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# How to Increase and Retain Interest in Power Quality Lectures

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## Abstract

This article discusses about Power Quality (PQ) as a teaching subject and addresses the methodology employed in the theoretical/expositive PQ lectures for undergraduate students held at the Laboratory of Analysis of Power Quality Monitoring (LAMQEE), located at Escola de Engenharia de São Carlos (EESC), University of São Paulo (USP). It will be covering challenges

handled, positive aspects and new learning opportunities based at adopted methodology. Theoretical classes were supported by new tools of pedagogical aid to develop learning skills. Examples of tools that could be mentioned are real time computer simulations projected in multi-media equipment, discussions of technical-scientific articles, as well as the use of a Digital Arbitrary Signal Generator combined with a PQ analyzer. With the aim of increase and retain the enrolled students' interest, practical exercises were added to the course and provided with performance comments concluded activities. This methodology was implemented with the vital cooperation of a student of the Program of Education Improvement (PAE) supported by USP. The PQ classes supervised in association of a PAE scholarship support in teaching activities, promoted better interest and involvement of students during the lectures. Additionally, it improves the teaching atmosphere quality, satisfy and lectures content. Students' self-confidence on the subject PQ concepts and developed performs was verified and the enhanced number of final course papers in topics correlated to PQ. Despite challenges and upgrades that should be applied, the effects observed so far show that many of the pedagogical instruments, when correctly applied, are capable of enhance the study and attention of significant topics associated to PQ. Likewise, the instruments also encourage and inspire students to learn PQ subjects key and initiate them to the academic research atmosphere and upcoming professional activities. Finally, other activities are still on the list of actions for future work, for example, it would be recommended to have a feedback mechanism of the students, validating all the methodology adopted, strengths and weaknesses of the material developed, the presentation of the lesson and the attendance after the lecture.

**Keywords:** Laboratory Activities, Pedagogical Tools, Power Quality, Teaching in Engineering, Teaching Methodology.

## 1. Power Quality

Generation and distribution of electricity in Brazil have very unique characteristics, which create a singular scenario in comparison to other international environments. In Brazil, a country with continental extension, the predominance of hydroelectric generation, the existence of a National Interconnected System (SIN) and strong state regulation, create a scenario that manages a gigantic productive proportion. In this context, Power Quality (PQ) is relevant and not yet widespread in the curricular basis of undergraduate and postgraduate courses in Brazil, especially those related to the area of Electric Power Systems.

Furthermore, the Brazilian electric power matrix has changed its scenario with continued increase of wind generation, which has currently a forecast of 15,000 MW to be installed in 2017<sup>1</sup>. This situation requires not only robust structures for the power production, but also continuous PQ monitoring to provide more reliable solutions, as wind production has inherent variability and unpredictability behavior.

This paper addresses the methodology adopted in the compulsory subject of PQ (SEL0409 -Power Quality), lectured to undergraduate students at the Laboratory of Analysis of Power Quality Monitoring (LAMQEE), Escola de Engenharia de São Carlos (EESC), Universidade de São Paulo (USP). Over the last few years, complementary lectures have been added to the theoretical lectures and new pedagogical tools have supported the development of learning skills. This paper will address the positive aspects and opportunities identified in this disciplinary scenario (between 2014 and 2016). Considering this, the laboratory lectures of PQ are relevant for the SEL0409 - Power Quality subject of the Electrical Engineer course, with emphasis on Energy and Automation Systems.

## 2. Power Quality at Universidade de São Paulo (USP)

The Power Quality subject (SEL0409) was initially made available in 2006 to fourth year students of the Electrical Engineering course, with emphasis on Energy and Automation Systems. This subject is offered in the second semester of each year as one of the compulsory subjects of the Electrical Engineering course. Typically, specific PQ topics are associated with other related disciplines, such as Electric Power Distribution and Electrical Power Systems Protection, but with an informative approach. Thus, it is remarkable that a PQ laboratory with wide resources and equipment for PQ study is dedicated to postgraduate and undergraduate students.

