ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research

Vol. 12, Issue, 03, pp. 54754-54770, March, 2022

https://doi.org/10.37118/ijdr.24153.03.2022

RESEARCH ARTICLE

OPEN ACCESS

PASSIVE FILTER DESIGN APPLIED TO INDUSTRIAL INSTALLATIONS

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ARTICLE INFO

Article History:
Received 14th January, 2022
Received in revised form
23rd January, 2022
Accepted 17th February, 2022
Published online 28th March, 2022

Key Words:

Capacitive-Harmonic Filter, Transients, Distortions, RLC, THDV, THDI.

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ABSTRACT

Due to a need to search for a new form and improvement in electric power quality, we can cite the best performance of capacitive filter installations, in order to remove from the electrical system the harmonics, transients, distortions among others, thus avoiding the burning of equipment, machines, lamps. This system in addition to protect system, provide energy saving due to the RLC system, in parallel acting together, removing all evils from the power grid and diverting to ground. The results show the efficiency of the application for the good economic performance of the companies.

Citation: ***Worlen Ferreira Gimack, Jandecy Cabral Leite, Ítalo Rodrigo Soares Silva and Ricardo Silva Parente***. "Passive filter design applied to industrial installations*", International Journal of Development Research*, 12, (03), 54754-54770.

INTRODUCTION

Power system harmonics is a subject of continuous research nowadays, when it comes to electric power quality (EQ). This research aims to present the application of state-of-the-art technology and advances in passive filters in an industrial network. It is a subject of interest to many power system professionals involved in harmonic analysis and mitigation and the applications in the modern climate when nonlinear loads on utility systems are increasing. Modern electrical systems contain a large amount of contaminant sources or producers of harmonics where nonlinear loads employed in industries, commercial and residential facilities stand out fundamentally (1). Research provides comprehensive coverage of harmonic generation, effects, and control. New harmonic mitigation technologies, detailed step-by-step passive filter design, interharmonics and flicker are covered. The intent of the research is that it will serve as a reference and practical guide on application of passive filters to combat harmonic impacts.For professionals it should be able to form a clear basis for understanding the subject of harmonics, and an advanced student/specialist interest should be simulated to explore further. A first reading of the dissertation is followed by a detailed critical reading is suggested, the references used in the text, examples and real world graphics pursue this goal and provide a clear understanding. The effects of harmonics can be experienced at a distance, and the effect on power system components is a dynamic and evolving field. These interactions have been analyzed in terms of current thinking (2). Protection relaying has been called "an art and science". The author will not hesitate to call passive harmonic filter designs and mitigation technologies the same. This is so because a lot of subjectivity is involved. Leaving aside high tech research tools such as simulations of various computational tools like Monte Carlo, Genetic Algorithms (NSGA II and III), Fuzzy Logic, Simulated Annealing, Ant Colony, Artificial Neural Networks among others are able to resolve an understanding to the experts for decision making. This research does not target these available computational mathematical models, but only the application of passive filter design in industrial electrical systems (2)(3). The techniques invariably require iterative studies to meet several conflicting objectives. The nature of harmonics, modeling of power system components, and filter characteristics, before attempting a practical filter design for real-world applications, is devoted to practical harmonic passive filter designs in a Manaus Industrial Pole (PIM) industry. The present research is justified by the need to overcome some limitations of the methods developed in the referenced bibliographies among which can be mentioned:

- A variety of approaches are shown on the objectives to be achieved with the installation of passive filters in the PIM industry, but with the aim of maximizing the economic benefits produced by these filters;
- They focus on determining the design parameters of particular filter types, whose configuration is selected prior to optimization, and never consider the optimization of the very selection of the filter type to be used;
- In many cases, the application is performed for a given load condition, which is opposed to the essentially variable nature of the load, and;
- Many authors analyze only a single scenario of grid operation, so that the results may not be adequate for another scenario with variations in the short-circuit level, and in filter parameters, for example.

