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Understanding Power Quality using IoT-based Smart Analyzers and Advanced Software Tools

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Abstract. Power Quality is an important topic for undergraduate electrical engineering students around the world. In addition to the theoretical contents prepared and explained by the lecturer to their students, this matter has an important practical focus. In this paper, a framework for teaching power quality in laboratories using IoT-based smart analyzers and advanced software tools is developed to provide the students the opportunity of studying real data with a high level of detail. In particular, practical lessons have been designed in such a way that the students are trained in the use of well-known commercial smart meters (like the Circutor MYeBOX 1500) or opensource systems (like the openZmeter) to acquire energy and power quality data from real world measurements and to analyze the data collected using advanced software tools (like PowerVision). The results obtained from several courses of electrical and electronic engineering show that the students acquire practical skills that allow them to reinforce their knowledge regarding power quality concepts, including harmonics, and power quality events such as voltage sag/swell, flicker, or waveform distortions. Therefore, this methodology can be applied for teaching power quality in undergraduate and graduate electrical engineering courses.

Key words. Power quality, teaching, learning, smart analyzers, Internet of Things.

1. Introduction

Power quality is an important topic that has been extensively investigated for decades [1]. It can be identified as deviations from nominal values and waveform shapes in the current, voltage or frequency that may cause a failure or malfunction in electrical appliances at the customer level.

The importance of power quality has increased in recent years due to the fact that equipments have become more sensitive to voltage disturbances. Moreover, companies have also become more sensitive to problems derived from power quality issues since they could provoke the loss of production time and, therefore, reduced profit margins. Negative effects caused by damages in the equipment are not the only problem in the power network system, but also interruptions of the supply can affect significantly to the planned operation of electric power facilities.

The growing demand for qualified engineers with advanced knowledge and skills in power quality is pushing teaching methods to project-based learning and practical applications. However, learning about harmonics, sags, dips, flicker and other power quality events [2] require not only theoretical developments but also to design experimental practices in order the students conduct experiments using real or simulated data.

This paper describes how students enrolled in subjects related to power quality can apply their knowledge to practical applications using data collected from real world measurements by using IoT-based smart power analyzers and advanced software tools that allow a detailed analysis of the complete scenario.

2. Teaching and learning power quality

Teaching and learning power quality is an important issue for electrical and electronic engineers. In fact, some studies have highlighted that contents studied in power quality are cross-disciplinary and motivational for the students [3]. A review of the literature shows the importance of this topic not only from the research viewpoint, but also from an educational perspective. Most practical activities related to power quality in undergraduate electrical and electronic courses are focused to the use of Information and Communication

Technologies (ICT). On the one hand, it is very common that lecturers propose activities in which students have to simulate and analyze power quality issues in circuits and power systems, in most cases using MATLAB/Simulink software. For example, MATLAB/Simulink is applied in [4] to simulate transients in linear high-order electrical circuits. Other authors have designed a MATLAB application for monitoring the operation and power quality of electrical machines [5]. In [6] it is proposed the use of MATLAB/Simulink to simulate power quality disturbances in power systems, including three phase faults and switching of large load to simulate voltage sag, removing of large loads from system to simulate voltage swell, three phase nonlinear load to simulate harmonics at the load side, or switching of large capacitor bank to simulate voltage transient at the transmission bus, among others. On the other hand, some studies suggest that virtual laboratories can be a suitable option for learning power quality. This is the case of [7], where it is presented a special LabVIEW based software intended for teaching harmonic filtering that can reduce the level of harmonics injected into the power grid, while LabVIEW is also used in [8] for designing virtual instruments in the study of power quality and deforming regime.

3. Proposal

The proposed educational methodology consists of four main phases: (1) Study of theoretical power quality contents; (2) Training about the installation of power quality analyzers (IoT-based smart analyzers) in real world scenarios; (3) Analysis of data using advanced software tools; (4) Proposing mitigation strategies and corrective actions for harmonics and power quality events. These phases are now described in detail.

