

A UTILIZAÇÃO DE SIMULADORES DE FINS ESPECIAIS COMO UMA FERRAMENTA DE TREINAMENTO PROFISSIONAL AVANÇADO SOB CONDIÇÕES DE E-LEARNING

THE USE OF SPECIAL-PURPOSE SIMULATORS AS AN ADVANCED PROFESSIONAL TRAINING TOOL UNDER E-LEARNING CONDITIONS

LA UTILIZACIÓN DE SIMULADORES PARA FINES ESPECIALES COMO INSTRUMENTO DE CAPACITACIÓN PROFESIONAL AVANZADA EN CONDICIONES DE ENSEÑANZA A DISTANCIA

MARTINEZ, Fredy^{1*}; MARTINEZ, Fernando¹; MONTIEL, Holman¹;

¹ Universidad Distrital Francisco José de Caldas, Facultad Tecnológica, Bogotá DC. Colombia.

* Corresponding author

e-mail: fhmartinezs@udistrital.edu.co

Received 14 August 2020; received in revised form 16 October 2020; accepted 27 October 2020

RESUMO

Tradicionalmente, a eletrônica de potência tem sido um campo de treinamento complexo para alunos de graduação na área elétrica da Universidade Distrital Francisco José de Caldas. Neste curso, múltiplas teorias e conceitos são difíceis de assimilar devido ao distanciamento de outros cursos do programa e à complexidade de conceituar elementos abstratos. Uma ferramenta fundamental de aprendizagem corresponde às práticas laboratoriais, que permitem visualizar conceitos, facilitando a sua compreensão e assimilação. No entanto, as restrições de mobilidade impostas em nível global têm impedido o acesso a esses espaços de aprendizagem, restringindo elementos fundamentais do processo, como a interação direta com circuitos e equipamentos de força e a socialização crítica entre os alunos. A eficácia do processo de aprendizagem está ligada aos recursos disponíveis, hoje esses recursos foram reduzidos em decorrência do isolamento social que se espera que continue nos próximos meses. Para reduzir este impacto, foi iniciado o desenvolvimento de uma ferramenta informática, capaz de substituir o trabalho dos alunos em laboratório em termos de interação direta com os circuitos, análise de comportamento e desenho de aplicações. A ferramenta é um simulador de circuitos especificamente orientado para a área da eletrônica de potência, pelo que é preferível para treino específico em comparação com os simuladores tradicionais, uma vez que permite simplificar o comportamento dos elementos ao nível do switch, eliminando a sua análise parasitária, e portanto reduzindo as demandas de capacidade de processamento, memória de armazenamento e tempo de simulação. O primeiro circuito implementado corresponde a um corretor de fator de potência ativo em um conversor do tipo *Boost*, aplicação que por si só justifica o uso da ferramenta. Como resultados preliminares, os educadores observaram um maior comprometimento e motivação dos alunos em seu trabalho autônomo.

Palavras-chave: *Simulador de circuitos, COVID-19, eletrônica de potência, corretor de fator de potência.*

ABSTRACT

Traditionally, power electronics has been a complex training field for undergraduate students in the electrical area of the Universidad Distrital Francisco José de Caldas. In this course, multiple theories and concepts are difficult to assimilate due to the distance from other program courses and the complexity of conceptualizing abstract elements. A fundamental learning tool corresponds to the laboratory practices, which allow visualizing concepts, facilitating their understanding and assimilation. However, the mobility restrictions imposed at a global level have prevented access to these learning spaces, restricting fundamental elements of the process, such as direct interaction with circuits and power equipment and critical socialization among students. The effectiveness of the learning process is linked to the resources available, today these resources have been reduced as a result of the social isolation that is expected to continue in the coming months. To reduce this impact, the development of a computer tool has been initiated, capable of replacing the work of students in the laboratory in terms of direct interaction with the circuits, analysis of behavior, and design of applications. The tool is a circuit simulator specifically oriented to the area of power electronics, which is why it is preferable for specific training compared to traditional simulators, since it allows simplifying the behavior of the elements at the switch level, eliminating their parasitic analysis, and therefore reducing the demands on processing capacity, storage memory and simulation time. The first circuit implemented corresponds to an active power factor corrector on a Boost type

converter, an application that in itself justifies the use of the tool. As preliminary results, educators have observed increased commitment and motivation of students in their autonomous work.

Keywords: *Circuit simulator, power electronics, power factor corrector.*

RESUMEN

Tradicionalmente, la electrónica de potencia ha sido un campo de entrenamiento complejo para los estudiantes de pregrado del área eléctrica de la Universidad Distrital Francisco José de Caldas. En este curso se aplican múltiples teorías y conceptos que son difíciles de asimilar debido a la distancia que existe con otros cursos del programa y a la complejidad de conceptualizar elementos abstractos. Una herramienta fundamental de aprendizaje es la práctica de laboratorio, que permite visualizar los conceptos, facilitando su comprensión y asimilación. Sin embargo, las restricciones de movilidad impuestas a nivel mundial han impedido el acceso a estos espacios de aprendizaje, restringiendo también elementos fundamentales del proceso como la interacción directa con los circuitos y equipos de potencia, y la socialización crítica entre los estudiantes. La eficacia del proceso de aprendizaje está vinculada a los recursos disponibles, que hoy en día se han reducido como resultado del aislamiento social que se prevé que continúe en los próximos meses. Para reducir este impacto, se ha iniciado el desarrollo de una herramienta informática capaz de sustituir el trabajo de los estudiantes en el laboratorio en cuanto a la interacción directa con los circuitos, el análisis del comportamiento y el diseño de aplicaciones. La herramienta es un simulador de circuitos orientado específicamente al área de la electrónica de potencia, por lo que es preferible para la formación específica en comparación con los simuladores tradicionales, ya que permite simplificar el comportamiento de los elementos a nivel de conmutador, eliminando su análisis parásito, y por lo tanto reduciendo las exigencias en cuanto a capacidad de procesamiento, memoria de almacenamiento y tiempo de simulación. El primer circuito implementado corresponde a un corrector del factor de potencia activo en un convertidor de tipo Boost, aplicación que por sí misma justifica el uso de la herramienta. Como resultados preliminares, los educadores han observado un aumento del compromiso y la motivación de los estudiantes en su trabajo autónomo.

