

Streamlining Power Electronics Teaching

Clovis Antonio Petry, Joabel Moia, Fernando Santana Pacheco
Electronics Department, Campus Florianópolis
Federal Institute of Santa Catarina
Av. Mauro Ramos, 950, 88.020-300
Florianópolis – SC, Brasil

Gustavo Ribeiro Alves, Manuel Carlos Felgueiras
Department of Electrical Engineering
Polytechnic of Porto – School of Engineering
Rua Dr. António Bernardino de Almeida, 431
4200 – 072 Porto, Portugal

Abstract—This work intends to introduce the use of remote laboratories for power electronics teaching, by means of VISIR (Virtual Instrument System in Reality). The system is applied for the analysis of two simple circuits, a RC filter and an AC measuring network. The proposed methodology introduces remote activities after theoretical lessons, pen and pencil exercises, circuit simulations, and on-site laboratory experimentation. This strategy has been validated by professors and a pilot group of students at the Electronics Department of the Federal Institute of Santa Catarina. As a general conclusion, remote labs contribute to learning, but cannot substitute completely on-site laboratories.

Keywords— remote laboratory, power electronics, VISIR.

I. INTRODUCTION

Teaching of power electronics is commonly accomplished by means of lectures, problem solving, circuit simulation, and laboratory activities [1]. Thus, the methodology for teaching power electronics is no different than the widespread analog electronics teaching approaches [2, 3]. In both contexts, some phenomena concerning the operation of power electronics components are discerned only by means of laboratory experiments, which reinforce the importance of hands-on activities for electronics learning [1–5].

Throughout the world, efforts have been made in order to spark the interest of students to themes related to power electronics. Problem based approaches allow the integration of interdisciplinary knowledge and learning of different skills, and constitute an interesting alternative as discussed in [1–3, 6–8].

Besides problem based learning (PBL), the use of remote laboratories seems to streamline the learning process of students, accompanied or not with hands-on activities and circuit simulation [9–16]. Comparative studies between remote, virtual, and hands-on laboratories applied in technical areas are presented in [9–10].

In the same way, professors of the Department of Electronics at the Federal Institute of Santa Catarina have been assessing strategies to make education more attractive and dynamic. Some of the initiatives to turn power electronics more attractive to students are discussed in this work.

Therefore, this work intends to introduce the use of remote laboratories for power electronics teaching with the aid of a tool called Virtual Instrument System in Reality (VISIR) [12]. In our study, we show the assessment of two circuits with small degree of difficulty either by students and by professors.

This paper is organized as follows. We present the challenges in teaching power electronics in Section II. In Section III, we present our proposal to introduce VISIR in power electronics classes. Section IV describes the assessment of VISIR by students and professors. Conclusions and suggestions for future work are presented in Section V.

II. TEACHING POWER ELECTRONICS

Power electronics is a multidisciplinary area inside the electrical engineering domain. Thus, teaching of power electronics implies, for the teacher, knowledge of diverse fields, among which electrical circuits, magnetic elements, power systems, signal processing, and control systems [19, 20].

On this basis, disciplines related to power electronics are placed at the end of electronics courses. In this context, the teaching of power electronics is at the same time rewarding and challenging, since the students have already accumulated knowledge to develop more comprehensive and deeper studies. On the other hand, at the end of a four or five-year course, students have acquired maturity to discern conventional strategies and inspiring teaching approaches. Many research groups in power electronics have conducted studies and attempts to make the teaching of this subject more attractive and dynamic for students at the end of the course or even for freshmen [1–3, 8, 17].

Over the years, we carried out various attempts to improve the teaching of power electronics for electronics technicians. Note that, in this level of formal education, students are teenagers and power electronics is at the final phase of the course. Our first inspiration was the solar climber [3], project carried out in the Power Electronic Systems Laboratory of ETH Zurich (Fig. 1). Their plan comprises a photovoltaic panel, power static converters, and motors, allowing the integration between the energy source, the load, and the processing circuitry.

In this regard, our first attempt to the final term project of power electronics was an electric cart, based on a toy vehicle platform (Fig. 2), commercially available. This project was carried out in 2010. The main goal was to apply photovoltaic cells to store energy in ultra capacitors, emulating a recharge station, and then perform a race with the carts, emphasizing the optimization of energy processing circuits (static converters).

Over the following semesters, the proposals were modified to ease the development of the projects by students. Fig. 3 shows one project using the Arduino platform [21] connected

to electronic circuits for energy processing and to drive a DC motor. Fig. 4 shows another project with Arduino, to control the brightness of a light bulb.

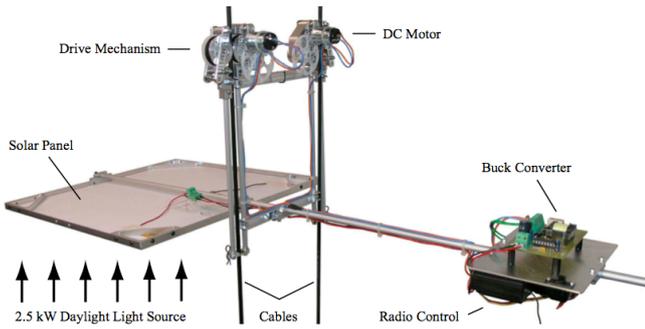


Fig. 1. Solar Climber of ETH Zurich [3].

