A NEW POWER ELECTRONICS CIRCUITS SIMULATION PROGRAM FOR EDUCATIONAL APPLICATIONS

Eduardo Deschamps, Anderson S.André and Valcir Pfiffer
Universidade Regional de Blumenau
Instituto de Pesquisas Tecnológicas (IPT/FURB)
Caixa Postal 1507
CEP 89.010-971 - Blumenau - SC - BRAZIL
Tel.: (047) 323-1596 - Fax: (047) 323-1596

Abstract

This paper is related to the development of a computational program that simulates power converters as rectifiers, cycloconverters, choppers and inverters, to be used in classroom by students of Power Electronics in Universities and Technical Schools.

Mathematical equations, that define the operation of this power converters, were determined and used in the program, that allows load values and control modes modifications with good results in simulation time and a very simple operation that makes the program suitable for students use.

Introduction

Power Electronics has getting an important place in the control of industrial systems and became one of the most important areas in Electrical Engineering.

In the 70's and specially in the 80's, the industrial use of power converters experienced an outstanding performance with the development of new power semiconductors (MOSFET, GTO and IGBT) and new circuits topologies that allows more efficient energy control.

The necessity of weight reduction, efficiency increase and energy conservation in electrical power processing, has lead to a great production of researches in power electronics area, all over the world.

Therefore, with the electronic use in industries increasing, the necessity of electronic teaching, in technical schools or universities, with tools that allow good studies of topologies and operation modes of power converters by the students is increasing too. One of this tools is the computer, which using simulation programs, leads to the possibility of circuits analysis, which is not possible to study in laboratory, due to security or financial questions.

The voltage and current waveforms observation in a circuit, using the computer, can provide a better comprehension of its behavior. Simulation can be used to substitute laboratory experiments, specially during the first studies of power electronics circuits, or during the preparation of laboratory works.

Observing voltage and current waveforms from a computer simulation accomplishes some of the same objectives as those of a laboratory experience. In a computer simulation, all of the circuit's voltages and currents can be investigated, usually much more efficiently than in a hardware laboratory. Variations in a circuit performance produced by a change in components or operating parameters can be accomplished more easily with computer simulation than in laboratory. In a laboratory exercise, problems may arise with components, equipment, and wiring, wich detract from the primary objective of understanding the operation of a circuit, and, in some instances, a laboratory experiment is not pratical. High-power equipments may not be available for student use, and suitable instrumentation must be employed for power measurements and spectrum analysis [5].

In this way, several computational programs have been developed to simulate power electronics circuits. Programs as PSPICE, Electronic Workbench and PROSCES are examples of this kind of programs. The majority of this programs are concerned with the complete power converters simulation - steady-state and transitory analysis - specially to develop researches in new topologies or control modes for them. This interest has lead to complex models used in the simulations, that needs simplifications to be used by beginners students in Power Electronics.

In order to simplify the use of a simulation program in Power Electronic classes of the Regional University of Blumenau - FURB, a simplified power electronics circuits program has been developed in the

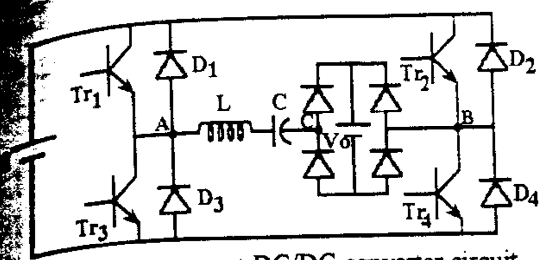


Fig. 3 - Series resonant DC/DC converter circuit

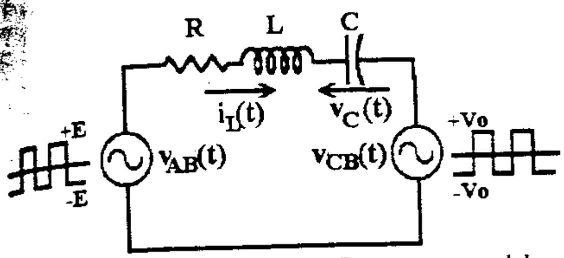


Fig. 4 - Series resonant DC/DC converter model

Circuit analysis:

$$v_{AB}(t) = \frac{4E}{\pi} \sum_{n=1,2}^{\infty} \frac{1}{n} \operatorname{sen}(wt) \quad (6)$$