### 2.1. About the Subject Availability and Lectures Environment

At the São Carlos campus of USP, PQ is a compulsory subject in the Electrical Engineering curriculum. Usually undergraduate students attend this subject in the 8th semester. However, under specific conditions, some third year students can also attend the subject.

SEL 0409 laboratory lectures are taught for two groups of approximately 25 students each, once a week, in two lectures of 50 minutes each. This subject is offered annually, usually in the second semester of each year. Currently, both theoretical and laboratory lectures are taught at LAMQEE. Up to 2015, most lectures were taught in the conventional classroom and eventually at LAMQEE. With the recent reorganization of the LAMQEE through refurbishing and expansion of the physical space, carried out from 2015 to 2016, a hybrid classroom and laboratory environment were built, allowing all activities of SEL 0409 to occur in the same place.

### 2.2. Equipment

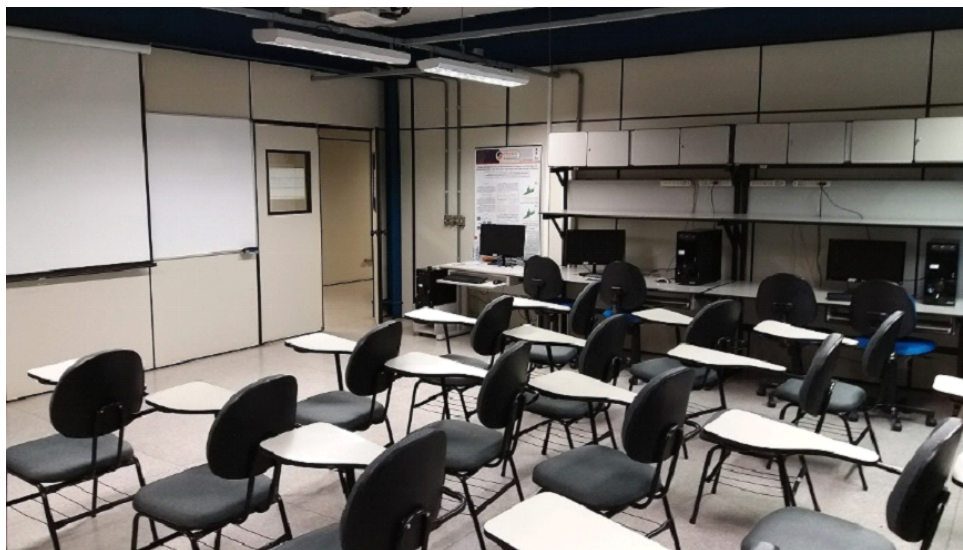
At LAMQEE, there are some outstanding equipment, such as the Digital Arbitrary Signal Generator (DASG) connected to a dedicated computer for its handling and management, signal analyzer and recorder, several test electrical charges, and other support devices.

DASG, Model 5001iX-208 (AC Power Source/Analyzer) is an equipment produced by the current Ametek Programmable Power, Inc, formerly California Instruments, which combines signal output precision with low distortion and built-in metering system (Photograph 1). The voltage output range is 150 Vca at 300 Vca RMS, which allows carrying out a wide range of Low Voltage (LV) experiments.

LAMQEE has a mix of laboratory equipment, projection screen, whiteboard, about 30 (thirty) desks, 6 (six) desktop computers for individual and group activities, partially illustrated by Photograph 2. Internet access is available in the entire building, which also includes other laboratories that serve the courses of Electrical Engineering, with emphasis on Electronics and Power Systems and Automation, and Computer Engineering. In LAMQEE, there are two computers for teaching support, where the main one is used for presentation (slides), and a second one is dedicated to DASG. Both support computers are connected to the projector, which allows real-time visualization of the practical activities performed in the generator, as well as the information content provided.



Photograph 1. DASG. Equipment used in LAMQEE lectures.



Photograph 2. Classroom in LAMQEE.

### 3. Subject Development

As previously mentioned, SEL 0409 started as a compulsory subject in 2006 in the Electrical Engineering course of the Escola de Engenharia de São Carlos, USP. Since that year, the subject has undergone several positive transformations and had at least four scholarship

holders over the last four years, who help in the activities during the semester with the financial support of the Program of Education Improvement (PAE)<sup>2</sup>.