Palabras clave: *Simulador de circuitos, electrónica de potencia, corrector del factor de potencia.*

1. INTRODUCTION:

As a consequence of COVID-19, governments in most countries have been quick to impose norms of social isolation and restrictions on activities involving groupings and meetings, which has directly impacted the dynamics of educational institutions, particularly those of higher education, with young people of working age and with emotional ties strongly linked to social interaction (Favale, Soro, Trevisan, Drago, and Mellia, 2020; Garcia, Corell, Abella, and Grande, 2020; Winarso, Yuliana, Muniroh, Halin, and Tyas, 2020). In Colombia, this occurs when higher education is making a strong commitment to technical and technological training as an alternative to traditional engineering training (Ospina and Galvis, 2017). This commitment has materialized in a staged training called propaedeutic cycles. In its basic design, the propaedeutic cycles are made up of three stages, a first technical stage, a second technological stage, and a final engineering stage. The first stages make a strong emphasis on the training for the work looking for fast labor bonding through specific professional qualifications in each cycle (Cuadros, Cáceres, and Lucena, 2018; Garzón, Silvera, and Garcés, 2018).

Colombian universities have had to implement very short time distance learning strategies that guarantee access to students while complying with national standards of isolation and guaranteeing the quality of their training processes (Bezerra, 2020). E-learning has become a generalized strategy that has helped in a short time to make the transition to a new training model that has resulted in greater interaction with concepts, more student dedication, a higher level of commitment, and better assimilation (Mystakidis, Berki, and Valtanen, 2019). However, it is also true that it has produced deficiencies at an emotional level in terms of social interaction between individuals and has neglected the practical aspects of laboratory and on-site training that are fundamental to technical and technological training courses (Baki, Birgoren, and Aktepe, 2018; You and Robert, 2018; Yue *et al.*, 2019). From these weaknesses of the new model arises the need for rapid update and improvement that allows the level of interaction of laboratories while strengthening the positive elements of E-learning and observing the rules of social isolation (Flor, Belmonte, and Fabregat, 2018; Lin, Wang, Wu, and Chen, 2019). Under this perspective, the research group has initiated specific application simulators as fundamental learning software tools in this new training scheme.

To develop the professional skills of the technologists, the traditional face-to-face scheme made a strong effort to have students interact directly with real-world situations involving the course concepts (Chorazy and Klinedinst, 2019). In the specific case of students in the Electrical Technology program, access was offered to specialized laboratories for electrical circuits, electronics, electrical machines, electronic instrumentation, electric drives, lighting, and electrical insulation. In these academic spaces, students developed practical work designed to put into practice theoretical concepts of design and manipulation, directly observing the effect of their actions in a controlled and safe environment (Mansor *et al.*, 2018; Oliveira, DAmore, Pinto, Urbina, and Souza, 2019). These conditions can hardly be replicated through audiovisual content on a screen. However, a specific design simulator can replicate many of the laboratory experiences under the current social restrictions. Furthermore, in the hands of the students, it can even increase their interaction and motivation.

When integrated into the learning process, these new software tools complement and enrich it, which occurs even under normal face-to-face operating conditions (Sanchez and Rios, 2015). The integration of digital environments in the learning and education processes has demonstrated strengths in comparison with the traditional scheme, particularly in what is related to encouraging self-critical thinking in the students' formation process, the creation of self-regulating structures, and the increase in motivational levels (Schwendimann, Kappeler, Mauroux, and Gurtner, 2018). Also, although the traditional social interaction between students is reduced, the truth is that another type of interaction is stimulated that is more focused on the process both between students and between students and educators (Alonso, Prieto, García, and Corchado, 2019; Sergeeva *et al.*, 2019).

The area of electrical energy is a discipline that cuts across all commercial enterprises and is a strong indicator of a society's level of industrial development. It is not the engineering field that most attracts young students, but it is one of the most complex in terms of concepts and content. On the other hand, the strong relationship between electrical engineering and computer science is becoming increasingly evident (Martínez, Marínez, and Jacinto, 2019; Wu, 2018), making it more dependent on computational tools for the design and operation of energy transformation systems and the provision of energy services within a circular economic system fed by

information (Martinez, Rendon, and Guevara, 2017). Therefore, the training process of future professionals must also be concerned with the development of computer skills and stress, particularly important if these stresses help to visualize concepts to facilitate learning (Jesiek and Jamieson, 2017).

The use of specialized software as a support tool in the training process of various disciplines has been widely documented by researchers in various disciplines 2018; (Stacey, Cheeseman, Glen, Moore, and Thomas, Suárez *et al.*, 2019). In the electrical area, it has a strong incidence, given the characteristic of electrical energy teaching. As such, concepts are difficult to visualize; asking a student to imagine an electron moving inside a conductor is a great act of faith that does not exist in other disciplines such as civil engineering or mechanical engineering. This is of great relevance since the importance of the principle of visualization in the learning process has been demonstrated (Chatzimparmpas *et al.*, 2020; Roberts, Ritsos, Jackson, and Headleand, 2018; Wang, Yuan, Kirschner, Kushniruk, and Peng, 2018). Consistent with this principle, the interactive visualization of signals in an electrical circuit facilitates understanding concepts and the development of tasks. The ability to visually represent behaviors is key to developing analysis and design skills and encourages students' critical and imaginative thinking. Therefore, the objective of this study was the development of a simulator for the power electronics area that helps to consolidate the concepts as well as to strengthen the students' critical thinking, the formation of self-regulatory structures in the training process, and increase their motivation levels.

2. MATERIALS AND METHODS:

2.1 Research Design

The research design that formulated the simulator profile was supported by a qualitative analysis developed with fourth and fifth-semester students of the Technology in Electricity program under face-to-face classroom conditions at the Universidad Distrital's Faculty of Technology. At first, the simulator was projected as a tool to support traditional training, so that the process shortcomings were investigated. Surveys were applied to the students to identify weaknesses in power electronics concepts at the end of the course according to the training criteria defined and validated by the research group. The instrument consists of 20 elements designed

around the following questions:

- Did the student understand the overall picture of the course?
- What did the student learn?
- What aspects are still unclear to the student?
- What developmental problems does the student identify within the course?

