High order experimental skills' gap identification – the need to reshape electronics teaching

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***Abstract*— Each knowledge area has its own evolutionary way, splitting in new knowledge areas, or simply abandoning some subjects to make room for new ones. As a result we can perceive the tendency for a given subject being treated differently, according to the course where it is taught. Thus, teaching electronics is different in an Electronics Course than in an Electric Power Systems Course. In the first this subject assumes some deepness while in the second it is, at best, only superficially presented. This strategy presents some advantages for the student, like cost and time requirements, and mainly the ability to move quickly into the labor market. Nevertheless we can identify some crucial drawbacks in this approach, mainly the very weak skill level attained in some crucial subjects, usually in the boundary between established knowledge areas. So, instead of getting solid skills about crucial electric and electronic components, students are often presented with simpler interface models, i.e. electronic "black boxes". Later on, when faced with a specific type of problems, graduated student are hardly able to identify solutions, due to their inherent lack of interdisciplinary skills. This work presents some perceptions related with the lack of some electronic concepts in engineering students, necessary to understand the implications on the electric power grid resulting from the use of non-linear loads. A methodology to characterize this situation and alternatives to overcome it are also presented.**

***Keywords*— Electronic teaching, non-linear electric loads, electric energy quality, engineering education.**

I. INTRODUCTION

Higher-level education is seen as an important factor in modern societies and as a key role for the future success. Nevertheless its importance, this objective assumes significant costs for every country since the number of persons who seek this level of education has risen tremendously in the last half century. This growth brought new challenges to the economy of each country, but also to teaching methodologies [1]. Traditional methods (centered on the teacher) were no longer as efficient when delivered for the masses [2]. This led to the diversification of teaching strategies and also to shifting the focus to students and then to teaching and learning methods [3,4]. The Bologna reform helped universities to re-organize and optimize education resources [5], which led to a trend of shortening their degrees and focusing them in a given knowledge area [6,7]. These "Bologna" degrees became very specific, with a high level of specialization but a narrower scope. This approach presents advantages and disadvantages, namely in the case of engineering education [8]. This strategy allows keeping the technological and education development processes close to each other [9], but on the other hand can bring the disadvantage of decreasing competences for dealing with multidisciplinary problems.

The function of the engineering profession is to manipulate materials, energy and information [10]. Engineering education is a complex process that generally makes students evolve from a *start state* to an *end state* using a *strategy*. The starting and ending state usually consider students' initial skills/knowledge and the ones desired at the end of the degree. The strategy plans how those final skills will be achieved at the final state. This process must be dynamic as those three components are constantly changing. The start state is not static because students can present different skill/expertise resulting from their individual choices and also due to environmental issues that affect their lives (technology issues, for instance). Thus, classes can be strongly heterogeneous and, as so, challenging to the teacher. The end state is also continuously changing as a consequence of the technological evolution. Thus, strategy should accompany these changes in order not only to link the start and end states but also to take advantage of technological and pedagogical advances in teaching. Examples of these developments have been reported and discussed in large scale in literature over the past years [6,7,11,12].

In order to follow, understand and act in the actual world, Engineering Education must be a dynamic adaptive process. This mean that changes in the real world should be followed by changes in the educational process. Teaching processes use subjects as pieces of information to build knowledge. Experience shows that higher efficiency can be achieved when theoretical concepts are complemented by experimentation. This completion can be a demonstration for something learned or for verifying if some experiment meets the specification. Changes in the real world must be followed by changes in the end state and its related subjects.

Therefore, according to its actual usage, subjects can gain or lose importance and so been adapted in Engineering Education [11,12]. As result we can see subjects getting importance at different levels inside the same department. Some subjects got so huge importance that moved out to form new departments.

As an example, a few years ago subjects related with computers and informatics were considering optional subjects inside the Electric Engineering whereas at present Informatics Engineering is an independent and specific engineering branch. Clearly focused on the use of ICT, an Informatics Engineering degree focuses on a high level of expertise in the software area while providing poor skills for interfacing it with real world through hardware stuff.