When the subject was implemented, there were not as many postgraduate students related to the PQ theme as nowadays, since it was a new research field when compared to others that are already consolidated in Electrical Engineering. Therefore, even with many people involved in supporting LAMQEE activities, many challenges were faced. There was a great effort of the Departamento de Engenharia Elétrica e Computação, professors and post-graduation students engaged in gathering financial resources and donation of equipment that would contribute to the laboratory teaching. Therefore, LAMQEE was elaborated in a joint action of laboratory technicians of the University staff and postgraduate students, who volunteered to help speed up the improvements at LAMQEE infrastructure and operation.

Furthermore, the experience that PAE scholarship holders acquired over the years in laboratory practices (which will be better detailed in the following section) is worth mentioning. Each year, those students manage better their responsibilities, performing improvements in the PQ lectures, and transmitting their acquired knowledge on to the next responsible person (usually a new PAE scholarship holder), which contributes to enhance the learning process of the students.

### **3.1. Program of Education Improvement (PAE)**

PAE is regulated since 2005 and is intended exclusively for postgraduate students enrolled at USP in master's and doctoral courses. The main objective of this program is to improve the postgraduate education in didactic undergraduate activities, and it basically consists of two stages: (i) Pedagogical Preparation; and (ii) Supervised Internship in Teaching<sup>2</sup>. This program plays a fundamental role in the activities of the scholarship holders, and also to the progress of laboratory classes, which is of paramount importance for a subject like PQ, as there are several laboratory lectures throughout the semester.

### **3.2. Selection Process of Scholarship Holders**

The students of Post-Graduation in Electrical Engineering of the USP must first attend the subject of Pedagogical Preparation (SEL5720). Currently this subject is lectured in the second semester of each year and is part of the curriculum and contributes to the completion of compulsory credits of the postgraduate program. Following this course, as a complement to the professional education, PAE gives the student the opportunity to attend one graduation subject per semester, supervised by a professor through a project previously approved in activities regarding a theme related to the research developed by the student. This stage was formally denominated Supervised Internship in Teaching. The project usually includes activities such as lecturing, updating didactic material, applying exercises, preparing laboratory material, correcting exercise lists and other activities. The postgraduate student may choose to work on a voluntary basis if they are not granted a scholarship.

## **4. Current Context**

The laboratory lectures of the PAE scholarship holder include the following items: (a) Analysis of technical-scientific article; (b) Presentation of the necessary content for the laboratory lecture; (c) Load Test through scheduled PQ disturbances; and (d) Classroom exercises with free method and tool.

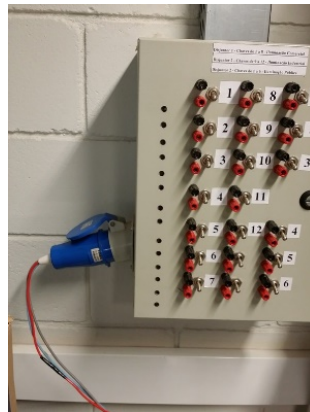
First, in the analysis of technical scientific articles, select those related to the PQ area, in which the students are previously prepared and specific parts of the technical-scientific article are presented in groups. In this activity, in 2016, the PAE scholarship holder and other invited postgraduate students evaluated the presentations, briefly complementing some of the themes addressed, and asking additional questions to the group. Students were encouraged to be prepared to answer the invited examiners' questions after their presentation. The evaluation was individual and was part of the grades related to the complementary activities.

The content of the theoretical revision presented in the laboratory lectures is composed of basically three parts: (Lecture 01) DASG, in which students are introduced to the PQ subject, laboratory layout, DASG and its software interface, and LAMQEE test loads; (Lecture 02) Short-Time Voltage Variation (STVV), which includes motivational introduction to the study of STVV, classification and definitions of voltage interruptions, voltage swell and sag, ending with some tests conceived to allow the observation of these PQ phenomena; and (Lecture 03) Harmonic Distortions, which presents motivational introduction and definitions related to the theme, waveform decomposition and harmonic PQ indicators.