From the analysis of the data, three problem topics were identified, organized by priority:

- Active power factor correction.
- Vector control of electrical machines.
- Average modeling of switched circuits.

Although the first two topics are developed with the support of the laboratories, it was observed that it is difficult for the students to understand the functional and theoretical details. Insufficient time was also identified in the student's dedication to the course outside the classroom. Therefore, it was outlined the design of a set of support tools capable of promoting self-training and critical processes focused initially on these topics, which also stimulate the student, and make the learning process more meaningful.

2.2 Tool Development

Based on the design profile defined from the analysis of the survey results, a methodological design was established that contemplated as a first step the definition of the competencies to be developed in the students. The curricular design of each one of the courses of the Electrical Technology program (as well as the other academic courses of the university) starts from the definition of the work competences to be developed in the student, and the necessary academic credits as a measure of dedication. Consequently, the first step corresponded to the definition of the levels of achievement expected in each competence. Later this definition was used to evaluate the performance of the tool. For the development of this definition, an environment was established for the implementation of different integrated tasks oriented to the practical application of these competencies in the specific field of action.

The first of the simulators were developed in the power electronics course, specifically in active power factor correction through a resistive emulator circuit. This problem was chosen as an initial prototype due to the theoretical complexity involved in the analysis and understanding of the

concept and the historical difficulty of the students during its development in the classroom, fact that was identified in the previous research. A particular feature of the concepts involved in this topic is the use of average models to analyze the behavior of non-linear circuits switching at high frequency (much higher than the frequency of the power grid). This strategy facilitates the analysis and development of the simulator. Each circuit setting is presented visually and interactively using waves of behavior concerning time to prioritize the stationary behavior of the circuit.

This methodological strategy aims to achieve cognitive activity through interactive visual stimulation about the operational parameters of the circuit. This strategy also focuses on the average behavior of the circuit, a key element in the design of DC/DC converters and many other inverter and rectifier circuits. The simulator algorithm was implemented in MathWorks' MatLab (MATrix LABoratory). The tool has a GUI (Graphical User Interface) developed for parameter capture and signal presentation (Figure 1). The entire application was compiled into binaries for both Windows and Linux operating systems. The circuit design corresponds to a single-phase medium-power converter; these design parameters are fixed as an analysis reference. This GUI is made up of several windows that allow to obtain usage information, configure the simulation parameters, and observe the detail of the circuit's behavior.



Figure 1. The initial window of the Boost Simulator

The simulator structure is based on three basic topology configurations, which characterize the operation of the circuit (Figure 2). These configurations are continuous or discontinuous conduction mode (CCM/DCM), activation or not the active power factor correction algorithm, and detailed display of switching diode and output

capacitor current curves. These three options can be combined to choose different circuit behavior and diversify current and voltage curves. For example, a single-phase rectifier without output factor correction but with a large inductive input filter (passive filtering), or a circuit with power factor correction in discontinuous mode, all for the same input and output load conditions, can be obtained as an alternative to the classic power factor correction.

3. RESULTS AND DISCUSSION:

The main window of the simulator presents most of the fields for parameter configuration and display of behavior curves (Figure 3). On the upper left side is the simplified schematic of the Boost converter, power topology used in the simulator. It is a DC/DC booster converter fed directly from the public single-phase grid through a full bridge rectifier. The Boost converter has a choke L for energy storage during switching, a controlled switch Q , and an uncontrolled switch D . The output is filtered with a capacitor. The load is resistive, and the control unit is responsible for keeping a constant output power of 250 W. The choke inductance can be adjusted with the slide control at the top of the circuit, allowing CCM and DCM.

In the upper-right part, the input signals for the selected simulation condition are displayed (input current in blue and mains voltage in red, Figure 4). Even without activating the power factor correction, it is possible to observe the behavior of the input current against variations in the inductance of the choke (Figure 5). The calculated values for each condition are shown in the GUI table at the bottom right of the window. This table is updated interactively for the new operating conditions of the circuit.

In the lower-left part of the window, it is possible to see the curves of the average behavior of the converter (Figure 6). These curves are activated by selecting the average current option at the bottom right of the window, to the right of the value table. The detail of the Q transistor duty cycle is shown in red, and the average value of the input current in the choke is shown in blue.

This option must be selected in the lower right part of the window to activate the active input current correction (the power factor correction) (Figure 7). When doing so, the input current curve automatically changes to a sinusoidal behavior. However, the behavior of this current signal depends on the inductance values in the choke and the output power of the converter (which is

kept constant by the control unit). Since both the input current and voltage behave more or less sinusoidally and in phase, this control circuit is a resistive emulator, even though what is connected to the single-phase network is not a resistor (in fact, it is a non-linear circuit). By moving the selection pointer over the input current curve, it is possible to change the point for which the useful cycle detail and the average current of the circuit are displayed (Figures 8 and 9).

Finally, the last two options at the bottom right of the window allow new windows to be opened with specific details of the current at the D diode and C capacitor (Figure 10), as well as the ripple in the output voltage (Figure 11). These parameters help evaluate the quality and performance of each converter configuration. The simulator allows us to quickly compare the behavior of all the curves of the regulator for CCM and DCM operations (Figure 12).

The development of the required skill in the design of these circuits and their integration to the concepts of the power electronics course, requires coordination and development of different specific training strategies. This simulator becomes a key tool since it is conceived from the training needs of the students, and it is designed, taking into account the objectives of the process and with the functional restrictions of the moment. Similar tools can close the gap not only of access to knowledge but also to specialized training laboratories.

