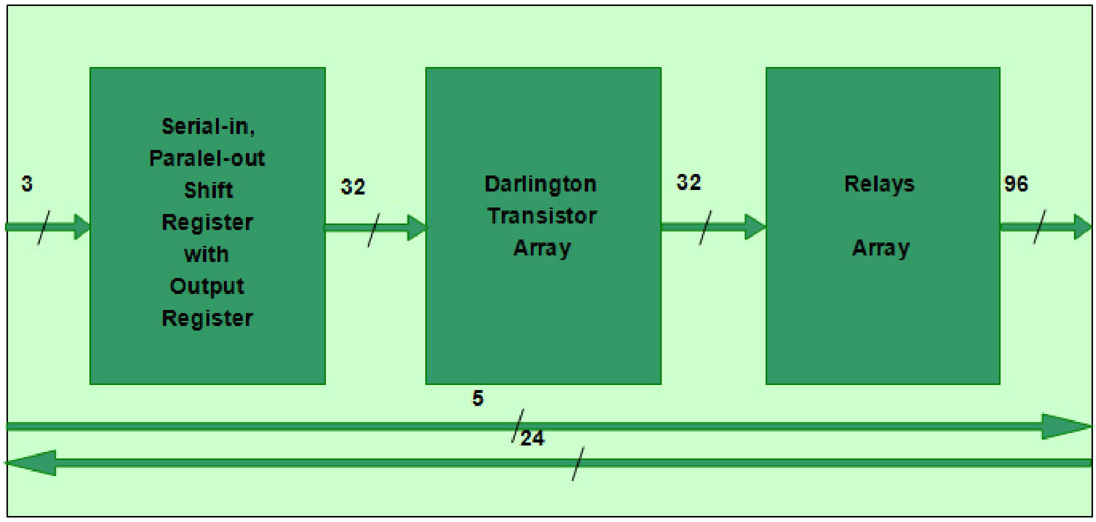

Fig. 4. The Switching Board Interface block diagram.

Fig. 2. The users are divided in two groups: authorized users and guests. Only authorized users can control the experiment. The guests can only observe measured values and waveforms but they have no control of any part of the system.

The local server uses LabVIEW [7] for controlling the experiment. The Web Publishing Tools that come with LabVIEW are used both for interfacing and remote controlling the experiment, namely to choose the converter type, select the desired waveforms and perform different measurements. The proposed hardware solution depicted in Fig. 3 is based on a so called "Power Board" manufactured in Politehnica University Timişoara that offers good modularity and simple connectivity. The PCI-MIO-16E-1 DAQ card together with the SCB-68 shielded I/O connector block for DAQ devices are used for acquisition and measurements. The Switching Board Interface (SBI) is controlled from LabVIEW and its purpose is for configuring the desired inverter topology and to select the signals for data acquisition. Its block diagram is presented in Fig. 4. It contains a 32 bit shift register, each output being buffered in order to be able to switch on and off a relay matrix. As the NI PCI-MIO-16E-1 acquisition board is used, the three inputs I_1, I_2 and I_3 in the register area are connected to the digital outputs O_1, O_2 and O_3 of the acquisition board respectively. The registers are 8-bit serial-in parallel-out D-type SN74HC594 [8] shift registers. The storage clock *SRCLK* of each register is connected to digital output O_1 of the acquisition board, while output O_2 is connected to each shift register clock *RCLK* input. Both clocks are positive edge triggered. Serial input data is provided by the digital output O_3. The parallel outputs of the registers form a 32-bit word, each bit addressing a relay in the relay matrix.

For buffering purposes, four ULN2804 high-voltage high-current Darlington arrays are used, allowing up to 500mA for driving the inductor coil of the relay. The relays play a double role: they contribute in the configuration of the desired inverter topology while other relays provide the signals of interest to the acquisition board as the number of analog inputs is limited. In order to ensure safe operation, the order the relays are switched is important, namely the configuration is settled without connecting the power supply. Only after that the power supply is connected. When finishing an experiment the power supply is disconnected first, then the rest of the power circuit and measured signals.

