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Comparative Study Between International Standards on the Parameters of Harmonic Currents in Residential Electrical Installations

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Abstract: The secondary electrical distribution system requires an improvement in electricity supply. Among the determining factors for the perfect functioning of the electrical system are disturbances resulting from equipment or devices connected to it. These disturbances occur due to eventual losses due to reactive energy and harmonic distortions present in the installation. Thus, this research aims to present disturbances of harmonic currents in the residential electrical system and to compare how different international standards (IEEE 519, IEC 610003-2, EN 50160 and module 8 of PRODIST/Brazil) apply harmonic control in residential electrical installations. Applying the comparative study of the different patterns, it was possible to generate a specific analysis on the effects of harmonic distortions. Thus, it was possible to conclude that it is necessary to mitigate the effects of harmonics in the distribution system and that each country adopts different parameters to mitigate this effect.
Keywords: Efficiency; Electrical system; Harmonic Distortions.

I. INTRODUCTION

Since the first alternating current generator started operating more than 100 years ago, electrical systems have become harmonics. The harmonics at the time were minor and had no harmful effects. The quality of electrical energy is related to anomalies in voltage, current or frequency that result in operational failures of the equipment[1].

When a sinusoidal voltage is applied to a given type of load, the current consumed by the load is proportional to the voltage and impedance following the contour of the voltage waveform. These loads are referred to as linear loads (loads where the voltage and current follow each other without any distortion of their pure sine waves). The existence of harmonics in an installation does not present a high risk. The main issue is the interaction with the electrical distribution system, triggering distortions and voltage losses[2].

Harmonics cause additional losses (Joule effect) in conductors and equipment in the distribution networks and within the consumer's installations. They also reduce the life expectancy of equipment such as transformers, motors and electronic circuits, cause conductors to overload and disturbing circuit breakers to trip. These issues affect the electricity distribution system and can result in the failure of the electrical system, reducing its reliability and efficiency.

The problem is the increased demand for the use of non-linear load equipment contributes to this. In this way, the harmonics will always be increasing. Nowadays almost all electrical charges, with the exception of incandescent lamps or a resistive heating charge, result in the appearance of harmonics. The existence of harmonic currents may require a greater power factor and, consequently, increase costs. In addition, utilities increasingly tend to charge customers for the main sources of harmonics.

Total harmonic distortion (THD) is the ratio of all harmonics present to the fundamental frequency. A significant increase in total harmonic distortion under variable load conditions, guarantees to know the effects created by each harmonic current and to compare them with the identified symptoms. Voltage disturbances and the creation of harmonic currents are the main factors in which they corroborate energy quality problems[3]. The THD is inversely proportional to the power factor. If a given load has a higher power factor, its THD factor is lower and the system is more efficient.

With the increasing technological evolution, there is a disposition for the appearance of adversities that are related to the efficiency of residential electrical distribution systems as well as the best performance and useful life. Considering the current scenario, residential consumers were encouraged to engage in actions that seek efficiency in a simple way, but which can result in a significant reduction in the consumption of their homes.

Among the main measures, the efficiency in the lighting system stands out. In view of the innovations in lighting systems, it is possible to highlight some negative points pertaining to energy quality due to the use of low-efficiency electronic devices. The massive use of electronic equipment in the energy system has led to an increase in awareness about the quality of energy in recent years[4].

The technical advantages transmitted by electronic power equipment have made them pass through all sectors of the power supply system. However, an adverse effect of electronic power equipment is that it achieves its intended function at the expense of generating harmonics that cause voltage and current distortions[4].

The damaging effects of harmonic voltages and currents on power system equipment often go unnoticed until a real failure occurs. Harmonic currents can cause conductors to overheat, dielectric failure or capacitor rupture, false operation of circuit breakers and also lead to excessive overheating of transformers[1].

Preliminary research reveals that non-linear loads such as fluorescent lighting, variable frequency inverters, switching power supplies and uninterruptible power supplies are the main sources of harmonics in an electrical distribution system[3]. Because of these factors, it is necessary to regulate and control loads that compromise the safety and efficiency of the residential electrical system.