4. CONCLUSIONS:

This technical note presents a software tool developed as a complement to professional training at the level of technologies in the area of power electronics in an undergraduate course in electrical engineering. The initial objective of the study was to develop a tool that would function as a temporary substitute for the course laboratories during the mandatory confinement due to the COVID-19 virus. This tool is a simulator of specific use related to the active correction of the power factor in a voltage regulator circuit. In addition to replacing the practical laboratories, it was intended to exploit the possible interactivity of the platform through visual stimulation, increase students' critical thinking, encourage self-training as well as motivational levels. This strategy has proven successful in previous cases and is expected to contribute to a deeper understanding of concepts and behaviors. Besides, it has been observed that this type of learning tool encourages self-study and motivation of the student and

promotes self-regulation (the student learns to control the duration, time, and place of his academic activities autonomously). To stimulate the use of computer tools familiar to the student and facilitate the implementation of algorithms, we implemented the simulator in MatLab, creating platform-independent executable binaries to facilitate their distribution. This research supports the demand for specialized tools in professional training in electrical engineering and raises the need for a study focused on evaluating the real effects of these tools on the training process and the effects on students.

5. ACKNOWLEDGMENTS:

This work was supported by the Universidad Distrital Francisco José de Caldas, partly through CIDC, and partly by the Facultad Tecnológica. Universidad Distrital does not necessarily endorse the views expressed in this technical note. The authors thank the research group ARMOS for supporting the development of the code.

6. REFERENCES:

- Alonso, R., Prieto, J., García, O., and Corchado, J. (2019). Collaborative learning via social computing. *Frontiers of Information Technology and Electronic Engineering*, 20(2), 265-282.
- Baki, R., Birgoren, B., and Aktepe, A. (2018). A meta analysis of factors affecting perceived usefulness and perceived ease of use in the adoption of e-learning systems. *Turkish Online Journal of Distance Education*, 19(4), 4-42.
- Bezerra, I. (2020). State of the art of nursing education and the challenges to use remote technologies in the time of corona virus pandemic. *Journal of Human Growth and Development*, 30(1), 141-147.
- Chatzimparmpas, A., Martins, R., Jusufi, I., Kucher, K., Rossi, F., and Kerren, A. (2020). The state of the art in enhancing trust in machine learning models with the use of visualizations. *Computer Graphics Forum*, 39(3), 713-756.
- Chorazy, M., and Klinedinst, K. (2019). Learn by doing: A model for incorporating high-impact experiential learning into an undergraduate public health curriculum. *Frontiers in Public Health*, 7(FEB).
- Cuadros, M., Cáceres, M., and Lucena, F. (2018). Analysis of leadership styles developed by teachers and administrators in technical-technological programs: the case of the Cooperative University of Colombia. *International Journal of Leadership in Education*, 21(1), 1-16.
- Favale, T., Soro, F., Trevisan, M., Drago, I., and Mellia, M. (2020). Campus traffic and e-learning during COVID-19 pandemic. *Computer Networks*, 176(1), 107290.
- Flor, S., Belmonte, A., and Fabregat, A. (2018). Improving students' engagement and performance through new e-learning tools in laboratory subjects in mechanical engineering. *International Journal of Engineering Education*, 34(4), 1273-1284.
- Garcia, F., Corell, A., Abella, V., and Grande, M. (2020). Online assessment in higher education in the time of covid-19. *Education in the Knowledge Society*, 21(1), 12.
- Garzón, C., Silvera, A., and Garcés, L. (2018). The institutional accreditation. a step towards quality in technical and technological institutions in Colombia. *Espacios*, 39(51), 1-11.
- Jesiek, B., and Jamieson, L. (2017). The expansive (dis)integration of electrical engineering education. *IEEE Access*, 5, 4561-4573.
- Lin, Y., Wang, S., Wu, Q., and Chen, L. (2019). Key technologies and solutions of remote distributed virtual laboratory for e-learning and e-education. *Mobile Networks and Applications*, 24(1), 18-24.
- Mansor, W., Sheikh, B., Taib, M., Mohamad, N., Abdul, M., and Mahmud, A. (2018). Effective sampling-based assessment method for evaluating electrical engineering programme performance. *Indonesian Journal of Electrical Engineering and Computer Science*, 9(2), 417-423.
- Martínez, F., Marínez, F., and Jacinto, E. (2019). Strategy for the selection of reactive power in an industrial installation using k-means clustering. *Communications in Computer and Information Science*, 1(1071), 146-153.
- Martinez, F., Rendon, A., and Guevara, P. (2017). A framework for knowledge creation based on m2m systems for the creation of flexible training environments for specific concepts in control. *Advances in Smart Systems Research*, 6(1), 36-43.
- Mystakidis, S., Berki, E., and Valtanen, J. (2019). The patras blended strategy model for deep and meaningful learning in quality

- life-long distance education. *Electronic Journal of e-Learning*, 17(2), 66-78.
17. Oliveira, N., D'Amore, R., Pinto, T., Urbina, L., and Souza, W. (2019). Interdisciplinary learning: An electronic and computer engineering case study to solve environmental problems. *International Journal of Engineering Education*, 35(4), 1206-1214.
 18. Ospina, Y., and Galvis, J. (2017). A novel design of an e-learning digital ecosystem. *Tekhnê*, 14(1), 55-60.
 19. Roberts, J., Ritsos, P., Jackson, J., and Headleand, C. (2018). The explanatory visualization framework: An active learning framework for teaching creative computing using explanatory visualizations. *IEEE Transactions on Visualization and Computer Graphics*, 24(1), 791-801.
 20. Sanchez, A., and Rios, J. (2015). Educational software for teaching of colors used in children under the age of five years. *Tekhnê*, 12(2), 65-74.
 21. Schwendimann, B., Kappeler, G., Mauroux, L., and Gurtner, J. (2018). What makes an online learning journal powerful for vet? distinguishing productive usage patterns and effective learning strategies. *Empirical Research in Vocational Education and Training*, 10(1).
 22. Sergeeva, M., Skvortsov, V., Sokolova, A., Rachek, S., Poyarkov, N., Konysheva, E., *et al.* (2019). Planning individual educational trajectory in continuing education. *International Journal of Recent Technology and Engineering*, 8(3), 654-658.
 23. Stacey, A., Cheeseman, E., Glen, K., Moore, R., and Thomas, R. (2018). Experimentally integrated dynamic modelling for intuitive optimisation of cell based processes and manufacture. *Biochemical Engineering Journal*, 132, 130-138.
 24. Suárez, M., Espina, R., Pacheco, V., Manso, A., Blanco, E., and Álvarez, E. (2019). A review of software tools to study the energetic potential of tidal currents. *Energies*, 12(9).
 25. Wang, M., Yuan, B., Kirschner, P., Kushniruk, A., and Peng, J. (2018). Reflective learning with complex problems in a visualization-based learning environment with expert support. *Computers in Human Behavior*, 87, 406-415.
 26. Winarso, W., Yuliana, Y., Muniroh, L., Halin, H., and Tyas, D. (2020). Changes in learning patterns during the pandemic covid-19; the case at university x in Bekasi, West Java, Indonesia. *International Journal of Advanced Science and Technology*, 29(6), 8535-8539.
 27. Wu, T. (2018). Exploration and practice of talent training mode of mechanical and electrical specialty under the background of engineering education. *IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association*, 30(4), 444-450.
 28. You, S., and Robert, L. (2018). Emotional attachment, performance, and viability in teams collaborating with embodied physical action (EPA) robots. *Journal of the Association for Information Systems*, 19(5), 377-407.
 29. Yue, J., Tian, F., Chao, K., Shah, N., Li, L., Chen, Y., *et al.* (2019). Recognizing multidimensional engagement of e-learners based on multi-channel data in e-learning environment. *IEEE Access*, 7, 149554-149567.