IV. DESCRIPTION OF THE LEARNING PROCESS

LabVIEW main program operates according to the flow chart depicted in Fig. 5. Functionally, it consists of two main WHILE loops: one for selecting the experiment from the list and one for performing measurements when an experiment is activated. In both loops, for security reasons, the program monitors the user's connection state such that if the remote panel window is left without normally exiting the program, the experiment is automatically closed and a warning message is displayed. Otherwise, the experiment would remain permanently connected, which could be dangerous for the power circuit. All LabVIEW classical buttons are disabled except for the START button, such that only the program buttons are available for the user. This allows that as long as the power circuit configuration is in establishment or the program is switching from one experiment to another, no control is available for the user, again for safety reasons.

Simulations are performed before any experiment in order to understand the basic operating principles of the resonant converter under study. The component values are the same as those that will be used later for breadboard. Simulations are performed using the Caspoc package [9]. The user friendly interface allows one to build and change the power circuit using drag and drop procedures. Another interesting feature of Caspoc is the animation capability which is extremely useful in switching circuits, as it reveals the on and off devices at a certain time moment and the currents paths as well. Of course, the simulated waveforms are obtained without parasitic elements or measurement noise, which is quite an advantage as it offers the possibility to compare them to the real ones and notice the differences. For example, the simulation results for

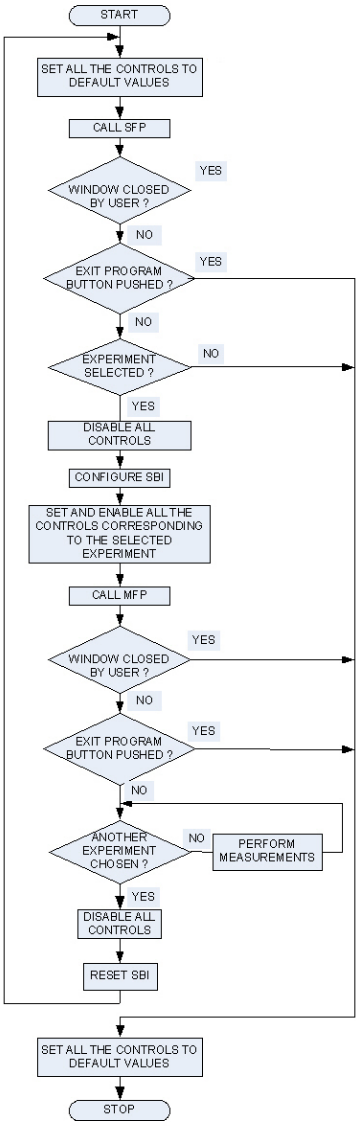

Fig. 5. Flow Chart of the main LabVIEW program.

