PEMCWebLab - Distance practical education for Power Electronics and Electrical Drives

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***Abstract*— Virtual and distance laboratories extend the application area of the web. This leads to an openly integrated environment which facilitates the sharing of not only educational material, but also hardware and software resources. This paper investigates distance learning with particular attention to experimental work. PEMCWebLab provides the user with a practical experience in Power Electronic education. It was designed based on leading ideas and had clear targets.**

Keywords: Distance education, Power electronics

I. Introduction

Distance learning has been promoted across the entire education sector due to the increasing number of people that educate themselves after their working hours, or as part of their professional development. Furthermore, universities and high schools already use the Internet extensively for communication with their students. This, combined with the recent developments with regards to the Internet and information technology, has seen the need for web-based teaching grow rapidly.

Distance-learning, via the Internet, focuses on the delivery of information to the student, typically via web pages which are rich with multi-media content. The student, sitting at home in front of the computer, receives lessons in a certain subject while keeping contact with the other students as well as with the teacher via e-mail, chat-rooms, on-line tests, etc. Other issues focus on the style of teaching by using multi-media like video-clips, audio or “slide shows” extensively within the classroom, or alternatively from a distance (internet). Advanced educational material makes use of interactive programs, in the form of little experiments performed via a simulator or alternatively solving some engineering problems, in combination with the text explaining the theory.

The rapid changes in both society and technology have also created a demand for engineers that are more flexible -- possess many more qualifications than just a high level of technical or scientific specialization. The drawback of a pure theoretical approach in an undergraduate electrical engineering (EE) curriculum is that less attention is paid to the phenomena that loom around laboratory experiments and the exploration of system components. The result of this, aided by the rapid development of computer applications, is that hands-on laboratory experience is vanishing and that computer simulations are receiving more and more attention.

However, it is crucial for students to gain this practical experience. Physical experiments give the students a feeling for practical testing. This also enables them to see the influence of second/higher-order, real-time and even parasitic effects which are often difficult or even impossible to simulate perfectly. The reason is that the simulations are always based on approximate or simplified models. Therefore it is important to give the students a real world experience. However, building an experiment is expensive and it is impossible for an educational institute to have the complete range of experiments. The hardware experiment should therefore be adapted in such a way that it can also be accessed from the Web. In this way the advances in ICT are combined with the real world. The proposed virtual (distance) laboratory is not a web-based simulation. It is a real electro-technical experiment conducted in the laboratory, but it is remotely controlled and monitored by web-based tools. It is even possible to visualize the measuring instrument, the electronic components and many more factors such as lay-out, for example. This facility is useful to fulfill today’s requirements for teaching over the Internet.

The experiments should not only be orientated to analysis (to measure and see the results) but also to synthesis. It should therefore include at least one design aspect. Therefore, the measurements are designed as a project based on a leading idea and with clear targets. First of all the technology of such an integration attempt, and thereafter guidelines to achieve distance Interactive Practical Education, are defined. This technology will be applied to the education of practical power electronics.

II. Leonardo da Vinci project.

Leanardo da Vinci EU project with an acronym EDIPE is suggested and approved to create a full set of distance and virtual laboratories. Twelve universities with the span across the EU are participating in the project. The expected specific results are:

- Learning objectives for the distance experimental education,
- The guidelines for project oriented measurements with the learning objectives for distance and /or virtual practical education,
- Synthesis oriented experimental measurements,
- Technology and technical documentation for distance practical education and measurements via the Internet,
- Different designed measurements each with its own philosophy.

The outputs from the project will present teaching material (in electronic form; guidelines, manuals, documentation in English and other languages), further distance and virtual

Laboratories approached via web, visualisation and the Lay out of the measured system and the measurement results obtained via Internet. The following modules are proposed (grouped into sets of modules) covering fundamentals and basic applications of the EE and advance topics including the application as well.

