Integration of Different Tools and Methods into Education of Power Electronics – – Lectures and Laboratory

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***Abstract*- The paper deals with integration of different tools and methods into power electronics education process. The intensive use of modern tools and methods is inevitable to make power electronics education process more interesting to new generations of students, belonging to informatics age. Proper selection of simulation and animation software, as well as proper measure between real circuit measurements and circuit simulation can lead to appropriate positive student's response.**

I. INTRODUCTION

It is a well known fact that the field of power electronics involves a multidisciplinary, demanding and broad theoretical knowledge for understanding and for practical application. The development of power semiconductor technology as well as microprocessor technology has incited the use of power electronics in many applications, starting from power range of a few watts to hundreds of megawatts. The industry requires at this moment, or in the near future, engineers with appropriate knowledge of power electronics. However, the current situation at universities is not promising. Very few students are interested in „hard working“ field of power electronics. Unlike computer science, it does not sound modern and attractive. Besides, the attitude of university management is often not positive, for the similar reasons as student have.

What can be done? One of possible urgent measures is – implementation of modern educational tools and methods in the education of power electronics. The intensive use of computers wherever it is possible is inevitable. Many papers have been written on that subject in the last 10 years, introducing different simulation packages, virtual laboratories, hardware laboratories, interactive simulation tools etc.

However, we still do not have a final answer to our question, what is an optimal method for teaching power electronics? In Croatia we have a specific situation. The old industry was practically destroyed during the last war and the new industry is being rebuilt, but on different foundations. We have now only one large company dealing intensively with power electronics. Although this company (KONCAR Industries, Zagreb) has developed and produces high tech power electronics products such as low floor tram, it is not enough to induce larger interest in student population. Starting from the last year, we have noticed significant growth of student's interest for studies dealing with electrical engineering, rather than computer engineering. This is very promising, but we do not know yet the reason for this, or if it is going to be permanent.

In this paper we shall describe the main idea of our approach in teaching power electronics in such environment. In short, we have to build our teaching concept in an environment where power electronics is not priority, demands from industry are not significant, but information infrastructure is developed. We have symbolic funds for laboratory hardware and considerable computer infrastructure with internet access. Animations, simulations and internet data mining should be used as much as possible, to make power electronics interesting and modern technical field. The usage of freeware is requested as well. Our power electronics laboratory is build on old foundations, but with new components and modern software environment.

II. LECTURES

We have converted all our lectures into form of Power Point presentations. All lectures are available to students on dedicated Web pages with other educational materials. Students have lecture materials printed (most of them) and there is enough place on the paper for additional comments. Lecture slides are only the basis for explanation of power electronics topics. We are intensively using computer as a tool for enhancing our lectures.

The most successful application with students is IPES, developed by Kolar and Drofenik [3,4]. This interactive simulation tool is well known in power electronics community. Students are really surprised with the possibilities of IPES.

