Electrical Vehicles Project: A Method to Learn Power Electronics for a Non-Specialized Engineer?

C. Paugam[1,2], A. André[1,2], X. Margueron[1,3], C. Raibaudo[1,2], A. Leblanc[1,4], E. Delmotte[1,2], P. Besse[5]
[1] Univ Lille Nord de France, F-59000 Lille, France
[2] ECLille, F-59650 Villeneuve d'Ascq, France
[3] ECLille, L2EP, F-59650 Villeneuve d'Ascq, France
[4] ECLille, LML, F-59650 Villeneuve d'Ascq, France
[5] Renault Technocentre, F-78280, Guyancourt, France
Xavier.Margueron@ec-lille.fr

***Abstract*-Active learning in high engineering school is a real opportunity for students. Indeed, it enables to discover some subject deeper than a traditional lectures classroom. In this paper a project example, mainly based on power electronics, has been described. This project has taken place in a non-specialized French engineer school with the financial partnership of Renault. Each actor gives its advice at the end of the project (student, professor and industrial partner) about the learning process in power electronics but also about the global project activity.**

I. Introduction

Power electronics has become essential for electrical conversion. Nowadays, static converters are used in almost every electrical system in different fields like industry, renewable energy, embedded system, transport or domestic applications. For an engineer education, it seems very important to include some electrical engineering and power electronics basic knowledge [1].

Contrary to other countries, in France, the most reputable high engineering schools form non-specialized engineer. These students are trained to high-level in multi-disciplinary like science, language, economics and business. Electrical engineering and more especially power system and power conversion are limited to few classes. For example, at the Ecole Centrale de Lille, only 108 hours (on 956 hours for engineer sciences) are dedicated to industrial electricity (40h), electrotechnical (36h) and power electronics (32h) in first (L3 level) and second year (M1 Level).

Active learning is more and more spread in Engineering schools. Attractiveness of traditional courses are often limited for students so more and more knowledge is acquired using active methods, like Problem Based Learning [2] or student project activities [3, 4]. These kinds of learning enable students to be active in their education. It also allows them to go deeper into scientific subjects, because hours dedicated to these learnings are often limited in student timetables. Moreover, the project activity and its final result enables students to be confronted to many difficulties like team working, project management, prototype design, industrial partnership, communication…

This paper deals with an assessment of a student project, financed by Renault in a French non-specialist engineering school. This project was mainly based on power electronics conception for car industry application so it enables to present the limits of a non-specialist engineer formation and also the limit of this kind of active learning on such specific discipline.

First, the non-specified engineer formation is presented. Then, the bid is given to each project's actor. The students will talk about the project sequence of events and the difficulties that they have encountered. The power electronics professor will give its vision on the student learning and the lack in the education. The car industrial partner will present expectations that an industrial has when he will recruit some young engineer in terms of power electronics. The last part of this paper presents some aspects that have not been treated in this project but which seems essential for an engineer who works in power electronics for car industry.

II. Non-Specialized Engineer at The Ecole Centrale of Lille

A. *What is a Non-Specialist Engineer?*

The non-specialist training is a French specificity. Indeed, after two (or three) years of high level courses in math and physic, students have to pass a competitive examination in order to be selected to very high reputable engineer schools. In France, the middle/superior ranking executors are not trained at the University but in these special schools.

The main part of these Engineer schools is non-specialized ones. Students are trained to high level with a wide range scientific culture (but not only). With this diploma, new engineers can adapt themselves to a lot of different jobs and career's opportunity in industry or in financial business.

B. *The Ecole Centrale de Lille*

The Ecole Centrale de Lille is one of these famous French high school. Every year, 250 students graduate the engineer level. This school has been classified at the 14th rank (on 94 engineer schools) in 2010 [5]. The schooling lasts three years with common courses for 2 years (Fig.1). The third year enables students to go deeper into a specific scientific field.