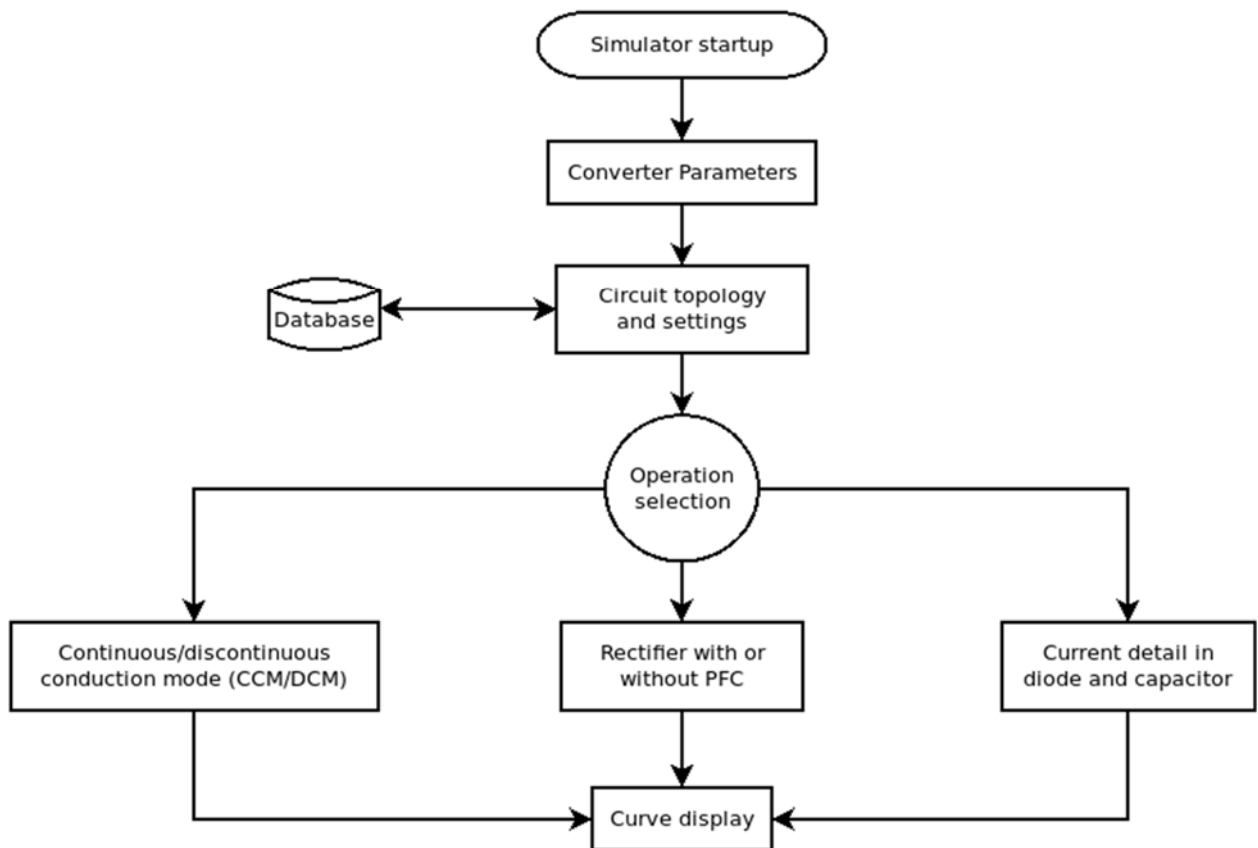


Figure 2. Simulator architecture. Source: the author

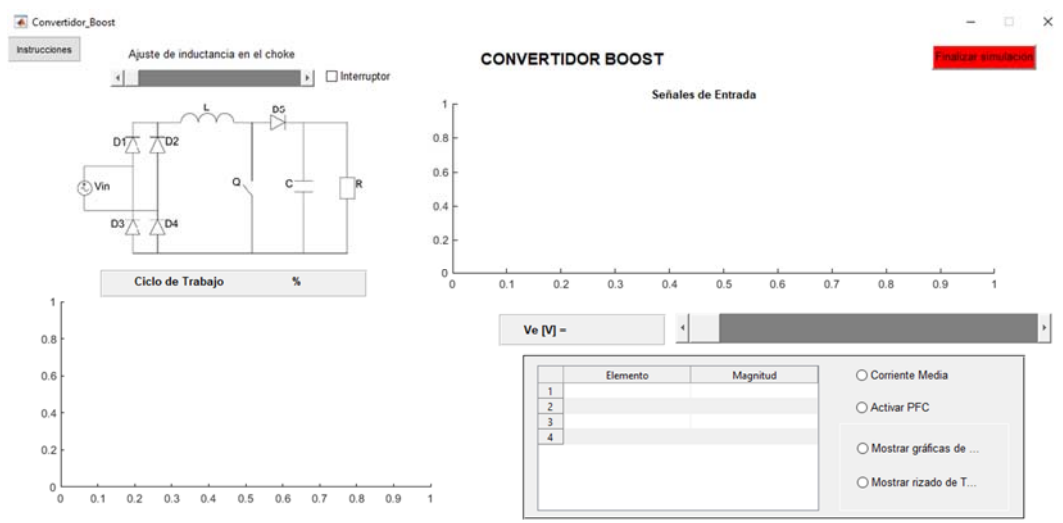


Figure 3. The main window of the simulator. Source: the author

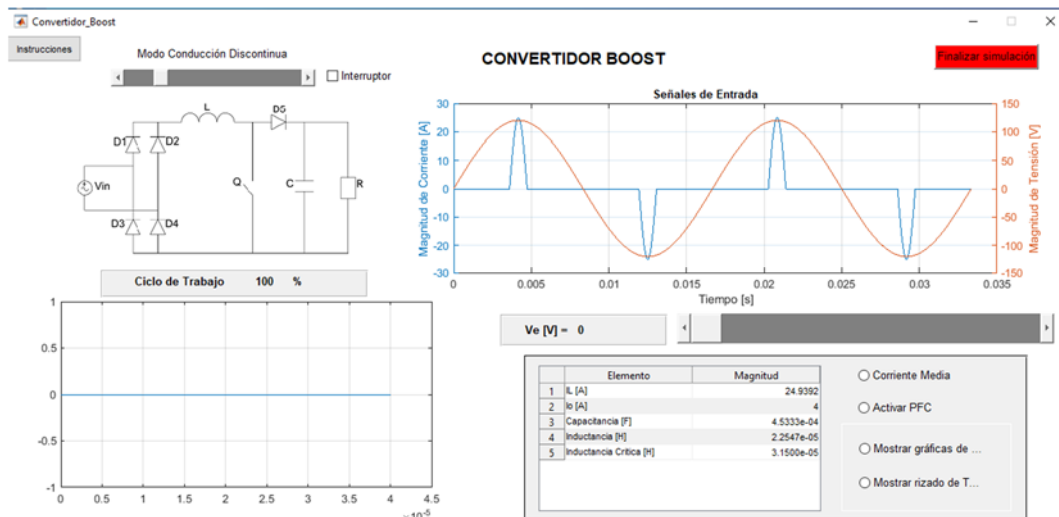


Figure 4. Operation as a rectifier without power factor correction with low inductance in the choke. Source: the author