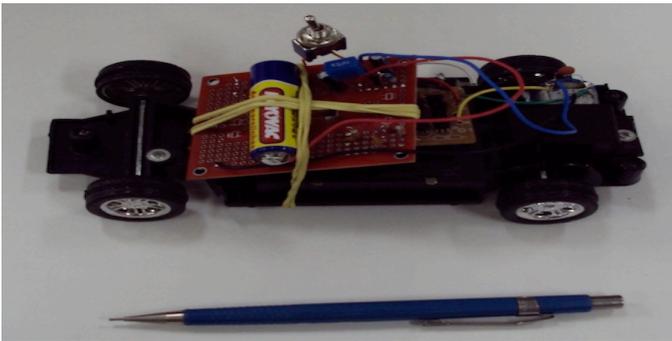


Fig. 2. Final term project employing toy carts.

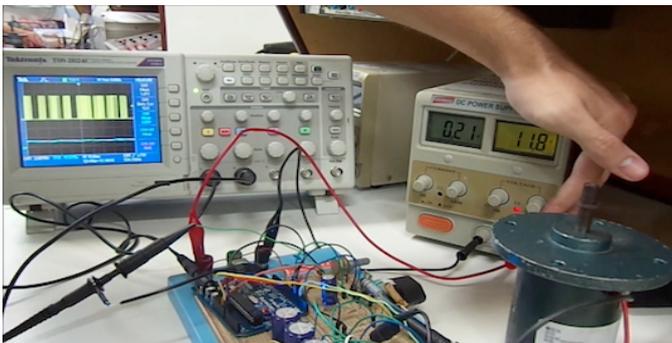


Fig. 3. Final term project with Arduino and DC motor drive.



Fig. 4. Final term project in which Arduino controls the brightness of light bulbs.

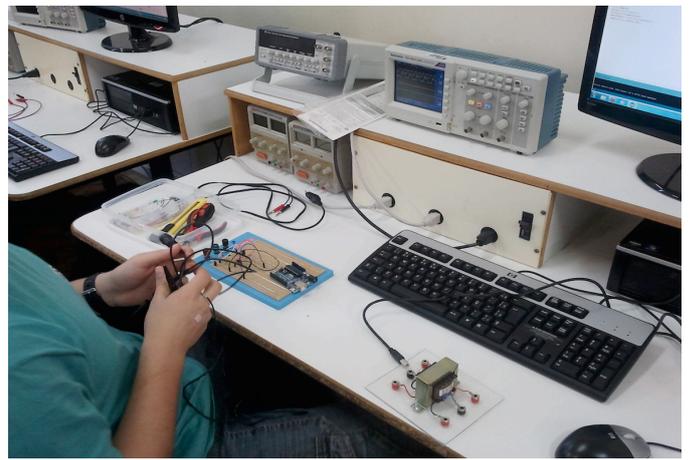


Fig. 5. Students using components of the final term project for activities developed during the classes.

Over the semesters in which the final term projects were carried out (from 2010 until 2013), we noticed a higher degree of involvement from students, and greater integration of different subjects learned throughout the semester. Our conclusion is that the use of a platform like Arduino allowed faster and easier work by students, increasing motivation, as well as enabled flexibility to applications in command and control of power electronics circuits. The biannual organization of the project activities allows the dilution of theoretical classes, simulation activities, and hands-on experiments throughout the semester. Practical activities, as shown in Fig. 5, let students increase their problem solving experience.

After our experience with final term projects, we began to discuss how students could use test equipments outside the labs. Some research works [9–10, 24] discuss key points regarding teaching of electronics or other technical areas using computer simulations, on-site lab activities, and remote laboratories. Currently, there is no consensus about what form is better for teaching topics related to engineering.

The use of remote laboratories are usually associated to cost reductions of laboratories facilities [17] or to make the experiments available at any time and at any place [11–16]. This way, remote labs become another tool to streamline power electronics teaching, joining to the list of resources: theoretical classes, resolution of exercises, simulation of circuits, and on-site laboratory activities.

Virtual Instrument System in Reality (VISIR) is discussed in [11–16] as a resource for carrying out different activities of a electronics laboratory. These research works focus on general electronics, addressing activities related to circuit analysis, filters, and operational amplifiers, among others. In [18], the use of VISIR is extended for different applications, including circuits for power electronics, as shown in Fig. 6. These circuits were implemented as part of the main platform, i.e., they are currently not available for partner institutions through standard modules.

The circuits shown in Fig. 6 are: (a) and (b) second order filter; (c) full wave rectifier with capacitive filter; (d) linear

voltage regulator, and (e) switched regulator. These circuits cover a broad range of topics studied in power electronics, from AC-DC converters to DC-DC converters, passive filters, and pulse-width modulation (PWM), among others.