978-1-4244-8218-4/10/$26.00 ©2010 IEEE

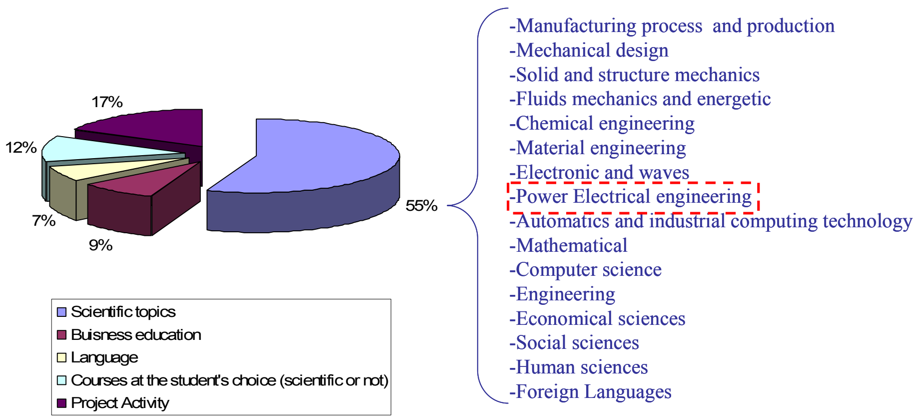

Fig. 1 First and second year overview (Total: 1750 hours)

The capabilities of a "Centralien" engineer at the end of his scholarship are: to design, to organize, to innovate, to lead, to train, to communicate... After the graduation, the young engineer mainly finds work like consultant (27%), in Finance (10%) or in public building construction (10%). 4% works in transportation domain and only 2% in energy [6]. These statistics are quickly changing and more and more graduated engineer work in the field of energy.

C. *Power Electronics course*

The power electronics course only lasts 32h. After a short introduction which enables to give an overview of power electronics and its applications, 14h are dedicated to classroom lecturers where switches, sources, losses, AC/DC, DC/DC power converter and reversibility are developed. 10h are used to work on exercises with smaller groups on different subjects like switching cell, diode rectifier, Power Factor Corrector (PFC), buck and boost chopper, reversible buck associated to DC motor.

Because, it is very important for students to practice in order to understand power electronics [7], 2 laboratories enable them to work on buck chopper and on single phase thyristor rectifier. For the moment, no simulations are realized which is quite damageable because it enables to increase the students ability to understand power converters [8]. Moreover, this kind of tool leads also to increase student interest [9], especially for a non-specialized engineer. This year, efforts have been realised in order to introduce and test small simulation times.

D. *Learning by Doing : The Project Activity at the Ecole Centrale of Lille*

The project activity is a non negligible part of the engineer formation process (Fig.1). Indeed, 300h (17%) are booked for this activity in first and second year. Students are grouped together by 7 on a scientific project. The goal of these projects is to achieve some prototype for an industrial partner. Students are supervised by two professors. The first one is in charge of the scientific part while the second one only supervises the project management. Besides, a lot of other school's staff like professors, engineers and technicians are here to help these students to achieve their project.

With this activity, students are also trained to every aspects of project management: schedule, team work, budget, promotion, communication… Technological innovation is at the centre of the project activity so students are made aware to such approaches.

E. *Power Electronics in the project activity*

Because of the non-specialized formation, only few projects deal with power electronics. Topics like renewable energy (Solar panel, wind generators…), new transport vehicles (Electric bike, Electric car, hybrid…) or embedded power system enable students to work deeply more on power electrical subjects and, of course, on power electronics. Due to the lack of hours in the initial scholarship, students have a lot of difficulties to appropriate themselves the necessary knowledge to achieve their project. The learning process is very long and it is made of success and failure which are going to be discussed right now.

III. Project Example : *E-CAR*

A. *Project presentation*

The student team has worked with the French company Renault on a project named *E-Car*. The aim of this work was to create an additional supply for a car application by putting solar panels on it. The principle is quite simple: First of all, the power, coming from the panels (Fig.2), has to be maximized thanks to a MPPT (Maximum Power Point Tracker) [10], and then stocked into a battery. All this process is realized using a buck-boost converter connected between the panels and the battery, and commanded via a microcontroller (Fig.3).

