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# Design tools and methods for Power Electronics

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## 1 Introduction

In this paper, the presentation of methods and tools dedicated to the domain of power electronics is proposed.

First, the main steps which lead to the design of a static converter are pointed out; then, for each of them, we present the different means which may be used to aid the designer.

Our point of view is illustrated by the presentation of tools which have been developed at the LEEI. Concerning the special case of the design, a set of softwares dedicated to the resonant DC-DC converters, capable of realizing an interactive design, for given specifications are presented.

## 2 Approach of the design process

Figure 1 presents the step-by-step design of a converter as a set of tasks, which are achieved in a logical order. The analysis of the specifications (*step 1*) leads to the choice of the structure of a converter, associated with a command and control strategy (*step 2*). Once the values of the components and parameters have been defined, (*step 3*), the performances and the characterization of the solutions in comparison to the specifications are evaluated by simulation, or on a real experimental realization. With the results of

this evaluation, we can at next step refine the design at component level and at circuit subset level, to try to reach an optimal solution (*step 5* and jump at *step 1* ou *step 3*).

<i>step 1</i>	analysis of the specifications
<i>step 2</i>	choice of a converter : - topology - command strategy
<i>step 3</i>	choice of the parameters : - components - control
<i>step 4</i>	evaluation of the performances - simulation - experience
<i>step 5</i>	refining and optimization - sub-circuits - components

FIG. 1 - Model of the design process

## 3 Synthesis

For the special case of direct-converters (converters without any L or C storage element), it is possible to define the topology, the type (i.e. 'diode', 'transistor', 'thyristor', 'dual of a thyristor', and any association of the former types) and the firing orders of the semi-conductors by analysis of required input and output current and voltage waveforms. This

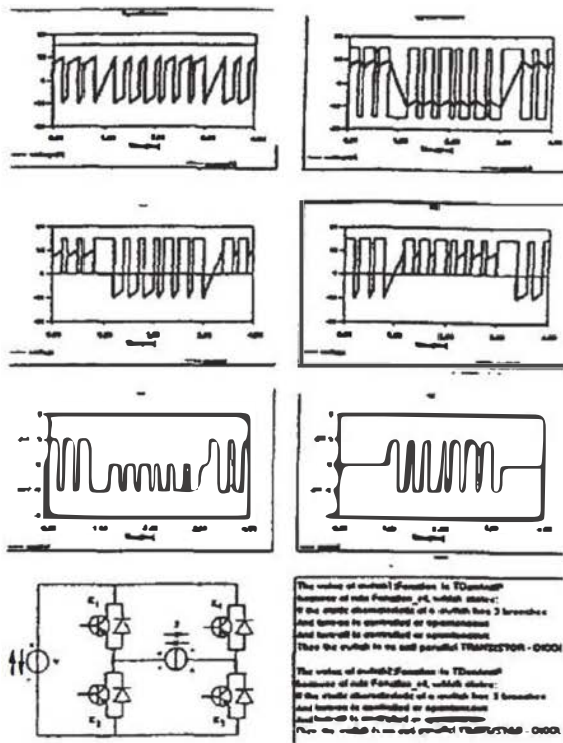


FIG. 2 - Specifications, electrical stresses, firing orders and synthesis of one of the switches.

analysis is based on rules which define the behavior of switches during the commutations in the commutation cells, and has been implemented in an expert system [1]. Figure 2 presents the design results for specifications which can be met by a four quadrant chopper.

#### 4 Design: the DC-DC serie resonant converter

Once the topology has been chosen, the next step is to determine the values of the components, and the parameters of the control elements. For some kinds of converters, such as the rectifiers, the choppers, the operating conditions are not deeply modified by the choice of the values of the components and the stresses on the components can be directly derived from the analysis of the specifications, making the choice of their values quite easy; but some other circuits have a behavior which basically depend on the values of the parameters. To

illustrate this purpose, we consider now the case of DC-DC serie resonant converters, as shown on figure 3.

