

Significance of didactic tools in power electronics teaching

Dunja Srpak, Ivan Šumiga, Josip Srpak

University North, Department of Electrical Engineering, 104. Brigade 3, 42000 Varaždin, Croatia
E-mail: dunja.srpak@unin.hr

Abstract. The paper presents results of a research made by teachers of undergraduate electrical engineering students in determining the significance of using didactic tools in order to increase the students' motivation to participate actively in the teaching process. Converters used in this research are designed and modelled by students themselves for laboratory power-electronics exercises. It is shown that using didactic tools improves understanding of complex subjects when the students have the opportunity to link practical exercises with the theoretical explanations given in lectures.

Keywords: didactic tools, power electronics, students, teaching

Pomen didaktičnih orodij pri poučevanju močnostne elektronike

V prispevku so predstavljeni rezultati raziskave učiteljev dodiplomskega elektrotehničnega študija pri določanju pomena uporabe didaktičnih orodij, da se poveča motivacija študentov za aktivno sodelovanje v učnem procesu. Pretvorniki, ki so bili uporabljeni v tej raziskavi, so zasnovali in modelirali sami študentje za laboratorijske vaje močnostne elektronike. Izkazalo se je, da uporaba didaktičnih orodij izboljša razumevanje kompleksnih predmetov, ko imajo študentje možnost povezati praktične vaje s teoretičnimi pojasnili, ki so podani na predavanjih.

Ključne besede: didaktična orodja, močnostna elektronika, študentje, poučevanje

1 INTRODUCTION

Different projects running at high-education institutions are intended to motivate students to merge their theoretical knowledge with their practical engineering assignment [1]. Challenging the students of undergraduate, graduate or postgraduate level to create solutions to real problems in a form of simulation [2] or physical device [3] shows their capabilities to apply the learned skills.

Power-electronic devices are often developed at universities with the intent to involve students in the development process, as well as in the process of testing and improving the devices. The developed converter with a hybrid communication described in [4] shows a good performance when compensating a certain single harmonic, but not several harmonics simultaneously. Testing the converter presented in [5] shows that it is possible to develop high-quality modern power-supply devices at universities. Then again, the use of low-cost platform or didactic modules [6]-[9] enables the

students to better understand complex subjects like power electronics, even with modest financial possibilities of a home institution.

As a support for practical teaching of power electronics, the didactic platform presented in [10] allows the student to develop the ability to analyse different operating conditions and different combinations of elements in rectifier circuits. A modular kit described in [11] is intended to involve the students in the process of modelling and designing the devices of power electronics and not only to learn about basic circuit techniques and topologies.

This paper analyses the significance of didactic tools in conducting practical exercises of complex high school courses like electric circuits, power electronics or electromotive drives. Two converters are described. They are built by undergraduate students and later used for laboratory exercises of the power electronics in the third year of professional study in electrical engineering. Successful passing of exams and in-depth understanding the operation of circuits and topologies of different power-electronic devices are observed over several generations of students. Results of testing the described converters in the university laboratories are presented and discussed. At the end of the paper, conclusions about evaluating the improvement of the students' results are given.

2 CONVERTERS BUILT BY STUDENTS

During the preparation of their final exam, undergraduate students of Electrical Engineering must demonstrate the acquired skills for independent execution of professional tasks. Therefore, they are asked to conduct an independent work on development of project documentation [12], problem solving in a

simulation software [13] or to build a functional real-size device or prototype model [14], [15]. Likewise, the converters described here were created as a part of the students' final exam works [16], [17].

2.1 High-frequency DC-DC converter

The DC-DC converters are electronic devices that convert the voltage and current values from one to another level. They are used in power-supply systems for voltage conversion and control and protection of sources and consumers from electromagnetic interferences. The frequency converters contain either a low- or high- frequency transformer and are consequently formed low-frequency (LF) or high-frequency (HF) converters.

The main characteristics of the HF converters are:

- small mass for a high power,
- work at a high-frequency level,
- variable range of the work signal (load-dependent),
- high efficiency,
- low noise.