After the theoretical revision of laboratory Lectures 02 and 03 described above, the application and evaluation of the voltage and current signals are carried out in real time. Those signals are resulting from some loads available in the laboratory, which were submitted through sequential disturbances applied via DASG. With the use of DASG, up to 32 sequential events of voltage sag disturbances are simulated, with variations of the intensity and duration of the input voltage form. For each applied disturbance, the behavior of the load (visual and functional effect until it is switched off) is evaluated. This procedure involves the following equipment that are available in LAMQEE: incandescent lamp (100 W); compact fluorescent lamp with electronic reactor (15 and 23 W); fluorescent tube lamp with electromagnetic reactors (20 W); hermetic compressor motor; computer (CPU and monitor); LED lamp (6 W); single-phase induction motor with soft starter; high power factor (PF) fluorescent lamp; low PF fluorescent lamp; halogen and dichroic lamps; sodium vapor, mercury vapor and mixed lamps; and photo-electric relay. The arrangements of these components are shown in Photograph 3 to 8.

There are two lectures of 50 (fifty) minutes each reserved to exercises related to PQ indicators. The digital material, called pre-lab, is given in portable document format (PDF) one week before each lecture. This document contains brief theoretical aspects and some application examples, totaling not more than ten pages (with illustrations) that the student should be able to read without any additional requirements. In the classroom, groups of maximum four students are composed, totaling approximately six groups. After a brief theoretical explanation of approximately twenty minutes, the exercise data are released to the students groups in a summarized way (numerical tables). Each group receives a card containing different numerical data so that each group of students has different results. In the first exercise, the harmonic components (even and odd) and their respective non-normalized values are presented. Total Harmonic Distortion (THD), Root Mean Square (RMS), Crest Factor (CF) and Individual Harmonic Distortion (IHD) values are to be found. At this point, no relation is made to the current or voltage. In the second exercise, a synthetic signal cycle, containing 32 samples generated in MatLab® software, is presented, where the phasors composing the signal (amplitudes, frequencies and phases) have to be calculated and, in addition, the same indexes required in the previous exercise must be calculated.

The students are free to choose the analyzing tool (ranging from mathematical software to electronic calculators, both exemplified and provided with source code in the pre-lab material), as well as the method to be used, and are called open solution method. The PAE scholarship holder directly supports each group of students while they are doing the exercises, helping them in case of difficulties during the time available for the activity. The exercise is corrected immediately after it is finished, i.e., as soon as each group completes the activity the scholarship holder verifies if it is within the range (tolerance) of the expected values that are available in a template (previously designed). Afterwards, the scholarship holder informs if there is any inconsistency in the results, and after all eventual adjustments needed, the effective participation grade is attributed.



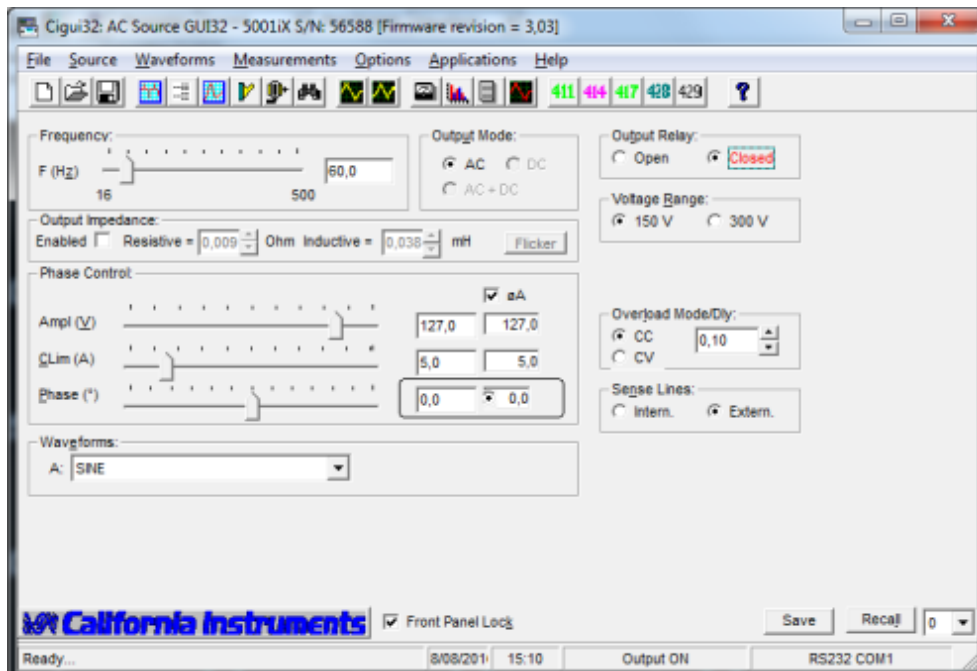
Photograph 3. Control panel of connections and switches of the lamps.