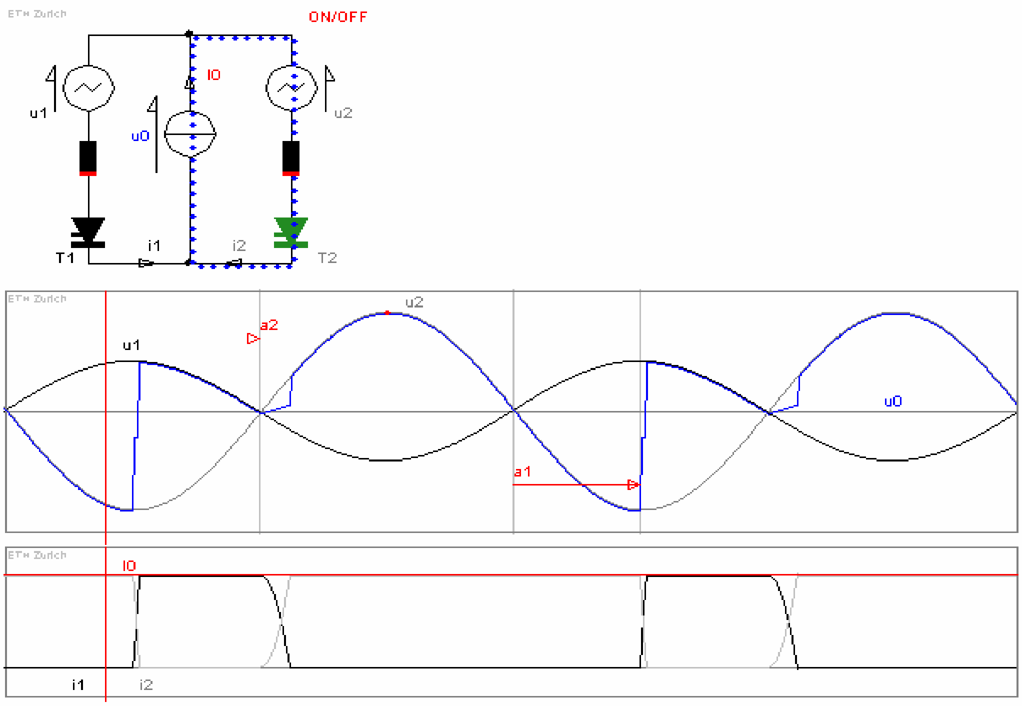

Figure 1. Explanation of commutation using IPES. User can change interactively the values of commutation inductances, control angles of both SCRs, amplitude of load current and amplitude of voltage source *u2*

The teacher can show directly the influence of different parameters on the circuit's behavior. An interesting example is the explanation of commutation in line converters using IPES. The effect of changing commutation inductance, delay angle, load current and line voltage can be clearly seen using appropriate Java applet implemented in IPES (Fig.1). (http://www.ipes.ethz.ch/ipes/2002ThyrZusatz/e_thyrEdu.html).

There are many more effective examples of using IPES, such as ***Single-Phase Power Factor Correction*** and ***Single-Phase PWM Converter***. The main advantage of using IPES in education is that it is freeware, teachers and students can use it free of charge.

Another interesting application in lectures is the usage of ***animated laboratory measurement results***. As it will be described later, we have developed laboratory models of many basic power electronics circuits. During preparation of laboratory, fundamental measurements of characteristic circuit waveforms are obtained, e.g. load voltage/current, line voltage/current and power switch voltage/current. Using one of existing GIF animation tools, a selection of characteristic waveform sets is animated. This procedure enables the teacher to show during lectures a real circuit operation under different conditions (change of control angle, change of modulation ratio etc.). Fig. 2 shows an example of line converter animation in the form of several slides.

As we have internet access during lectures, it is possible to visit Web pages of leading power electronics companies, showing students the latest applications, datasheets and products. Students are aware of the fact that they are looking at brand new information, not the old fashioned lectures written several years ago. This ***on-line approach*** during lectures has also very positive response with students.

III. Laboratory

Our Laboratory for power electronics at Faculty of Electrical Engineering and Computing in Zagreb consists of two strongly connected parts, hardware part and software part. We believe that simultaneous simulations and measurements are the best solution for basic power electronics laboratory. The similar opinions and approaches can be found in literature as well [1,2].

A. Hardware Part of Laboratory

The hardware part of power electronics laboratory is based on the old modeling benches dedicated for SCR based power electronic circuits, mainly line converters. The old control units were replaced with modern SCR driver/control boards from ENERPRO. With this newer SCR driver/control boards it is possible to implement several control schemes, but this option is not used in basic course. Modern power electronics is obviously MOSFET and IGBT based, so the next step was the development of control unit for autonomous converters based on MOSFET and IGBT power switches. For the first phase we have chosen analogue technology for generation of control signals for power switches. The developed control unit is able to generate control signals for dc-dc converters as well as dc-ac converters with several types of modulations (square wave, quasi square wave, unipolar and bipolar natural sine PWM). In the second phase we are planning the implementation of digital technology for the control of our

