IEEE Standard 519-1992 Application in Industrial Power Distribution Networks with a New Monitoring Approach

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Abstract: - This article presents a new concept of application for the IEEE Standard 519-1992 in industrial environments achieved through the spreading of networked remote acquisition systems. This new monitoring approach concept for the IEEE Standard application, inside the industrial power distribution, has the capability to remotely study the propagation of harmonic disturbances, to determine the waveform distortion caused by harmonic sources, to quantify the impact of these disturbances and to elaborate quality indexes reports based on recent harmonics analysis techniques. It is presented experimental results made in a real industrial plant, proving the system viability and value added in this problematic area.

Key-Words: - Harmonic Distortion, Harmonic Analysis, Power Quality, Industrial Plants, Power System Monitoring, Harmonic Standards.

1 Introduction

In the past few years, the power supply network inside the industrial plants, herein called Industrial Power Distributions (IPD), has been perturbed by harmonics pollution, generated by equipments inside the plant installation or resulting from a neighbourhood installation. This problem can present harmful effects, with different consequences depending on the application domain.

The liberalization of the electric energy market, costs reduction policies and the proliferation of sensitive equipment with regard to voltage disturbances (in its majority also source of disturbances) [1] require well defined rules in order to keep the Power Quality (PQ) of the energy supplied to industrial networks. In this context, monitor systems allow the control of normative rates and the study of the best place for the most sensitive and/or disturbing equipment in the facilities [3].

The harmonic distortion of voltage and/or current waveform corresponds to a specific case in the PQ problematic issues. In power networks that have current and voltage harmonic sources (arc furnaces, static power converters, illumination, etc.) exceeding the permissible limits [3-5] there is the need to correct this distortion.

Typically, the standard limits are applied to individual loads. Nevertheless, monitoring all the loads is a strong challenge, from the point of view of the measurement equipment technology and, obviously, of its associated costs. Also, as the distortion levels defined by the norms can be quickly exceed, at some points inside the customer facility, when heavy pollutant loads are present, it can lead to unnecessary worries because the basic functions of these loads are not directly affected.

On the other hand, the existence of high distortion next to specific loads does not necessarily result in out-of-limit distortion in the interconnection between the electrical distribution system and the plant installation [2]. According to this fact, some standards specify that the PQ only needs to be kept under surveillance at the networks interconnection point.

Between these two methodologies – monitoring all the loads or only the networks interconnection point – sometimes there is the need of a different approach. Indeed, for example inside a big manufacturing plant, it is possible to have circuits of the IPD explored by different sub-companies with some of them affecting the others with poor PQ, leading to equipment degradation and misfunction, and also to difficulties to determine the responsibility and the distortion and problems sources. To overcome situations like the aforementioned, it is necessary a global perspective of these problems – including the knowledge of the network structure and of the most problematic or sensible loads – and also a new approach to the standards' application. Therefore, in this paper, we will present a new concept of application for the IEEE Standard 519-1992 in industrial environments achieved through the spreading of networked remote acquisition systems.

This paper is organized as follows. Section 2 presents the relevant standards used in electric energy power distribution. Section 3, introduces the main effect of the electrical energy disturbances in industrial plants. Section 4, describes the new approach monitoring concept for application of those main standards. Section 5, shows experimental results of a cement industry power plant with the application of the IEEE Standard, and finally conclusion remarks are made.

2. Most Relevant Standards

Although distortion problems happen particularly in the final customer, this problematic issue has other implications to be considered: the production, propagation and resolution of this type of disturbances. The harmonics increasing disturbances brought a set of standards (resulting from previous guidelines), recommendations and limits, to assure the compatibility between equipment, devices and power distribution systems [4].