Photograph 4. Set of test lamps installed at LAMQEE.

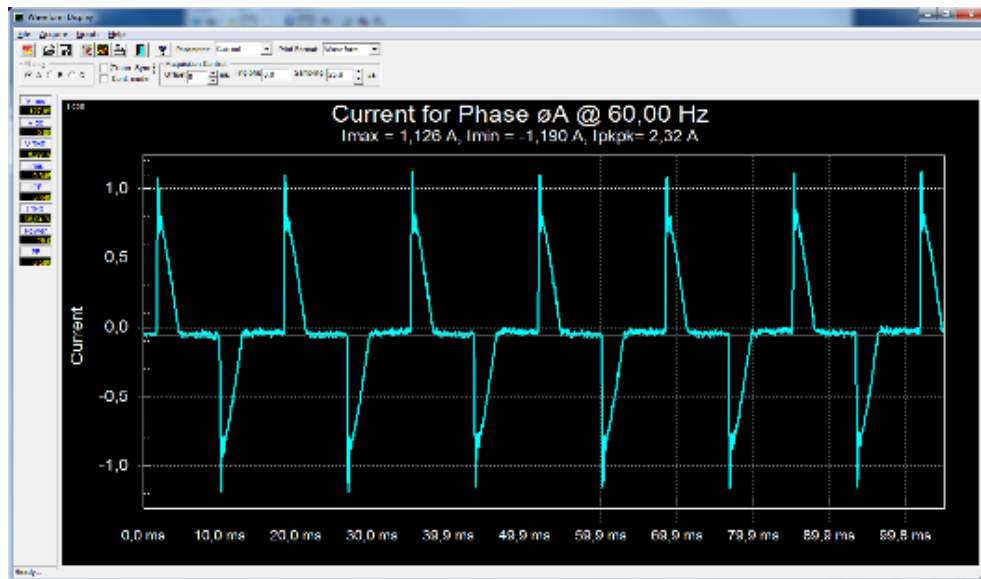


Photograph 5. Testing panel with typical loads for PQ evaluation.