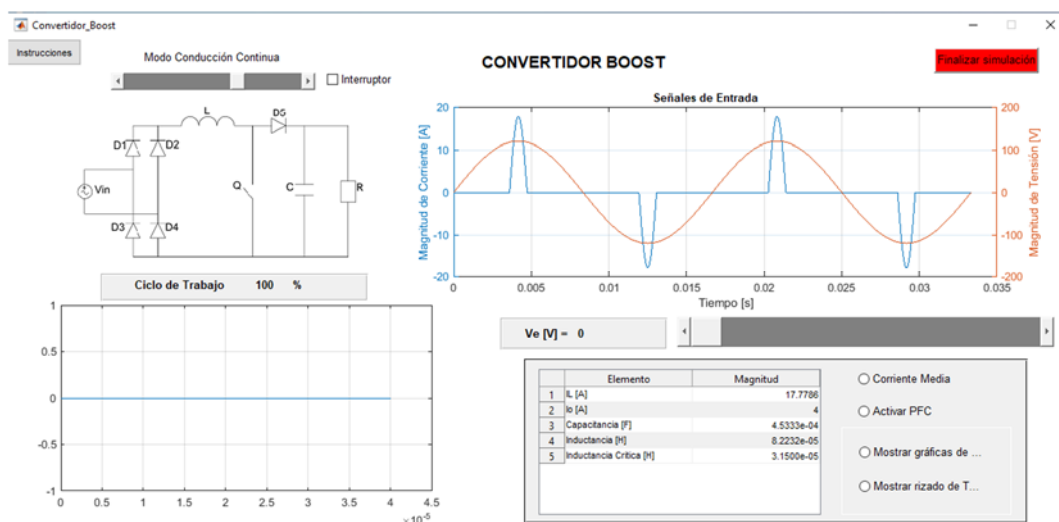


Figure 5. Operation as a rectifier without power factor correction with high inductance in the choke. Source: the author

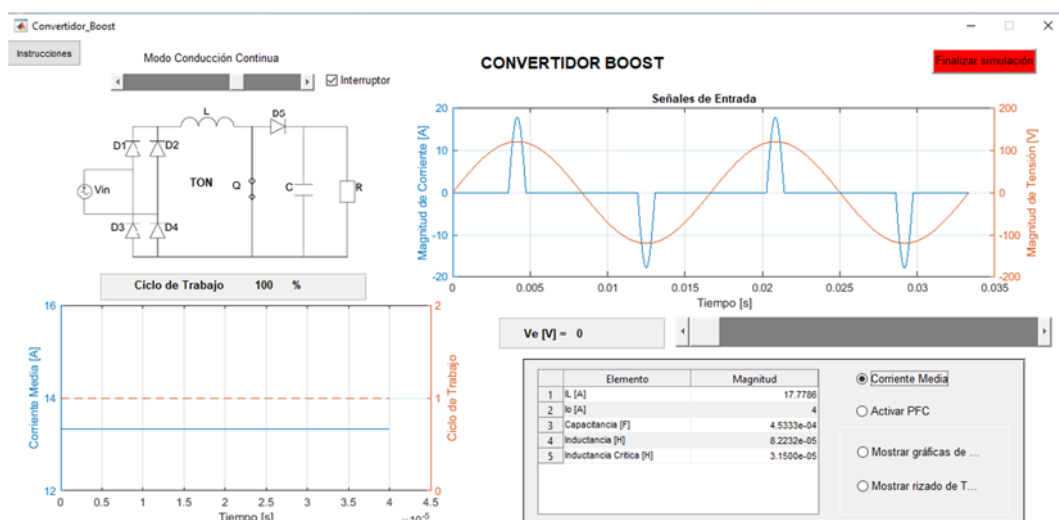


Figure 6. Activation of circuit average curves (input current and duty cycle). Source: the author