The printed circuit board (PCB) for the converter presented in [16] is assembled with electronic components according to the electrical scheme in Fig. 1 [18]. This converter consists of several basic parts:

1. IC1 - a control integrated circuit that controls the switches with phase-shifted rectangular signals. It consists of a frequency oscillator, signal comparator, pulse-width modulator, reference

voltage source and output-control transistors.

2. Two pairs of MOSFET transistors (switches) guided by a control integrated circuit, voltage-controlled, designed to withstand sufficient voltage and current loads.
3. A T1 ferrite transformer with two primary and two secondary windings for high frequencies, of up to 200KHz.
4. Rectifying diodes – high-frequency diodes connected to a diode bridge.
5. Input stabilization capacitors – providing the power to the control circuit for a stable operation of the system at a maximum converter load.
6. Output stabilization capacitors - smoothing the waveform of the output voltage and providing sufficient energy at a maximum load and positive feedback.
7. Feedback – controlling the output voltage at the set values at any load (adjusted by the VR1 resistor).
8. Potentiometer VR2 - adjusting the frequency at which the transformer power is maximal.
9. Control transistors - providing the minimum and maximum permissible voltage value for the output switches (a small error in the control circuit causes a large error in the transformer circuit).

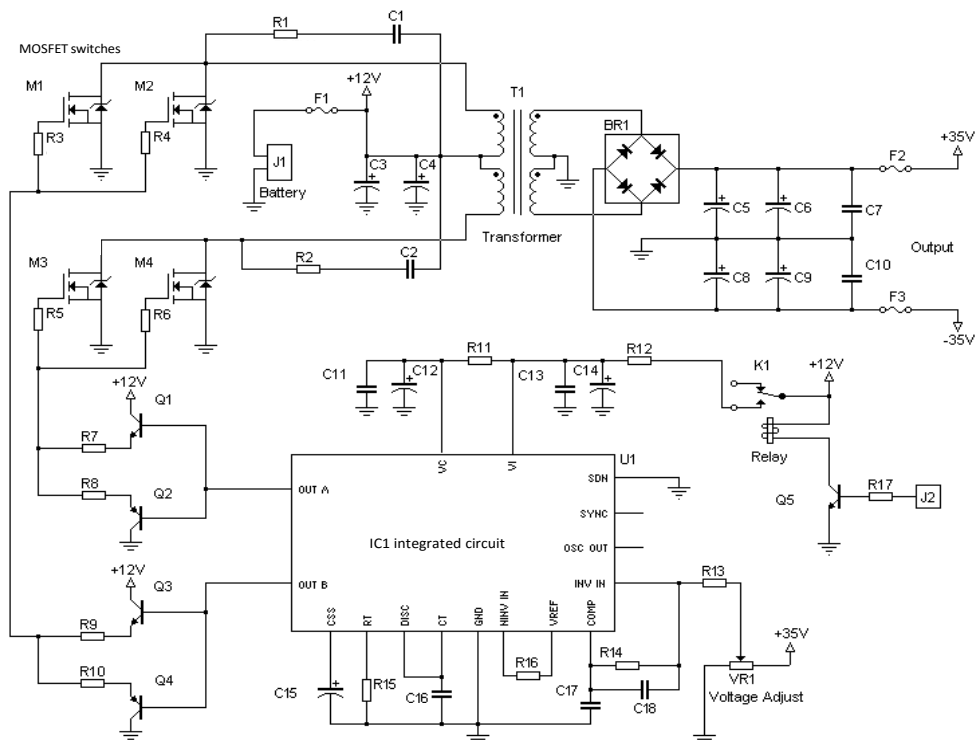


Figure 1. Electric scheme of the HF converter.

10. An output inductor (L) - smoothing the output current and storing and providing the energy when both switches are off.
11. An RC filter - removing the interference caused by the leakage flux on the transformer coils.

Fig. 2 shows the developed PCB with the pertaining elements, just before being placed in the PCB housing.