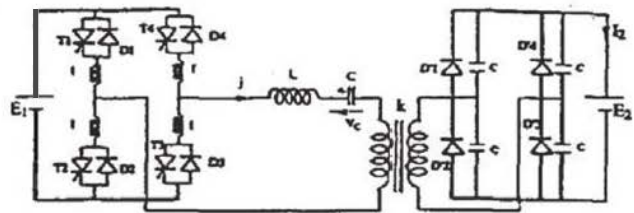


FIG. 3 - Series resonant converters

These converters allow reducing the losses in switches and permit operating at higher switching frequency. As first consequence it allows to reduce the sizes of both inductor and capacitor of the resonant branch. Under such circumstances, the values of the components of the snubber  $l$  and  $c$  cannot be anymore considered as negligible compared to the values of  $L$  and  $C$  of the resonant circuit. These snubbers deeply modify the operation of the converter which results in output characteristics that depend on the choice of the  $L, C, l, c$  parameters, of the operating boundaries...

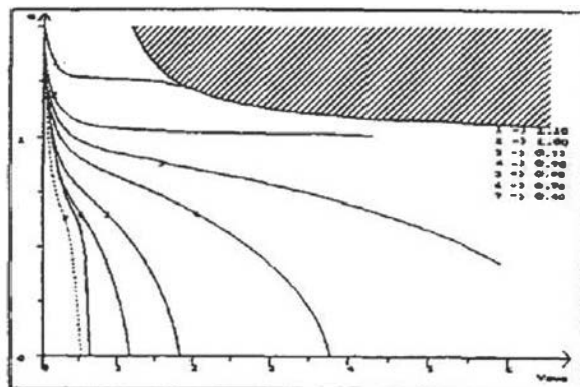


FIG. 4 - Output characteristics:  $f/fr = \text{parameter}$ ,  $l/L = \text{cte}$ ,  $c/C = \text{cte}$

The behavior of the converter can be completely known *only* when the values of the components are determined; this causes great difficulties in the design of this kind of structure.

It becomes necessary to plot directly these output characteristics and operating boundaries, and to compute data which are necessary for the design: peak currents, rms currents, voltage overshots...

The SUDIM software has been developed in this scope; it is based on analytical modeling of the converter since using simulation softwares with parameters variations should involve exaggerated computation time [2].

This program allows:

- to derive the values of the components from the input voltage, the input ripple and the load area (output voltage and output current);
- to plot any characteristic between two electrical values of the converter;
- to generate a netlist compatible with the SUCCESS software to simulate the converter at a given operating point.

This association of the SUDIM and SUCCESS softwares is by our meaning truly representative of a real CAD activity in power electronics.

## 5 Numerical simulation

### 5.1 Modelization of the components

The most difficult and important point deals with the switches; in most cases, the passive components can be considered as ideals and taking their imperfections into account can be achieved by mean of equivalent circuits.

Considering the converter as an electrical circuit leads to a modeling of the switches as a binary impedance; the simplest solution is to choose a binary resistance (a low value, associated with the

'on' state and a high value for the 'off' state); this modeling is able to take the switching behavior into account [3] [4].

The transition between the two values must be achieved according to the commutation rules, and the instant at which the phenomena which causes the transition appears must be precisely determined.

The binary resistor model of the switches does not permit considering the voltage in on-state and the current in off-state as truly representative of the behavior of the switch. Neither does it give any information relative to the internal operating conditions of the semi-conductor.

### 5.2 Precise modelization of the components

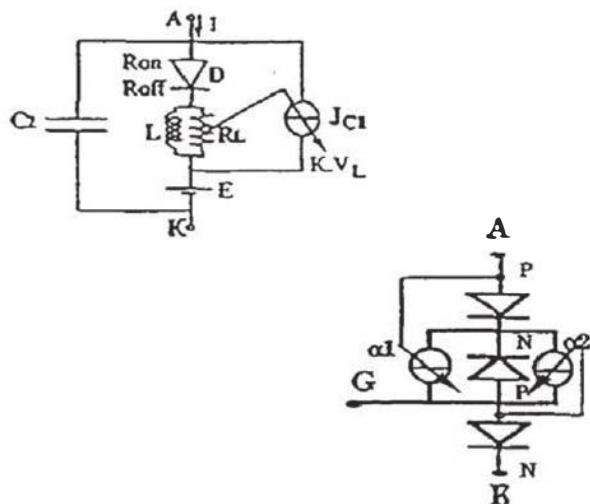


FIG. 5 - PN junction model; GTO model

As a second approach, the designer may need to use a more precise modeling of the commutation phenomena, for example to predict the value of recovery currents of diodes, to realize the design of snubbers or firing circuits.