$$i_L(t) = \sum_{n=1,2}^{\infty} \frac{4E}{n\pi Zn} \operatorname{sen}(nwt - \theta_{Zn}) - \sum_{n=1,2}^{\infty} \frac{4Vo}{n\pi Zn} \operatorname{sen}(nwt - \delta n\phi - \theta_{Zn}) \quad (7)$$

$$v_C(t) = \sum_{n=1,2}^{\infty} \frac{4X_{Cn}E}{n\pi Zn} \operatorname{sen}\left(nwt - \frac{\pi}{2} - \theta_{Zn}\right) - \sum_{n=1,2}^{\infty} \frac{4X_{Cn}Vo}{n\pi Zn} \operatorname{sen}\left(nwt - \delta n\phi - \frac{\pi}{2} - \theta_{Zn}\right) \quad (8)$$

$$Zn = \sqrt{R^2 + (X_{Ln} - X_{Cn})^2} \quad (9)$$

$$\theta_{Zn} = tg^{-1} \frac{X_{Ln} - X_{Cn}}{R} \quad (10)$$

$$\delta = \frac{X_{Ln} - X_{Cn}}{|X_{Ln} - X_{Cn}|} \quad (11)$$

$$X_{Ln} = nwL \quad (12)$$

$$X_{Cn} = \frac{1}{nwC} \quad (13)$$

where:
$v_{AB}(t)$ = inverter output voltage
$i_L(t)$ = resonant inductor current
$v_C(t)$ = resonant capacitor voltage
E = input voltage
Vo = output voltage
n = harmonic order
R = small resistance from the inductor coil

The angle ϕ is obtained from the expression (7), when wt = ϕ, $i_L(t) = 0$. The resultant expression is solved numerically by the Newton-Raphson method.

With these expressions, the series resonant converter behavior can be simulated with switch frequencies above and below the resonant frequency.

Program Organization

The language C was chosen to be used in the computational program because of its many facilities to build graphics on computer screen, allowing better presentation to the program and a good interface between program and user.

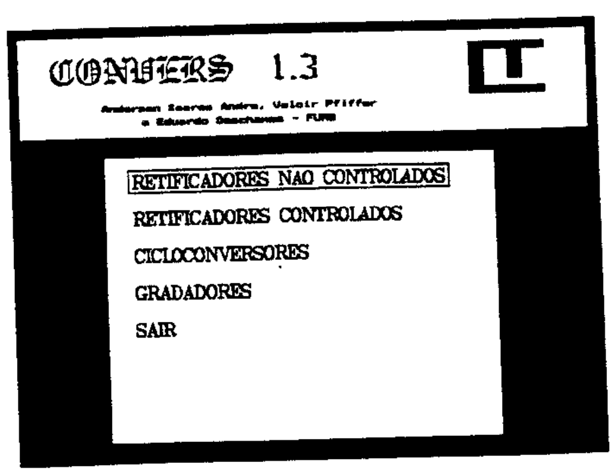
The program is divided in two main parts:

1. CIRCUIT SELECTION MENU: where is possible to choose the power electronics circuit to be simulated;
2. FUNCTION SELECTION MENU: where is possible to select one of the following functions:
   a) HELP [F1]
   b) TOPOLOGY PRESENTATION [F2]
   c) DATA INPUT [F3]
   d) SIMULATION RESULTS [F4]
   e) WAVEFORMS SELECTION [F5]
   f) GRAPHICS ZOOM [F6]
   g) AVERAGE AND RMS VALUES [F7]
   h) RESULTS HARDCOPY [F8]
   i) RETURN TO MAIN MENU [F9]

Examples

The simulation results for a single-phase half-wave diode rectifier with inductive load and for a series resonant converter obtained with the program developed are presented with the more important screens.

Single phase half wave diode rectifier



Technological Research Institute of FURB - IPT/FURB.

This program simulates controlled and non-controlled AC/DC converters, DC/DC and DC/AC converters, presenting their circuits and more important waveforms, with a simple conception, allowing its use in theoretical classes or in the preparation of laboratory classes, by students of Power Electronics in Electrical Engineering courses or Technical courses. With its use, can be studied the operation basic principles of classical static converters, more employed in industrial process.

Circuit Modeling and Mathematical Expressions

The choice of a circuit model depends upon the objectives of the simulation. If the goal is to predict the behavior of a circuit before it is built, components should be modeled in detail. However, if the goal is to study a circuit to gain an understanding of the principles of operation, component models should be kept as elementary as possible. In some cases, devices can be modeled as ideal components [5]. So, in this program the switches were always considered as *open circuits in off-state and short* circuits in on-state.