The currents from personal computer power supplies can generate 3rd order harmonics and reach 87% of the fundamental current and represent a 70% increase in the phase's nominal current. This increase in current can overheat the conductors and compromise the safety and reliability of the system. Therefore, it is necessary to resize the section of the neutral conductors, taking into account the excessive current[5].

The International Electrotechnical Commission (IEC) is an international organization for the standardization of electrical, electronic and related technologies. Some of its standards are developed in conjunction with the International Organization for Standardization (ISO). IEC's headquarters, founded in 1906, is located in Geneva, Switzerland. Another example is the Institute of Electrical and Electronics Engineers (IEEE), which is a professional non-profit organization, founded in the United States. There is also the European Standards (EN) prepared by members of the European Committee for Standardization (CEN).

Several countries make use of technical standards and recommendations as a guideline. In the United States, for example, the standards IEEE 519[6] (International standard usually used in the USA), EN 50160[7] (international standard that regulates concessionaires, adopted by the European Union) and IEC 61000-3-2[8] (international standard that limits harmonics inserted in the distribution) are used. In Brazil, module 8 of PRODIST[9] (Electricity Distribution Procedures in the National Electric System) of the National Electric Energy Agency (ANEEL) serves as a parameter for the control of generated harmonics. Therefore, in order to minimize the impact of harmonics on the electrical network and to guarantee the quality of the energy supply, some countries have established standards for harmonic limits according to the actual situation of the electrical system.

Given the above, there is a need to control the presence of harmonic distortions in residential electrical installations. Each country currently has specific standards, but the comparison between standards may favor the adjustment of a standard seeking more security and savings in homes. Thus, this research aims to compare the parameters of THD between the international standards IEEE 519[6], EN 50160[7] and IEC 61000-3-2[8] and module 8 of PRODIST[9] regarding the methodology used in the characterization and quantification of harmonic currents in the distribution network, generated by residential consumers.

II. METHODOLOGY

In order to carry out the research, the values from the IEEE 519[6], EN 50160[7], IEC 61000-3-2[8] and module 8 of PRODIST[9] were extracted. The values referring to the levels of THD, currents and their limits were evaluated according to the specific methodology adopted by each standard. The IEEE 519[6] and EN 50160[7] use harmonic order as a reference, whereas IEC 61000-3-2[8] considers power and type of equipment, while module 8 of PRODIST[9] classifies according to voltage levels.

These particularities of the standards were considered due to the analytical syllogism that each standard considers. Mitigating measures such as filters and conductor sizing had their characteristics and performance evaluated.

The limits of THD of the IEEE 519[6], EN 50160[7] and module 8 of PRODIST[9] were evaluated and compared with each other taking into account their application purpose. The IEC 61000-3-2[8] standard was assessed individually due to its methodology that is applied directly to the equipment.

The formulation of the results was obtained through the analysis from the comparative values, verifying and correlating the levels of THD or current distortion between the standards. In addition, infrastructure solutions such as the adoption of filters.

III. RESULTS AND DISCUSSION

The two main standards adopted worldwide, sometimes with local adaptations, are IEEE 519[6] and EN 50160[7]. The EN 50160[7] describes a wide range of power quality measurements, including voltage drops, increases, interruptions, imbalances and oscillations.

IEEE 519[6]

The IEEE 519[6] focuses only on harmonics, providing guidance for acceptable levels and discussing voltage and current distortions, with emphasis on the load current. Electric utilities are responsible for controlling individual and total voltage harmonic distortions, while consumers are responsible for controlling the injection of THD harmonic currents into the power grid.

EN 50160[7]

The EN 50160[7] specifies voltage characteristics at the customer's supply terminals or in public high and low voltage electricity distribution systems under normal operating conditions. In other words, EN 50160[7] is restricted to the voltage characteristics in the distribution and does not specify the power quality requirements in the supply system or at the customer's installations.

The harmonic voltage limits of EN 50160[7] are given as a percentage of the fundamental voltage. The limits apply to systems supplied at low voltage and high voltage levels, that is, from 230 V nominal to 35 kV. The average voltage is between 1 and 35 kV. The THD of the supply voltage, including all harmonics of order 40, must not exceed 8%.