According to the International Standards, the norms 1000 of the International Electrotechnical Commission (IEC) define the current and voltage harmonic levels that must not to be exceeded. The IEC 61000-3-2 Standard foresees limits for the current harmonics components emission in equipment (class grouped) for lesser than 16 A rms (per phase). For equipment with current superior to 16 A, this Standard recommends the application of the IEC 61000-3-4. [4]

Norms IEC-1000-2-2 and IEC-1000-2-4 specify the voltage harmonic levels to be respected at the interconnection point of low voltage distribution network, for public and industrial customers, respectively. [4]

The European Standard EN 50 160:1994 gives the main characteristics of the voltage, including harmonics voltage, in the customer delivery point for low and medium voltage under normal operating conditions. [4]

However, the main reference for this subject is the American Standard that was presented by the IEEE in the recommendation 519-1992: "IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems", initially proposed in 1981 and revised in 1992 [5].

The earlier version, IEEE 519-1981, established levels of acceptable voltage distortion for typical distribution systems. However, with the increase in industrial usage of adjustable speed drives, rectifiers, and other nonlinear loads, it became apparent that a rewrite of the IEEE 519 was necessary, with a specific focus on the relation between harmonic voltages and harmonic currents flowing within industrial plants. IEEE 519-1992, the result of this rewrite effort, sets forth limits for harmonic voltages on the utility transmission and distribution system, as well as for harmonic currents within industrial distribution systems.

This Standard describes the main causing harmonic distortion phenomena, indicates measuring methods and limits of distortion. The approach followed diverse from the IEC's, because it sates that the established limits values should be measured in the Point of Common Coupling (PCC), and not in each individual equipment. Furthermore, it recommends two distinct criteria for harmonics limit values: a) the quantity of harmonic currents, which a customer can set up in the network distribution, has become limited; b) the voltages harmonic distortion level present in the power supplied by the energy deliverer to the customer has been limited. [5]

These limit values are dependant of several variables and concepts – namely the interconnection point PCC, the short circuit current at PCC (I_{SC}), the maximum demand load current at PCC for a period of 15 or 30 minutes (I_L) and the requested total distortion (TDD - Total Demand Distortion) – are based on the maximum demand load current (fundamental frequency component), as well as on a measure of the total harmonic distortion (THD) of the current at the PCC for the total connected load [5]. Obviously, the bigger is the I_{SC} relatively to the current load, the greater will be the permissible current distortions, because they will distort the voltage at the PCC with less intensity. Whenever the voltage level increases the acceptable limits diminish.

For this recommendation, it is of no interest what occurs inside the installation, but what it reflects externally, when the other costumers are hardwired with the same feeding network. However, it relatively defines the guidelines for current harmonic levels and voltage distortions to the transmission lines, distribution and interconnection point with the customers.

3. Harmonic Effects on the Industrial Electrical Power System

The harmonic distortion effect is evident, in the peak values increase (that can lead the insulation system to rupture), in the rms values increase (leads to augment the losses) and in the voltage and current frequency spectrum increase (vibrations and mechanical exhausting) [2] – the current harmonics circulation produces the heating of the transformers, feeding cables, motors, alternators and power factor compensation capacitors.

Also, the cathode devices and illumination systems start to flicker due to the presence of harmonic voltage (consequence of the increase of the harmonics current circulation through the network impedance), and the unexpected start of protection devices, wrong operation in sensitive electronic equipments (computers, command and control equipments, etc.) and errors in the values of the measurement equipment (e.g. electronic industrial balances, hospital equipment, etc.) can occur [3]. The most significant disturbances take place with conducted phenomena, but in specific circumstances, they can also happen with radiated phenomena.

The long term effect cannot be directly related with the explicit form of the waveform distortion presence, because it is a sufficiently dissimulated effect, corresponding overall to a speed up of equipment exhaustion, that can lead to the reduction of its usefulness [3].

Since the symptoms' origin is unknown, it is then necessary to look for potentially generating sources of harmonics in the plant installation. Firstly, the effect will be felt inside the plant before appearing in the electrical distribution network.