B. *The different steps*

This project activity has required different steps to be achieved:

1) The understanding of the power structure.
2) Knowledge acquisition on the different power components.
3) Simulation of the power converter.
4) Simulation of the MPP control algorithm.
5) Choice of the components.

6) Conception of the electronic solution.
7) Test of power prototypes.
8) Command implementation.

Of course, this process (steps 5 to 8) should be repeated because the first try is never conclusive, and the solution has to be improved in order to meet the specifications.

C. Detailed Conception process

1) The model of a buck-boost converter (Fig.4) [11] is well known from engineers. However, its structure had to be studied in details because it had not been explained in lecture courses. For the *E-Car* application, the buck-boost converter is used to tune the voltage V_p to the value that enable to maximize the power from the solar panels. Both voltage are linked with (1).

$$\frac{V_{batt}}{V_p} = \frac{\alpha}{1-\alpha} \Rightarrow V_p = \frac{1-\alpha}{\alpha} V_{batt} \quad (1)$$

with α : duty cycle

2) The understanding of the power structure required the understanding of every power components. At the beginning of this project activity, most of the students had never heard about power transistors and its applications. Hopefully, this component is studied in lecture courses. After a brief period of training, everybody, in the project team, was able to understand the aim of each power component.

3) The next step was to define the specifications of the buck-boost converter applied to the project. This was made thanks to the software Psim [12]. It allowed the students to check and understand the behavior of the converter.

The MPP of the panel (Fig.2) was approximately located at 18V at 25°C, and the simulation shows this voltage is reached for α ~ 0.4 (Fig.5). With the increase of the temperature, it is known that this MPP voltage will decrease while with lower sun illumination, this voltage will stay close to 18V. The main interest of using such buck-boost chopper is that the created system is not depending of input and output voltage level, so different batteries can be used, as well as different solar panels.

4) Then, the MPP control algorithm was also simulated using Psim. At this time in the project, the students had never heard of automatic control. It was also the first time that they had to use such software. The command algorithm was established using Psim toolbox. Despite a long time respond for the system, the algorithm was validated and the panels' electrical power was tending toward the maximum.

5) Psim was used finally for sizing the components. Indeed, this software gives an approximation of the currents and voltages of each component. These data are necessary when designing a power converter.

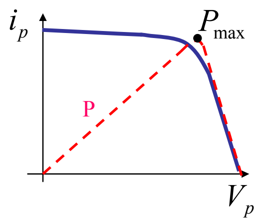

Fig. 2 Solar Panel characteristic

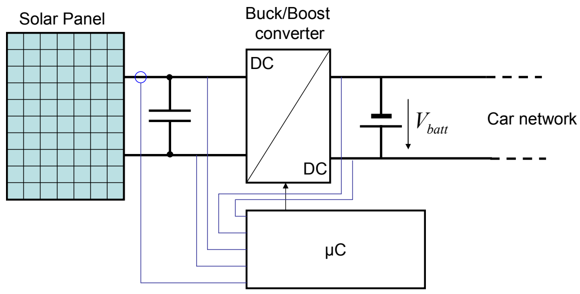

Fig. 3 Part of the project overview

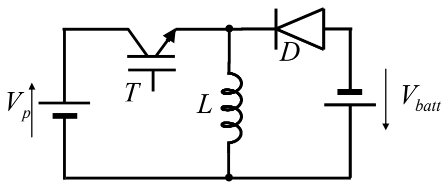

Fig. 4 Buck-Boost converter

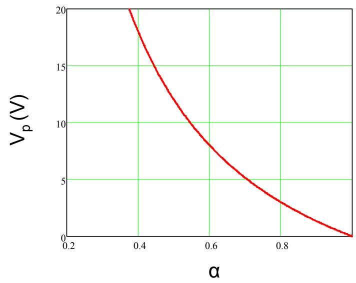

Fig. 5 V_p as a function of α for V_{batt}=12V

With these data, the students have set specifications. Then, their requirements were compared to many datasheets in order to find the suitable component. Of course, the first decisions were not the good ones, and many components were not well sized. This resulted in many problems during experimentations: explosions of capacitors or overheat of active components…

Most of all, the MOSFET's driver appeared to be really problematic and hard to choose. Due to its high-side topology the drivers' schematic was not as simple. The team has tested (and burned) many technologies before finding one which could meet their specifications.