Other research works [22–24] also discuss power electronics teaching, with a focus on online simulations and applets. An important comparative study between the main teaching techniques for power electronics is shown in [24]. At that time (2002), authors classified teaching tools into the following types:

- Slideshow – A standard tool for teaching, in the most diverse areas of knowledge and also in industry. A practical, easy, and flexible system. The passiveness of the student is pointed out as a disadvantage as well as the fact that usually slides are not prepared for self-study. Slideshows are adequate for presenting content quickly and in a focused manner.
- Slideshow with movies, text and audio – The inclusion of multimedia content increases the possibility of using slideshows for self-study.
- Numerical Simulation – Computer simulations for circuit design are commonplace both in academia or in industry. Numerical simulations enable cost reduction, increase flexibility, and prevent the risk of mistakes made by students in real experiments. However, simulations only become effective tools for learning when associated with the familiarity with physical elements obtained in lab activities.
- Web-Based Simulation – For an administrative point of view, it is better than conventional simulation packages, since it dispenses the purchase of software, and usually permits operation under different operating systems. The dependency on a reliable internet connection, and the difficulty simulation results are pointed out as disadvantages.
- Simulation combined with text – Here, it presents the content directly on the website, incorporating simulations in Java, videos, exercises, among other resources.
- Interactive Animations with the iPES – Authors discuss a system developed and used at ETH Zurich, which has an emphasis on content interactivity, reducing the focus on simulation. It has as a main advantage the quick response, since students can change any parameter and examine the result immediately, because it operates as an animation and not as a simulation. Flexibility is not a key point; students must follow exactly what is expected in a set of predetermined circuits.

As a conclusion, any tool has advantages and disadvantages, and none of the previously shown can replace completely the others. It is the main responsibility of professors and administrative staff take into account the characteristics of the content, analyze the previous experience

of students, and the environment in which the student is, to select the best option.

Especially in power electronics, some topics are better understood during the experimentation in the laboratory; for example, semiconductors under switching operation, the performance of elements with heat sinks, and the analysis of speed variation of an engine. Other contents may be exploited by numerical simulation; for instance, modulation circuits, signal filtering and conditioning. Some issues require repetition of exercises and circuit modifications to assure students understand how elements work. As an example, driver circuits for power transistors. Finally, learning with error is important in some topics, where students should think how to obtain the expected results. For example, the generation of command signals for transistors from sinusoidal PWM modulation requires this kind of thinking.

Thereby, this work proposes the inclusion of remote lab activities to the usual “toolbox” for power electronics teaching. This way, topics are introduced with theoretical lessons, and are advanced through exercises for fixing the content, numerical simulation of circuits, on-site laboratory experimentation and activities in remote labs. Fig. 7 shows briefly these different steps for teaching electronics and power electronics.

III. PROPOSAL OF A NEW METHODOLOGY

Power electronics circuits usually exhibit two stages: energy processing, and signal processing. The energy processing stage consists of passive components and high voltage and/or high current power semiconductors. Signal processing circuits drive such power semiconductors, apply a closed-loop control for power converters, are responsible for system protection, and operation supervision [1]. Among signal processing circuits, circuits for measuring electrical quantities are usual in power electronics applications. Moreover, passive filters and resistive networks are commonly employed to reduce the amplitude of the signals under analysis [19–20]. Power circuits, on the other hand, are usually classified in the following categories: AC-DC, AC-AC, DC-DC, and DC-AC converters [19]. Among AC-DC converters, it is common practice to begin the study by simpler circuits with diodes and sinusoidal signals [19].

After a first contact with power semiconductor devices, students are introduced to rectifiers and filters by lectures. Pen and pencil exercises and software simulations are the next activities. The last stage is the practical implementation, where students assemble the circuits on a breadboard and perform the measurements. Remote laboratories are a complement here, giving the opportunity to students repeat the laboratory activities, reinforcing the knowledge acquired and exploring some advanced topics better. The main concepts of the subject being studied will be addressed both in the lectures, during the simulations, and with the laboratory classes. This way, students have three distinct moments to absorb and to understand the contents.

The teaching methodology for power electronics proposed in this work have been implemented in three stages. In the first one, professors evaluate the methodology, making some

experiments with the remote lab platform VISIR. In the second stage, all proposed steps are developed, checking for improvement points and trying to predict some difficulties that students could find in their development. This validation phase was implemented with a pilot group of students in the beginning of 2014. This paper reports results from this two phases, collecting opinions from professors and students. The final stage is the application of this methodology for different classes of electronics technician students, through a cooperative project between IFSC and the Porto Superior Institute of Engineering (ISEP).