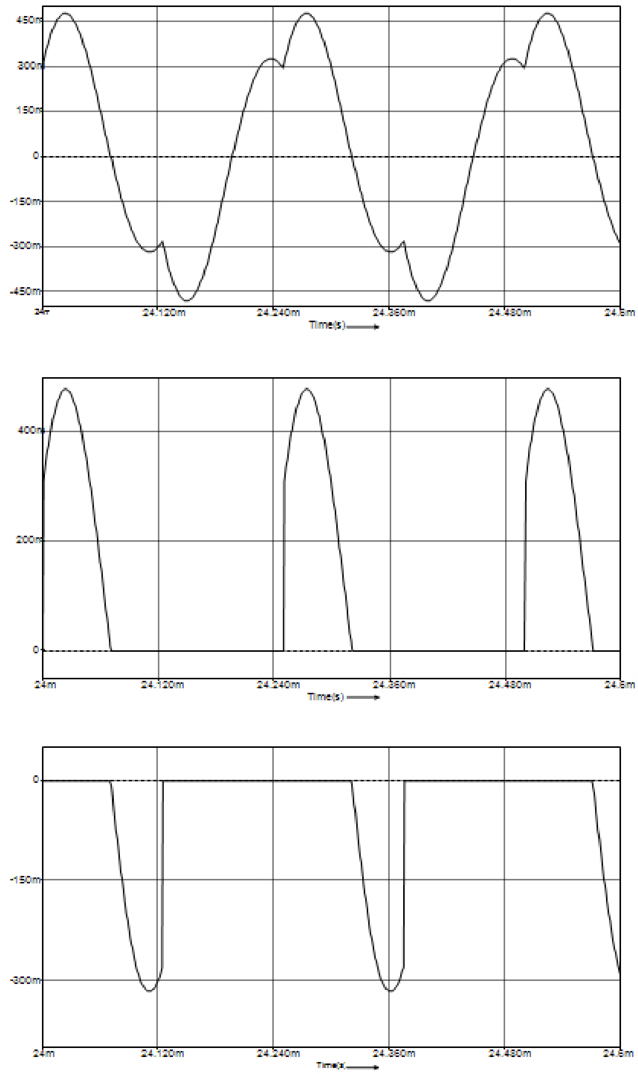

Fig. 6. Simulated waveforms in the LCC resonant inverter: resonant current, transister current and transistor corresponding freewheel diode, this up to down order.

the LCC resonant inverter below resonance are depicted in Fig. 6. State plane trajectories are also possible. The hard turn on and soft (zero-current) turn off transitions of the transistors are obvious. The student will have to decide whether it is possible to replace the transistors with naturally-commutated thyristors and to justify the answer. From the simulation results it is also clear that diode turn-off transition is not lossless. This is a good starting point to put the student to anticipate what will happen when real diodes will be used. Then he or she will be asked to provide a solution to assist the transistors turn on process and finally the small inductors introduced into the legs of the bridge will be the expected answer. Each of these will be verified by simulation, which is very simple as they imply minor modifications of the circuit.

Corresponding to the two mail WHILE loops in the main program two panels are handled by the user. When entering the experiment the Selection Front Panel (SFP) is displayed. It is a simple panel where the user only selects the desired topology for investigation: series resonant inverter (SRC), LCC inverter, parallel inverter (PRC), LLC inverter or the dual of the series inverter. An example of SFP is presented in Fig. 7 for the LCC inverter. The panel dedicated for measurements, visualizing waveforms and for changing parameters is the Measurement Front Panel (MFP). For the LCC resonant converter the MFP is shown in Fig. 8. In the main program each experiment is assigned its own DAQ Assistant. This individualization is necessary because each experiment has its specific signals set required to be analyzed. Any signal from the list can be displayed with a selectable gain and analyzed separately or together with any other signal or removed from the displayed signal list. As two or more signals can be displayed in a scope, phase shift between them can be revealed which is important in studying zero voltage or zero current switching. Acquisition can be frozen any time thus facilitating to perform measurements on the displayed waveforms using cursors. The user can measure time, dc, amplitude or rms of harmonics, overall rms, phase shift and total harmonic distortion (THD). The spectrum is also available in the dedicated spectrum analyzer.