A. Study of theoretical power quality contents

The first phase for learning power quality is to study the theoretical concepts, including harmonics and power quality disturbances (events). Table 1 summarizes the main concepts the lecturer should explain in the theoretical lessons, which are often considered in the literature [9,10].

On the one hand, harmonic distortion represents the deviation between the ideal sinusoidal and the present network voltage or load current waveform. Generally speaking, a harmonic is a voltage or current at a multiple of the nominal frequency of the system (also known as fundamental). Figure 1 shows an example of harmonic distortion. Harmonics are often produced by electronic equipment with nonlinear loads such as rectifiers, discharge lighting, or saturated magnetic devices. On the other hand, power quality disturbances can be occurred due to dynamic operations as well as faults. Several power quality events can be usually of a short duration, making them easy to overlook and difficult to diagnose. The students must learn the meaning of these events and the techniques required to identify and classify these disturbances.

B. Training about handling and operation of power quality analyzers

The second step of the proposed methodology is to instruct the students about handling and operation of power quality analyzers in distribution panels. For safety reasons, it is not suitable that the students can manipulate the wires or the switches in the panel, so they will observe how it is done by the lecturer.

Table I. – Main power quality events (adapted from [9]).

Category of disturbance	Type of disturbance		Duration	Range: Min. value	Range: Max. value
Voltage	Average voltage		10 min	0.85 Un	1.1 Un
	Flicker		–	–	7 %
	Sag	Short	10 ms-1s	0.1 U	0.9 U
		Long	1 s- 1 min	0.1 U	0.9 U
		Long-time disturbance	> 1 min	0.1 U	0.9 U
	Under-voltage	Short	< 3 min	0.99 U	
		Long	> 3 min	0.99 U	
	Swell	Temporary Short	10 ms … 1 s	1.1 U	1.5 kV
		Temporary Long	1 s … …1 min	1.1 U	1.5 KV
		Temporary Long- time	> 1 min	1.1 U	1.5 KV
		Over voltage	< 10 ms	1.1 U	6kV
Frequency	Slight deviation		10 s	49.5 Hz	50.5 Hz
	Severe deviation		10 s	47.0 Hz	52.0 Hz
Harmonics	Harmonics			THD > 8 %	

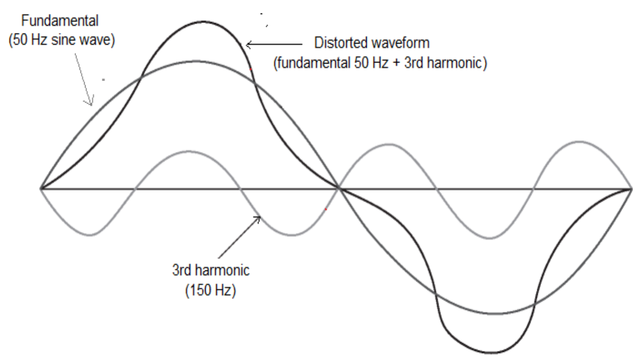

Fig. 1. Example of harmonic distortion.

Alternatively, if the group of students is large, the lecturer can record a video about this installation process in order to explain in practical sessions. Figure 2 shows the elements included in a commercial power quality analyzer from Circutor manufacturer. The model is the MYeBOX 1500 kit (smart meter, 600 V CAT III double-insulated voltage cables/ crocodile clamps, current clamps/Rogowski coils, tablet), while Figure 3 shows an image of the installation of the smart meter in a distribution panel.

Fig. 2. MYeBOX 1500 Kit (Circutor).

Fig. 3. Installation of MYeBOX 1500 in a distribution panel.

Furthermore, the lecturer also provides information about other alternatives to MYeBOX 1500, including commercial and opensource smart analyzers. For example, Figure 4 shows the openZmeter [11], an autonomous open-source system that is used for computation and interpretation of power quality events as well as energy consumption with the advantage that is designed in a solely piece of hardware of small dimensions that can be allocated in any distribution panel for general or individual appliance measurements.