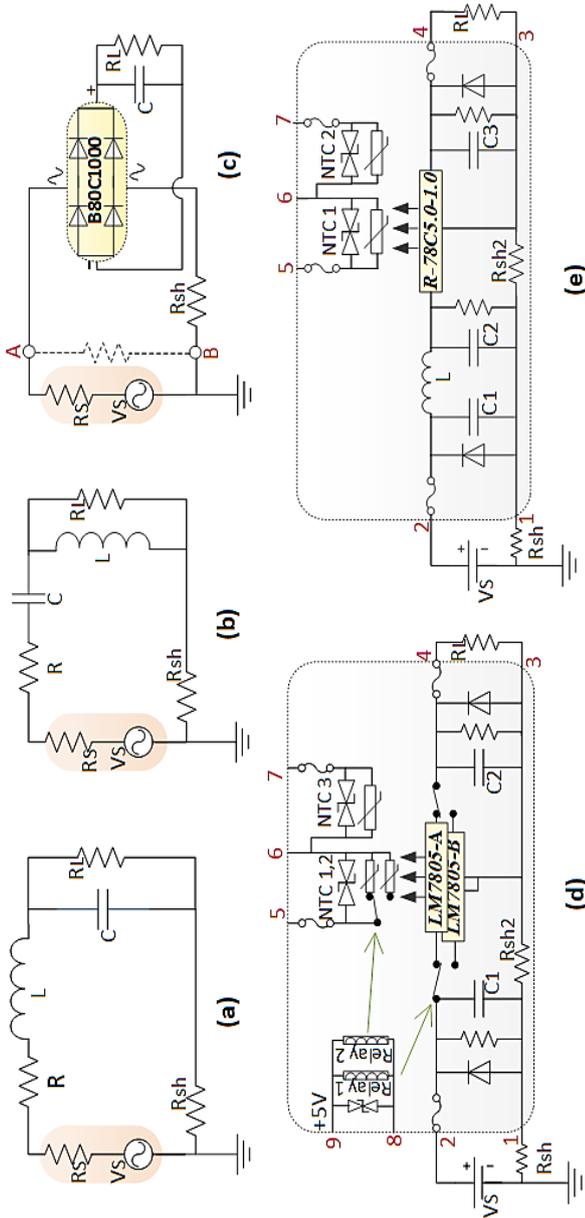


Fig. 6. Power electronic circuits implemented in [18] using the VISIR.

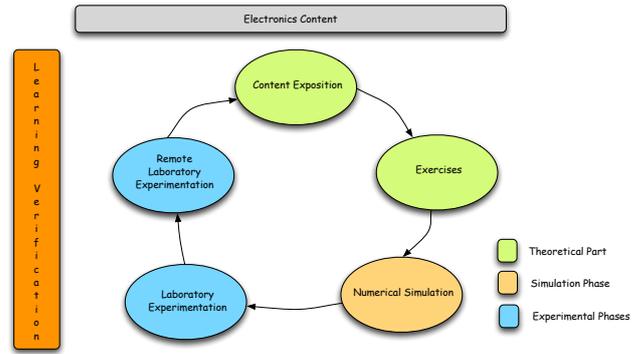


Fig. 7. Activities carried out by the student for studies in power electronics.

IV. EXPERIMENTS USING VISIR

In this pilot study, the proposed experiments with VISIR (Virtual Instrument System in Reality) comprise two simple circuits with passive elements (resistors and capacitors). These circuits can be implemented using a guest account in the virtual experimentation environment. Both experiments require to measure an output voltage considering a variation of frequency in the input signal.

Experiments were carried out by professors and students as specified in Section III. Students' learning path followed all the steps shown in Fig. 7.

A. Experiment 1 – RC Filter

The first experiment is a first order lowpass filter, with only a resistor and a capacitor, as shown in Fig. 8. The input and output voltage waveforms are also shown in this Figure. A typical application for this circuit is in filtering a pulse width modulation (PWM) signal generated by a microcontroller for an analog circuit application.

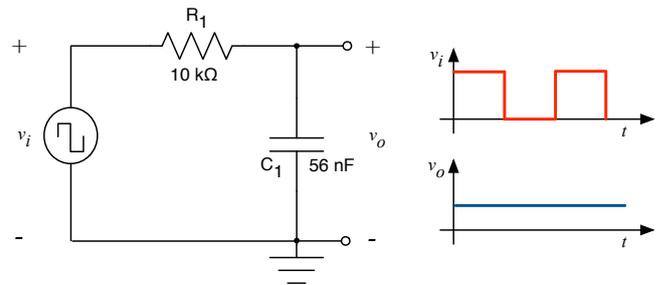


Fig. 8. Lowpass filter circuit, and input and output voltage waveforms.

Three different professors and eight students have implemented this circuit using VISIR. Fig. 9 shows one session of such an experiment, with the circuit elements, and the connections to the function generator and oscilloscope.

The input voltage is a square signal with amplitude of 2 V and 2 V of mean value, as shown in Fig. 10. Professors measured the ripple in the output voltage signal and filled Table I, for the first stage.

For the pilot group of students, we modified the input signal. Since their class assignment involved sinusoidal

signals, the input signal was modified to a sinusoidal one with amplitude of 1 V and variable frequency as shown in Table II. Since values obtained by the eight students are similar, Table II shows only the results from one of them. Students were introduced to the circuit topology and with pencil and pen calculations, filled the columns “Voltage gain” and “Calculated output voltage”. After that, using a simulation software (Proteus from Labcenter Electronics), they obtained the values in the column “Simulated output voltage”. An on-site laboratory was set up and with testing equipments (oscilloscope being the main one) they obtained values in the column “Experimental output voltage”. Finally, they had their first contact with VISIR (Figs. 6 and 7) and filled the column “VISIR output voltage”. After the experiments, users (professors and students) answered a form pointing out their opinion about the virtual experimentation platform.