By use of basic components (reactive components and switches modeled with a binary resistance), it has been shown that it was possible to define equivalent circuits for the diodes, the BJT, the thyristors [5, 6]...

Figure 5 presents a model of a PN junction and the use of this model to build the equivalent circuit of a GTO.

By comparison to the 'physical approach' used by the designers of the components, these equivalent circuits have the advantage to be directly compatible with the simulation tools used at the former step and to be able to be used in any circuit, even in the most complicated ones. Nevertheless, in most cases they do not allow to predict precisely the losses in the switches.

Figure 6 presents for example the simulation results of a IGBT turn-on.

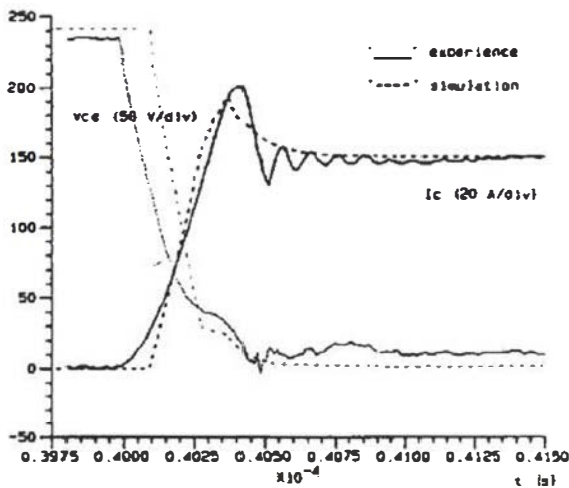


FIG. 6 - IGBT turn-on (simulation with SUCCESS software)

### 5.3 The SUCCESS software

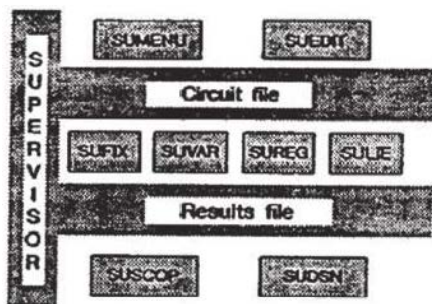


FIG. 7 - The SUCCESS software

The SUCCESS software has been developed at the LEEI [7], [8]. It consists of a set of programs connected together by a 'supervisor' file.

The netlists are generated by the SUE-DIT or SUMENU programs; the circuits are simulated by use of SUREG, SULIE... The simulation results are graphically plotted with SUDSN or post processed with SUSCOP.

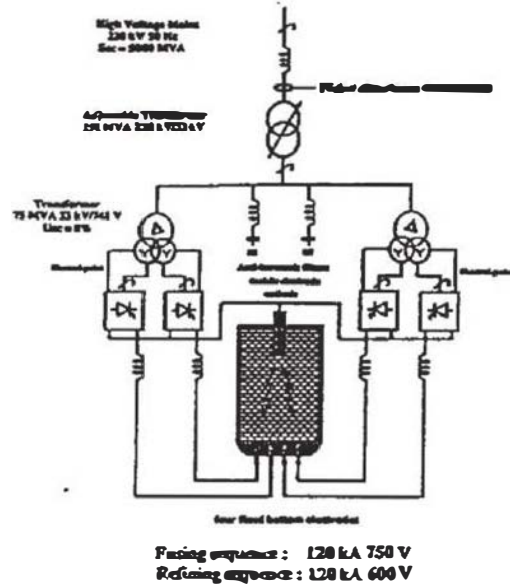


FIG. 8 - Arc furnace; this plant has been simulated with help from CEGE-LEC MS

To describe the circuit of the converters, the available components are the inductors, the resistors, the capacitors, the diodes, the transistors, the thyristors, the diodes of the thyristors and the independent, the voltage controlled and the current controlled voltage and current sources. The transformers are modeled with coupled inductors.

The transitions of states of the switches are implemented by use of Petri nets; the instants of the switching are precisely determined with procedures which detect zero-crossing of voltage and current of the switches and reduce the computation step.

The state equations of the circuit of the converter are automatically determined by the analysis of the topology and the evaluation of the values of the components. These equations are solved by the method of the exponential of a matrix; including the sources in the state

vector permits to make use of a variable integration step, which leads to a faster and more accurate resolution.