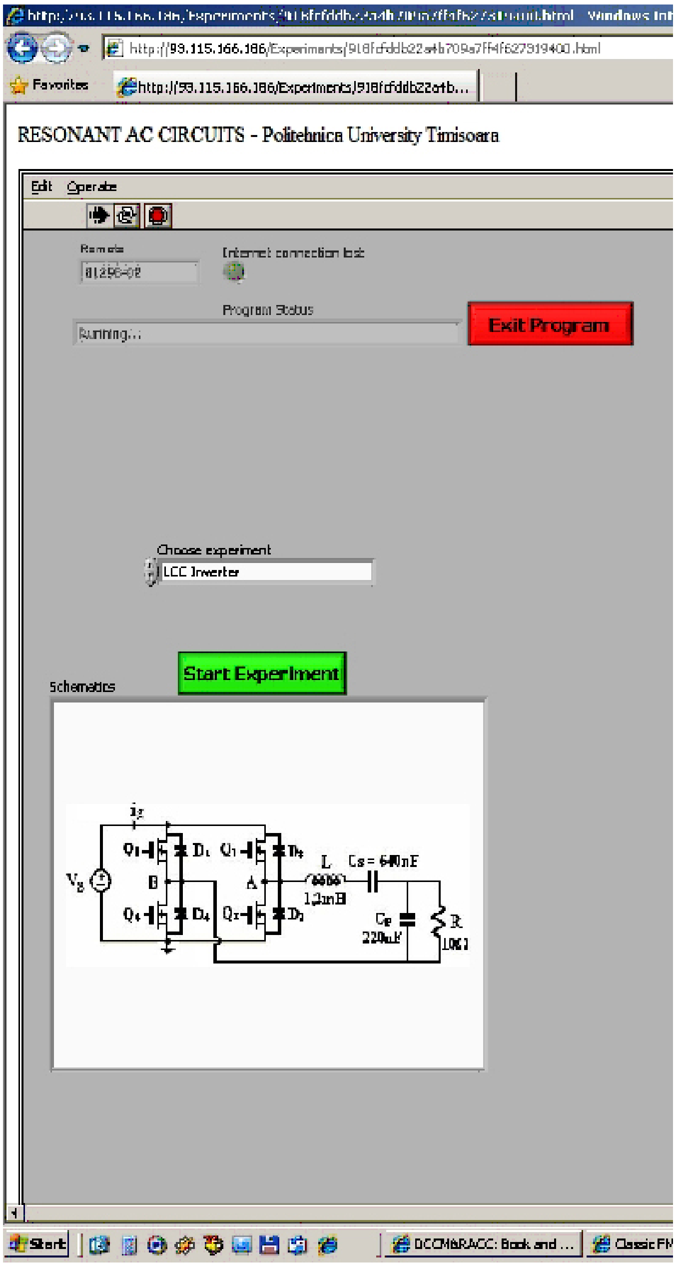

Fig. 7. Selection front paid

As resonant inverters operation strongly depends on the switching frequency that is the main control parameter, the switching frequency can be adjusted from the MFP with some upper and lower default limits for safety reasons.

In each experiment the equivalent quality factor is estimated and the student is asked to draw a conclusion in what circumstances the sinusoidal approximation [10] is valid and how the real measurements match or not with the results provided by the sinusoidal approximation. Emphasis is devoted also to device stresses such as peak resonant currents and peak resonant voltages. For the LCC and LLC inverters the other important frequencies such f_m and f_∞ that result from the Bode diagrams [10] are put in evidence.

As an example, the same LCC inverter simulated in Fig. 6 is practically investigated. The waveforms are those in Fig. 8 when the switching frequency is chosen to be 4 kHz. Soft zero current switching turn off can be observed. Compared to the simulation, it can be seen that the hard turn on transistor, similar to PWM, is accompanied by high current spikes. The high current spikes are due to the freewheel diode in antiparallel with the transistor in the same leg, corroborated with the energy stored in the drain-to-source capacitances and in the depletion layer capacitance of diodes, that is also lost when the transistor turns on. This is a typical phenomenon when the LCC converter is operated below resonance.

Figure 9 presents the same converter when operated at 7kHz, that is above resonance. It is obvious that soft zero voltage switching turn on is achieved since the transistors conduct after their respective antiparallel diodes.

On the other side, it can be seen that transistor turn off transitions are not lossless as neither the transistor current nor the transistor voltage is zero. Different other tasks have to be performed by the students, such as operation above resonance, operation at f_m and f_∞, in each situation examining the soft switching condition. Then, for a fixed switching frequency, the student will be asked to measure the amplitude of output voltage and current fundamentals, in open circuit, short circuit and for different resistive loads. Finally he has to come out to the elliptical nature of the output characteristic.