The harmonic pollution presents ominous effect for various equipments of the electric installations, even if its consequences are not immediately observable. Therefore, it is a good policy to keep the levels of this distortion within the established band of the main standards and in order to do this it must be implemented corrective options concerning this pollution reduction.

4. Disturbances Analysis in the Industry Sector

Today it is frequently necessary to continuously monitor the power network system's performance in order to characterize possible disturbance impacts and put into practice the main standards [7]. A global and complete system data analysis must be flexible, capable of operating with a large variety of monitoring equipment and keeping a database that can be shared between different applications and be the most adequate to control the normative limits [6]. This concept is illustrated in Fig. 1. The architecture presented depicts a possible PQ integrated monitoring and analysis system organization. This type of system must be flexible enough so it can be adapted to different users' applications necessities.

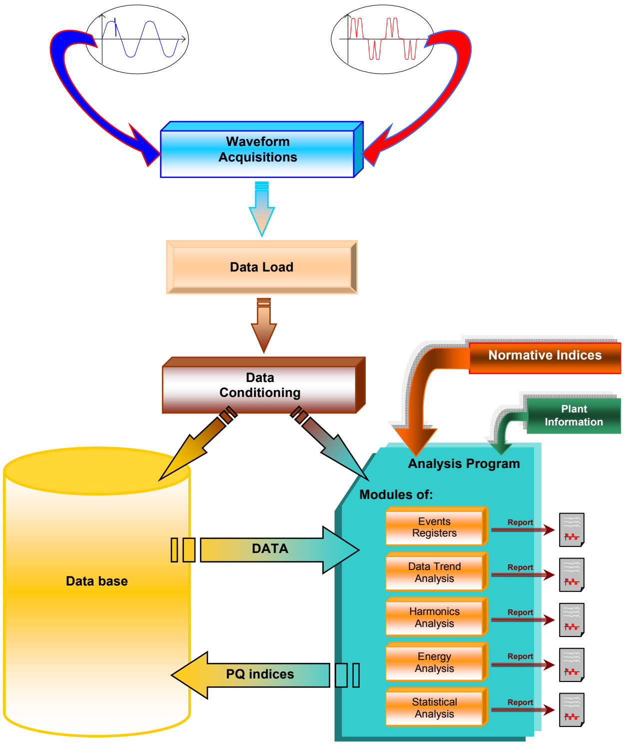

Fig. 1 – Data acquisition system architecture for PQ monitoring and analysis for standards application.

In addition, the system must be able to create automatic reports based on the legal normative limits.

Any PQ monitoring and control system must necessarily include the calculation of algorithms for the power flows and PQ indices. The methods considered in literature are several and a number of researchers have proposed different approaches for the power calculation in electrical network with harmonic distortion. Each of these theories has their individual usefulness, but has also its individual drawbacks. Unfortunately, the different approaches diverge and emphasize distinct qualities that are suited to particular applications, ranging from that of calculating the required capacities of compensating equipment to locating distortion sources in networks. Alternative approaches can be confusing to those in the industry wishing to use it for specifying, designing and service equipment. There is a demand for one method that alone could be capable of satisfying all the practical needs. The approach of the IEEE Working Group on Non-Sinusoidal Situation is the most appropriate to support the implementation control of the IEEE Standard 519-1992, because it is the best approach in terms of practical utility in the search of an optimal compensating topology for an industrial plant [8].

The recent work of this IEEE Working Group, suggests a set of practical definitions, with a simple form to determine the distortion power as a function of the terms: total, fundamental and harmonic constituents [8].