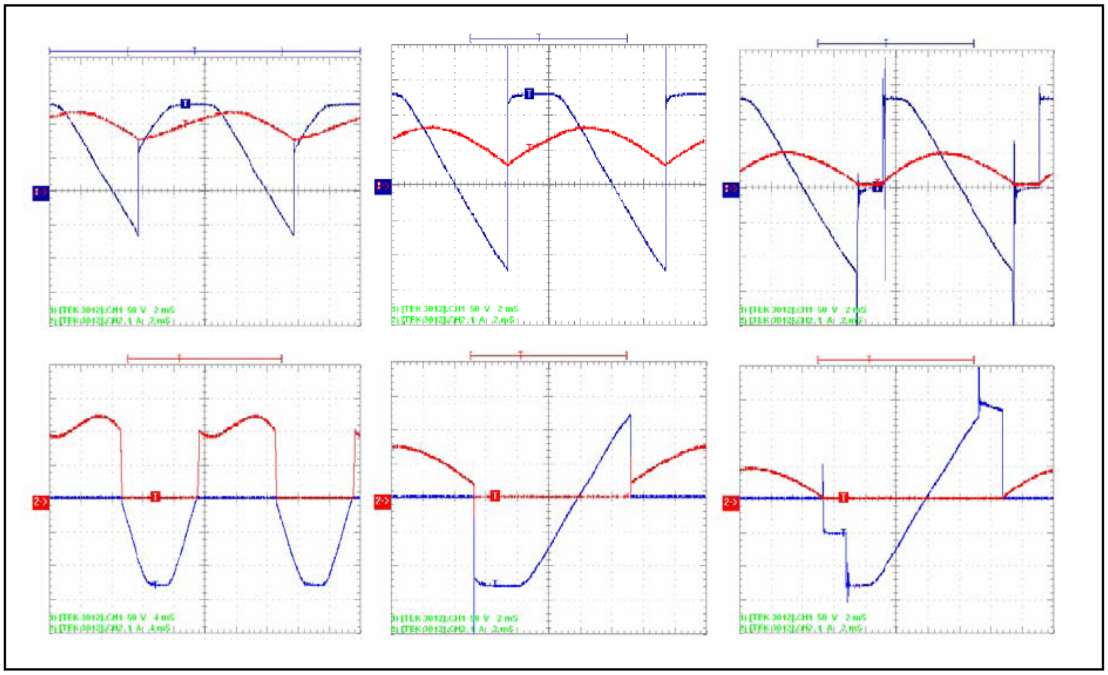

Figure 2. Basic waveforms (load voltage and current, SCR voltage and current) building animation of line converter operation

power switches, enabling realization of more complex control schemes.

The power switches (SCRs, MOSFETs and IGBTs) are mounted on heat sinks with protection circuits. Together with plexiglas front plate, this forms a power switch module to be inserted into appropriate slots of modeling bench. The IGBT module is a new development, based on 50 A SEMIKRON IGBT/diode module and SEMIKRON SKHI 22 driver circuit. Such power switch modules are reliable and safe for usage in educational power electronics laboratory.

For the measurements we are using modern and relatively cheap digital scopes from TEKTRONIX, series TDS2000. These scopes are very simple to use, have a nice color screen and students simply like them.

B. Software Part of Laboratory

It was not an easy decision to select appropriate software as the base for modern power electronics laboratory. We have tried many software tools, but finally we selected SIMPLORER from ANSOFT as the best solution for our idea of integrated laboratory. The professional version of this software is very expensive, but ANSOFT is offering university plans, and what is the most important, there is a student version of SIMPLORER. The student version has very large modeling capabilities and is free of charge for student use. This fact enables students to work at home and prepare well for laboratory exercises.

C. Connecting Hardware and Software

Since the basic idea of our laboratory is the integration of measurement and simulation, it was important to find a solution for simple and cheap connection between the digital scope from the measurement world and the computer from the virtual, simulation world. We have chosen RS-232 connection and WAVESTAR software. This is a slow connection, but for educational laboratory transfer speed is satisfactory. The WAVESTAR software for acquiring measured data from TEK scopes is a simple and efficient solution. It enables transfer of waveform data and screenshots from the scope. In addition, the control of all scope functions is possible from a PC console. The transferred data can be saved in different data formats for the use in simulation software. Fig. 3 shows how it looks like when measured waveforms on digital scope are transferred to PC.

IV. BASIC EXERCISES

The laboratory is dedicated for basic power electronics course, for undergraduate students. At the time of attending power electronics course, students have not yet finished the basic control course. This is the reason why there are no control problems in basic exercises. For all power electronics circuits modeled on test benches, there are appropriate simulation models in professional and student version of SIMPLORER. There is a list of prepared basic laboratory exercises.

1. Basic Power Electronics Switches
2. Basic Power Electronics Circuits
3. AC/AC Conversion – Single Phase Voltage Controller
4. AC/DC Conversion – Mid-point Line Converters
5. AC/DC Conversion – Bridge Line Converters
6. AC/DC Conversion – Application of Line Converters
7. DC/DC Conversion – Switched Mode Converters (single switch)