Step by step, all the components had been sized and chosen. Also, it appeared that the inductor had to be designed by the team. This passive component requires a lot of precautions in order to be design correctly with low losses, a small size… One student of the team has decided to specialize himself on this specific component. The result of this work will be discussed in section *IV*.

6) The conception of the electronic device was quite complicated. The printed circuit board (PCB) was designed with the software Eagle [13]. Many boards have been edited during the project, along with the improvements brought to the prototype. The conception got better as the students got more and more hints and tips from application notices, professors' advice and technicians' cleverness.

At this step of the project, the team only wanted to design a buck-boost converter, with an external alimentation (V_e) instead of the panels and a resistor (R_{load}) instead of the battery and without the MPPT command implementation. Only an arbitrary signal generator was used to command the duty cycle of the transistor (Fig.6).

7) During the tests, the students could assess their scientific behavior, by putting a rigorous test protocol and trying to find the origins of malfunctioning. Thanks to the results of their experiments, they could have a feedback on conception and so, the prototype got improved until the final device was made.

For example, the first prototype was a complete failure. Many components got burned during the tests, and the buck-boost chopper did not work at all. After that, the team changed the reference of many of their components, and re-edited a board. This second prototype worked better, and allowed the students to compare their results with the theory of the buck-boost converter (Fig.7).

Great differences exist between the theory (green curve) and the experiments (purple curve). They have subsequently been explained, because of the internal resistance *r* of the inductor. The theory considers that the ratio R_{load}/r is infinite, but the experiments were conducted with low values of R_{load} (5 Ω).

Finally, the experiments on the final prototype matched exactly the expectations of the team (Fig.8). The theory is represented by the green curve, and the other ones are experimental results with different values of R_{load} (blue: 13 Ω, purple: 40 Ω, red: 255 Ω). Experiment results are really close to the theory. The Fig. 9 presents some measurement results for the power converter. On this figure, the system is working as expected: the current in the inductance is quite triangular while its voltage is rectangular (Fig.9).