In general, the mathematical expressions were determined through a research on classical Power Electronics literature as the references [1], [2] and [3], and in some cases on recent publications about converters analysis [6], [7], where can be found the basic expressions that define the operation modes of the converters under study, as the load and switches voltages and currents.

For the controlled and non-controlled AC/DC converters, the load and switches average and RMS current and voltages, were determined, to be used as design parameters to laboratory experiments.

As example of the expressions used in the program, the mathematical equations of two different converters simulated by the program are presented below.

Single phase half- wave diode rectifier

The first topic in the Power Electronics course is the single phase half-wave rectifier.

In this case, the circuits were analyzed for the different operating steps, where their switches were substituted by the model equivalent to its conduction state (on-off). For each step were deduced the voltage and current expressions that defined the behavior of the circuit during the time period under analysis.

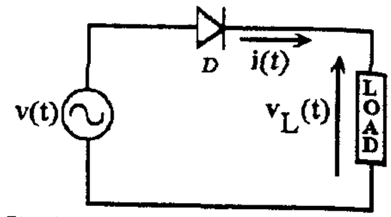


Fig. 1 - Single phase half-wave diode rectifier circ

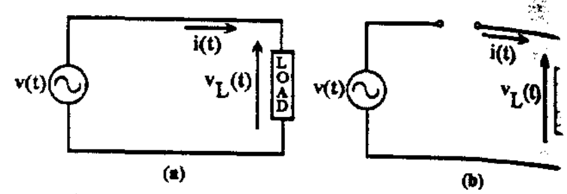


Fig. 2 - Single phase half-wave diode rectifier mode
a) $0 \le wt \le \beta$ b) $\beta \le wt \le 2\pi$

Circuit analysis:

For $0 \le wt \le \beta$ period:

$$v(t) = \sqrt{2}Vo\,sen(wt) \quad (1$$
$$v_L(t) = \sqrt{2}Vo\,sen(wt) \quad (2$$
$$i_L(t) = \frac{\sqrt{2}Vo}{\sqrt{R^2 + (wL)^2}}[sen(wt - \phi) - sen(-\phi)e^{-t/\tau}] \quad (3$$
$$v_D(t) = 0 \quad (4$$

For $\beta \le wt \le 2\pi$ period:

$$v(t) = \sqrt{2}Vo\,sen(wt) \quad (5$$
$$v_L(t) = 0 \quad (6)$$
$$i_L(t) = 0 \quad (7)$$
$$v_D(t) = \sqrt{2}Vo\,sen(wt) \quad (8)$$

where:

$v(t)$ = input voltage
$v_L(t)$ = load voltage
$i_L(t)$ = current and diode current
$v_D(t)$ = diode voltage
Vo = RMS input voltage
β = current extinction angle

The angle β is determined from the expression (3). When $wt = \beta$, $i_L(wt) = 0$. The resultant expression is solved numerically by the Newton-Raphson method.

Series resonant DC/DC converter

The circuit was analyzed using an specific method or model, the frequency domain model [6],[7], to voltage and current expression deduction.

