Embedded Electricity Quality Analyzer

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***Abstract*—Electric installations are traditionally designed for supplying an electric service. The only one associated instrument is the energy meter that is introduced only for measure the total amount of energy that will be charged to the user. However, the exploration of parameters associated with electricity can provide several advantages such the household performance devices, legal issues and later one a more sustainable way to use the electricity energy. This work presents the principle of a low cost energy analyzer that will be part of an electric home installation. Electric parameters are measured and then transmitted via Wi-Fi to a domestic server where all data are stored. This data exploitation can be later one used for several purposes, since electric efficiency to electric charges prediction.**

***Index Terms*—power quality energy, renewable energy sources, electricity energy monitoring**

I. Introduction

Energy is a key issue to development since it is use in many human activities (industry, agriculture, etc.). Traditionally energy systems are based on fossil fuel but its scarcity, uneven distribution, increasing demand and consequently economic constraints (e.g. price) and environmental problems such as Climate Change have led to a shift in energy policies. Increase efficiency and use of RES (Renewable Energy Sources) are main features of today's new energy policies. In modern societies the use of energy is becoming more and more usual, and everyday new electric appliances reach the market contributing to increase the energy demand. On the other hand the development of BRIC (Brazil, Russia, India and China) countries also contribute to aggravated this problem. Many countries around the world including European Union (EU) are trying to implement measures to increase efficiency and share of RES, what will contribute to increase sustainability. Increasing efficiency is a task that involves everyone in the chain from the producers of energy and equipment to distributors and consumers.

Firsts step was done by the efficiency increasing (light bulbs, household appliances, etc.). The second one will be the use of RES. However this last imposes deep changes at paradigm electricity production. In fact the Electric energy production paradigm relies mainly in controllable primary energy sources and is thus viewed as a scarce one. The migration for a different energy paradigm able to accommodate more, and virtually unlimited, amount of electric energy, involves the use of ICT (Information and communications technology) from the production to the end user.

Concepts associated with sustainability include the rational use of electricity that includes the electricity quality and its verification relies on a set of adequate means to verify it. To perform this activity we need an energy parameter monitor but small industrial/domestic electric energy installations were traditionally designed only to supply an electric service and not to quantifying it. The only associated measurement device is the energy meter but is just included to inform the electric service provider about the total energy amount that should be charged and thus not useful to perform any activity related with the electric energy quality analysis.

The use of commercial available solutions is not a feasible solution for large number of industrial or domestic electric installations because it's high price. Some examples of this kind of devices include Alpes Techlologies, Qualitrol and Chauvin Arnoux. Nowadays, one an attractive strategy is taking advantage from the ICT home technologies already installed. In this way, a quality energy analyzer can be shortened to an energy analyzer block and the associated circuitry to transmit data via internet/Wi-Fi.

This work relates the development of a low-cost energy analyzer that justifies their inclusion in the target industrial or domestic electric installation. Although being an equipment with reduced complexity when compared to a conventional energy analyzer, it includes electronic components that reflect the latest advances in the analysis of electrical energy. This low cost equipment have advanced features (e.g. Fast Fourier Transform and Discrete Fourier Transform), which allows for example the detection of harmonics up to the order 63, overvoltage and over-current, voltage spikes and current detecting the mismatch between the phases, among others.

Note that this paper engages a multidisciplinary development, involving concepts on the topics of electricity, electronics and electricity standardization.

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II. Energy Quality Indicators

The electric quality energy involves not only a continuity service but also its quality. The lack of power quality results in many problems such as high electrical costs, production losses, increased cost of maintenance, stops of the production process, equipment failures, among others. Several studies reveal costs related to loss of power quality. In particular, in Europe the costs related to the degradation of power quality can take "1.5% of Gross Domestic Product (GDP)" [1]. In Portugal, studies show significant values related to the occurrence incidents and losses related to the degradation of power quality [2]. They are considering several kinds of incidents such under-voltage, service interruptions and harmonic distortions as the most important type of incidents. Losses resulting from the occurrence of anomalies in electricity quality either the network side or the side of the companies represents annually several million Euros. If this value is added with other costs (e.g. the operator of a distribution network) this number will rise considerably. Besides these figures are high, it is estimated that they will rise quickly if some measures are not taken. This is due to the cumulative effects from the loss of quality may impose, either by reducing the lifespan of devices, limiting the effective capacity of the equipment or malfunction of the machinery.