From this point of view, taking into account the high rate of economic growth of the PIM, the introduction of new electronic and telecommunications technologies has been observed in the automation processes of the industries, in the same way that the presence of loads increases, which, due to their non-linear characteristics, directly affects the QEE indexes in these installations. The need to maintain a high power factor together with the maintenance of the EQ parameters is an issue from the point of view of energy efficiency that impacts the profitability rates of industries. The applications of the results obtained in this dissertation, without a doubt, constitute a contribution for the improvement of the installed electrical system.

LITERATURE REVIEW

Power Quality and Standards: In this chapter we will discuss electric power quality (EQ) and national and international technical standards that establish the quality limits that the electric system must meet to provide good electrical service to consumers (4)(5). Currently the electrical system has been experiencing an increase in its generation, transmission and distribution capacity(6). The advances in technology that have occurred in the last decades have propitiated the achievement of great developments in the area of electronics, the increase in the use of non-linear loads by residential, commercial and industrial consumers, has required from the power utilities an increasing concern regarding the quality of electric power in the power electrical systems (7). Such loads known as "Non-linear" or "Special Electrical Loads" cause voltage and/or current distortions in the electrical networks (8). National and international standards defined for the control of voltage waveform distortion (THDV) and current (THDI), are recommended by standards where we highlight: the (9-11)(3). In Brazil, ANEEL has the (13).

General Power Quality Concepts: Electric power quality is the condition of the electrical signal voltage and current that allows electrical equipment, processes, facilities, and systems to operate satisfactorily without performance and life impairment (14)(15). The expression is used to describe the electrical power that drives an electrical load, making it operate correctly. Without an adequate power supply of a certain quality standard, the load may operate inadequately or incorrectly, fail prematurely, or simply not work at all (16)(17). Electric utilities and power end users are becoming increasingly concerned about power quality. The term power quality has become one of the power industry's most prolific buzzwords since the late 1980s. It is a generic concept for a multitude of different types of power system disturbances. The issues that fall under this subject are not necessarily new. What is new, is that engineers are now trying to deal with these issues using a system approach, rather than dealing with them as individual problems (18). In (18), defines power quality as any problem manifested in the deviation of current, voltage, or frequency that results in faults or failures in the operation of customer equipment. There cannot be completely different definitions for power quality depending on one of reference framework. For example, a utility may define power quality with reliability and demonstrating statistics that its system is 99.98 percent reliable. Criteria set by regulatory agencies are usually along these lines. The load equipment manufacturer may define power quality as the characteristics of the power supply that allow the equipment to function properly. These characteristics can be very different for different criteria (19)(20).

Harmonic Distortions: Harmonics are sinusoidal currents or voltages of multiple frequencies (of integers) of the frequency that the system is designed to operate (21). Harmonic components, combined with the fundamental voltage or current, produce changes in the waveform. Harmonic distortion exists due to nonlinear characteristics of devices and loads in the electrical system. Voltage distortion results from the voltage drop caused by current (injected by a nonlinear load) passing through the system impedance (22). It is important to note that harmonic distortion is a phenomenon that should be treated as being permanent regime. The waveform distortion, caused by the harmonic components, must be present, continuously, for at least a few seconds (23). According to (18), with the presence of harmonics in the electrical systems, they no longer operate in sinusoidal conditions, therefore the simplifications made by engineers in the analyses for the fundamental frequency are no longer applicable. The presence of harmonics in an electrical system causes distortions in the voltage and current waveform, since they are added to the fundamental component. Besides that, harmonics are generated by equipment's or loads that present non-linear characteristics between voltage and current (24). For (9), the following terms and definitions apply. The third harmonic (component): A component of order greater than one of the Fourier series of a periodic quantity. For example, in a 60 Hz system, the 3rd. order harmonic, also known as the "third harmonic," is 180 Hz (25).