TABLE I
DISTANCE LABORATORIES WITHIN PEMCWebLab

1. Fundamentals of Electrical Engineering
   - 1.1 Single Phase and Three Phase Rectifier Circuits
   - 1.2 DC Circuit Measurements and Resonant AC Circuits
2. Power Electronics
   - 2.1 Power Converters
   - 2.2 Power Factor Correction
   - 2.3 PWM Modulation
   - 2.4 DC-DC Converter for Renewable Energy Sources and Microgrid
   - 2.5 Power Quality and Active Filters
   - 2.6 Power Quality and/or Electromagnetic Compatibility
3. Electrical Machines
   - 3.1 Basic Electrical Machinery – Synchronous Generator
   - 3.2 DC Machines
   - 3.3 Basic Electrical Machinery – DC Motor
   - 3.4 Basic Electrical Machinery – Asynchronous Motor
4. Electro-Mechanical and Motion Control Systems
   - 4.1 Basic Elements of Internet based Telemanipulation
   - 4.2 Mechatronics, HIL (Hardware in the Loop) Simulation
   - 4.3 High Dynamic Drives - Motion Control
   - 4.4 A Automotive Electrical Drive
   - 4.5 Complex Control of a Servodrive by a Small Logic Controller
   - 4.6 Intelligent Gate Control by a Small Logic Controller (SLC)

In this paper the examples of some modules for Power Electronics (module 2.1) in the chapter III Power electronic experiment is introduced. Modules 3.4 Asynchronous motor and 3.1 Synchronous generators from the group Electrical machines are introduced in chapter IV and Chapter V.

The principle functionality of a typical PEMCWebLab system is showed in Figure 1. There are several parts of the system. The main part is the 'Measuring and web server'.

Communication with the measurement instrument, the control of the power supplies of all the components of PEMCWebLab and the displaying of the web pages with measured values, are provided by the computer. The users are divided into groups: the authorized users and the guests. Only authorized users can control the measurement. The guests can observe measured values but they can't control any part of system.

III. Power Electronic Experiment

In the DelftWebLab which is a part of PEMCWebLab system, two complex measurements have been prepared (see Figure 2). These are the two basic conversion possibilities, namely dc-dc and dc-ac.

Only the first application measurements, namely with the dc-dc converter is described here. The dc-dc buck converter was selected (step down chopper) with a resistive load which will later be extended to a dc machine. This converter topology is selected because it forms a basic building block for a voltage source inverter. This practical set-up of a buck converter is therefore extended to a switching leg of an inverter in the final part.

A dc-dc converter, and the demonstration of a three-phase inverter with vector modulation, was thus selected as the two systems to be measured in this way. General learning objective is to be able to follow some design steps of a power converter on a well structured way

The general objective is to be achieved by the following specific objectives:

- Understand the structured design methodology
- Learning the different energy conversion methods
- Learning, that the lay-out of the real system has some rules. (hypotheses that the rules are known)
- See the volume, lay-out and relate it to the power.
- Be able to analyze an existing system in a structured way
- Complex systems divide to subsystems for functional level