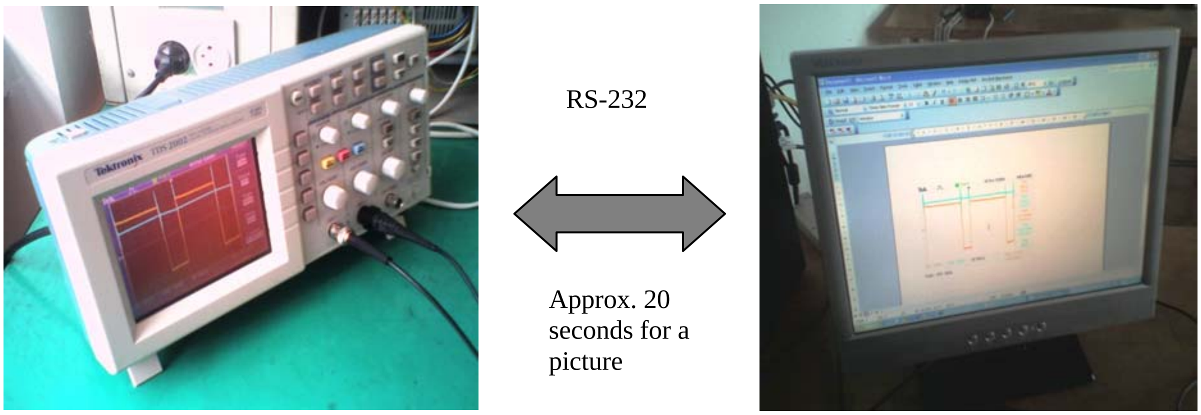

Figure 3. Transfer of measured waveforms between digital scope and PC is done through RS-232 interface using WAVESTAR software. The data flow is bidirectional. The scope can be managed from PC.

8. DC/DC Conversion – Switched Mode Converters (H-bridge)
9. DC/AC Conversion – Resonant and Square Wave VSI
10. DC/AC Conversion – Sinusoidal PWM VSI

V. Typical Exercise Example

A typical example of basic exercise is illustrating the idea of integrated laboratory. Only basic features and possibilities are described in the paper. There is not enough time on basic course to use all possible features of simulation models.

A Single Phase Bridge Line Converter

The simulation model of a single-phase bridge line converter is made to be as universal as possible and also to enable successful comparison with real laboratory model of the same converter. Fig. 4 shows SIMPLORER worksheet for simulation of the single-phase bridge line converter.

Let us explain interesting features of SIMPLORER model. Two possible types of load are modeled, ideal current source load (not shown on picture) and real RLE type of load. Topology of the circuit can be easily modified using "*Do not add to SML*" option. The application of this option can be seen on Fig. 4, as a shadowed free-wheeling diode. If an element is shadowed, it is not included in the model. This is a very efficient way of modifying the topology, or even the control law.

One can see many Petri net elements, belonging to the state simulator of SIMPLORER. We are using intensively this feature for sophisticated control of simulation, especially for interactive change of parameters. In the line converter example, with the change of active states, one can select if an ideal or a *real* circuit is modeled, or if a control angle is set up by hand, or it is controlled by a ramp generator. In the same way one can change values of load elements.

The average and RMS values of voltages and currents are calculated during simulation, and used for the calculation of real and apparent power, as well as power factor. These are virtual instruments. There are basically two ways of displaying results, classical one with entire window displaying all results during simulation, and *View element*, where scope-like display on the worksheet with animated symbols is used.

What is the difference between an ideal and a real converter model? On the worksheet one can see only two states, but with definition of each state, one can define precisely what properties of real world to include in the model. In this simple case the ideal converter has ideal switches without losses and commutation inductance, while the real converter has switches with only static losses and real commutation inductance. This is important for modeling real world effects. In the case of line converter, students are initially simulating the ideal converter. Then, during measurements, they can see voltage distortion on measured line voltage. They return back to simulation, trying to find reasons for the distortion. After selecting *Real Converter* option, a student can see that commutation inductance causes voltage drops during commutation. Fig. 5 shows measured and simulated results of the line current and voltage for single-phase bridge line converter.

Another interesting and useful feature of simulation is the possibility to make virtual measurements that are not easy to perform in educational laboratory, e.g. output and control characteristic of line converter. With simulation it is possible to perform for ideal and real converter case.

What is the difference between professional and student version of simulation model for this circuit? Only virtual instruments are not included in the student version, all other main features are included.

VI. Typical Exercise Course

Before accessing laboratory, students attend sufficient number of lectures dedicated to a specific area. On the dedicated Web-pages students can find all required materials for laboratory exercise, preparation for the exercise, instructions for measurement and simulation, instructions for writing report, and finally files with simulation models to be used on exercise.