Fig. 4. Open-source device (openZmeter).

C. Analysis of data using advanced software tools

Once the students have understood how the smart analyzers are installed in industrial voltage distribution panels, the data retrieved must be analyzed using specialized software. Considering that this paper describes the use of MYeBOX 1500, the PowerVision v1.8c software [12] will be used. PowerVision is used for remote control and metering of the information recorded in network analyzers, including MYeBOX 1500. This software allows to analyze and visualize data retrieved from the smart meter using any computer, so it allows the user to get the full benefit from MYeBOX 1500 by simplifying the study of network data in an intuitive and interactive manner. In particular, PowerVision allows to visualize and process a large number of energy and power quality variables, as it is listed in Table 2.

The information processed by MYeBOX 1500 must be analyzed using specialized software. With this aim, the PowerVision software will be used. Power Vision is a program specifically designed to operate with network analysers, including MYeBOX 1500. This software allows to analyze and visualized data retrieved from the smart meter using any computer, such that it permits the user to get the full benefit from MYeBOX 1500 by simplifying the study of network data in an intuitive and interactive manner. The students must open (load) the data acquired by MYeBOX 1500 in PowerVision selecting the desired time resolution (e.g., 5 minutes, 15 minutes, 1 day).

D. Proposing mitigation strategies and corrective actions for harmonics and power quality events

At this point, the students have already studied the state of the electrical system and, therefore, have determined the main power quality parameters. Now, they should determine which actions should be undertaken to mitigate and correct the effect of harmonics and power quality events.

The study of harmonics using indicators such as power factor, crest factor or total harmonic distortion (THD) will provide information about the state of the electrical system in order to prevent the negative effects (resonance effects, increased losses, overload of equipment, etc.). With this information the students should be able to propose solutions in order to reduce the negative impact of harmonics, including the use of harmonic filters (active, passive or hybrid) or other basic solutions to mitigate harmonics (group the non-linear loads, locate the non-linear loads upstream in the system, create separate sources, etc.).

It is important to remark that students should not only indicate the steps to be undertaken, but also to incorporate information about the devices that could be installed, including the manufacturers and models.

4. Case of study

The following case of study applies the proposed method to a group of undergraduate students of electrical engineering at the University of Almeria. They must analyse the data obtained by the smart analyzer in a real-world scenario. Specifically, the existing data corresponds to an industrial facility, in which measurements were carried out for about four weeks.