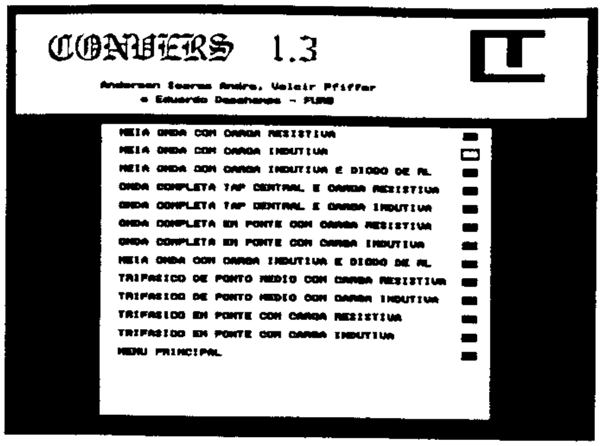


Fig. 5 - Circuit Selection Menu

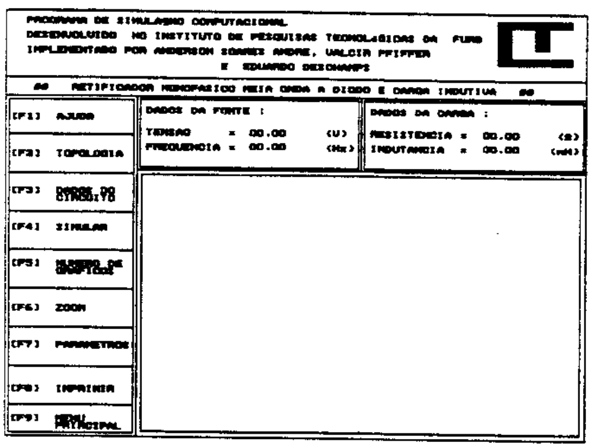


Fig. 6 - Function Selection Menu

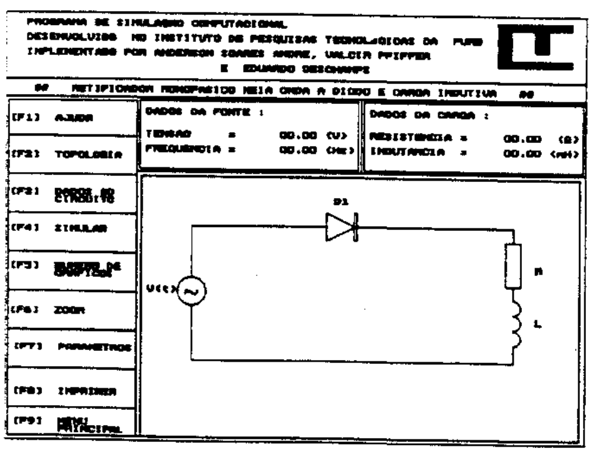


Fig. 7 - Topology Presentation Screen

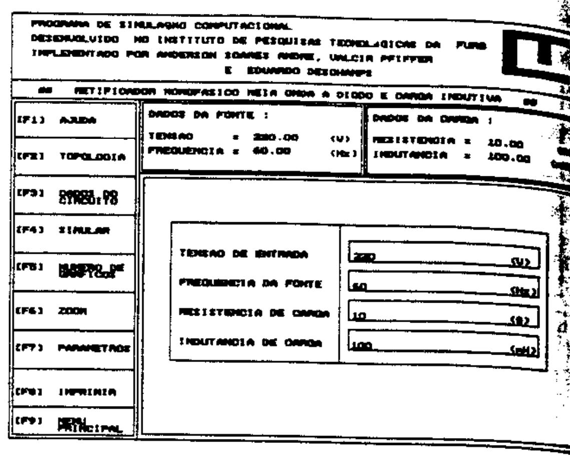


Fig. 8 - Data Input Screen

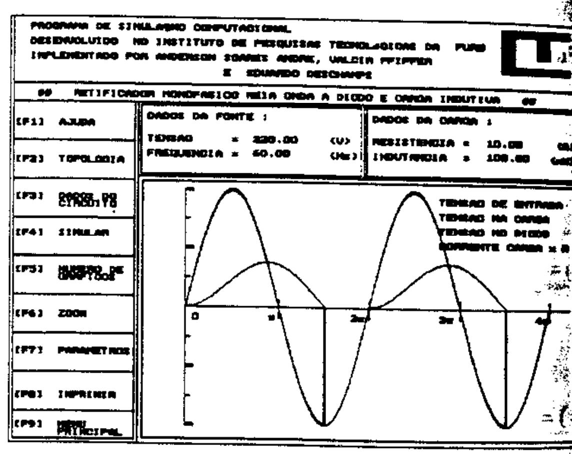


Fig. 9 - Simulations Results Screen

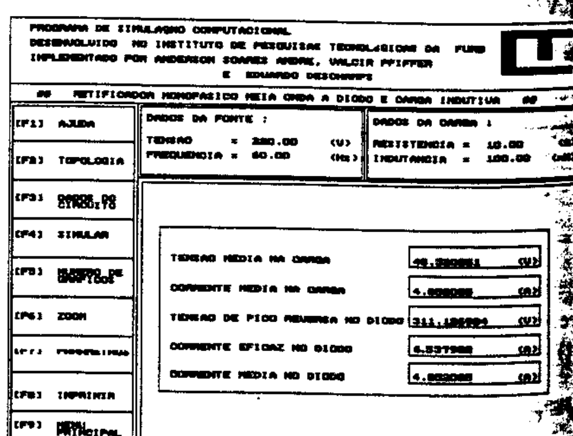


Fig. 10 - Average and RMS Values Screen

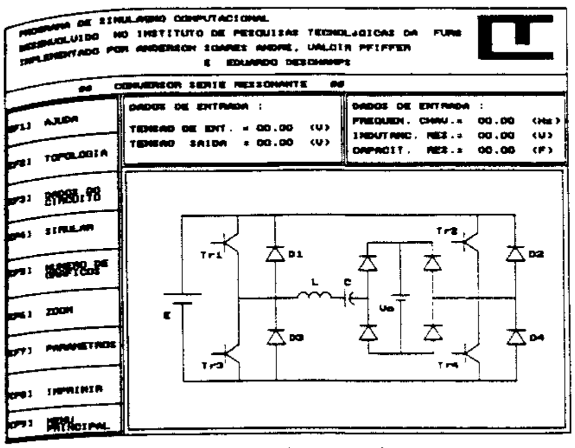


Fig. 11 - Topology Presentation Screen

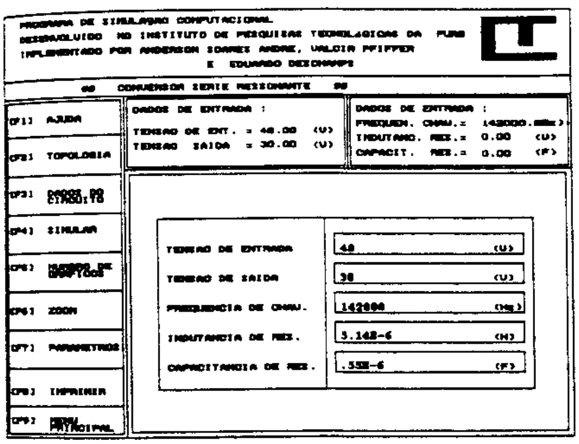


Fig. 12 - Data Input Screen

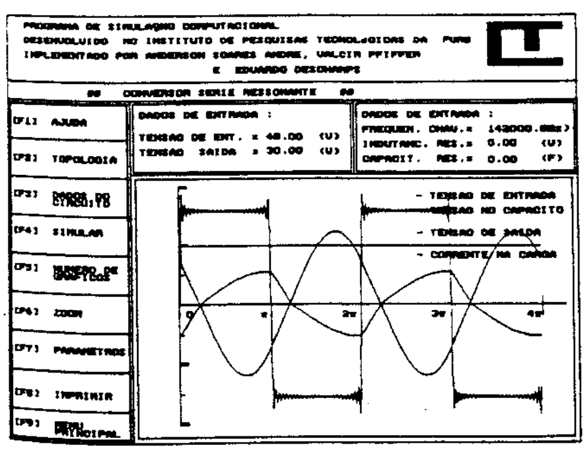


Fig. 13 - Simulations Results Screen

CONCLUSIONS

The program has presented a good performance in tests made with Power Electronics students of FURB, with a very simple utilization in comparison with other simulations programs as PROSCES and PSPICE. This happened because this program was made to be a dedicated program for students, to be used in basic Power Electronics courses.

The next step of this work is the determination of the main equations that define the operating mode of others DC/DC, DC/AC and AC/AC converters, with the definition of the most important waveforms to the basic study of these converters.

Other points under study are the increment of the graphic presentation of the program, in order to simplify the use of the program in classroom, the development of the program in Windows environment.