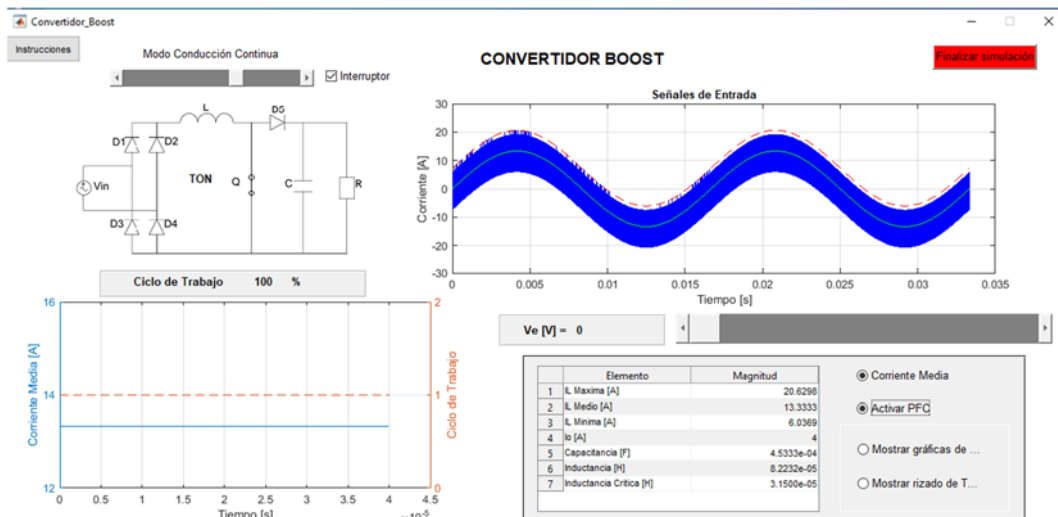


Figure 7. Operation as a rectifier with power factor correction. Source: the author

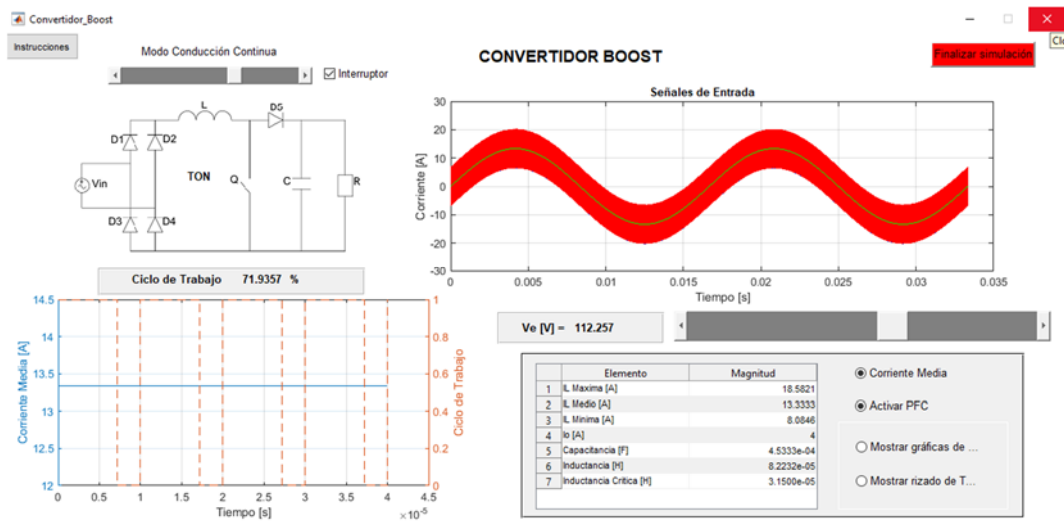


Figure 8. Operation as a rectifier with power factor correction and duty cycle detail 1. Source: the author

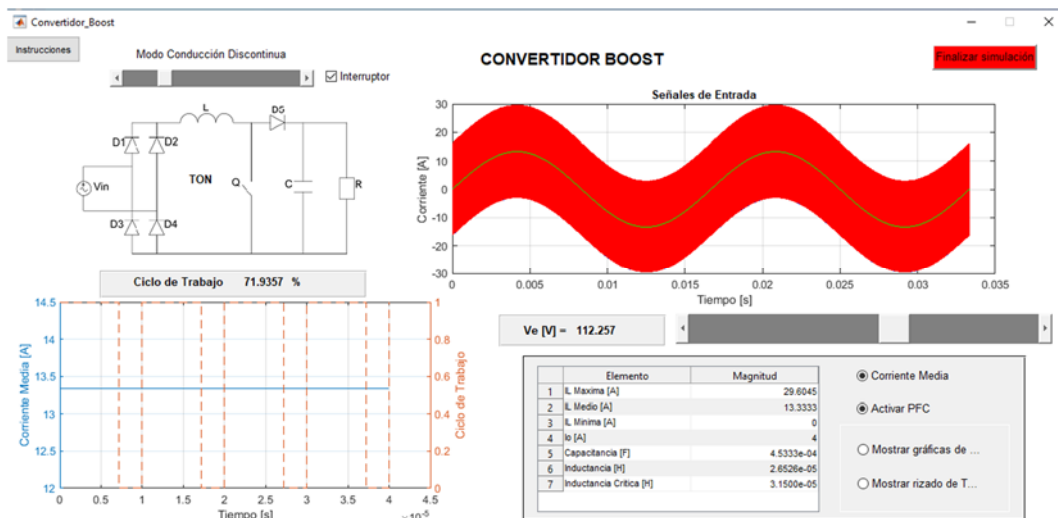


Figure 9. Operation as a rectifier with power factor correction and duty cycle detail 2. Source: the author