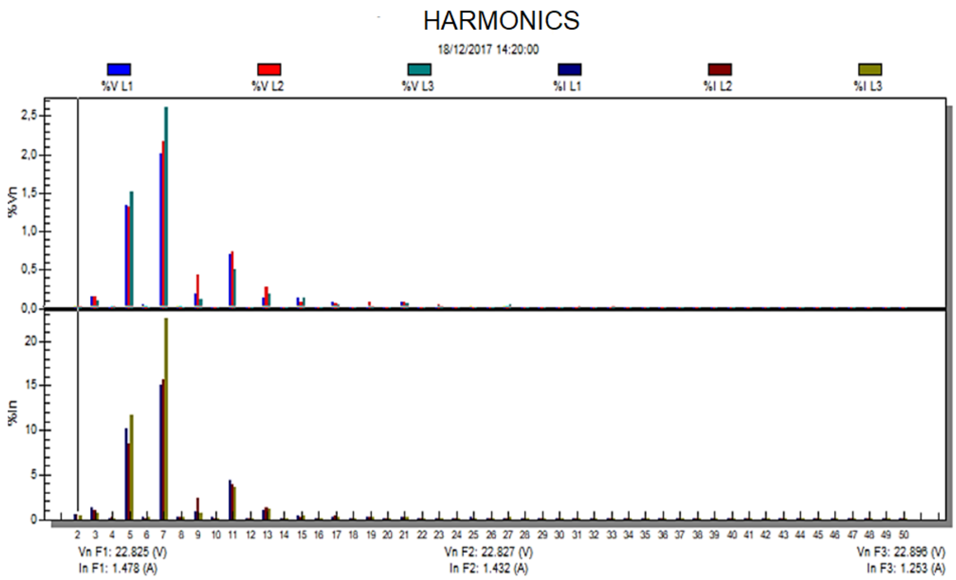

Fig. 5. Voltage and current harmonics for the three phases

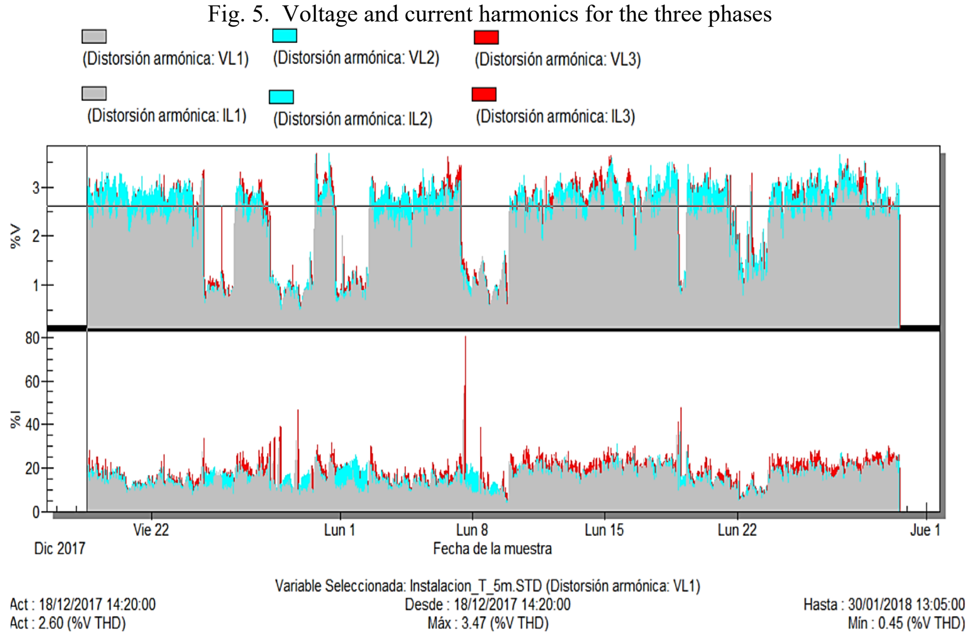

Fig. 6. Harmonic distortion (voltage and current) in the three phases.

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The lecturer first described the system in which the smart analyzer was installed (olive oil mill plant), and the process required to install the smart analyzer in the electric panel of this system. Students were then instructed to download the data recorded by MYeBOX 1500 available in the content area of online content management software of the university (Blackboard Learn) and open it using the PowerVision software. The practice will be carried out in groups of 2 people, although optionally, it can be delivered by individuals. The data to be analyzed is accessible by the students through the virtual classroom platform After this process, the teacher explained the data visualisation format and the different type of analysis that the tool allows, after which the students were asked to develop a set of activities: (i) an analysis of the state of the installation during said period, with special attention to the study of harmonics and other events described in the theoretical contents; (ii) a reflection on the possible causes that could lead to the different events that may have occurred in the system during said period; (iii) a proposal for measures to eliminate or mitigate the problems detected. All of the above, indicating that the lecturer will give priority to the application of theoretical knowledge when carrying out the analysis and establishing proposals for improvement. In what follows, some important issues that are analyzed by the students are described, although there are many other aspects than can be also observed from the analysis of the voltage and current waveforms.

A. Harmonics

The first aspect to be analyzed is the existence of harmonics in the electrical system. Figure 5 shows the harmonics up to order 50. This graph provides valuable information to the students in order to reinforce the theoretical contents. In particular, as they can observe in this graph, the most frequently encountered harmonics in three-phase distribution systems are the odd orders. Further, it is also shown how harmonic amplitudes often decrease as the frequency increases up to the point that above order 50 harmonics are imperceptible and measurements are no longer useless, being more than sufficient to measure harmonics up to order 30.