Other knowledge areas remain in the same department but only with a just few links in common, implying serious consequences when solutions involving several knowledge areas are required. This is the case, for instance, of Electronic Engineering and Electric Power Systems Engineering. Even both belonging to the Electric Engineering Department, the first is clearly oriented for electronic design while the second focuses on electric installations design and exploitation. As discussed before, a senior student from one of these degrees will clearly be a specialist in a specific subject, but due to the narrower common basic knowledge branch of his degree, he might struggle in the analysis of more interdisciplinary problems.

The paper objective is to call for attention on this delicate issue. This work identifies an existing gap in Electronics degrees due to this separation, which importance has grown with the rapid advances in technology. In section 2 the contextualization of the problem is presented. In section 3 the methodology of this work is lined up and in section 4 the corresponding obtained results are discussed. Finally in section 5 some conclusions are taken and future work directions defined.

II. ENERGY RELATED SUBJECTS

Electric Energy is an actual engineering hot topic and closely linked with sustainability and home appliance efficiency concepts. Several reasons can be given, but the probably more important ones are ecology and economy. The first is related with the greenhouse gases production while the second is associated with energy dependency. At planetary level, 50% of the total energy produced is consumed in buildings and the UE presents an external energy dependency of around 50% [13]. To invert this situation some policies had been taken into use: (i) increasing the renewable energy sources and reduce the energy demand by (ii) changing the consumer behavior and (iii) improving the electric appliances performance. The first policy achieved a mature development state in some areas such as Eolic power, and photovoltaic solar panels usage also increased considerably, although its efficiency needs to be improved. Researchers are now faced with the problem of how to inject the all renewable energy produced in the electric grid. This issue is not easy to treat as it is now necessary to develop a new electric energy paradigm, involving informatics, networks, electrotechnics, electronics, etc. Specialization sustained and accelerated the development of each technology, independently building up a solution involving all those technologies, but simultaneously transforming the problem into a multidisciplinary question [14].

The second policy, the consumer behavior, is currently under study and depends mostly on individuals practice having a special impact on the performance of public buildings [15].

The third policy is only technological dependent and has been improved via the use of the last generation materials and electronics. Old TVs were replaced by new flat screen models; the same for computers monitors; motors with embedded speed variation embedded, UPS, etc. Take HVAC systems as an example: traditional versions one use an on-off switch to control an electric motor associated to the compressor, whereas the modern versions include a speed variation that puts the motor running in a exact speed needed to achieve a given temperature. At a performance level the second is better than the first but at electric grid level a significant change took place, as in the first case we have a linear load whilst in the second we have a non-linear one. The use of non-linear loads has two main consequences: (i) better efficiency and (ii) harmonic distortion in the electric power grid. The advantage of the first is largely known while the second is, at best, only slightly perceived by engineering students. In fact, the use of those loads has its own negative impact in the electricity quality imposing losses that can ascend to 1.5 % of the PIB [16].

AC loads can be grouped in three main types:

- Type 1 - Linear loads;
- Type 2 - Phase controlled loads; and
- Type 3 - Rectification at first stage loads.

Type 1, linear loads, results from the usage of only linear components like resistors, capacitors and inductances. The use of those loads in AC results in sinusoidal currents as largely studied and depicted in Figure 1.

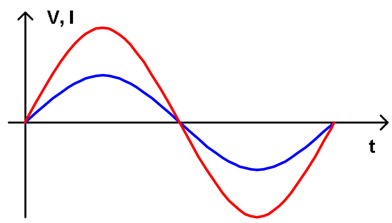

Fig. 1. Voltage and current at Type 1 load.

Examples include incandescent light bulbs, motors, ovens, etc. However experience shows that those types of loads have the tendency to be replaced by Type 3 loads.

Type 2 are loads directly controlled through phase techniques using power electronic components such as TRIACs and TIRISTORs. Typical household applications include light intensity control or vacuum cleaner power variation. In this kind of power control, from each half sinusoid cycle only one part is delivered to the load as depicted in Figure 2.

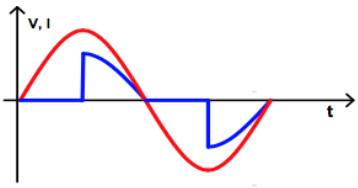

Fig. 2. Voltage and current at Type 2 load.