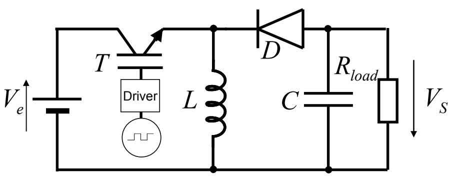

Fig. 6 Chopper first test

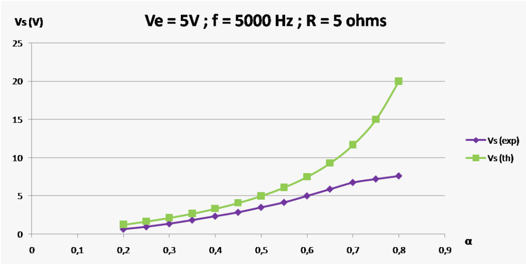

Fig. 7 Vs as a function of α for the 2nd prototype

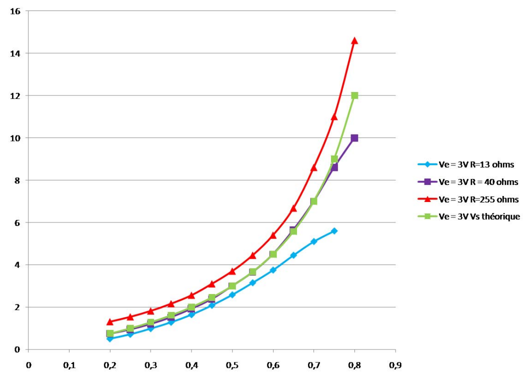

Fig. 8 Vs as a function of α for the last prototype

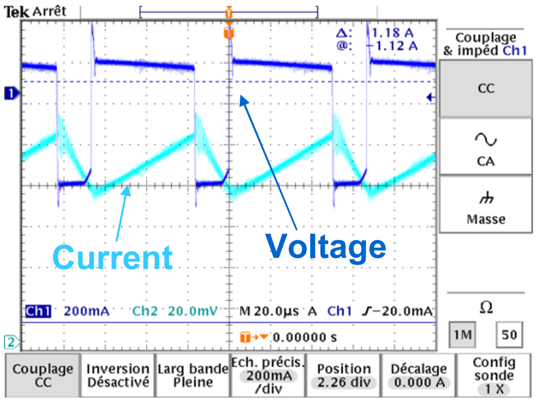

Fig. 9 Inductor current and voltage

8) After the power structure has been validated by the previous tests, the team decided to:

- -implement the command in order to pilot the panels' voltage thanks to the duty cycle. This operation came very smoothly, and no major incident occurred during the tests.
- -implement the MPPT command algorithm inside the µ-controller.

After having worked two weeks on the way to improve this algorithm, the team obtained satisfying results. The MPPT was stable enough, and could optimize the panels' electrical power in a few seconds. The Fig.10 presents the final prototype connected with a µ-controller PIC18F4620. The Fig.11 shows the experimental bench where chopper prototypes were tested.

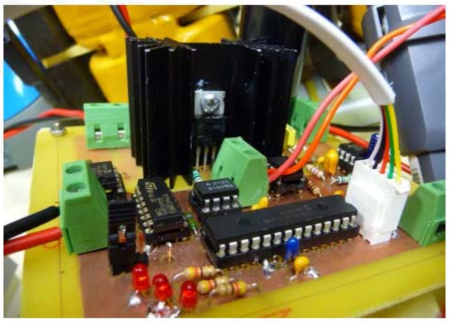

Fig. 10 Final PCB

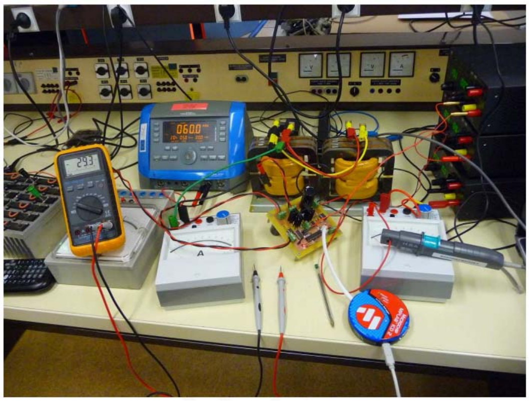

Fig. 11 Experimental bench

IV. DIFFERENT POINT OF VIEWS

A. *Student vision*

The first purpose of the project activity is to confront students with the practical realities of engineering sciences. This activity, which takes place in parallel courses dispensed at the Ecole Centrale de Lille, is about a vaster educational project, which is to prepare students in the best way to their future function of non-specialized Engineer.

The partnership with Renault for the project *E-Car* was a good mean for the team to develop skills and knowledge in power electronics, because of the common interest of its member for this discipline. Here is a partial assessment concerning the technical difficulties met by the team, and a thought about the limits of the learning by project

During the first year, the main difficulty for project *E-Car* was the establishment of a model and then the simulation of the MPPT. To understand the functioning of this converter, the software Psim has to be used by the team. The first use of this software (and later, the use of Eagle) was not easy-to-do: the first simulations did not give the expected results, or just partially, and the values of electronic components (their characteristics, their field of action and how they were modeled in the software) have to be revised to obtain acceptable results. Once this phase of tests was finished, the team had to focus on the conception of the power electronic board. There were few difficulties like sizing the components, the organization of the PCB, the use of Eagle or the welds realization. Most of all, the main conclusion of the team during this project step is that the experiments (when they finally work…) give results quite different from the theory. These differences were hardly understandable with our small background in electrical engineering.