TABLE I. MEASURED VALUES FOR THE FIRST EXPERIMENT MADE BY PROFESSORS

Frequency [kHz]	User 1	User 2	User 3
	Output Voltage [V]	Output Voltage [V]	Output Voltage [V]
1	1.8800	1.7660	1.7980
2	0.9807	0.9814	1.0620
3	0.6538	0.6706	0.6530
4	0.5721	0.5234	0.5721
5	0.4903	0.4412	0.4086
10	0.2452	0.2860	0.2452

TABLE II. MEASURED VALUES FOR THE FIRST EXPERIMENT MADE BY STUDENTS

Frequency [kHz]	Voltage Gain [V/V]	Calculated Output Voltage [V]	Simulated Output Voltage [V]	Experimental Output Voltage [V]	VISIR Output Voltage [V]
1	0,273	0,273	0,270	0,280	0,300
2	0,140	0,140	0,135	0,140	0,150
3	0,094	0,094	0,094	0,100	0,100
4	0,071	0,071	0,070	0,080	0,080
5	0,057	0,057	0,050	0,060	0,060
10	0,028	0,028	0,028	0,040	0,060

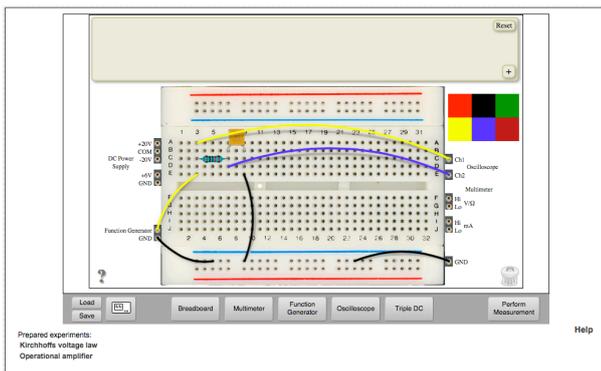


Fig. 9. A session of VISIR with the first circuit (lowpass filter).

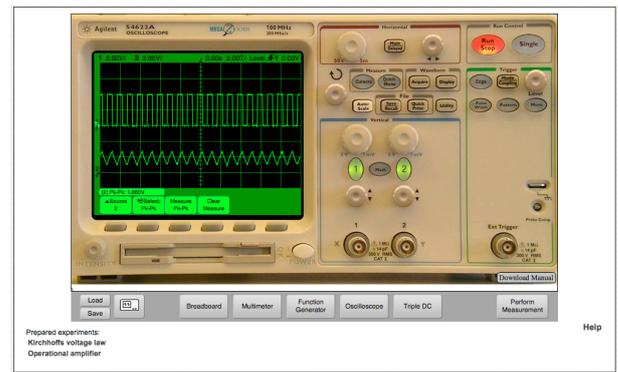


Fig. 10. Oscilloscope view inside VISIR with input (upper signal) and output (lower signal) voltage waveforms for the first experiment.

B. Experiment 2 – AC measuring circuit

The following circuit comprises a resistive network with a capacitive filter (Fig. 11). This circuit is commonly employed for measuring sinusoidal signals. The resistive network reduces the amplitude of the signal while the RC filter fades high frequency noise.

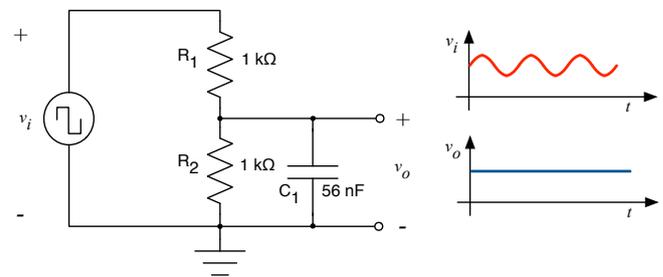


Fig. 11. Circuit for the second experiment, with applications in sinusoidal signal measuring.

Here we followed the same methodology of the first experiment. Three professors and a pilot group of eight students take part in the tests. One session of VISIR is shown in Fig. 12. The input voltage is a sinusoidal signal with amplitude of 1 V and 2 V of mean value, as shown in Fig. 13. Professors should measure the ripple in the output voltage signal and fill Table III.

With the same procedure described for the first experiment, students filled Table IV. For their session, input signal was sinusoidal, with null mean value and amplitude of 1 V.

TABLE III. MEASURED VALUES FOR THE SECOND EXPERIMENT MADE BY PROFESSORS

Frequency [kHz]	User 1	User 2	User 3
	Output Voltage [V]	Output Voltage [V]	Output Voltage [V]
1	1.0220	1.0210	1.0620
4	0.8581	0.8497	0.9399
8	0.6947	0.6455	0.6538
10	0.6538	0.5719	0.5312
20	0.4904	0.3186	0.3678
30	0.2816	0.3714	0.2861

TABLE IV. MEASURED VALUES FOR THE SECOND EXPERIMENT MADE BY STUDENTS

Frequency [kHz]	Voltage Gain [V/V]	Calculated Output Voltage [V]	Simulated Output Voltage [V]	Experimental Output Voltage [V]	VISIR Output Voltage [V]
1	0,492	0,492	0,490	0,480	0,450
4	0,408	0,408	0,398	0,412	0,400
8	0,289	0,289	0,282	0,304	0,280
10	0,247	0,247	0,236	0,264	0,260
20	0,136	0,136	0,138	0,150	0,120
30	0,093	0,093	0,089	0,116	0,090

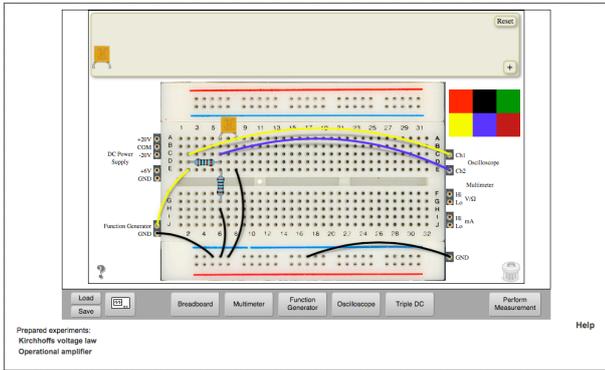


Fig. 12. A session of VISIR with the second circuit (resistive network for measuring sinusoidal signals).