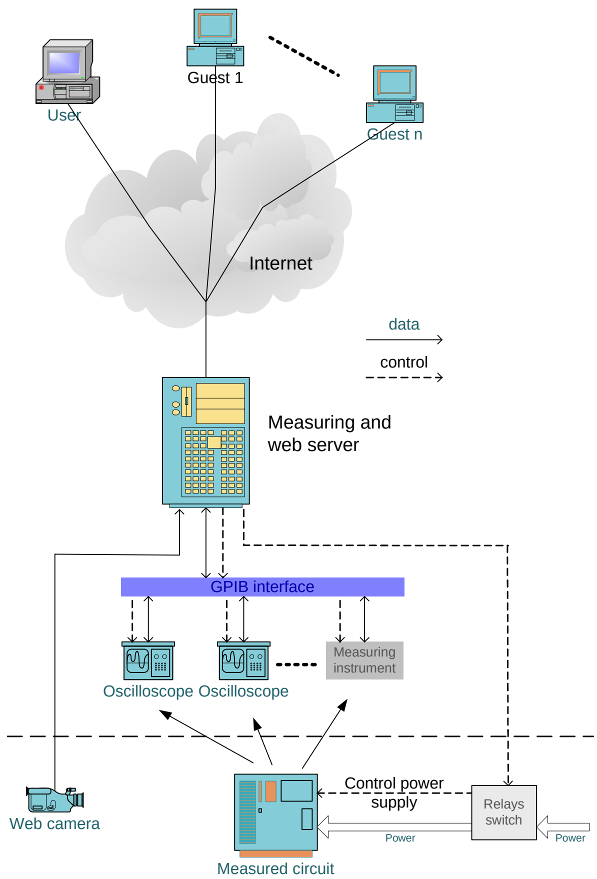

Figure 1 Principle structure of distance laboratory

- Learning, that the simulation (PC) and the real world effects are different and be able to understand the differences. Simulation (models) simplification of the reality
- Be able to select an apparatus
- To program the microcontroller with a specific goal
- To understand the delays in the drivers

Requirements on the system are:

- See and control the real system
- Must be accessible for all students

Design issue is to design a dc/dc converter with the given load and requested current ripple

The objectives of the practical can be summarized by the following points:

- Simulate a typical design process of a converter
- Show the physical layout and construction of a modern converter
- Demonstrate the switching effects of power semiconductor switches (e.g. switching on/off and reverse recovery)
- Demonstrate the real time effects, delays in the drivers etc.
- Compare the simulated and measured waveforms. Show the influence of the parasitic elements

A. *Design process*

The main idea behind this practical is to simulate a typical design process of a power converter. The design aspect has already been identified a very important part, and is in contrast with the traditional practical where the objective is to only observe the different phenomena.

The design process can be characterized with the following steps:

- Simulation of the desired system
- Programming of a microcontroller to generate pulses for the power converter
- Assembling of the breadboard using the available building blocks
- Measuring the real signals of the system and running the breadboard with a self-built (programmed) modulator
- Comparison of simulated and measured waveforms concerning delays and real time effects, etc.

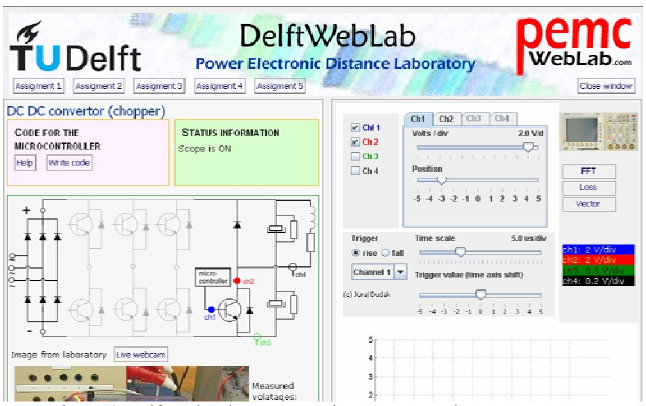

Figure 2 DelftWebLab system and measurent points

To guide the design process five different assignments are prepared.

B. *Assignment 1:Simulation and animation*

The aim of the simulation is to prepare the student for the practical, get acquainted with the basic problems and the working of the converter. The component values for the simulated system are the same as will be used later for the breadboard. There is an option to connect to remote simulation tools shown in Figure 2 to DelftWebLab. A vnc server web interface was used as the connecting application. After clicking on the remote simulation icon, a new page will be displayed prompting the user to enter a password. This password is needed in order to provide a secure connection. (To use this connection, the Java support must be installed on the users' computer.) After connecting to the remote computer, a simulation program can be run. Simulation of the converter system is performed with the simulation program labelled Caspoc [20]. The user-friendly interface allows one to simulate simple examples such as the buck converter. The use of a Scope feature is in this case similar to a real scope (Figure 2).

Performing simulations is an excellent preparation for the measurement itself. There is a possibility to change the power circuit and its configuration by dragging and dropping of the respective components. One of the interesting features of Caspoc is its animation capability: next to the oscilloscope waveforms it is possible to see whether the switch is on or off, or to follow the flow of the current. A change in the control strategy or any of the circuit parameters influences the power flow. This remains in spite of the fact that the simulated waveforms are somehow idealized. In fact, it can be considered as an advantage that the simulated waveforms are measured without parasitic and hindrance of measurement noise, for the comparison with the real-time effects will be made later during the actual measurement.