The voltage and current waveforms rms values, V_{RMS} and I_{RMS}, considering the mean value equal to zero, can be separated in two terms, fundamental and other harmonic frequency components, through expressions (1) and (2):

$$V_{RMS}^2 = V_1^2 + V_h^2 \quad \text{with} \quad V_h = \sqrt{\sum_{h=2}^{\infty} V_h^2}\,, \tag{1}$$

and

$$I_{RMS}^2 = I_1^2 + I_h^2 \quad \text{with} \quad I_h = \sqrt{\sum_{h=2}^{\infty} I_h^2}\,. \tag{2}$$

Then:

$$S^2 = (V_1 I_1)^2 + (V_1 I_h)^2 + (V_h I_1)^2 + (V_h I_h)^2, \tag{3}$$

or regrouping:

$$S^2 = S_1^{\,2} + S_N^{\,2}, \tag{4}$$

where S_1 is Fundamental Apparent Power and S_N Non-fundamental Apparent Power, being these given by:

$$S_1^{\,2} = (V_1 I_1)^2 = V_1 I_1 \cos(\theta_1 - \delta_1)^2 + \\ + V_1 I_1 sin(\theta_1 - \delta_1)^2 = P_1^2 + Q_1^2, \tag{5}$$

and

$$S_N^{\,2} = (V_1 I_h)^2 + (V_h I_1)^2 + (V_h I_h)^2 = P_N^2 + Q_N^2\,. \tag{6}$$

In (6), the term $(V_1 I_h)$ is called the Current Distortion Power, $(V_h I_1)$ the Voltage Distortion Power and $(V_h I_h)$ the Harmonic Apparent Power being divided in: Total Harmonic Active Power, P_h, and Total Harmonic Non-active Power, Q_h, as exemplified by (7):

$$S_h^{\,2} = (V_h I_h)^2 = P_h^2 + Q_h^2\,. \tag{7}$$

One other expression can be achieved, when (6) is divided by (5):

$$\left(\frac{S_N}{S_1}\right)^2 = \left(\frac{I_h}{I_1}\right)^2 + \left(\frac{V_h}{V_1}\right)^2 + \left(\frac{S_H}{S_1}\right)^2, \tag{8}$$

origin of the Normalized Non-fundamental Distortion Power, when it is rewritten on the form:

$$\left(\frac{S_N}{S_1}\right)^2 = (THD_i)^2 + (THD_v)^2 + (THD_v \cdot THD_i)^2\,. \tag{9}$$

The three terms of (9) appropriately represent the current THD, the voltage THD and the product of the previous two.

The application of the IEEE Working Group method results in useful information, classified as fundamental apparent power (S_1) and fundamental reactive power (Q_1); this one indicates the value of the correction capacitors for the fundamental power factor, to be used in the passive filters configuration. The non-fundamental apparent power (S_N) and the non-fundamental reactive power (Q_N), provide indications of the required capacity for the dynamic compensator for the non-fundamental distortion, when used alone. The term $(V_1 I_h)$ indicates the level of the current distortion, and the term $(V_h I_1)$ presents the same information relatively to the voltage. On the other hand, the THD's taxes can be taken from these power values [8]. Such values are extremely important for the good application of this IEEE Standard since any monitoring system must have a correct evaluation of the PQ implemented in industrial environment.

To increase the interest concerning the area of PQ prevention by the application of normative rules with the presented methodology, a small dimensions modular system is proposed in [3]. This modular system, depicted in Fig. 2, is focused on three-phase power networked systems study. Its main characteristics are: current and voltage precision transducers (±3% in a bandwidth of 20 kHz); synchronous acquisition of all signals in real time, by user request or by pooling on every 15 minutes, in 5 periods packages, with 40 µs sampling rate, corresponding to 2500 points on a 100 ms time space, with a ultra fast microcontroller; Ethernet remote access and large local data storage capacity based on an IPC@CHIP SC12 (BECK IPC GmbH); low cost system modules. These systems allow an easy dissemination in IPD and a short investment recovery time. The modular architecture system was developed in order to be easily expanded within the industry, depending on its necessities. [3]