On the other hand, the students also analyze the harmonic distortion, as Figure 6 shows. From this figure, they can reinforce their theoretical background, since it shows how harmonic distortion is often higher in current than in voltage and different for each phase.

B. Frequency

Other important concept related to power quality is the frequency. The main reason is that equipment in industries, urban cities and residential buildings are designed to operate at 50Hz (in the case of Europe) within a narrow tolerance specified by international regulations such as IEC61000-4-30 or EN50160. In order to keep the frequency of the power supply within limits, the generators in power plants (connected to the high voltage transmission system) are synchronized with each other generator, such that all them tends to rotate at the same angular speed to provide the nominal frequency of 50Hz and to maintain a stable supply. Figure 7 displays the frequency measured by MYeBOX 1500, including a zoom with more detail for one day.

C. Power Quality Events

In addition to the study of the voltage and current harmonics (mainly related to deviation in waveform shape from nominal) and frequency, the students can also verify the existence of power quality events. With this purpose, PowerVision allows to generate the CBEMA/ITIC curves. CBEMA-ITIC is the modified version of the CBEMA power acceptability, that is often used to analyze power quality events. Figure 8 shows the CBEMA/ITIC curve generated by PowerVision from the data collected by MYeBOX 1500 during the measurement period.

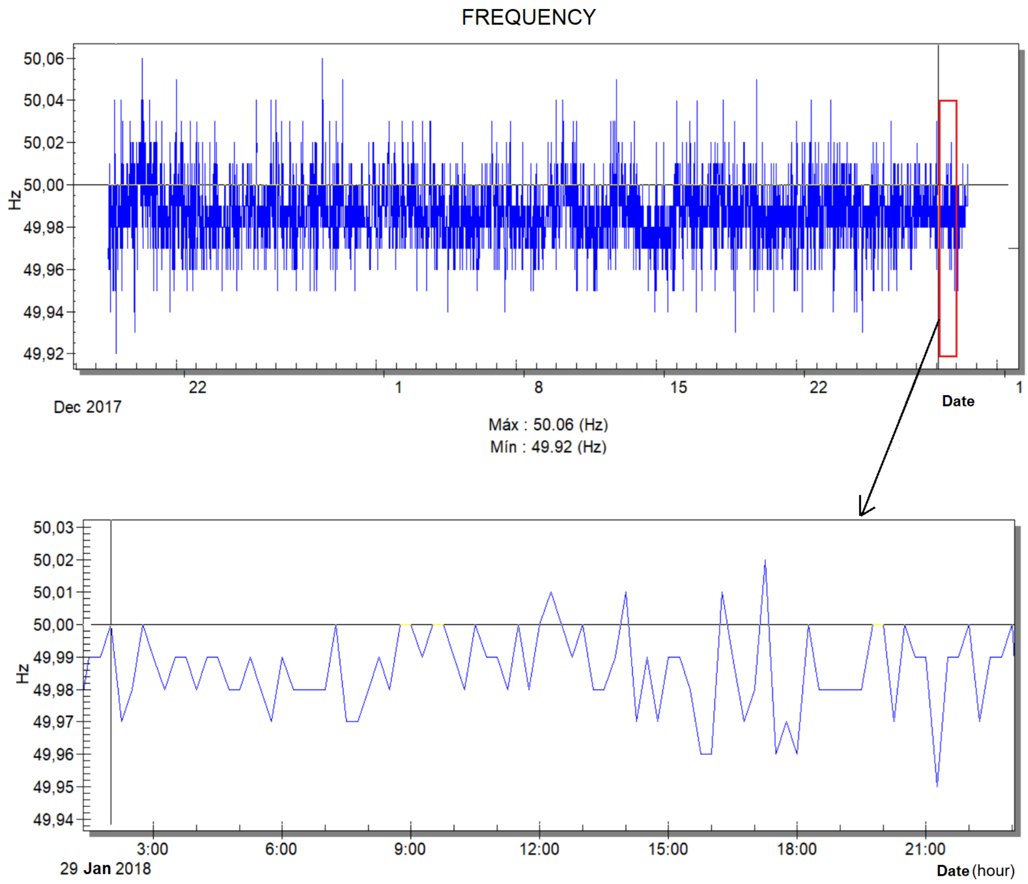

Fig. 7. Frequency measured by MYeBOX 1500 in the real installation (zoom to January 29th, 2018).