Finally, there are ideas to link the program to a components data record in order to allow the choice of the best components to be used in the devices design, and introduce electric drives simulation.

Acknowledgment

The authors wish to thank the CNPq and FURB for the financial support to development of this work.

References

[1] BARBI, I. Eletronica de Potência. Florianópolis, Editora da UFSC, 1986.

[2] RASHID, M.H. Power Electronics: Circuits, Devices and Apliccations. Englewood Cliffs, Prentice Hall, 1988.

[3] MOHAN, UNDELAND, ROBBINS. Power Electronics: Circuits, Applications and Design. New York, Wiley & Sons, 1990.

[4] TUINENGA, P.W. SPICE: A Guide to Circuit Simulation and Analysis Using PSPICE. Englewoods Cliffs, Prentice Hall, 1992.

[5] HART, D. Circuit Simulation as an Aid in Teaching The Principles of Power Electronics. IEEE Transactions on Education, v.36 n.1, p.10-16, February 1993.

[6] DEB, S.; JOSHI, A.; DORADLA, S.R. A Novel Frequency Domain Model for a Parallel Resonant Converter. PESC'87: Conference record. IEEE, 1987, p.221-30

[7] DESCHAMPS, E.; BARBI, I. Análise de Conversores Série Ressonantes com Método no Domínio da Freqüência. In: SEMINÁRIO DE ELETRÔNICA DE POTÊNCIA, 3., Florianópolis, 1990. SEP-90: Conference record. Florianópolis, UFSC/SOBRAEP, 1990, p. 237-45.