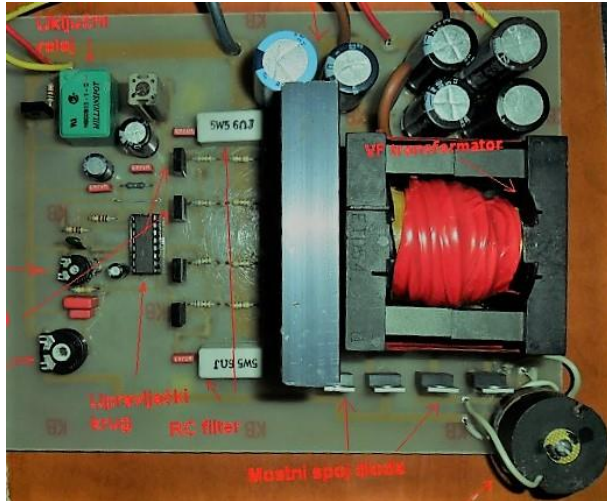


Figure 2. PCB with electronic components of the HF converter.

2.2 Indirect frequency converter

The most common way to control the rotating speed of asynchronous motors is by applying frequency converters. There are two basic groups of the frequency converters, direct and indirect. While the direct converters do not have the DC circuit, the indirect frequency converters convert the AC voltage (with a fixed frequency) into the DC voltage and then that DC voltage into the AC voltage of a variable amplitude and frequency. The block diagram of the indirect converter is shown in Fig. 3.

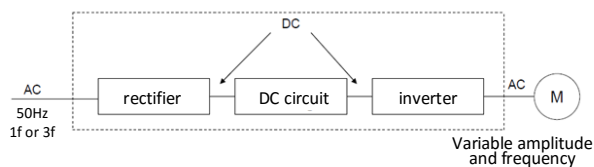


Figure 3. Block scheme of indirect frequency converter.

The inner part of the converter is described in [17]. Its electronic components are shown in Fig. 4. The rectifier of this converter is built as a full-wave uncontrolled diode bridge. The rectifier nominal data are 1000V, 35A. The total capacity of the twelve capacitors connected in parallel in the DC circuit is 1777 μF . They are used for smoothing the voltage from the rectifier. There is also a braking resistor taking over the kinetic energy during the counter current braking.

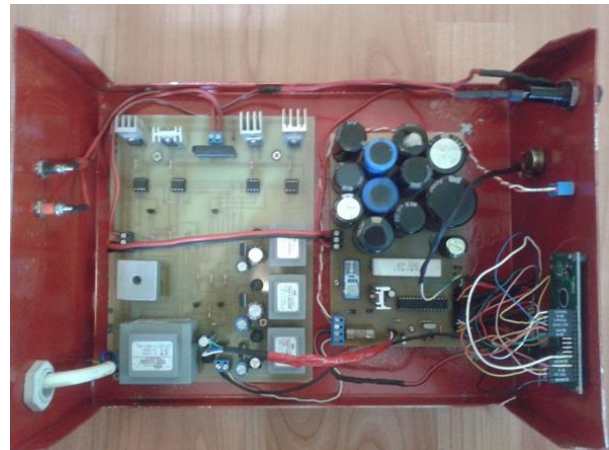


Figure 4. Inner part of the built frequency converter.

The inverter consists of four IGBT transistors (Q1, Q2, Q3 and Q4) connected to the H-bridge (Fig. 5). Transistors Q1 and Q4 are activated during the positive half-period and transistors Q3 and Q2 during the negative half-period. Transistors Q2 and Q4 are turned-on during the entire half-period, while the PWM signal is sent to transistors Q1 and Q3.

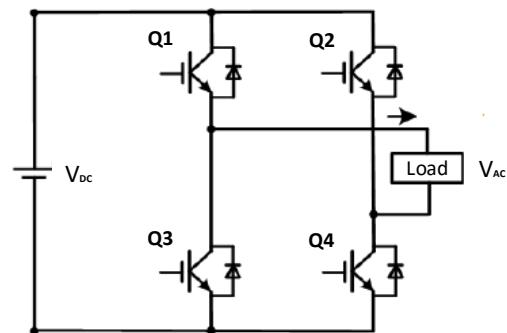


Figure 5. General scheme of the inverter.