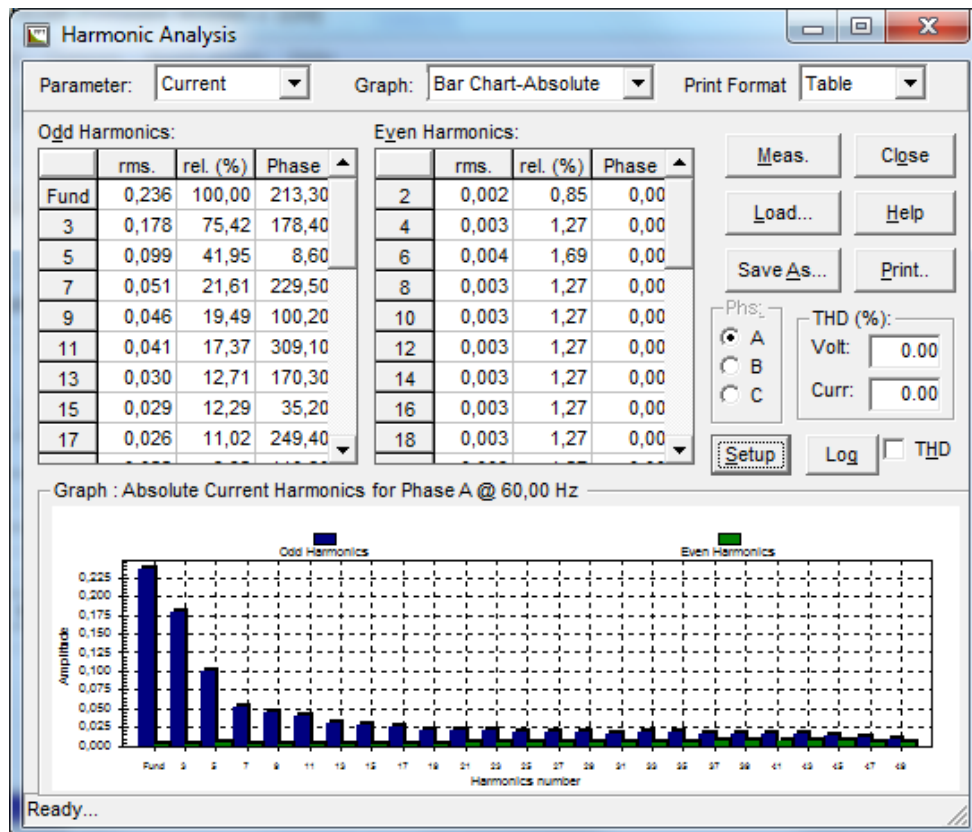


Photograph 6. Typical DASG initial configuration screen.





Photograph 7. Distorted current waveform of a load with non-linear characteristics.



Photograph 8. Analysis of the current harmonic spectrum of a load with non-linear characteristics.

## 4.1. Positive Aspects

The analysis and discussion of the technical-scientific articles by the students helps getting in contact with the research lines trends in PQ. Group presentations allow all students to be more confident about the exposed content. The article content assigned to each group is relatively small, which gives the opportunity for extra comments and even surprising results, such as the search and complementary information available in the article references. Some of the groups have used the opportunity to comment more about the method used, by using the explanation indicated in the references of the base article. It was observed that even though the presentations were done in a relatively short time, it was enough for a good analysis and discussion of the material.

Although much of the content is addressed during conventional lectures, when reviewing the theoretical content required for the laboratory lectures, the undergraduate student consolidates their knowledge because of the alternative explanation given by the scholarship holder. As discussed in section five of this paper, this item of laboratory lectures is the longest in formal presentation. Some adjustments may be necessary in the future in order to better catch students' attention and improve their learning experience.

Despite the large variety of test loads (equipment), PQ disturbances are applied only in some of them, respecting their similarity group, for example: fluorescent lamps (only one of them), sodium vapor lamp, mercury vapor and single-phase induction motors. For the application of voltage sags, the PAE scholarship holder follows a script, as they have prior knowledge of the point of disconnection or equipment reset. This knowledge facilitates the interaction process with the students. Usually, the students' involvement is limited to making assumptions, orally expressed during the lecture, of the intensity and duration on the observed PQ disturbance, which is then confirmed in the test carried out by the scholarship holder. These tests clearly show students how to obtain the lower part of the Information Technology Industry Council (ITIC) curve<sup>3</sup>. The top of the ITIC curve is not conducted in the laboratory, as it would have a much more premature destructive effect on the test loads. In DASG, the values of RMS voltage and current, frequency, active, reactive and apparent power, and peak current are also presented, opportunely commented and evaluated in the context of PQ.

The first assignment of the exercises lecture helps students to gain confidence and has not presented major difficulties. Most groups complete this task very quickly and rarely make mistakes. The fact that the correction is done right after the end of the activity ensures that everybody gets the expected result, without gross errors that are typical in the process of calculating the phasors of the sampled signal and their respective indices. This method has generated satisfaction and visible contentment for the students at the end of the lecture, as they really understand the meaning of the PQ indexes numerically. Although it seems to be a short time activity, they ended ten minutes before the total time (composed of two lectures), which allowed the opportunity to discuss about the adopted method. In general, students used the tool and solution proposal indicated in the pre-lab material, i.e., Discrete Fourier Transform (TDF) or Fast Fourier Transform (FFT), in the mathematical environment of the MatLab® software. In parallel, some students also calculated those values by using the HP 50G calculator (also suggested in the previous laboratory material), to check the results, even if only the phasors were obtained, seemingly complex in a calculator from a small set of 32 samples. Despite using two decimal places, the samples present phasor values very close to the template, accepted by the scholarship holder who monitors the activities.