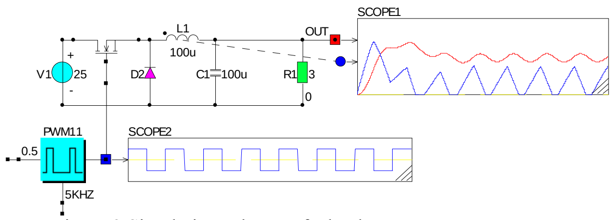

Figure 3 Simulation scheme of a buck converter

C. *Assignment 2: Programing the microcontroller*

To generate the pulses, the capture/compare unit (CCU) of the XC866 microcontroller is used. Every register is divided into 2 parts: the lower word and upper word (see Figure 4); because the CCU works in a 16-bit mode. The program shown below generates pulses at a frequency of 5 kHz. To be able to use the code for other micro controllers we will use the high-level language C instead of assembler. Once we have the C-code, this code can be converted to controller-specific assembler code with an appropriate conversion programme. The C-program that is needed for this practical consists of a limited number of lines of source code. The complete development cycle from 'idea' to working system will be demonstrated with a completely integrated development environment that will show all the steps that have to be done to obtain a working pulse width modulator. Exactly the same procedure has to be followed to realize much more complicated real-time applications.

To minimize the programming and assembly effort a so-called SoC (System on a Chip) is used, that enable effective use of libraries of subsystems that are supplied by the manufacturer of the system. Within certain system architecture, most

manufacturers have developed a range of specific modules and subsystems for different application fields. Typical modules are CPU's, memories, interfaces but also modulators. For high volume markets these modules may be integrated on a single chip resulting in a SoC, One of the application fields is power electronics, as it requires high speed real-time signal processing and control. Modules for power electronic have in common that they should be able to generate PWM signals (pulse width modulated).
The micro controller that is used for this practical is the C504 manufactured by Infineon (was Siemens). The C504 is an 8-bit micro controller universally applicable for speed control of (small) AC induction motors.

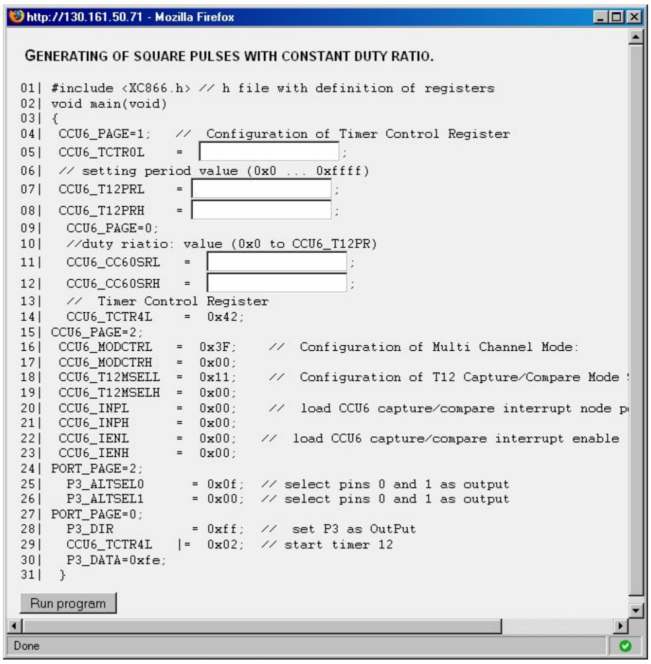

Figure 4 Listing of sample program

D. *Assignment 3: Measurement of the delays*

After the microcontroller has been successfully programmed the measurement of the buck converter can commence. On the circuit diagram several measurement points (colored circles) have been prepared. The filled circles represent voltage values, and the clear circles represent current values. The measured points of the dc-dc buck converter are shown in Figure 2. They are the voltage over the switching device, over the gate driver and the current through the load. Comparing the simulation and the real time aspects measured on the system is an important aspect. The delays in the control electronics, switching operation and other important issues can be studied in detail at this stage. The third assignment is thus to consider the switching behaviour such as the delay and the transition times of the switch. The questions to answer are: What is the delay in the drivers and in the switch? What is the rise and fall time of the used IGBT switch? In Figure 5 measurement result of the delays measurement is shown.