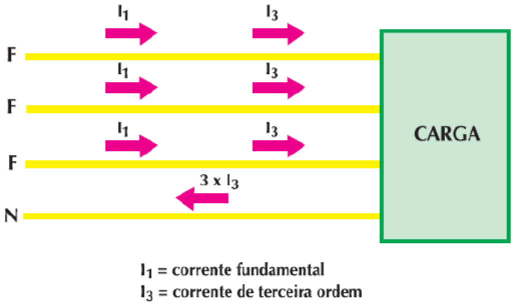
Frequency Order and Sequence of Harmonics: Harmonic signals are classified as to their order, frequency, and sequence according to Table 1 below. In the case of balanced three-phase electrical systems, when the decomposition of a distorted voltage or current waveform, the harmonic orders arising from this decomposition in terms of symmetrical components. In an ideal situation, where only a 60 Hz frequency signal existed, only the harmonic of order 1, called fundamental, would exist (21)(22). In Table 1 below, we will see two types of harmonics: odd and even. The odd ones are found in electrical installations in general, and the even harmonics exist in cases of signal asymmetries due to the presence of continuous components. The sequence can be positive, negative or null (zero). Taking as an example a three-phase asynchronous motor fed by four conductors (3F+ N), the positive sequence harmonics would tend to make the motor turn in the same direction as the fundamental component, thus provoking an over current in its windings, which would cause a temperature increase, reducing the useful life and allowing the occurrence of motor damage. These positive sequence harmonics usually cause unwanted heating in conductors, motors, transformers, etc. (26).

Table 1. Order, frequency and sequence of harmonics

Order	Frequency (Hz)	Sequence
1	60	+
2	120	-
3	180	0
4	240	+
5	300	-
6	360	0
n	*n*.60	-

Source: (26)

In significantly unbalanced systems, each harmonic can be broken down into the three symmetrical components, i.e. positive sequence, negative sequence, and zero sequence. The negative sequence harmonics would cause the motor to rotate in the opposite direction to the rotation produced by the fundamental, thus braking the motor and also causing unwanted heating. In turn, the zero sequence harmonics, zero or also known as homopolar, do not cause effects in the direction of rotation of the motor, but algebraically sum the currents in the neutral conductor, this implies that situations can occur in which the neutral conductor can circulate a third order current that is three times greater than the third order current that travels through each phase conductor. With this, excessive heating of the neutral conductor, destruction of capacitor banks, etc. occur. (26). The nature and intensity of the harmonics generated by non-linear loads depend on each load specifically, but three aspects should be considered general: - It is a continuous phenomenon, that is, of long duration; - Due to the similar behavior in the positive semicycle and negative semicycle of almost all loads, the odd order harmonics are more frequent and with higher intensity and, therefore, are usually the troublemakers; - The higher the order or frequency of the harmonic the lower its intensity. Known the values of harmonic voltages or currents present in the system, quantitative procedures are used to express the influence of the harmonic content in a waveform (27)(28). The nature and intensity of the harmonics generated by non-linear loads depend on each load specifically, but three aspects must be considered general: It is a continuous phenomenon, that is, of long duration; Due to the similar behavior in the positive semicycle and negative semicycle of almost all loads, the odd order harmonics are more frequent and with higher intensity and, therefore, are usually the cause of problems; The higher the order or frequency of the harmonic, the lower its intensity.Once the values of harmonic voltages or currents present in the system are known, quantitative procedures are used to express the influence of the harmonic content in a waveform. One of the most used is the "Total Harmonic Distortion", which can be used for both voltage and current signals (26).



Source: (26).

Figure 1. Zero-sequence harmonic

Normally, when the analysis of voltage and/or current harmonic components is performed on power electronic systems, the extraction of harmonic frequencies above the 63rd order is not taken into consideration, because the equipment would require higher accuracy, which would come with a high cost associated with the inference equipment (18).