IEC 61000-3-2[8]

The IEC 61000-3-2[8] deals with the limitation of harmonic currents injected into the public supply system. The IEC 61000-3-2[8] is applicable to electrical and electronic equipment with a rated input current of up to 16 A per phase. This standard aims to limit the harmonic emissions of equipment connected to the public low voltage network, so that compliance with the limits ensures that the voltage in the public network meets the limits.

Module 8 of PRODIST[9]

In Brazil, the module 8 of PRODIST[9] is applied. Among the quantities and parameters used in the inspection allusive to harmonics, the most used is THD. However, ANEEL investigates the parameters of harmonic distortion through the values of individual harmonic distortion of voltage and total harmonic distortion of voltage.

Comparison of standards

In North America, alternating current (AC) electrical energy is generated and distributed in the form of a sinusoidal voltage wave with a fundamental frequency of 60 cycles/sec or 60 Hz. In Europe the frequency used is 50 Hz, which concomitantly it is used by some countries in South America such as Paraguay, Bolivia, Argentina and Chile[10].

In the context of electrical energy distribution, harmonics are voltage and current waveforms superimposed on the fundamental, with frequencies multiple of the fundamental. These higher frequencies distort the intended ideal sine wave into a periodic, but very different, waveform.

The most common equipment has power less than or equal to 600W. They are class D, we have computers, monitors and television equipment. Table no 1 shows the current limits of IEC 61000-3-2.

Table no 1: Current limits of IEC 61000-3-2[8].

Numeric harmonic order (n)	Maximum harmonic current allowed per watt (mA/W)	Maximum harmonic current (A)
3	3.4	2.30
5	1.9	1.14
7	1.0	0.77
9	0.5	0.40
11	0.35	0.33
13<=n<=39 (only odd harmonics)	3.85/n	See table for class A

In Europe, EN 50160[7] specifies the quality of energy that utilities need to meet. The distortion must be less than 5% at 95% of the time and cannot exceed 8% at any time. Other regions of the world also have formal laws that govern power quality or generally accept current specifications (such as IEEE 519[6] in the USA). Therefore, as distortion can be present all the time, electrical equipment must be able to handle these conditions.

The IEEE-519[6] is a recommendation, so it is not a standard, created by IEEE. It exposes the main phenomena causing harmonic distortion, suggests measurement methods and distortion limits. Their point of view is different from the IEC approach, related to the point where the measurement needs to be performed. The philosophy is that the system is not concerned with what happens inside an installation, but what it conjectures to the outside, that is, for other consumers connected to the same distribution system.

There are guidelines on acceptable levels of harmonic distortion: total harmonic distortion (THD) and total demand distortion (TDD). The THD is generally considered in relation to voltage distortion (although it can also be applied to current). The TDD applies distortion in relation to current at peak load consumption, usually performed in an interval of 15 to 30 minutes.

Table no 2 shows the limit values for electrical systems that operate below 1,000 V for EN 50160[7] and up to 69 kV for IEEE 519[6] and are measured at the common coupling point.

Table no 2: Acceptable levels of distortion adopted by IEEE 519[6] and EN 50160[7].

Parameter	IEEE 519[6] (THD)	EN 50160[7] (THD)
Total Voltage Harmonic Distortion	8%	8%
3rd order harmonic	5%	5%
5th order harmonic	5%	6%
7th order harmonic	5%	5%
9th order harmonic	5%	1,5%
11th order harmonic	5%	3,5%

The THD levels compared between IEEE 519[6] and EN 50160[7] were of an odd order and remained close to their values, with an emphasis on EM 50160, which deals more rigorously with harmonics greater than nine.

The current distortion limits mentioned in IEEE 519[6] are a little more complicated. In this case, the prospective short-circuit current (Isc) is considered together with the load current (IL). The two values are considered as a ratio (Isc/IL). This provides parameters about the impedance of the electrical source and its ability to handle harmonics. The higher the Isc value compared to IL, the less likely the circuit is to be affected by the presence of harmonics as shown in Table no 3.