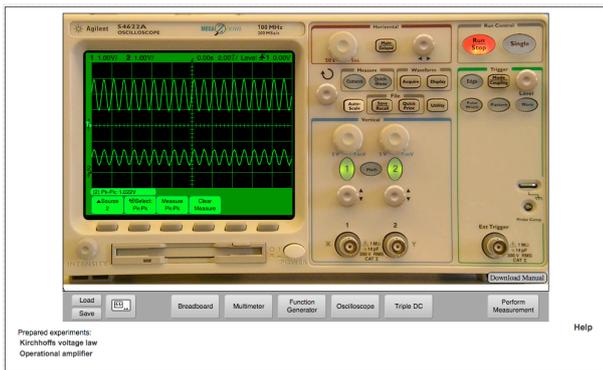


Fig. 13. Oscilloscope view inside VISIR with input (upper signal) and output (lower signal) voltage waveforms for the second experiment.

C. Discussion about users' answers

After the experiments, users answered some questions regarding the use of the virtual instrumentation environment. The form is the following:

1) Circuit implementation using VISIR was?

- Easy
- Intermediate
- Hard

2) Equipment adjustments inside VISIR were?

- Easy
- Intermediate
- Hard

3) Measuring electrical quantities using VISIR instrumentation was?

- Easy
- Intermediate
- Hard

4) Time spent for virtual experiments, when compared with real experiments?

- Small
- Medium
- Large

5) Your general impression about the use of VISIR for these activities was?

- Bad
- Good
- Very good

6) Considering these experiments, the potential for using VISIR in classes is?

- Small
- Medium
- Large

Users' answers are shown from Fig. 14 until Fig. 19.

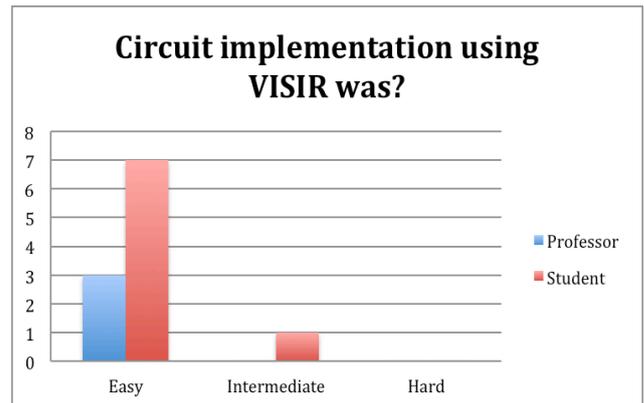


Fig. 14. Answers for question 1.

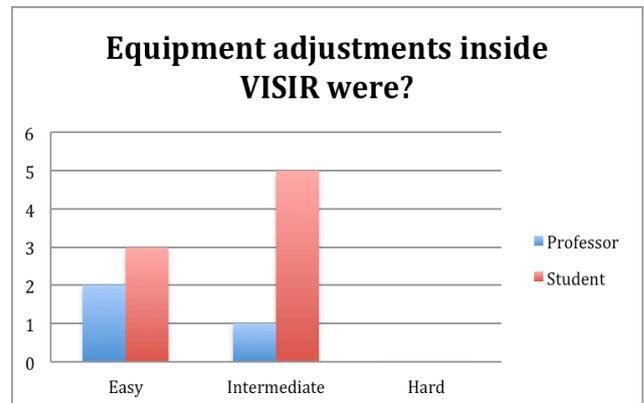


Fig. 15. Answers for question 2.

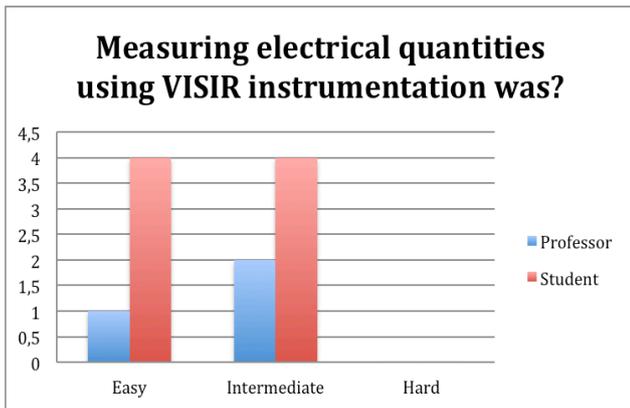


Fig. 16. Answers for question 3.