The current shape is now completely different from the sinusoidal. Note that the load voltage varies from zero voltage to a high value (that depends on the trigger phase angle) in a very short time. When using resistive loads, such as incandescent bulbs, some micro glitches can appear in the grid voltage sinusoidal wave.

A Type 3 load is the most important one because it is a group with the highest usage. Those loads include a full rectifier bridge and a capacitor at the first stage. Figure 3 presents a block diagram of the presented load scheme.

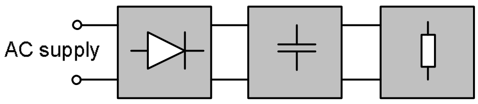

Fig. 3. Type 3 load blocks diagram.

Examples include high efficiency light bulbs, variable-frequency drives for induction motors, uninterruptible power supplies and switched-mode power supplies. The last one has a increasing importance as it has a growing utilization in a very large number of household and office appliances such as TVs, PCs, PC monitors, mobile phone chargers, entertainment devices, etc. This type of load is non-linear and imposes pulsed currents on the grid instead the more desirable sinusoid shaped ones, as depicted in Figure 4.

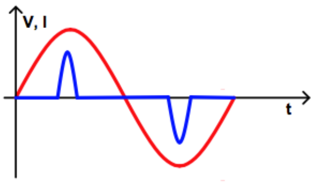

Fig. 4. Voltage and current at Type 3 load.

A real electric AC installation has a variable mix of loads, belonging to some or all the mentioned types, resulting in a complex equivalent load and a corresponding complex current shape.

III. METHODOLOGY

The aim of this work is to perceive weather electronic students are prepared to deal with these different loads imposed by real problems, identify their difficulties and link them to actual gaps in their education. The method of research is ex post facto research [17] since the researcher takes the effect and examines the data retrospectively in order to establish causes, relationships and explanations. The collected data consisted in some class discussions transcriptions and courses and degrees curricula analysis. The results relate to Electric Power Systems Engineering at ISEP (Polytechnic of Porto School of Engineering) students at the end of their first year, second semester (2013).

A teacher/researcher perception triggered this research. In order to test his perception, he placed the hypothesis of his students in the end of his course “Electronics” not being able to explain nor comprehend the actual behavior of an electronic device in terms of current and tension. He then tested his hypothesis in several classes using a competence question discussion. After this step, the teacher reflected upon the courses students had had until then and the ones they would have in the future in order to understand if this presented a real problem or if this gap in students’ comprehension would be dissolved in other courses.

IV. RESULTS AND DISCUSSION

In this section we outline the scope of the problem, present the test case used to identify and diagnosis it. And finally we make a retrospective analysis of the possible causes of the problem.

A. *Scope: The new loads impact*

Only the use of the Type 1 loads (see section 2) results in sinusoidal wave shaped currents but, as said, these kinds of loads have the tendency to be replaced by the Type 3 version. However those also have some disadvantages from the electric grid point of view, which originated new directives to impose some restrictions on their use and incentive the use of more modern solutions. The electric diagram of an electric Type 3 load is presented in Figure 5.

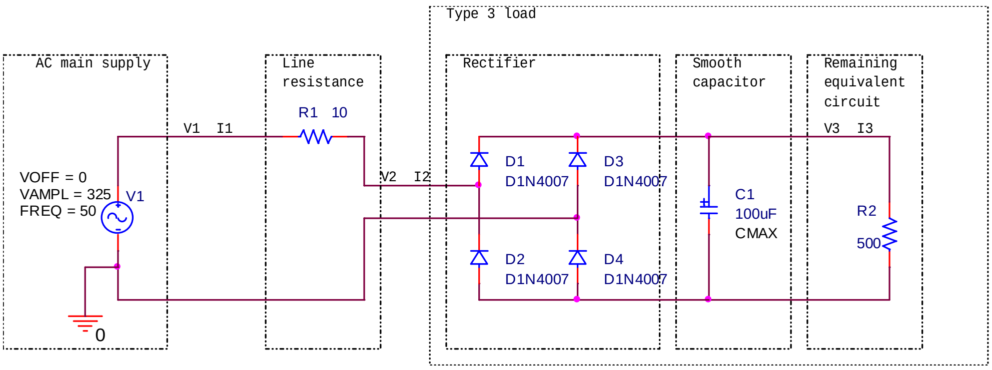

Fig. 5. Type 3 circuit connected to the AC main supply.