3 TESTING RESULTS AND DISCUSSION

The developed converters were tested in the university laboratory by undergraduate electrical-engineering students under their teachers' supervision.

3.1 Voltage measurements on the DC-DC converter

The undergraduate electrical-engineering students are asked to test the DC-DC converters in university laboratory. For this purpose, they have to refresh their theoretical knowledge of boost converter with galvanic insulation, identify the components of the converter model and measure the converter-voltage waveforms.

The oscilloscope 1 mass is connected to the mass of the converter input voltage. The waveforms to be recorded are:

- channel CH1 - the control voltage of the M1 switch realized by the MOSFET transistor,

- channel CH2 - the control voltage of the M3 switch M3 realized by the MOSFET transistor.

The oscilloscope 2 mass is connected to the mass of the converter output voltage to record the following waveforms:

- CH1 - 35V at the output of the converter,
- CH2 + 35V at the output of the converter.
- CH3 - the voltage at one secondary winding of the T1 transformer,
- CH4 - the voltage at one output of the rectifier bridge connected to the secondary winding of the T1 transformer.

From the recorded images, the students read the signal values and the work frequency of the converter. At the end, they prepare a report about their exercises. Figs. 6 and 7 show the recorded results from a report of one of the students, for the two oscilloscopes.

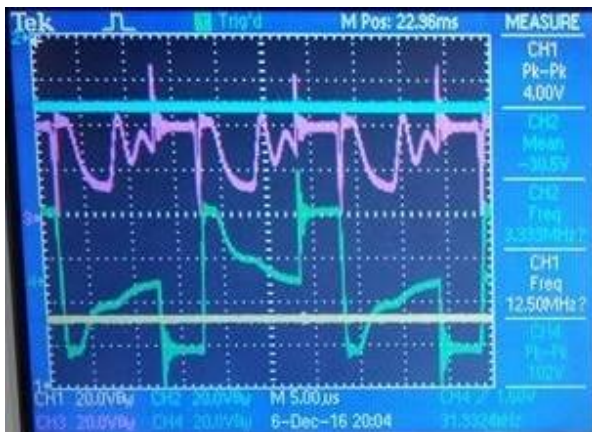


Figure 6. Measurement results from oscilloscope no. 1.



Figure 7. Measurement results from oscilloscope no. 2.

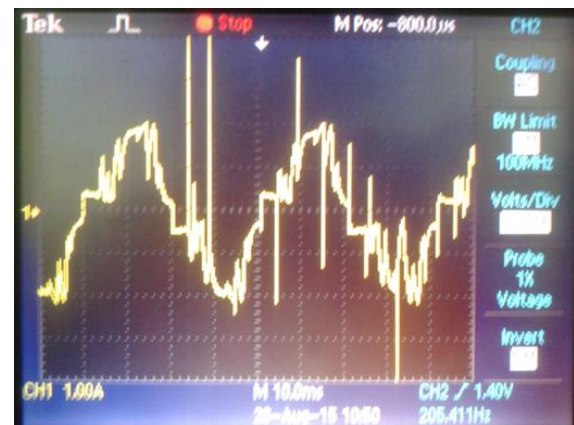
In Fig. 6, the waveform from CH4 (after the rectifier bridge) is irregular, there are many voltage drops. The DC value is very stable; it is + 35 V at the converter output after the LC filter (CH1).

3.2 Results of testing the indirect frequency converter

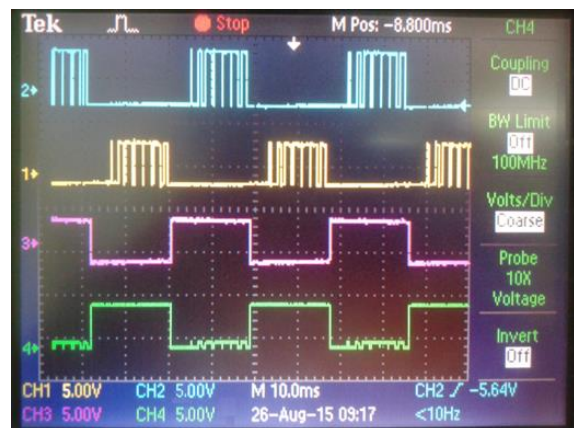
This converter is tested at the frequencies of 35 Hz, 50 Hz and 65 Hz with a single-phase asynchronous motor. Its nominal data are given in Table. Fig. 8 shows results of the device testing taken at 35 Hz output frequency.