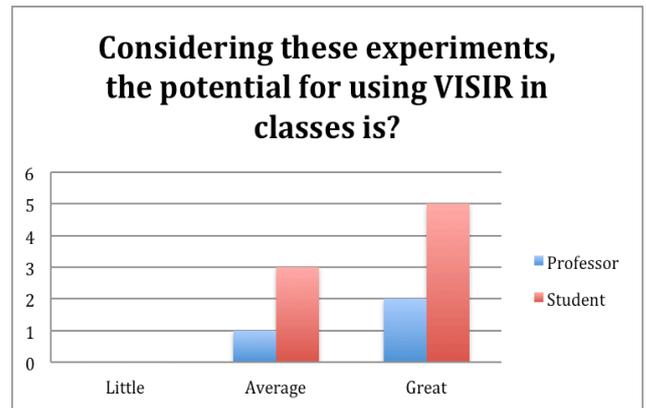


Fig. 19. Answers for question 6.

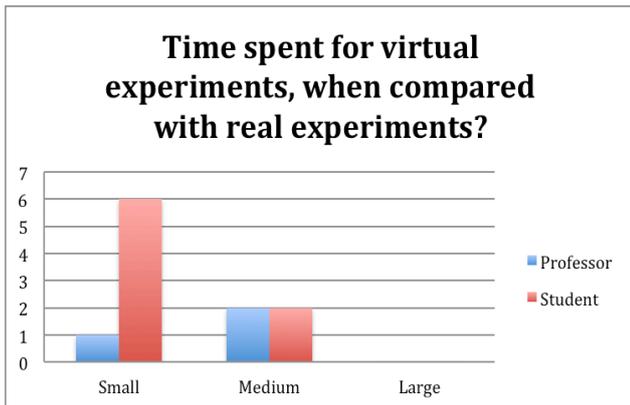


Fig. 17. Answers for question 4.

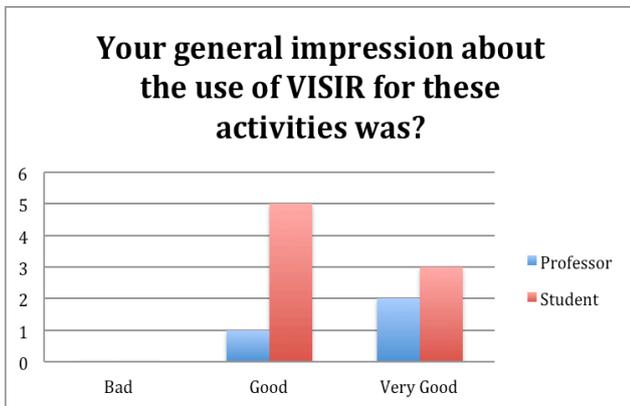


Fig. 18. Answers for question 5.

Opinions from professors and students are convergent, with some differences about equipment adjustment and the overall impression about VISIR. As the first general conclusion, the introduction of the remote lab with VISIR had a positive effect.

From professors' answers, we can infer that:

- Users considered the implementation with VISIR easy, what is also expected from students;

- Equipment adjustment inside VISIR was considered easy and of intermediate difficulty, what is probably associated with previous experience with similar equipment;
- Measurement using VISIR equipment were considered easy and of intermediate difficulty, maybe expressing the difficulty with the first use of the system;
- Regarding time spent with the experiments, users considered the activities quicker than conventional experiments, that are usually slow;
- The general perception of the users regarding VISIR was between “good” and “very good”, what is positive and indicates a good acceptance of the platform;
- The potential for the use of VISIR in teaching environments was considered between medium and large, what indicates its prospective use for power electronics classes.

Otherwise, from students' answers, we can infer that:

- VISIR is an adequate choice for circuit verification. However, students consider on-site laboratory experiments indispensable;
- Students also pointed out the agreement in results from VISIR and on-site experiments. However, they again stressed the importance of hands-on experience;
- VISIR user interface is considered enjoyable and easy to use. It is a good complement to classes, and to reinforce some topics, mainly because one can access from home;
- As a general opinion, students think remote labs contribute to learning, but cannot substitute on-site laboratories.

In short, we can conclude that VISIR has a good potential of application in some topics of electronics, especially in power electronics when combined with traditional teaching.

V. CONCLUSIONS AND FUTURE WORK

The use of remote laboratories to teaching has been promising, and seems to be an effective way to spark student's interest.

From our first experience and from the literature, we can conclude that remote experimentation platforms like VISIR are very promising for electronics teaching. Two simple experiments were done in this work using the guest account, without any modification in VISIR hardware. This way, the three professors could be in the role of students, giving their opinion about the use of the platform, as well as eight students evaluated the use of this new tool.

Our users in this work (professors and students) judged the potential of remote laboratories for electronics as very high, combining different strategies like lectures, problem solving, simulation, and experiments in standard laboratories.

This way, the effective use of VISIR, even for simple circuits, allows students to reproduce experiments many times, giving confidence and improving the success rate. Moreover, VISIR gives flexibility regarding the time schedule and number of simultaneous users.

Finally, we can conclude that VISIR is appropriate for power electronics teaching, firstly with simple circuits like the ones presented here. Thus, students and professors can learn how to use the platform, and, after some time, they can develop more complex activities. In a future work, we plan to extend these activities to a larger group of students and also to introduce new circuit topologies like modulation circuits.

ACKNOWLEDGMENT

Authors would like to thank students of Electronics at IFSC for their contribution in this research.