In this diagram we can identify several electric elements and parameters:

- The AC main electric source from the power service provider represented by V1. This wave is sinusoidal and has the maximum value of 230 VRMS (or 230√2 Vmax = 325 V)
- The equivalent electric transport lines resistance between the power service provider and the building installation, simulated by R1.
- The voltage delivered to the building main entrance, represented by V2
- Inside the building we have a type 3 load appliance that includes a full rectifier bridge (four diodes), the electric capacitor and the remaining circuit represented by R2.
- I1 represents the current at the building.

Figure 6 presents the waveform associated with V1, V2, V3 and I1.

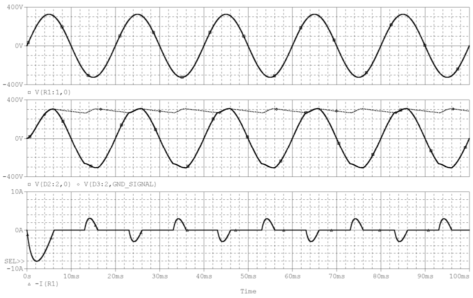

Fig. 6. Voltages and current at Type 3 load.

Ignoring the initial transient due the presence of a discharged capacitor, we can see that the inside circuit represented by R2 is supplied by the capacitor, whose voltage goes down to zero. Meanwhile, the rectified voltage falls to zero and rises again to the maximum value. During all this time the circuit does not demand current from the AC main grid. When the increasing mains voltage crosses the capacitor voltage then we have a huge current demand to both supply the load and recharge the capacitor. The main grid current is zero during 4/5 of each half period of time, assuming huge values during the remaining 1/5.

In this simple simulation we can identify two big differences from the use of linear loads: (i) the voltage distortion in V2 and (ii) the impulse shaped current at I1, clearly different from the typical sinusoidal shape from the linear loads.

The I1 Fast Fourier Transform (FFT) shows the high level of harmonics and distortion as presented in figure 7.

As seen, the use of Type 3 loads has consequences, not only for the consumer installation but also in the voltage distortion that is propagated to the entire neighborhood. To avoid the negative impact on the electric grid, resulting from the use of Type 3 loads, some specific directives [18] appeared grouping the loads in several groups of appliances and imposing the maximum harmonic content for each one. The target can be achieved by using passive or active solutions as seen in Figure 8.

FOURIER COMPONENTS OF TRANSIENT RESPONSE I(R_R1)

DC COMPONENT = 9.598502E-07

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	1.123E+00	1.000E+00	1.030E+01	0.000E+00
2	1.000E+02	2.753E-06	2.452E-06	-1.394E+01	-3.454E+01
3	1.500E+02	9.418E-01	8.389E-01	-1.487E+02	-1.796E+02
4	2.000E+02	2.933E-06	2.613E-06	-1.507E+02	-1.919E+02
5	2.500E+02	6.436E-01	5.733E-01	5.375E+01	2.244E+00
6	3.000E+02	1.536E-06	1.369E-06	8.391E+01	2.210E+01
7	3.500E+02	3.274E-01	2.917E-01	-9.882E+01	-1.709E+02
8	4.000E+02	1.667E-06	1.485E-06	2.564E+01	-5.677E+01
9	4.500E+02	1.002E-01	8.922E-02	1.373E+02	4.461E+01
10	5.000E+02	2.718E-06	2.421E-06	-1.058E+02	-2.088E+02

TOTAL HARMONIC DISTORTION = 1.060881E+02 PERCENT

Fig. 7. Fast Fourier Transform analysis for the current I1.