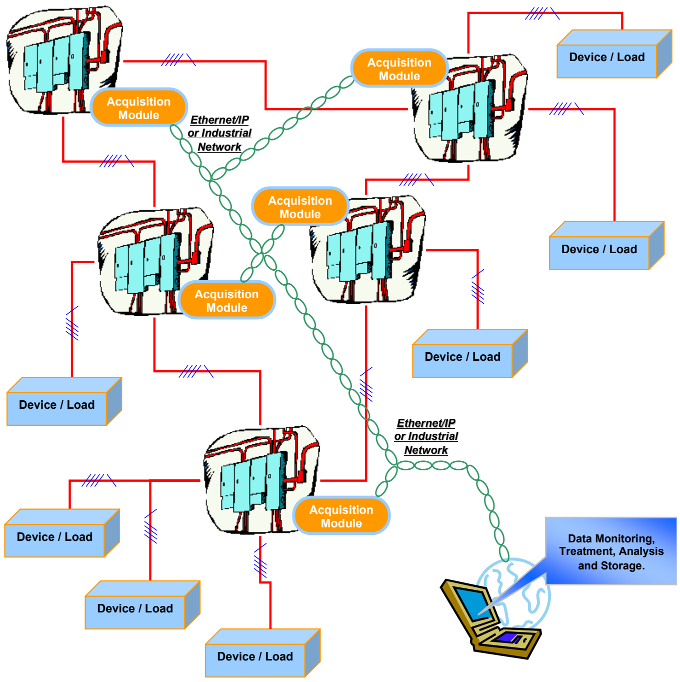

Fig. 2 – Remote acquisition system implementation in industrial power distributions.

Taking this into account, many acquisition systems can be used, specially in primary and secondary of power transformer(s), in PCC(s) and next to critical or special machines, susceptible to produce distortion or that need more rigorous feeding conditions.

5. IEEE Standard Application in a Cement Industry – Case Study

The application domain of the analysis and monitoring integrated system presented is extremely vast. At this point, it is presented its use in the IPD of a cement production centre (CIMPOR Cement Industry, S.A.), in order to perform a waveform disturbance analysis. This production unit has a huge power plant and possesses a complex electrical installation. Although the limits imposed by the power supplier and by the IEEE Standard were both respected at the PCC, there were malfunction problems in critical equipments of the production line 3 cooling system (Fig. 3). It was then decided to monitor this production line. This installation is made up of three step-down transformers (T1, T2, T3), whose primary is fed by a distribution industrial link (6 kV). T1 secondary supplies the Motor Control Center 1 (MCC_1). T2 supplies the MCC_2 and T3 is a double secondary transformer that supplies the MCC_3 frequency converter.

The MCC_1 essentially supplies fans powered by induction motors controlled by Variable Frequency Drives (VFD). There are six 75 kW fans, two of 132 kW and two of 160 kW. It also supplies low power induction motors and a local cabinet.

The MCC_2, supplies twelve VFD of 37 kW each (that control the induction motors of the cooling system fans), oil pumps, sleeve filter extractors and compressors (also powered by induction motors).

The two MCCs also have power factor compensation.

The MCC_3 frequency converter is made up by a twelve pulses rectifier (two six pulses) and corresponding inverter for supplying the induction motor (785 kW) of the drawing fan.

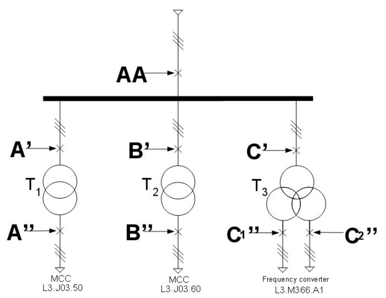

Fig. 3 – Production line 3 cooling system schema.

5.1 Analysis Results

For study and analysis purposes, the collected results (Fig. 4) regarding the new approach system monitoring [3] are confronted by the reference standards IEEE Std. 519-1992 [4, 5].

From a global point of view, disturbance levels presented in the medium-voltage link (6 kV) are not adjusted for this sort of system distribution. There are voltage and current harmonic disturbance values above the maximum suggested for the IEEE Standard. The current harmonic disturbance value is high, mainly in the 250 Hz and 350 Hz frequency amplitudes. However, in the AA interconnection point the current sum provides a harmonic level slightly below the IEEE Standard reference for this power class.