REFERENCES

- [1] P. Bauer, J. W. Kolar, "Teaching Power Electronics in the 21st Century". 15th European Conference on Power Electronics and Applications, EPE Journal, Vol.13 n° 4, Lille, France, November 2003.
- [2] Jiang W., Yu, F., Mo, Y., "A problem oriented model for teaching power electronic circuits". IEEE 10th International Conference on Power Electronics and Drive Systems (PEDS 2013), Kitakyushu, Japan, pp: 142 – 146.
- [3] T. Friedli et al., "Modelling the Space Elevator - A Project Oriented Approach for Teaching Experimental Power Electronics", Proceedings of the 12th European Conference on Power Electronics and Applications (EPE 2007), Denmark, Aalborg, CD-ROM, ISBN: 9-7890-7581-5108, September 2-5, 2007.
- [4] A. R. Marchezan et al., "Laboratório Remoto aplicado ao Ensino de Engenharia Eletrônica". Available in: <<http://inf.unisul.br/~ines/workcomp/cd/pdfs/2211.pdf>> Accessed on June 2011 (in Portuguese).
- [5] J. Juan et al., "Methodology updating experience in basic digital electronics teaching". Technologies Applied to Electronics Teaching (TAEE 2012), Vigo, Spain, pp: 58 – 62.
- [6] H. Xu et al., "Exploring research of "Project-driven" teaching methods of Electronic Technology courses". International Conference on E-Health Networking, Digital Ecosystems and Technologies (EDT 2010), Shenzhen, China, pp: 273 – 276.
- [7] O. Rompelman, M. Vellekoop, "A first year course in integrative learning: A practical example of back to the basics". Anders Hagström (Ed.): Engineering education: Rediscovering the Centre; Proceedings of the SEFI Annual Conference, Winterthur/Zurich, Sept. 1-3, 1999, pp. 225-230.
- [8] W. Sulkowski et al., "The one year project as a method for fusion of power electronics with other studies"; EPE-PEMC 2002, Cavtat/Dubrovnik, ISBN 953-184-047-4.
- [9] J. E. Corter et al., "Remote Versus Hands-On Labs: A Comparative Study", 34th ASEE/IEEE Frontiers in Education Conference. October 20-23, 2004, Savannah, GA USA.
- [10] Michael E. A., "Virtual Lab versus Remote Lab.", 20th World Conf. on Open Learning and Distance Education. Dusseldorf (Germany), April 2001.
- [11] J. Lloret et al. "A remote network laboratory to improve university classes", WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering. Eds. J. L. Mauri, et al. No. 5. WSEAS, 2008.
- [12] M. Tawfik et al., "Virtual Instrument Systems in Reality (VISIR) for Remote Wiring and Measurement of Electronic Circuits on Breadboard". IEEE Trans. Learning Technologies, Vol.6 n° 1, pp: 60 – 72.
- [13] G. R. Alves, "Using VISIR in a large undergraduate course: Preliminary assessment results". Global Engineering Education Conference (EDUCON 2011), Amman, Jordan, pp: 1125 – 1132.
- [14] M. E. Auer, "Remote Laboratory of the Carinthia Tech Institute". International Conference on Blended Learning, Florianópolis, 2008.
- [15] N. Sousa et al., "An Integrated Reusable Remote Laboratory to Complement Electronics Teaching". IEEE Trans. Learning Technologies, Vol.3 n° 3, pp: 265 – 271.
- [16] M. A. Marques et al., "How Remote Labs Impact on Course Outcomes: Various Practices Using VISIR". Education, IEEE Transactions on, Vol. PP n° 99.
- [17] J. O. Pacheco et al., "Multi-platform education system of frequency inverters", Industry Applications (INDUSCON), 2012 10th IEEE/IAS International Conference on Industry Applications, 2012, Fortaleza. Power Electronics, 2012.
- [18] M. S. T. Abuelela, MSc, "Laboratory as a Service (LaaS): a Paradigm for Developing and Implementing Modular Remote Laboratories", Ingeniería Electrónica, Universidad Nacional de Educación a Distancia, Madrid, España (2011) BSc, Ingeniería Eléctrica, Universidad de Ain Shams, El Cairo, Egipto (2008).
- [19] N. Mohan, "Power Electronic Converters, Application and Design". New York: IE-Wilwy, 2003.
- [20] R. W. Erickson, "Fundamentals of Power Electronics". New York, EUA – Chapman & Hall, 1997.
- [21] Arduino, "Platform of Development of Projects". Available in: www.arduino.cc. Access in 18/02/2014.
- [22] U. Drogenik, J. W. Kolar, "Teaching Thermal Design of Power Electronic Systems with Web-Based Interactive Educational Software", Proceedings of the 18th Annual IEEE Applied Power Electronics Conference and Exposition, Miami Beach (Florida), USA, Vol. 2, pp. 1029-1037, February 9-13, 2003.
- [23] U. Drogenik, J. W. Kolar, "Teaching Basics of Inductive Power Components Using Interactive Java Applets Performing FEM-Based On-Line Calculation of the Magnetic Flux Distribution", Proceedings of the 10th International Power Electronics and Motion Control Conference (PEMC 2002), Dubrovnik, Croatia, September 9-11, 2002, CD-ROM, ISBN: 953-184-047-4.
- [24] U. Drogenik, J. W. Kolar, "Survey of Modern Approaches of Education in Power Electronics", Proceedings of the 17th Annual IEEE Applied Power Electronics Conference and Exposition (APEC 2002), Dallas, USA, Vol. 2, pp. 749-755, March 10-14, 2002.