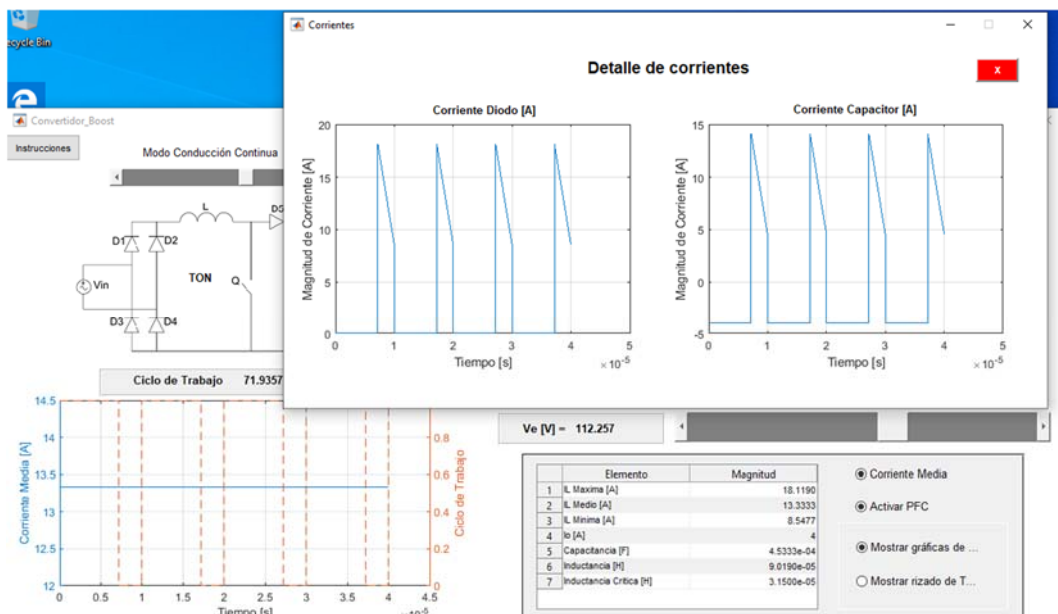


Figure 10. Operation as a rectifier with power factor correction and current detail. Source: the author

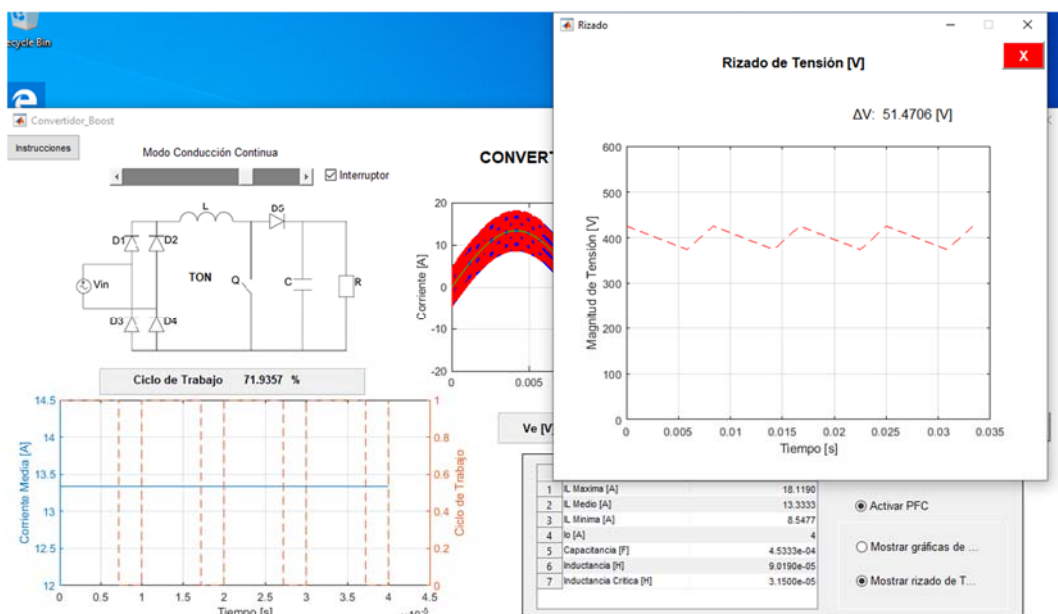


Figure 11. Operation as a rectifier with power factor correction and output voltage ripple detail. Source: the author

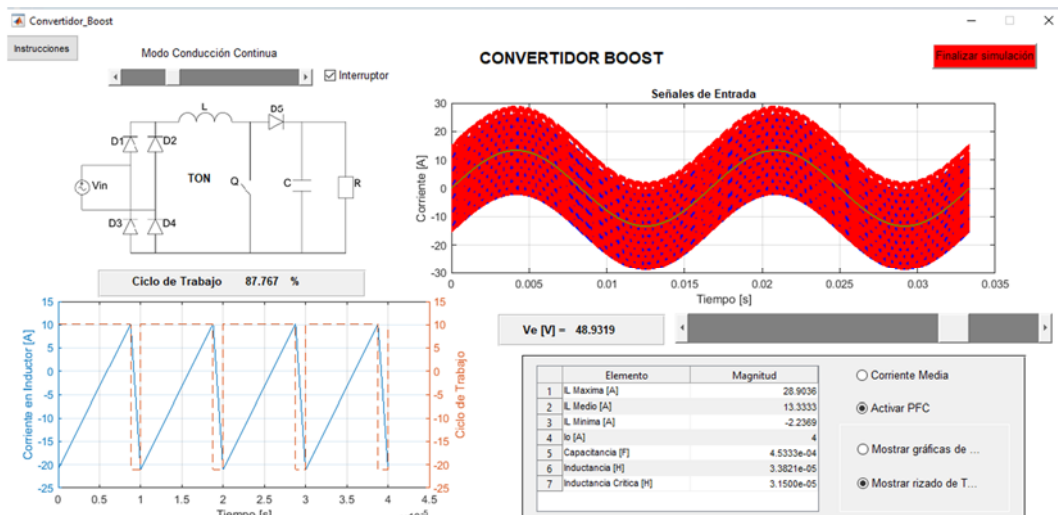


Figure 12. Operation as a rectifier with power factor correction in DCM. Source: the author