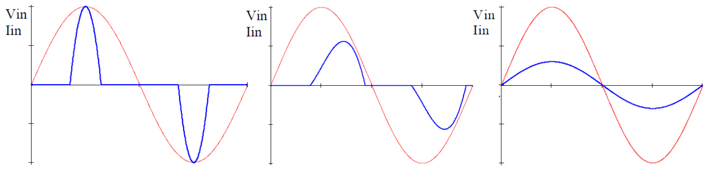

Fig. 8. Typical waveforms from the use of Type 3 loads (a) and those resulting from the use of passive (b) and active (c) compensation [18].

As we can see, the use of Type 3 loads in conjunction with active compensation allows an appliance high performance and minimal impacts on the electric grid. However, for some appliances active compensation is not economically feasible yet, and for such cases the directive defines a maximum content for each group of appliances.

B. *Test and diagnosis of students' difficulties*

Based on the electronic equipment present in the classroom, the teacher discussed with his students (in different classes) several questions in order to test his hypothesis. He elaborated a set of questions, starting with the simple questions and then evolving to more complex ones, which would demand students to have developed and mastered competencies inherent with the theme addressed in the scope of this section. Here it is presented the result of this discussion (similar in every class):

(T: Teacher; S: Students)

T: When applied a sine wave voltage of 230 V to an incandescent bulb, what kind of current shape can we expect?

S: A sine wave, with no phase!

T: And if we use a modern high efficiency light bulb?

S: Certainly a sine wave current but I don't know about the phase…

T: And when using a motor with a variable speed based on a frequency variation?

S: A sine wave current shape and a positive phase angle!

T: …and this old PC…

S: ...a sine wave current but again I don't know about the phase…

In fact only the first answer is correct because this case corresponds to a linear load. This very simple piece of dialogue shows that students tend to see all loads as linear ones and so for a sine wave voltage applied should result a sine wave current, only hesitating about the corresponding phase. Being recurrent, these results indicated that there was a real problem behind this lack of competence to deal with real problems. The question was if this was temporary or if students would not have the opportunity to address this kind of situations again in their following years.

C. *Retrospective Analysis of the problem*

Electric Power Systems Engineering students have the idea of the absolute linearity applied to any king of loads. Teaching these subjects should take into attention the educational objective and the level of initial skills required. At the end it is important that the student knows how to relate several concepts taught in several courses. This objective is not easy to attain due to the present tendency to shorten the degrees and associated courses, in order to provide the widespread of knowledge deemed necessary. One way to accomplish these objectives can be through (i) a close adaptation of each subject to the course specific objectives, or (ii) the use of ICT and e-learning in teaching, including virtual and remote experimentation. In this last case, the students can see the experiment and identify what they already understand but also study and comprehend the remaining (and important) pieces of knowledge.

Traditionally the methodology used to teach the electronics subject depends on the specific electricity engineering degree. This subject is traditionally more deeply taught in electronic oriented courses whereas is only slightly introduced, or not taught at all, in electric power systems courses. In this last sort of courses, all line voltages are considered sinusoidal and applied to abstract linear loads. This traditional teaching approach has been extensively used in the past, as in the real world the loads were mainly linear, e.g. such as incandescent light bulbs. Nowadays a large part of the actual loads are non linear ones, as is the case of the high efficiency light bulbs. As seen, the advantage of using Type 3 devices, this carries also disadvantages as the line current shape becomes pulsed with a high level of line harmonics instead ideal a sinusoidal one. The reason for this behavior is the use of full wave rectifiers directly linked to the main line, which has an impact on the power factor and in the harmonic content. However the full wave rectifier has different importance according the considered degree. For Electronic Engineering student it is only important to understand its use to convert AC into DC for its own purposes. Conversely for the Electric Power Systems Engineering student it is important understand its consequences in the electric grid. This means that the same subject part (e.g. the full rectifier bridge) should be adapted to each degree course.