The main difficulty the team had to face during the conception was learning all the hints of construction and other tips. Where to begin when it is the first time you make an electronic board? Other problems dealing with driver, supply, PCB conception, lack of practical knowledge have been met by the team.

In the end, the *E-Car* project students have had to face numerous technical or practical problems during this phase of realization, but this is a way of learning various things: the practical reality is often very different from the theory, and to understand power electronics well, nothing is better that to experiment.

This project also allows to make a comment on the idea of learning by project activity: if this educational method turns out to be gratifying (because she allows students to have real responsibilities and talks with industrial partners) and very formative, for the moment students don't have enough technical abilities to bring to a successful conclusion such projects by their own way. The school set up a system of consulting, so that the researchers, the teachers, the engineers and the technicians can assist the student in their works.

B. *Power Electronics professor vision*

It is very difficult, for a non-specialized student to learn power electronics by himself. Too few hours are dedicated in the scholarship to be comfortable with such problem. Power electronics basis have been taught but when it is necessary to be faced to another not-yet-studied converter, the challenge is important for the students.

Numerous topics have never been taught to these students and to achieve their project, they have to answer one by one to a huge range of questions: What is a driver? What is the difference between low side and high side driver? How can I size component? What is the main difference between an IGBT or a MOS transistor? How can I choose a component? How can I choose a switching frequency?...

Maybe the biggest difficulty that these students have faced was the problem of practice. They have never been faced to an electronic board that doesn't work correctly. In case of failure, what must a student do in order to make the converter work properly? What should be checked first? It has never been taught because in traditional laboratories… every device works!

Another main problem is dealing with components and their datasheets. It was also the first time that they had to read and understand some technical datasheet. For a non-specialized, the amount of information is not quite simple to filter and select.

The passive component and the inductor design also brought some surprises. It is important to specify that these students have never heard before about power inductor. So, they work using [14] and [15] to "size" an inductance using 3C90 magnetic material [16]. The first prototype realized is presented in Fig.12.

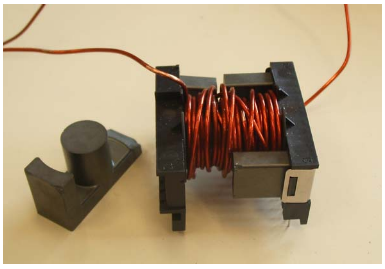

Fig. 12 First broken inductor (ETD 59 core)

With this inductance, problems of parasitic effects, High Frequency losses, saturation of the magnetic core have been pointed out so a student has decided to realize some other prototypes with the goal of reducing the size and the losses of the inductance. The goal was to conceive first an optimized ETD inductor and then to advance, in terms of integration, using planar technology [17]. The objectives were not reached mainly because of a lack of interest for such subject.

Finally, to conclude this advice, such pedagogical approach is very interesting in order students to be more interested in the field of power electronics. The use of simulation software is also very positive for the learning process even for a non-specialized engineer. On the other hand, such teaching method is really time consuming for supervisors especially when students try to realize experimentations. The practical part is a really lack in an Engineer education. When its lack is combined with a lack of meticulousness, the work becomes very hard for students and each valid prototype can be felt as a victory.

C. Industrial Partner

Nowadays, in the car industry, various profiles (specialist or not) are required but high level of qualification is always expected. An engineer who just graduated must be capable of achieving a project, even if he did not have the opportunity to deal with similar subjects during his studies. Thus he must have:

-a good mastery of project management, that is to say how to define qualitative and quantitative objectives, the project deliverable and most of all he must manage to determine with all the staff he is working with the conditions that lead to the sucess of the project.

-a good mastery of basics in power electronics: components, how to read a scheme and explain the principles, how to size an electric or thermic device.