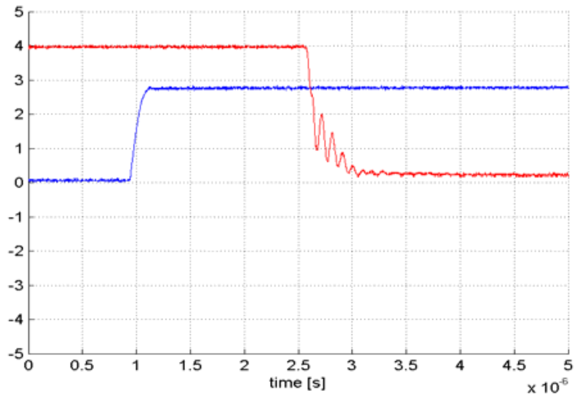

Figure 5 Measurement of the delay in the drivers and switch

E. *Assignment 4: Switching losses and diode reverse recovery*

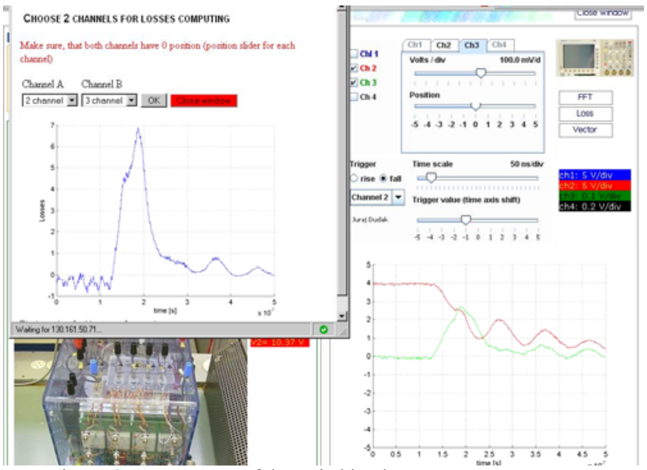

Figure 6 Measurement of the switching losses

Loss measurement is enabled and pre-programmed within the DelftWEbLab. Two scope channels are multiplied within the Matlab and hereby e.g. losses of the semiconductor switch (voltage x current) measured, The assignment is to measure the switching losses and conducting losses during one switching cycle. The assignment and questions to answer are: Which losses are higher the turn on or the turn off losses? The student can use hereby for the multiplication the button losses. Task 2 is to measure the reverse recovery of the diode.

F. *Assignment 5: DC machine*

In last assignment the student has to replace the RL load by a DC machine, where the machine parameters are known from the simulation. The assignment is to control the voltage at the armature of the DC machine such that the DC machine will rotate at a predetermined speed. For these machines a speed of 1200 rpm corresponds to an armature voltage of 100V.

- Calculate the required values of D for 300, 600 and 1000 rpm.
- Set D at the appropriate value and check the speed.
- Compare the voltages (V_1 & V_2) and the current I_2 with the results of the simulation.

- Consider the switching behaviour such as the delay and the transition times of the switch.

G. Assessment

Important part is assessment. The learning objectives are verified by:

Delays and maximum switching frequency
Switching losses
Achieved current ripple

IV. Asynchronous motor

The students will learn about basic principles of torque generation and possible practical applications, where one of these is the asynchronous motor (actuator). One of the most important output is the understanding the principles of balance of two "relatively" independent torque sources, where on of them is the electrical machine (e.g. asynchronous) and the second one represents the applied external load. The importance of torque vs. speed characteristic is described to students with special respect to expected dependence of external load (usually can be considered either constant or linear) and expected dependence of torque vs. speed characteristic of used electrical machinery (this may vary according to mechanical and electrical conditions). The principles of stable equilibrium (see Fig. 1) are explained to students, before the experiments will start. The general principles of measurements are described in [4].