V. Conclusions

The PEMCWebLab was conceived as a complete educational solution in the field of Power Electronics and Electrical Drives. The “Resonant AC Circuits” module described in the paper offers five types of resonant inverters to be studied. The simulation and animation before any experiment help the student to understand the basic operation principles of these topologies. Although simulation is useful, the real distance experiments allow the user to see the differences between ideal and real waveforms affected by nonidealities and parasitics. The students can both visualize the main waveforms and to perform a lot of measurements on the acquired signals. In Politehnica University Timişoara a Distance Learning Centrum (see http://www.csid.upt.ro/) exists where students from different companies of electronic profile do their studies in electronics. We also carried out an investigation focused on students’ opinions and views about this modern teaching tool and how they perceive the E-learning concept. They were asked to fill in a questionnaire in which an evaluation of the remote laboratory was performed. Their opinions were favourable and they really got it as an educational benefit.

Acknowledgment

This work has been performed within the project ”Elearning Distance Interactive Practical Education (EDIPE)”. The project was supported by the European Community within framework of Leonardo da Vinci II programme (project No CZ/06/B/F/PP-168022). The opinions expressed by the authors do not necessarily reflect the position of the European Community, nor does it involve any responsibility on its part.

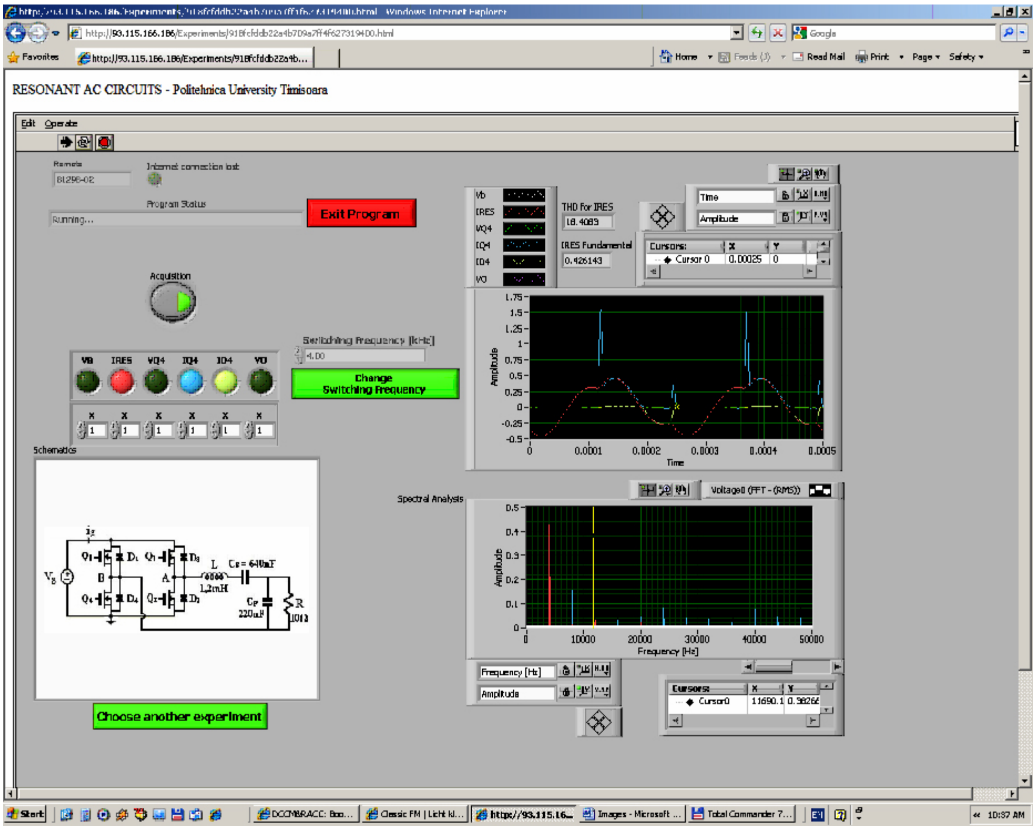

Fig. 8. Measurement front panel – LCC resonant converter experiment, $f_S = 4$kHz.