V. POWER ELECTRONICS IN ELECTRICAL VEHICLES

This project has been achieved and a prototype has been delivered to the industrial partner. Finally, a power converter has been realized by novice students but this DC/DC converter can not be used directly inside a car. Indeed, firstly, this prototype has not been optimized in terms of losses and size. Secondly a lot of topics have not been studied yet like thermal management, packaging, reliability, high temperature components, EMC… These subjects are essentials in power electronics and more especially, for some of them in car industry. These topics needs a higher level in order to understand so maybe these non-specialized engineer will acquire this knowledge later, when they will have to face such problematic.

VI. CONCLUSION

In this paper, a student project, *E-Car*, has been presented. This project was financially supported by Renault. Students have realized a DC/DC buck-boost chopper for maximizing the power from a solar panel using a MPPT algorithm. The subject has given the author the opportunity to discuss about power electronics in French non-specialized school and the learning process that is linked to a project activity.

While this activity is very interesting and valuable for a young engineer in terms of project management and team working, the technical part is still limited due to the lack of backgrounds in power electronics. The professors associated to this project hope that with such approach, power electronics will appear more attractive, even for a non-specialized engineer.

REFERENCES

[1] N. Mohan, "Power electronics circuits: An overview" in Conf. Rec. *14th Annu. Conf. IEEE Industrial Electronics Society* (IECON'88), Oct. 1988, pp. 522–527.

[2] R. Delisle, "*How to Use Problem-Based Learning in the Classroom*", ASCD (Association for the suppervision and Curriculum Development), 1997, ISBN 0-87120-291-3

[3] D. A. Torrey, "A project-oriented power electronics laboratory", *IEEE Trans. Power Electron.*, vol. 9, no. 3, pp. 250–255, May 1994.

[4] R. H. Chu, D. Dah-Chuan Lu, S. Sathiakumar, "Project-Based Lab Teaching for Power Electronics and Drives", *IEEE Trans. on Education*, vol. 51, no. 1, pp. 108–113, February 2008.

[5] "*French Enginneer School classification 2010*", more info at http://www.letudiant.fr/palmares/classement-ecole-ingenieur-apres-prepa.html

[6] "Observatoire de l'emploi – Ecole Centrale de Lille – Enquete 2009", more info at http://www.ec-lille.fr/12933582/0/fiche___pagelibre/"

[7] J. M. Jiménez-Martínez, F. Soto, E. de Jódar, J. A. Villarejo, J. Roca-Dorda, "A New Approach for Teaching Power Electronics Converter Experiments", *IEEE Trans. on Education*, vol. 48, no. 3, pp. 513–519, August 2005.

[8] D. W. Hart, " Circuit Simulation as an Aid in Teaching the Principles of Power Electronics", *IEEE Trans. on Education*, vol. 36, no. 1, pp. 10–16, February 1993.

[9] G. G. Karady and G. T. Heydt, "Increasing student interest and comprehension in power engineering at the graduate and undergraduate levels", *IEEE Trans. Power Syst.*, vol. 15, no. 1, pp. 16–21, Feb. 2000.

[10] J. Applebaum, "The Quality of Load Matching in a direct-coupling Photovoltaïc System", *IEEE Trans. on Energy Conversion*, Vol. EC-2, No. 4, pp.534-541,December 1987.

[11] J. P. Ferrieux, F. Forest, "*Alimentation à découpage, convertisseurs à résonances*", Editions Dunod, 3ième édition, 1999, ISBN 9782100505395.

[12] PSIM 6.0, Power Sim Inc, http://www.powersimtech.com.

[13] EAGLE Light Edition, http://www.cadsoft.de/.

[14] Colonel WM. T. McLyman, *Transformer and Inductor Design Handbook*, Third Edition, Revised and Expanded, ISBN: 0-8247-5393-3, 2004.

[15] R. W. Erickson, D. Maksimovic, "*Fundamental of power Electronics*", Second Edition, Secaucus, NJ, USA: Kluwer Academic Publishers, 2000.

[16] Ferroxube, "*Soft Ferrite and Accessories*", 2009, more information at http://www.ferroxcube.com/

[17] Philips Magnetic Products, "Planar E-core", Application Note, July 1997.