## 5. Challenges and Opportunities

During the described teaching experience, some challenges and opportunities were identified. One of the challenges is related to the use of mobile devices in the classroom. As an opportunity, there is the use of other computational tools and even a deeper use of DASG.

One of the characteristics observed in the classroom is the intensive use of mobile devices, predominantly smartphones associated with social networks and chat applications, even during the presentation of introductory content in the laboratory lectures. The big challenge is how to deal with this current trend. The students have paid more attention to the more practical parts of the lectures when compared to the theoretical revision.

Currently, students usually bring their own computational equipment as a matter of preference or even familiarity with the chosen analyzing tool. For future lectures, it is intended to employ the available computers in new activities in the classroom. There are proposals for future improvements that need to be validated and put into practice to meet this challenge.

The institution owns about 500 licenses of Matlab® 2015 software<sup>4</sup> to be used on the campuses, which also allows easy access to the tool. USP, through agreements, also has an unlimited number of Maple 18<sup>5</sup> and Mathematica 10<sup>6</sup> licenses. All these tools are an incentive for the use of mathematical software to support classroom activities not restricted to a single vendor. In addition, there are well-known open source options, such as Octave<sup>7</sup> and SciLab<sup>8</sup> for alternative use on personal equipment at zero cost. Finally, MatLab® licenses are available to students in the whole country for about USD 55.00 (Dec/2016)<sup>9</sup>, including at least 10 specific modules of knowledge areas, called toolbox, as well as a software that allows simulations through dynamics assembly of blocks, called Simulink. Several additional modules (optional) are available to students at an estimated cost of USD 6.00 with no restriction.

The DASG used in the laboratory has a module called Power Analysis and Conditioning System (PACS) that allows using the EM/IEC 61000-4-7 standard<sup>10</sup>. This tool brings the opportunity for future work on conformity assessment within the context of PQ.

## 6. Conclusions

The theoretical classes and laboratory expository lectures of SEL 0409 are both taught in the same LAMQEE environment since 2016, providing an integrated learning environment. The lectures, allied to the computational tools available (MatLab®, Maple®, Mathematica® and others), as well as experimental scheme (DASG, bench test and others), optimize the research related to PQ, stimulate, and motivate the students' learning process and introduce them to the academic research environment. The authors of this paper believe that the envisaged opportunities, and those coming with this new hybrid environment (theoretical and laboratory expository lectures), will help students to better retain the knowledge applied and directed to PQ.

Some of the learning opportunities have been identified over the last three years. Some of them have already been put into practice and others are on the list of actions for future work. The following list briefly describes some of these ideas:

a) Considering direct (expository lectures, exercise application, presentation of experiments, etc.) and regular participation (where every semester PAE scholarship or volunteer opportunities are offered) of post-graduation students. It would be recommended to have a feedback mechanism of the students, validating the methodology adopted, strengths and weaknesses of the material developed, the deployment of the student as presenter and

attendance after the lecture;

b) Creation of a set of exercises based on the digitized data collected by DASG that could be part of a set of exercises to be done as homework, using one of the computational mathematical tools mentioned above and chosen by the student;

c) More intensive use of laboratory desktops and/or laptop computers (currently predominant), thereby better distributing the members of the groups to have less students in each group. Thus, students will be more involved in the proposed activities, being able to participate more actively;

d) In smaller classes, it is possible to have direct involvement of students in laboratory tests. Since there are several programmable events, it is reasonable to leave it to the groups to draw a draft of ITIC curve (bottom) of one of the available test loads. An additional evaluation, although not common, is the variation not only of the intensity and duration of the signal, but also of the frequency; and

e) In the exercise lectures, an interpretation of the values under the PRODIST (Procedures for Distribution of Electric Power in the National Electrical System) aspect, module 8<sup>11</sup>, is not required so far. These exercises will be further explored if this type of additional analysis is adopted.

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