Non-linear loads: A non-linear load is one that, when fed with a sinusoidal voltage, absorbs a non-sinusoidal current, that is, the non-linear load has the characteristic to deform the waveform of the absorbed current. In this definition it is implicit that it is a permanent sinusoidal regime, so it is said that a linear load is one where there is a proportionality between voltage and current through an impedance Z which affects the amplitude and phase of the current maintaining the sinusoidal waveform; the same does not happen with nonlinear loads that deform the waveform and therefore are also called deforming loads (29)(30). Nonlinear loads cause distorted currents even when fed by a source with a non-distorted (sinusoidal) voltage. If a distorted voltage is applied to a linear load, the waveform of the current in the load will be distorted like the voltage. However, if a non-linear load is fed by a non-sinusoidal voltage, the waveform of the correte will be distorted because of the distorted voltage and the non-linearity of the load (31). In any such cases, the relationship between voltage and current is not constant (32). Harmonic generating devices are present in all industrial, tertiary and domestic sectors. Harmonics are the effect of non-linear loads. A load is said to be non-linear when the current it draws does not have the same shape as the voltage that feeds it. Typically, loads using power electronics are nonlinear (33). Examples of nonlinear loads: computers, bridge rectifiers, variable speed drives, arc furnaces, fluorescent lighting (34-37). These are loads in which the current flowing through it is not directly proportional to the voltage supplied. Therefore, any load that requests a non-sinusoidal current from a sinusoidal voltage is non-linear (38)(39).

Power Quality Standards: The concern with the quality of electric power supplied to consumers was born along with the first commercial experiences related to the generation, transmission and distribution of energy, in the nineteenth century. As early as 1934, Brazilian legislation established, in its Water Code, the first control indicators for this quality (40). It is due in part to the reformulation that the electrical sector has been experiencing, to enable the implementation of a consumer market, in which the marketed product becomes the electrical energy itself (41). Power quality standards comprise a set of regulations that establish the quality limits that the electrical system must meet in order to provide good electrical service to consumers. International standards and recommendations are also used as a reference for the evaluation of power quality. They are:

Most common IEEE standards used in Power Quality:

- *IEEE 446 - Emergency and Standby Power*
- *IEEE 519 – Harmonic Control*
- *IEEE 1001 - Interface with Dispersed Generation*
- *IEEE 1100 - Power and Grounding Electronics*
- *IEEE 1159 - Monitoring Power Quality*
- *IEEE 1250 - Service to Critical Loads*
- *IEEE 1346 - System Compatibility in Industrial Environments*
- *IEEE 1366 - Electric Utility Reliability Indices*

Most common IEC standards used in Power Quality:

- *IEC 61000-2-2 - General guide on harmonics and interharmonics measurements and instrumentation for power supply systems and equipment connected thereto*

- *IEC 61000-2-4 - Compatibilitylevels in industrial plants low frequency conducted disturbances*
- *IEC 61000-4-7 - Compatibility levels for low-frequency conducted disturbances and signaling public low-voltage power supply systems*
- *IEC 61000-4-11 – Voltage dips/interruptions/variation immunity*
- *IEC 61000-4-14 – Voltage fluctuation immunity*
- *IEC 61000-4-13 - Harmonics/interharmonics immunity*
- *IEC 61000-4-15 - Flickermeter*
- *IEC 61000-4-16 - Test for immunity to conducted common mode disturbances in the frequency range 0 Hz to150 kHz*
- *IEC 61000-4-17 - Ripple on d.c. input power port, immunity test*
- *IEC 61000-4-27 - Unbalance, immunitytest*
- *IEC 61000-4-28 - Variation of power frequency, immunity test*
- *IEC 61000-4-29 - Voltage dips, short interruptions and voltage variations on D.C. input power port, immunity tests*
- *IEC 61000-4-30 - Power quality measurements methods*

In Brazil, Agência Nacional de Energia Elétrica (National Electrical Power Agency (ANEEL), an autarchy under a special regime linked to the Ministry of Mines and Energy, was created to regulate the Brazilian electrical sector, through Law 9.427/1996 and Decree 2.335/1997. The (13), are documents elaborated by ANEEL and normatize and standardize the technical activities related to the operation and performance of the electrical energy distribution systems. The (13) current version is effective as of 01/01/2022. 13) establish the procedures related to Electric Energy Quality (QEE), addressing the quality of the product and the quality of the service. For the product quality, this module defines the terminology and indicators, characterizes the phenomena, establishes the limits or reference values, the measurement methodology, the management of complaints regarding voltage compliance in permanent regime and voltage waveform disturbances, and the specific studies of electric power quality for the purpose of access to distribution systems.