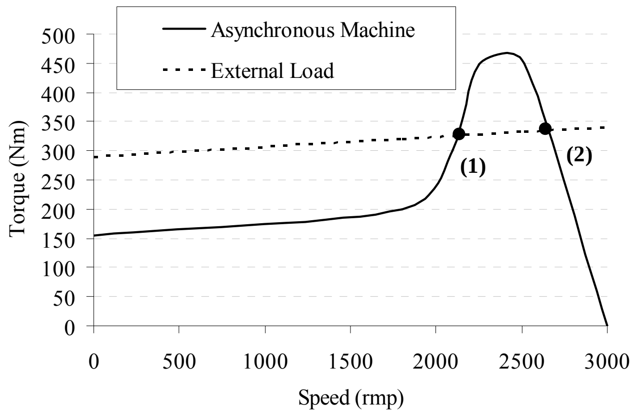

Figure 7. Stable (2) and labile (1) equilibrium of two torque generating plants

The students will learn how to operate and control the torque of asynchronous motor; they will observe the response of motor to change of different external electrical parameters, as frequency or voltage. They will observe the change of supply current, depending on operating conditions and will compare the obtained values to rated ones prescribed by manufacturer.

Once when they become familiar to parameters and behavior of asynchronous motor they will start the measurement itself. The basic point of measurement is in predicting the operating point of asynchronous motor loaded by given external load. The students, except controlling the electrical inputs for the motor, are able to set either the external torque values or required speed of the machinery. They will observe that by increasing the external torque also the supply current will increase. When reaching the rated values, they must find the solution, how to continue the measurement (decrease the voltage and recalculate the load). After reaching the maximal possible torque they must find the solution how to measure the labile part of torque characteristic (of course, with reduced supply voltage, and, consecutive, current), including the pull-up torque of the machine. All these values must be recalculated by students to be able to compose the whole torque vs. speed characteristic valid for rated supply voltage, where the theoretical maximal torque and real maximal torque values are indicated.

V. Synchronous generator

While operating the asynchronous machine as a motor, it is necessary to discuss the possibilities of operating the asynchronous generator. In case of synchronous machine the required frequency as well as the required voltage should be easily obtained. Students are able to observe and verify the basic principles of synchronous machinery (the influence of speed change on frequency, the influence of exciting current on output voltage). Theirs task is to set the excitation current to appropriate values, since the required voltage (and frequency) is prescribed. One of synchronous generator basic characteristic (no-load characteristic: output voltage as a function of excitation current) is obtained by comparison of measured results.

Also the influence of direct current passing through the excitation circuit can be observed, while different results are obtained when increasing and/or decreasing the current values. The students are asked to explain the cause of this effect.

Figure 8. View on electrical machinery of PEMCWebLab in laboratories of TnUAD in Trencin, Slovakia

The main objectives hereby achieved are:

- students become familiar with distance (internet) control of power electronics,

- students will be able to work with electrical machinery, power electronics and measuring apparatus from their homes, so the number of passing through students can be enlarged. This should lead to increase of interest to study power electronics, especially electrical machinery,
- the possible way of connecting the computer science, web design and power electronics is given to students,
- students will be able to predict the possible operation point of asynchronous motor, possibilities of use of asynchronous motor, depending on load conditions, and will be able to operate and control the motor,
- students will be able to measure the pull-up torque of the motor and predict the behavior of electrical and mechanical parameters of the machinery during the start and operation.
- students will be able to compare the operating principles, as well as advantages and disadvantages of asynchronous and synchronous machinery. They will be able to follow the basic physical dependencies between speed, frequency, excitation current, output voltage etc.

Further experience of presented project realization team can be found in [5], where the web supported learning minimizing the gap between theory and practice is presented.

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REFERENCES

[1] P. Bauer, et al. "Distance Practical Education in Power Electronics". *International Journal of Engineering Education*. 2007, 9. pages. ISSN 0949-149X/91, in press.