As preparation for the exercise, students are requested to answer the questions, to solve some numerical examples, and to make some initial simulations. This makes work in the

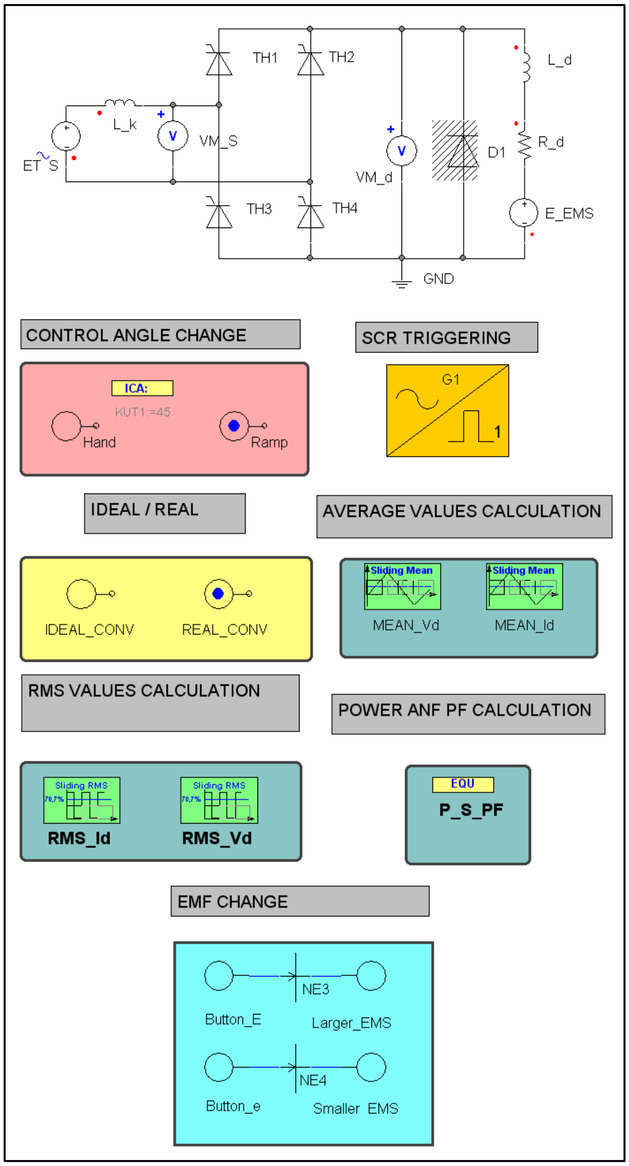

Figure 4. SIMPLORER worksheet for interactive simulation of single phase bridge line converter.

laboratory more efficient. During the exercise, students are firstly making measurements and after that they are comparing measurement results with results obtained with ideal model simulation. The next step is the appropriate change of model structure or model parameters to obtain more accurate simulation model able to describe behavior of real power electronics circuit. Finally, the results of measurements and simulation are transferred to the electronic form of laboratory report.

Conclusion

Only implementation of modern educational tools and methods in the education of power electronics can enhance

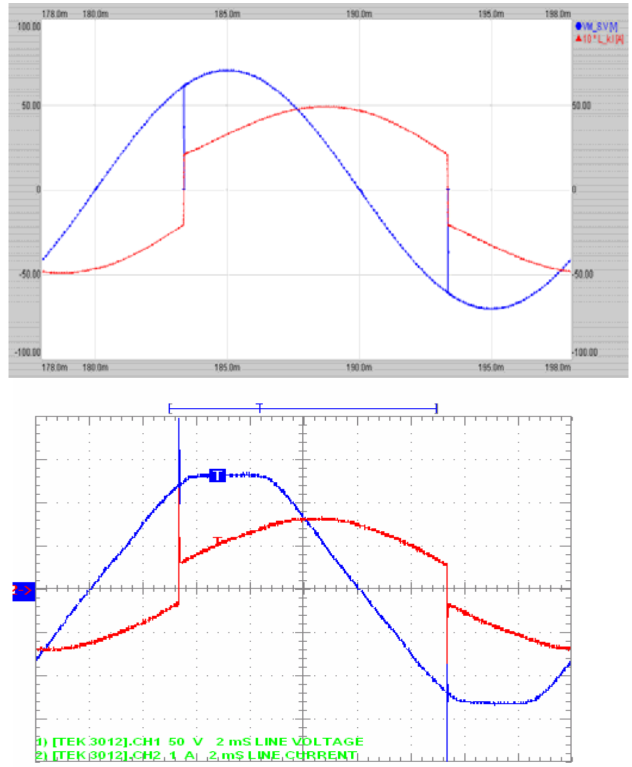

Fig.5. Comparison of measured (lower figure) and simulated (upper figure) line voltage and current waveforms of single phase bridge line converter.

student's interest for the subject. These tools and methods are used in lectures and in laboratory. The laboratory measurement results can also be used in lectures. The integration of measurement and simulation in power electronics laboratory, while maintaining proper measure of both methods, gives new quality to educational laboratory for power electronics. Student's assessment at the end of semester shows that students are satisfied with such approach to power electronics education.

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