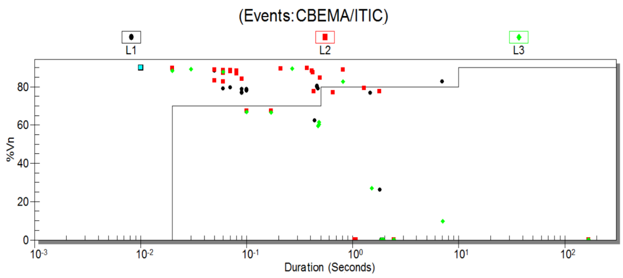

Fig. 8. CBEMA/ITIC curve generated during the measurement period.

This figure allows the students to visualize in a practical way the features of the CBEMA/ITIC curves. In particular, they can observe as the events are represented in a plane where vertical axis is the magnitude of the event and horizontal axis is its time duration. The area located above the line represents the acceptable region, i.e., here it is expected the equipment operate properly. The region below the line represents the prohibited region, where there is risk of damage, overload, or malfunction for the equipment is high.

D. Data sheet about the data analyzed

From the analysis performed in previous steps, the students should create result sheets where they should register the detected events. Table 2 shows a typical template of this sheet.

Table II. – Sheet of results to be filled by the students.

CATEGORY	EVENT	YES	NO
Short duration variation	Sag (dip)		
	Swell		
	Interruption		
Long duration variation	Sustained interruption		
	Under-voltage		
	Over-voltage		
Transients	Impulsive		
	Oscillatory		
Voltage imbalance	Voltage imbalance		
Waveform distortion	Harmonics		
	Notching		
	Noise		

E. Mitigation strategies

As stated in previous sections, in addition to the analysis of power quality measurements, the students should include effective actions to mitigate the power quality problems found in the installation being analyzed. This includes not only the enumeration of these actions, but also they must indicate specific devices to be incorporated to the system. In other words, if the students concluded that harmonic distortion is high, it is expected they indicate that it can be mitigated using filters, including some available models. For example, the students involved in previous courses proposed to reduce harmonic distortion in the system by using different active and passive filters, as those presented in Figure 9.

Fig. 9. (a) Active harmonic filter (model: AccuSine PCS+ manufactured by Schneider) and (b) Passive harmonic filter (model: ECOsine manufactured by Schaffner).

5. Conclusions

This paper presents a framework for teaching-learning power quality by using IoT-based smart power analyzers to collect power quality measurements from real world systems which are later analyzed using advanced software tools. In particular, it is used the commercial smart analyzer MYeBOX 1500 (Circutor) to acquire energy and power quality data from real systems and PowerVision software to analyze the data. However, other smart analyzers such as openZmeter could be used in the same way. The advantage of this approach is that it allows the students to know the procedure to install and acquire data in electrical systems and to understand theoretical concepts by visualising and analyzing the various types of power quality issues often encountered in electrical networks. After applying this methodology in several courses, it can be concluded that students reinforce their theoretical background with practical skills. Furthermore, this proposal can be used not only as teaching strategy for undergraduate students enrolled in electrical and electronic engineering degrees, but also for experienced engineers as a method for lifelong learning. In addition to the use of smart analyzers for educational purposes, the information provided in this paper can be also useful for some researchers interested in acquiring power quality measures in any electrical system. The main limitation of this methodology comes from the fact that undergraduate students are not allowed to manage and operate the smart analyzers in industrial voltage distribution panel due to safety reasons, but this can be compensated if the lecturer provides an accurate explanation about how this process can be performed in a safe way.

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