The electric energy deal involves electricity suppliers and consumers through contractual rules establishing obligations for each of the entities. However, often disagreements appear regarding the quality of service transacted. There are no rare circumstances where consumer claims damages resulting from excessive variability of some parameters of service, such as overvoltage or undervoltage. The traditional way of trying to assess these differences involves the temporary installation of one monitoring equipment for electrical energy that can detect if a parameter exceeds its threshold making use of the monitoring operation by condition (Watch-point) or the operation of monitoring real-time (Real-Time Monitoring) which consists in storing a wide range of values of several parameters. In any case this traditional way of using this means of monitoring the quality of the network has the disadvantage of only being used after the presumed deficiencies in the quality of energy. Being a post monitoring process is not the original disturbance that is measured but others that we can only found to be expected to be relatively similar replicas of the original anomaly. An alternative to overcome the limitation is aimed at keeping always on the analyzer power quality into the installation, but this strategy it is rarely used once the energy analyzers normally have very good features but a very high and unattractive price.

An alternative would be more assertive use of simple equipment, with less potential and precision but with sufficiently low cost to make it attractive to be used as a device that took part of the electric installation. Indeed much of the disputes between distributor and consumer of energy are based on the gross non-fulfillment of obligations contracted by the verification of the parameters requires no equipment with high accuracy requirements.

III. Quality Energy Regulations and Monitoring Model

An international standardization organization uses an open participation through cooperation of all existing national standardization bodies in the world. International standards are technical standards established by an international standards body for use in global scope. Among the main international standards are the ones from IEC (International Electrotechnical Commission), namely the IEC 61000-4-3 and IEC 61000-4-7 standards have a special place in this work.

The set of rules establishing IEC 61000 standards regarding Electromagnetic Compatibility (EMC) including terminology, descriptions of electromagnetic phenomena, testing and measurement techniques and guidelines for installation and mitigation. This set of rules is divided into the following six parts IEC 61000 - xx, as follows [3]:

IEC 61000-1 - x, Generalities.
IEC 61000-2 x- Electromagnetic environment.
IEC 61000-3 x- Limits.
IEC 61000-4 - x, Test and measurement techniques.
IEC 61000-5 - x, Guidelines.
IEC 61000-6 x- Generic standards.
IEC 61000-6 x- Miscellaneous.

IEC 61000-1 standards include general considerations of PQ (Power Quality), terminology, definitions, etc.

The IEC 61000-2 series of standards define the electromagnetic conditions for the installation of equipment and the level of compatibility between the equipment and the environment in which it lies.

In relation to the limits, the set of standards IEC 61000-3 explain the limits of disturbance allowed by equipment connected to the mains and the limits of immunity.

The IEC 61000-4 standards provide a guideline on techniques and methods for performing measurements and evaluation of conformity between the equipment and the environment.

The set of standards IEC 61000-5 provides guidelines for facilities and mitigation of problems that also include suggestions about installing equipment.

Finally, levels of immunity to electromagnetic disturbances that a given equipment should include are provided through a set of IEC 61000-5 standards.

For the preparation of this paper, we highlight the use of IEC 61000-4-30 [4] and IEC 61000-4-7 [5] standards. These, will be addressed below.

The IEC 61000-4-30 standard defines the measurement methods and interpretation of results from the power quality in networks with frequency equal to 50Hz or 60Hz The patterns presented in this standard clarifies methods of measurement and interpretation of some parameters, namely, the amplitude of the power, voltage interruptions, flicker (flickers), voltage dips, transient voltages, voltage imbalances, voltage and current harmonics and inter- harmonics and rapid voltage changes voltage. Also evident in this set of standards are performance classes and measurement, these being:

Performance and measurement class A.
Performance and measurement class B.