(a)



(b)



(c)

Figure 8. Waveforms of the voltage and current at 35Hz, (a) voltage of the inverter output, (b) current of the inverter output, (c) voltages of the gate of each IGBT (from top to bottom: Q1, Q3, Q4, Q2)

The PWM modulation of the voltage waveform at the inverter output can be noticed. If an asynchronous motor is powered via a frequency converter, the output current assumes a sinusoidal waveform, due to the motor inductance.

Table 1: Nominal data of the motor for converter testing

Parameter	Value
Rated voltage	220 V
Rated current	1.6 A
Rated power	0.18 kW
$\cos\phi$	0.87
Rated speed	1390 r/min
Rated frequency	50 Hz
Capacitor	8 μ F

The designed indirect frequency converter can change the frequency of the output current in the range from 1 to 100 Hz. Since the voltage of the DC circuit is invariable, only the voltage frequency can be changed, not the amplitude. When generating a PWM control signal, it is necessary to use high frequencies to get a more sinusoidal shape of the motor current.

4 CONCLUSION

Using simple didactic tools in power-electronics teaching increases the students motivation. The advantage of using converters created by the students themselves instead of commercial devices provides an easier access to the measuring points. Moreover, they cost much less due to the use of cheaper and simpler components, and in case of being damaged by the students while learning on them, the loss is not considerable. The students use the commercial devices for practicing only after their warranty expiration and if their units are not highly integrated.

Although the recorded waveforms are therefore not perfect, the students find it easier to connect such practical measurements with their theoretical knowledge acquired at lectures than when using professional commercial devices. By using various didactic tools in practical exercises, the students achieve better examination results and there is an increased level of competence noted in their understanding and applying the acquired knowledge when using the power electronic devices.