[2] P. Bauer, J. Dudak, and D. Maga, "Distance Practical Education with DelftWebLab". In *EPE-PEMC 2006*. Maribor: [University of Maribor], 2006. pp. 2111-2117. ISBN 1-4244-0121-6.

[3] D. Maga, et al. "E-learn Laboratory of Electromechanical Actuators". In *Mechatronika 2005*. Trenčín: TnUAD Trenčín, 2005. pp. 46 – 51. ISBN 80-8075-058-0.

[4] D. Maga, *Elektromechanics 2 – guides to laboratory excercises* (in Slovak). Trenčín: TnUAD Trenčín, 2002. 75 pages. ISBN 80-88914-59-0.

[5] S. Uran, D. Hercog, and K. Jezernik, "Remote Lab Experiment RC Oscillator for Learning of Control", *International Journal of Online Engineering*, vol. 2, no. 4, 2006.

[6] G.W.Chang ,Z.M Yeh, H.M,Chang, S.Y.Pan, "Teaching Photonics Laboratory Using Remote Control Web Technologies" *IEEE Trans. On Eduction,* Vol. A247, pp. 529–551, April 1955.

[7] B.Szabados: Interactive Outcome based Assesment using Multimedia, Int. J. Engng Ed. Vol. 20, No.2, pp. 141-151, 2004

[8] P.Penfield, R.C.Larson,"Education via Advanced Technologies, *IEEE Trans. On Eduction, V*ol. 39,No 3, pp. 436–442, April 1996.

[9] C.Fernandez, O.Garcia.J.A.Cobos, J.Uceda,"Self-learning Laboratory Set up for Teaching Power Electronics Combining Simulations and Measurements

[10] K.W.E Cheng, C.L.Chan, N.C.Cheung, D.Sutanto,"Virtual Laboratory Development for Teaching Power Electronics, EPE-PEMC 2004 Riga, Latvia

[11] Z.Yi, J.Jian-jun, F.S.Chun: A LabVIEW –based ,Interactive Virtual Laboratory for Electronic Engineering Education; Int. J. Engng Ed. Vol. 21, No. 1, pp. 94-103, 2005

[12] A. B. Buckman: VI-Based Introductory Electrical Engineering Laboratory Course; Int. J. Engng Ed. Vol. 16, No. 3, pp. 212±217, 2000

[13] C. S. Peek, O. D. Crisalle,S. Deapraz, D. GILLET: The Virtual Control Laboratory Paradigm: Architectural Design Requirements and Realization Through a DC-Motor Example; Int. J. Engng Ed. Vol. 21, No. 6, pp. 1134±1147, 2005

[14] C. Fernandez, M A. Vicente, L.M. Jimenez: Virtual Laboratories for Control Education: a Combined Methodology; Int. J. Engng Ed. Vol. 21, No. 6, pp. 1059±1067, 2005

[15] N. Ertugrul: New Era in Engineering Experiments: an Integrated and Interactive Teaching/Learning Approach, and Real-Time Visualisations; Int. J. Engng Ed. Vol. 14, No. 5, pp. 344±355, 1998

[16] V. G. Agelidis: A Laboratory-Supported Power Electronics and Related Technologies Undergraduate Curriculum for Aerospace Engineering Students, Int. J. Engng Ed. Vol. 21, No. 6, pp. 1177±1188, 2005

[17] P. H. Gregson, T. A. Little: Designing Contests for Teaching Electrical Engineering Design; Int. J. Engng Ed. Vol. 14, No. 5, pp. 367±374, 1998

[18] N. Ertugrul: Towards Virtual Laboratories: a Survey of LabVIEW-based Teaching/ Learning Tools and Future Trends; Int. J. Engng Ed. Vol. 16, No. 3, pp. 171±180, 2000

[19] Matlab, www.mathwors.com

[20] Caspoc, www.caspoc.com

[21] B. Lu, X. Wu, H. Figueroa, and A. Monti, "Implementation of a lowcost real-time virtue test bed for hardware-in-the-loop testing," in *Proc. The 31st Annual Conference of the IEEE Industrial Electronics Society (IECON'2005)*, North Carolina, USA, Nov. 2005, pp. 239–244.