The performance class A is used when precise measurements are needed, using specific features such as bandwidth and sampling rate associated with the specified for each parameter uncertainty.

The performance class B is used in statistical surveys, problem solving, and other applications where uncertainty is low and is not required.

For each performance class is a set of factors that must be met. It is the user who selects the equipment class of performance measurement, taking into account the application of the equipment (IEC, 2003).

The IEC 61000-4-7 standard contains information about EMC on technical test and measurement, instrumentation and measurements of harmonics and inters - harmonics in power supply and equipment connected to these systems. It also defines the methods for measuring the spectral components with frequencies above 9kHz, which overlap the fundamental frequency in power systems with frequency equal to 50 Hz and 60 Hz (IEC). This model includes references for measuring instruments to measure individual quantities of equipment, according to the emission limits in certain patterns, as well as instruments to measure current harmonics in power systems.

Patterns for interpretation, for events from the energy supply systems, such inter-harmonic and harmonics are defined by transform Discrete Fourier Transform (DFT). This produces accurate results only for stationary signals and the signals whose amplitude varies with time cannot be described accurately by the harmonic components. The IEC 61000-4-7 standard also clarifies the new model of instrumentation that determines the use of quick algorithm called Fast Fourier Transform (FFT) associated with DFT.

Both IEC 61000-4-30 and IEC 61000-4-7 defines two classes of accuracy and instrumentation, Class I and Class II, allowing the use of simple tools and low cost, in accordance with the requirements the application.

As seen, regulation imposes a set of rules for monitoring some parameters related with the energy quality. The proposed monitoring model is presented in the Fig. 1.

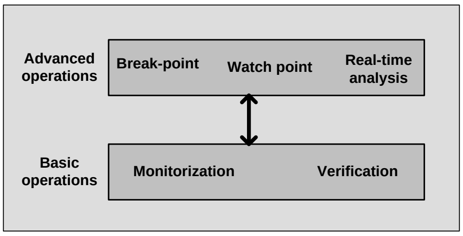

Figure 1. Monitoring model for the electric energy analyzer.

According this model we can divide all operations in two levels that we call Basic Operations and Advanced Operations.

The first is defines only the basic mechanisms for *Monitor* some parameters (e.g. voltage, current or frequency). The *Verification* results from the compassion from the monitor data against a given threshold and using an operations (e.g., Data>A; Data=A, Data inside interval, etc.).

The second group of operation uses the means provided by the first to supply advanced operations such the Watch-point, Breakpoint or Real-time Analysis. The Watch-point is a mechanism that informs another device that a given operation have a valid result (e.g. logic 1). The Break-point operation is similar but is validation has a special significance with potential catastrophic consequence and is used to stop a process. The Real-Time Analysis is used to storage a large amount of data to be used an analyzed later to debug some event. This last advanced of operation have a similar role than a plane black box.

All presented requirements should be taken in consideration during the electronic design. Note that this model can evolve for another one that includes also *control operations* in order to be able to imposing a given state in the electric grid.

IV. Energy Monitoring Design

The principle design for the electric energy analyzer is presented in the Fig. 2.

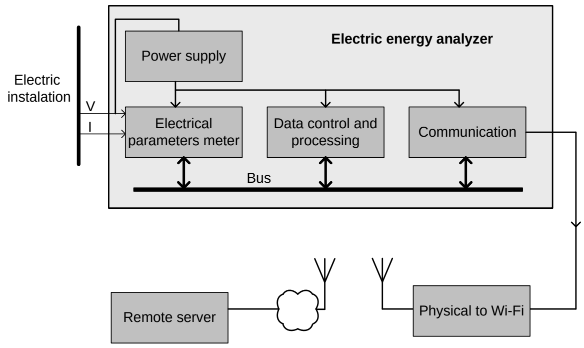

Figure 2. Monitoring model for the electric energy analyzer.