Voltage harmonic distortion levels above normal values are present in point A" and B" in Fig. 3. This disturbance caused malfunctioning on more sensitive equipment connected to these network points. The most critical current component frequency values presented were for 250 Hz and 350 Hz. The audit results suggested then the use of solutions that minimize the 5^{th} and 7^{th} order harmonic current. Consequently it was proposed a solution based on passive filters, that taking into account the installation type and it's functioning, was the most appropriate.

The interaction between the voltage distortion and the current harmonic amplitudes can be observed, because T1 secondary with 63.4% load level presents greater voltage distortion than T2 secondary with 15% load level, although T1 and T2 are identical transformers.

In the specific case of the T3 secondary, it is important to mention that, although the rectifiers absorbed current harmonic levels are above standard boundaries, working in such conditions is not

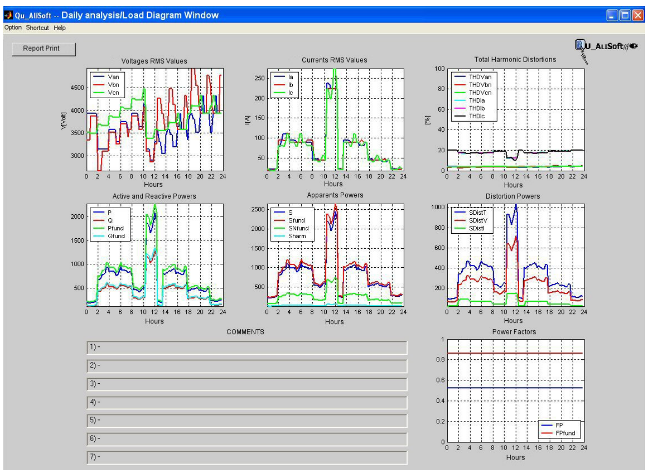

Fig. 4 – Daily analysis/Load Diagram window for the IEEE 519-1992 Standard.

problematic, because the load is made up by only one equipment. Furthermore, it is verified that voltage distortion values for both secondaries of T3 transformer are above the suggested standard limits.

The power factor presented in the IPD production line 3 has a compatible value with the requested for the energy distribution company, corresponding to an efficient use of the IPD energy (see Fig. 4).

6. Conclusion

The most effective way to meet harmonic distortion limits is to filter the harmonics at each individual load. But if it is attempted to monitor and enforce the PQ limits at each individual load, the most common available technology is incapable of doing the work and very high-cost equipment will be needed.

On the other hand, distortions produced by drives located inside the customer facility, normally will not affect the drive's functions, and high distortion at particular points does not necessarily result in out-of-limit distortion at the PCC. The IEEE Std. 519-1992 recommends values of harmonic distortion for the electric power system (not for individual loads), focusing on the PCC with the consumer-utility interface.

However, between those two approaches, sometimes there is the need to monitor and enforce the PQ in some areas inside plant installations. It was presented the case of a big plant, where there are parts of the IPD explored by different sub-companies and with some of them affecting the others with poor PQ, causing malfunctions on critical equipments. In this case, it was decided to implement the guidelines of IEEE Std. 519-1992 not only at the PCC but at carefully chosen “internal PCCs” inside the plant. For this objective, it was developed and used by the authors [3] a low cost monitoring system that detected and quantified harmonic pollution problems in the analysed circuits. Based on the analysis results, corrective measures were suggested.

It should also be mentioned that the remote use of the monitoring system, through the internal power plant computer network, as well as the implementation of the system without disturbing labouring on the manufacture unit, was very appreciated by maintenance people and plant administration.

To conclude, the proposed approach and the used integrated system proved large viability in industrial environment, in low and medium-voltage, for a good control of the rates of normative limit values.

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