The SUREG program is able to take account of control loops [7]; the command and control algorithm is implemented in a user-defined subroutine, which is linked to the program; this module is called with a fixed time period, which permits to define sampled regulations.

The SULIE program is used to simulate circuits which are including controlled sources and is especially devoted to the analysis of the converters in which the semi-conductors are modeled with equivalent circuits.

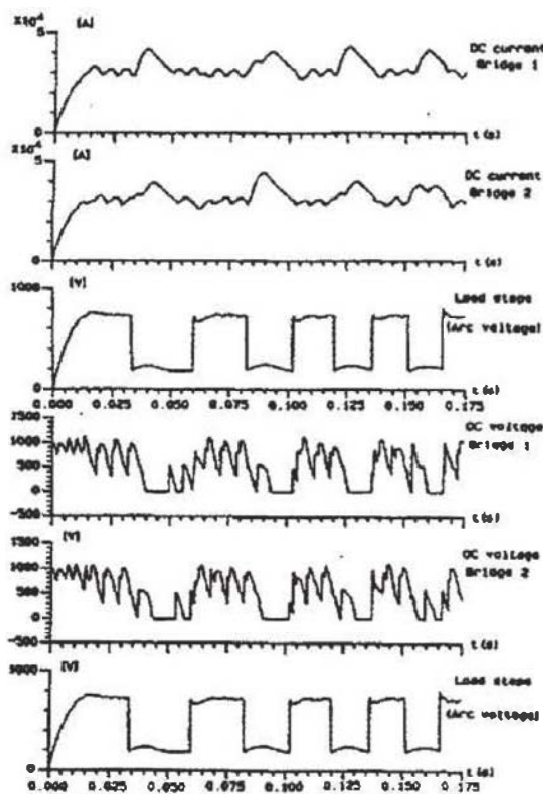


FIG. 9 - Load steps

In order to point out the capabilities of these tools, we present the results of the study of the control strategies of an arc furnace; figure 8 presents the studied circuit.

Figure 9 presents the performances of the control elements in case of load steps (the converter has been simulated with the SUREG program).

## 6 Post-processing and optimization

In most cases, the simulations do not permit predicting the losses in the switches. Nevertheless, this information is of most importance in the design process, to define snubbers, radiators...

In this scope, the SUPERTES module (compatible with the programs of SUCCESS) has been developed. It makes use of the simulation results to determine the stresses of a switch in given operating conditions: duration of the on-state, number of switchings, voltage and current levels at turn-on or turn-off.

These data are used in combination with experimental measures to determine the losses of the switch in the simulated operating conditions. The temperature of the junction is also taken into account and may be chosen by the user; if the thermal equivalent circuit can be defined, it can also be used to compute the steady state temperature.

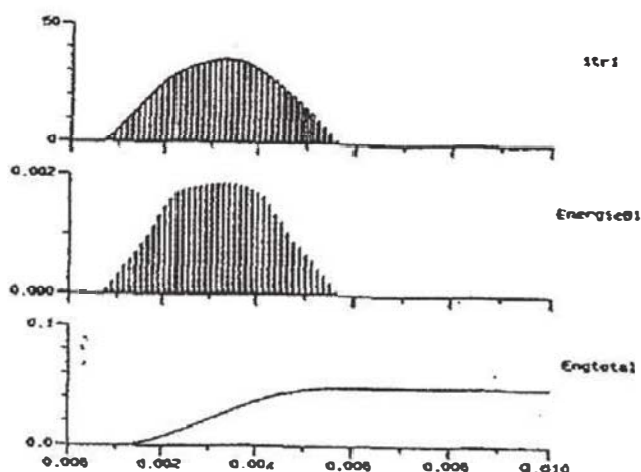


FIG. 10 - losses of an IGBT; case of a PWM inverter

Figure 10 presents the results of the study of switching losses of an IGBT.

## 7 Conclusion

In this paper, we have been pointing out the different steps of the design of a static converter; for each of these aspects, we have analyzed and presented the tools which have been developed at the LEEI to aid the designer:

- to choose a converter able to fulfill the requirements of the specifications
- to realize the design of the components
- to analyze the performances of the previous choices
- to refine and to optimize the design

A special attention has been paid to the necessity to guaranty their compatibility, in order to build true CAD tools.

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