REFERENCES

- [1] Urban Burnik, Dejan Križaj, Zmurek Topčagić, Marko Meža "Measuring impedance using an open-source instrumentation platform", *International Journal of Electrical Engineering Education*, 55(2), pp. 168-185, 2018.
- [2] Matevž Bošnjak, Drago Matko, Sašo Blažič "Razvoj simulatorja vesoljskega plovila za projekt Evropske vesoljske agencije ESMO", *Elektrotehniški vestnik*, 77(4), pp. 194-199, 2010.
- [3] Primož Sukič "Izdelava električnega kolesa za študentsko tekmovanje 2012", 22. posavetovanje "Komunalna energetika / Power engineering", Maribor, 2013, pp. 1-18, 2013.
- [4] Horia Balan, Aurel Botezan, Radu Tirnovan, Ioan Vadan, Ana Iacob "Inverter with hybrid commutation for DC-AC conversion systems", *IFAC Workshop ICPS'07 2007, July 09-11, Cluj-Napoca, Romania*, pp.193-196, 2007.
- [5] Aleš Leban, Danijel Vončina, Peter Zajec "Nizkonapetostni napajalni modul z galvansko ločitvijo in enofazno PFC stopnjo", *Elektrotehniški vestnik*, 81(3), pp. 115-122, 2014.
- [6] Erica N. Nishida, Robson B. Gonzatti, Sílvia C. Ferreira, Rondineli R. Pereira, Carlos H. da Silva, Ismael Noronha, Luiz E. B. da Silva, Germano Lambert-Torres "Low-cost platform for electrical measurement and frequency analysis in power electronic education", *2015 IEEE 13th Brazilian Power Electronics Conference and 1st Southern Power Electronics Conference (COBEP/SPEC)*, pp. 1-6, 2015.
- [7] Luiz Pedro D. Silva, Rondineli R. Pereira, Robson B. Gonzatti, Luiz E. B. da Silva, Germano Lambert-Torres, Denis Mollica, Joselino Santana Filho "Low-cost didactic module for single-phase inverter teaching", *2017 Brazilian Power Electronics Conference (COBEP)*, pp. 1-6, 2017.
- [8] Matheus Bortoloti Dias, Flavio Alessandro Serrao Goncalves, Fernando P. Marafao, Helmo K. M. Paredes "Low cost digital module for demonstration of modulation strategies in DC-to-AC converters", *2017 Brazilian Power Electronics Conference (COBEP)*, pp. 1-6, 2017.
- [9] Salatiel de Castro Lobato, Diego Albuquerque Carvalho, André Augusto Ferreira, Vinicius Foletto Montagner "Didactic prototype to model and to design linear control applied to a RLC plant", *2017 Brazilian Power Electronics Conference (COBEP)*, pp. 1-6, 2017.
- [10] Marcelo R. S. Brito, Fernando C. Melo, Luiz C. Freitas, João B. Vieira Jr., Emrane A. A. Coelho, Valdeir J. Farias, Luiz C. G. Freitas "Didactic platform for teaching of three-phase rectifier circuits in power electronics", *International Journal of Electrical Engineering Education*, 51(4), pp. 279-291 2014.
- [11] Anas Al Bastami, Al-Thaddeus Avestruz, Steven B. Leeb "Teaching modeling, control, and simulation in a modular kit for power electronics", *2014 IEEE 15th Workshop on Control and Modeling for Power Electronics (COMPEL)*, pp. 1-10, 2014.
- [12] Dunja Srpak, Ivan Sranković, Josip Huček "Modernizacija postrojenja ugradnjom frekventnih pretvarača", *Technical Journal*, 4(1-2), pp. 88-93, 2010.
- [13] Nikola Turk "Impulsno-širinska modulacija prostornog vektora", *Final work No 192/EL/2011, Polytechnic of Varaždin*, pp. 1-85, 2011.
- [14] David Naglaš, Ivan Šumiga, Miroslav Horvatić "Prototyping of a CNC machine", *Technical Journal*, 8(2), pp. 171-175, 2014.
- [15] Antonio Auker "Izrada prototipa preklopne pile upravljane PLC-om / Construction of the PLC controlled prototype cut off saw", *Final work No 392/EL/2016, University North*, <https://urn.nsk.hr/urn:nbn:hr:122:648144>, pp. 1-58, 2017.
- [16] Igor Gombar "Istosmjerni DC-DC pretvarači", *Final work No 278/EL/2012, Polytechnic of Varaždin*, pp. 1-69, 2012.
- [17] Ivan Šantalab "Izrada neizravnog frekvencijskog pretvarača pomoću Arduina", *Final work No 356/EL/2015, University North*, <https://urn.nsk.hr/urn:nbn:hr:122:593822>, pp. 1-72, 2015.
- [18] http://electronics-diy.com/electronic_schematic.php?id=883, available on May 2018.

Dunja Srpak received her M.E. degree in electric power engineering from the University of Zagreb in 1993 and Ph.D. degree from the University of Maribor in 2018. She has been working as a project designer and project manager since her graduation and since 2009 she has been lecturing at the Department of Electrical Engineering in Varaždin. Her area of interest includes power electronics and electromotive drives, renewable energy sources, especially wind-energy converting power plants and their impact on the power system operation.

Ivan Šumiga received his M.E. and M.Sc. degrees in electrical engineering from the University of Zagreb in 1986 and 1989, respectively. He worked as a research software development engineer, and since 2005 he has been giving lectures at the Department of Electrical Engineering in Varaždin. His area of interest includes electronics and control systems.

Josip Srpak received his M.E. degree in electrical engineering from the University of Zagreb in 1993. He has been working as a project designer since his graduation and has been a part-time lecturer at the Department of Electrical Engineering in Varaždin since 2011. His area of interest includes electromotive drives, electronics and automation systems.