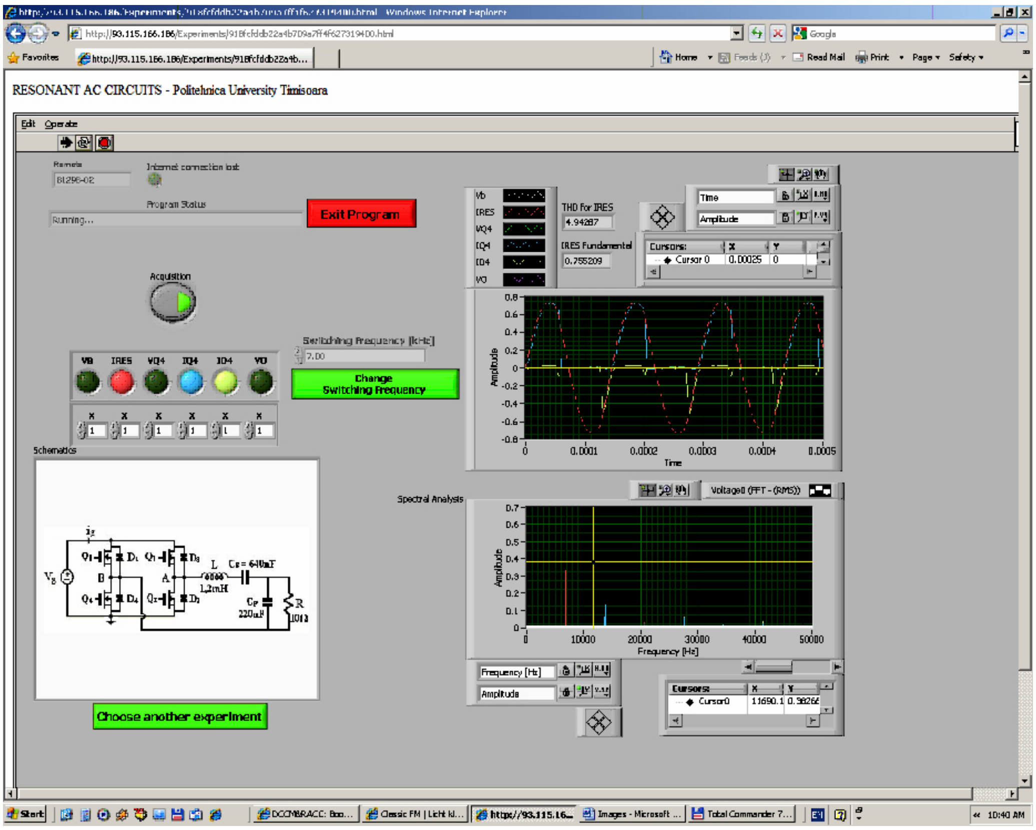

Fig. 9. Measurement front panel – LCC resonant converter experiment $f_S = 7$kHz

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Mircea Băbăiţă was born in Orastie, Hunedoara, Romania on July 18, 1964. He received the degree in electrical engineering from the Politehnica University of Timişoara in 1989. Since 1991 he has been with the Politehnica University Timişoara, Faculty of Electronics and Telecommunications, Applied Electronics Department. He had 6 weeks scholarship at University of Strathclyde, Glasgow, Scotland – 2000, 2 weeks scholarship at Uninersity of Mannheim, Germany – 2002. He has published more than 50 technical papers, 6 books and 20 grants in the field of digital logic, motor drives and power electronics. M. Băbăiţă is a member of the Romanian Electronics Engineer Association (AIE) and a member of the Romanian Robotics Engineer Association (AIR).

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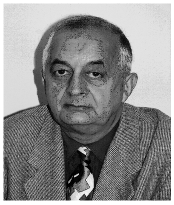

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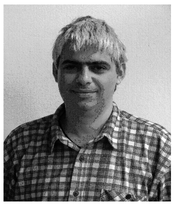

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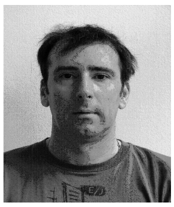

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