To fully understand Type 3 loads it is also important to have some knowledge about harmonics. The paradox is that the Electric Power Systems Engineering students who need to understand this problem usually do not have the necessary knowledge. Conversely, the students who are able to understand it are usually into Telecommunications specialization. Some very simple surveys have shown that at the end of the course degree, Electric Power Systems Engineering students have difficulties on interpreting voltage or currents waveforms shapes from the power grid. New electric equipment' analysis is quite advanced and provides a set of important information [19]. However the diagnosis remains that graduate students don't develop the ability in full during their education. When questioned about the current shape resulting from the use of incandescent light bulbs, high efficiency light bulbs, or desktop PCs a large number of students indicate the sinusoidal as the answer. When questioned about the importance of power harmonics of voltage or current only a few have a right perception. Also the deformed sinusoidal wave from the power line has no reasonable explanation. The competencies students needed to master in order to address this problem were (i) identify different kind of loads (type1, 2 or 3) and know its implications at harmonics content level. Analyzing their degree curricula and comparing it to related degrees (neighboring knowledge areas) at the same school, we can identify more clearly this problem (Table I).

TABLE I. IDENTIFICATION COURSES WHERE SOME OF THESE COMPETENCES ARE DEVELOPED IN ELECTRIC RELATED DEGREES

Engineering degrees:	**1st year**	**2nd year**	**3rd year**	**Professional needs**
Electric Power Systems	Essentials of electronics	Essentials of harmonics	None	Type of loads, Harmonics
Electronic and Computers	None	Harmonics (Telecommunications)	None	Harmonics and communications. Issues concerning power supply aren't considered requirements.
Informatics	None	None	None	None if not considering the power supply and power back-up systems such UPS.

This problem originated from the separation of Electronics knowledge area in different branches. The second step, which aggravated the problem, was the Bologna's reform and the shortening of the number of courses and its curricula. Summing to this effect are the continuously growth of electronic devices with loads of Type 2 and 3. So, the existing gap present nowadays can be summarized as follows:

- Electric Power Systems students understand very well how linear loads work, but they revealed some difficulties at identification of several kinds of loads and its impacts at electric grid namely at harmonic content level. Later they will need both.

- Electronic and Computers students understand very well how works the Type 1, 2 and 3 kind of loads but they concerning about the behavior in forward direction, i.e., what they need to design in order to obtain a desired supply to a given circuit (e.g. a microcontroller) and are not focused or concerned about its implications in backwards, i.e. in the electric grid.

- Informatics students understand very well all thinks related with code development but they don't have a clue of the impact in the electric grid due to the used of an Uninterruptible Power Supply (UPS).

Students are suffering from this detachment. The first step was identifying the problem. Now, more clearly teachers can think of a solution. As mentioned before, teaching is a dynamic activity that should be driven in the correct direction. Currently some difficulties have been identified linked to curricula issues. The next step is to characterize the present situation and submit to the degree direction a resolution proposal that will include the use of ICTs and remote experimentation [20,21]. Some proposals might include animation multimedia, circuits' simulation and remote experimentation and eventually the reorganization of the actual hands-on target circuits used on the electronic classes.

V. CONCLUSIONS AND FUTURE WORK

Engineering Teaching is a dynamic and adaptive process that faces some challenges. On one hand we can see the engineering degrees decreasing in size and being likely to be focused in one specific expertise area. On another hand, to really understand some real phenomena it is necessary to also have acquaintance with neighboring knowledge areas, but to do so engineering degrees should be less focused and more generic, i.e. the reverse of the actual tendency. In this work some gaps in recent engineering graduated students have been identified and linked to issues related to course degrees curricula.

Teaching electronics is different in an Electronics Degree than in an Electric Power Systems Degree. In the first this subject assumes some deepness but on the other hand they will not usually be dealing with energy issues. While in the second is, at best, this subject is only superficially presented and in their profession, they will need to understand energy issues related. The strategy of specialization degrees presents some advantages like cost and time requirements, and mainly the need to move quickly into the labor market. Nevertheless we can identify some crucial disadvantages in this approach, mainly the weak development of skills and competence level in some crucial subjects, usually in the boundary between accepted main knowledge areas. So, instead of getting solid skills about crucial electric and electronic components students are often presented with simpler interface models, i.e. electronic "black boxes". Later on, when faced with a specific type of problems graduated student are hardly able to point solutions due to their inherent lack of interdisciplinary features. To surpass this problem, as future work, we plan on proposing a methodology to help solving this issue that will include the adaptation of some subject curricula to each specific degree course and the production of a set of learning means based on ICTs based on the use of virtual instrumentation or remote experimentation.

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