Table no 3: Maximum harmonic distortion of the current as a percentage of IL by IEEE 519[6].

Isc/IL	3<=h<11	11<=h<17	TDD
<20	4.0	2.0	5.0
20<50	7.0	3.5	8.0
50<100	10.0	4.5	12.0
100<1000	12.0	5.5	15.0
>1000	15.0	7.0	20.0

In addition, EN 50160[7] and IEEE 519[6] suggest that measurements be made at the common coupling point. This measurement point is usually the point at which the utility has its revenue meter connected. This agreed connection becomes the reference point for the utility, as the utility is more concerned with harmonics in its network than with harmonics in the users' network. Table no 4 shows the comparison in voltage and THD levels of IEE519[6] in relation to module 8 of PRODIST[9].

Table no 4: THD comparison of IEEE 519[6] and module 8 of PRODIST[9].

Voltage	THD (IEEE 519[6])	THD (module 8 of PRODIST[9])
V<=1,0 KV	8.0%	10%
1 kv <V<= 69 KV	5.0%	6%
69 KV <V<= 161KV	2.5%	3%
161 KV<V	1.5%	3%

It being emphasized that IEEE 519[6], is quite comprehensive. It describes notes for techniques recommended to individual users and utilities. Finally, it recommends methodologies for analyzing future harmonic sources. Due to the extent of this issue, only a few main points are emphasized, such as the limit of harmonic currents for the user and the limits of general harmonic voltages for the distribution system (concessionaires).

The harmonic levels recommended in IEEE 519[6] and EN 50160[7] provide a good guide for users when considering whether the harmonics in their facilities may be causing a power quality problem. If the levels are below the recommended levels, it is safe to assume that harmonics are not a problem. The module 8 of PRODIST[9] delimits the harmonics according to voltage levels, while IEC 60001-3-2[8] considers the type of equipment and its respective power, making the analysis thorough and not verifying the installation in a macro way.

The examination of the energy quality of the installation can be carried out by conducting an energy quality audit. In addition, it is necessary to pay attention to the level of voltage distortion in the concessionaire's feeders to ensure that they do not exceed the established limits, in order to have the desired efficiency and safety.

Although each set of limits is different, there is clearly some agreement on the approximate magnitude of the recommended limit value. If higher levels are measured, the next step should be to find out which loads are creating the harmonics. Once established, the feasibility of installing a harmonic filter must be considered.

The harmonic data collected during measurement will be the first point of reference when consulting a filter supplier. Harmonic filtering of individual loads is usually the most economical solution.

The adoption of filters and technological solutions in the installations, thus, makes this study justified, as it will bring possible benefits for the concessionaire and for the final consumers, with a better quality energy and high equipment efficiency. In cases where measures taken in the infrastructure and equipment are insufficient, it is necessary to provide the installation with filtration systems.

IV. CONCLUSION

By addressing current harmonic distortion at individual sources, problems in the electrical system can be avoided. The harmonic current limits established in the standards are proposed with the intention of minimizing the impact on the design of existing equipment.

The EN 50160[7] standard is widely used by some European countries. It is aimed at the power system of a grid user in public low and medium voltage electricity distribution systems under normal operating conditions and ends up highlighting the effects on a global scale. The module 8 of PRODIST[9] quantifies and qualifies harmonics due to voltage values.

Through the analysis of the IEEE 519[6] and IEC 61000-3-2[8], it was possible to note the particularities of approaches of the respective standards. In the case of IEC 61000-3-2[8], the harmonic current limitation parameters are defined for each equipment. The objective of IEEE 519[6] is to analyze the loads at the feeder input, that is, the amount of harmonic components present in the installation is not taken into account. The distribution system of IEEE 519[6] is more comprehensive because it considers voltage levels, degree of harmonic distortion and TDD, so it could serve as a mirror for other standards. On the other hand, it could take into account the amount of harmonic components present in the installation like IEC 61000-3-2[8].

Thus, when improving the criteria of different international standards through adaptations of other standards, there would be a better dimensioning of the electrical system, avoiding an under-dimensioning that can compromise the safety of the system, which may cause overload of conductors and the incidence of failure in the devices of protection.

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