The electric energy analyzer is directly connected to the main electric power supply. The physical direct connections are only the voltage and current. As output the unit has wireless communication Wi-Fi. A remote server is able to receive all data for storage and visualization. The unit includes four internal blocs as follows:

- Power supply
- Electric parameters meter
- Data control and processing
- Communication

Power Supply is responsible for supply the remaining blocks have special features such a back-up battery that allows the unit memorize data for periods of several days in case of power supply interruption. Several types of behaviors can be selected regarding the target installation and the battery life.

The Electrical Parameter Meter is the core of the unit and probably the most critical block. This block is based in an Integrated Circuit (IC) specially oriented to electrical parameters measurements. The studied components that were found eligible included ADE7880- Analog Devices [6], [7] and CS5463 - Cirrus Logic [8] but in the end we selected the first option, the ADE7880. Some of features includes (from manufacturer):

- Highly accurate; supports IEC 62053-21, IEC 62053-22, IEC 62053-23, EN 50470-1, EN 50470-3, ANSI C12.20, and IEEE1459 standards
- Supports IEC 61000-4-7 Class I and Class II accuracy specification
- Compatible with 3-phase, 3- or 4-wire and other 3-phase services
- Supplies RMS, active, reactive and apparent powers, power factor, THD, and harmonic distortion of all harmonics within 2.8kHz pass band on all phases.
- Supplies RMS and harmonic distortions of all harmonics within 2.8kHz pass band on neutral current
- Less than 1% error in harmonic current and voltage RMS, harmonic active and reactive powers over a dynamic range of 2000 to 1 at TA=25 ℃
- Supplies total (fundamental and harmonic) active and apparent energy and fundamental active/reactive energy on each phase and on the overall system
- Less than 0.1% error in active and fundamental reactive energy over a dynamic range of 1000 to 1 at TA=25 ℃
- Less than 0.2% error in active and fundamental reactive energy over a dynamic range of 5000 to 1 at TA=25 ℃
- Less than 0.1% error in voltage and current rms over a dynamic range of 1000 to 1 at TA=25 ℃
- Battery supply input for missing neutral operation
- Wide-supply voltage operation: 2.4V to 3.7V

As seen, this component is, by itself, low cost energy analyzer. The use of ADE7880 analyzer as Electric Energy Analyzer is a very interesting alternative to the use of the conventional equipment. As previously mentioned, this IC has a small cost associated with a set of important potential which makes it a preferred option for the application in question. Note that the ADE7880 includes features that show the most recent advances in the analysis of electrical power, such as the use of FFT and DFT potential, detection of harmonics up to order 63, among others already referred. However, all these possibilities make the IC ADE7880 a relatively high complexity to use.

The Data Control and Processing is realized by the microcontroller (μC) of PIC 18F47J53 - Microchip [9]. This microcontroller has the advantage of using a USB low voltage system, when compared to traditional PIC18 microcontrollers, allowing a high computational performance and a set of available resources at a competitive price. Regarding memory, PIC 18F47J53 presents a 128Kb memory.

The Communication block is performed by the IC ENC424J600, which is designed with an interface Ethernet for μC equipped with a SPI serial interface or parallel port [10]. In order to facilitate its use, the IC is pre-programmed with a unique Media Access Control (MAC) nonvolatile.

At present moment we have developed the necessary means to validate only the Hardware circuit that includes a resident program in the microcontroller and an applet resident in a remote server. Preliminary tests indicate that the developed circuit is validated at Hardware level. Next step will be the development of generic Software to include the developed Electric Energy Analyzer in a generic platform oriented to applications of energy management.

V. Conclusion

Electric energy is an important issue once is obtained from expensive and limited resources. Its use should be done in an efficient and correct manner otherwise we can impose very important restrictions for present and future generations. The traditional way of obtaining valid data from the electric grid consists on the use of commercial analyzers. Its high price imposes its utilization only during short period of time. This strategy does not provide the necessary amount of data to take the adequate management actions.

The present work proposes the use of one Electric Energy Analyzer sufficiently cheep to justify its inclusion permanently in the electric installation. In spite of its expected low price, it has a set of high-quality characteristics comparable to the most expansive Electric Energy Analyzers.

Future work embraces the development of the necessary means to include this device in Electricity Management Platform.

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