IEC 61000-3-6 Electromagnetic Compatibility Standard: *The International Electrotechnical Commission (IEC) 61000* series comprises a comprehensive set of power quality regulations. In particular, IEC 61000-3-6 (IEC/TR, 61000-3-6, 2008) sets harmonic emission limits for installations connected to power electrical systems. For theelectricalvoltagethis standard defines:

The Total Harmonic Voltage Distortion (%THDV). Calculated as the ratio between the rms voltage of the considered upper harmonics and the fundamental voltage (V1), presented in (1) (3).

$$\%THDV = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} 100 \tag{1}$$

The Individual Harmonic Distortion of voltage of order h (%IHDV$_h$). Calculated as the ratio of the voltage of an individual harmonic (Vh) to the fundamental voltage according to (2) (3).

$$\%IHDV_h = \frac{V_h}{V_1} 100 \tag{2}$$

The standard reference establishes two types of limits: (1) compatibility levels as shown in Table 2 and Table 3 present the planning levels, as presented in Table 3. When harmonic emissions from non-linear loads do not exceed the established compatibility levels, good power quality is assured. On the other hand, the planning levels (more restrictive than the compatibility levels) are followed as guides for system planning and they ensure compliance with the compatibility levels (10).

Table 2. Compatibility levels for individual harmonic voltages in low (LV) and medium voltage (MV) networks

Odd-numbered non-multiple of 3		Odd multiplesof 3		Pairs	
HarmonicOrder h	HarmonicVoltage %	HarmonicOrder h	HarmonicVoltage %	HarmonicOrder h	HarmonicVoltage%
5	6	3	2	2	2
7	5	9	1.5	4	1
11	3.5	15	0.4	6	0.5
13	3	21	0.3	8	0.5
17 ≤ h ≤ 49	2.27(17/h) - 0.27	21 ≤ h ≤ 45	0.2	10 ≤ h ≤ 50	0.25(10/h) + 0.25

Source: (3)(10).

Voltage harmonic limits are established to avoid the harmful effects of harmonics on a permanent and short term basis which are defined as:

- Permanent regime effects are fundamentally related to thermal effects in capacitors, cables, transformers, motors and others, and are measured on average at 10-minute intervals.
- Short term effects that manifest themselves in electronic equipment sensitive to harmonic levels, having as interval of interest for registration the range of 3 seconds or less.

The THDV compatibility level for medium and low voltage is 8% for permanent regime harmonics (10 minutes intervals) and 11% for short duration harmonics (intervals shorter than 3 seconds). The compatibility limits in Table 2 and planning limits in Table 3 for individual harmonic voltages are valid for stationary harmonics. These limits must be modified by the factor Khvs to be used with short duration harmonics according to (3) (3).

$$K_{hvs} = 1.3 + 0.7\,\frac{h-5}{45} \tag{3}$$

The referred standard does not establish explicit limits for the distortion of the current at the PCC, however, it contemplates the possibility of converting the distortion limits for the voltage into distortion limits for the current by using the impedance at harmonic frequencies of the external power system.

IEEE Standard 519-2014 IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems

The standard (9), which has undergone changes and is currently called IEEE 519-2014. It is a widely adopted document for controlling harmonics at the point of electrical coupling between industry and the utility. The philosophy of this standard is not to be concerned with what occurs inside the facility, but rather with what the facility can inject into the grid and therefore reach other consumers (9). The referred standard proposes a responsibility sharing for the maintenance of harmonics in the PAC, where consumers should ensure that harmonic currents are limited and the utilities, in turn, ensure the limits of voltage harmonics. This recommendation proposes the evaluation of harmonics in PAC, because then, one can determine how a consumer affects both the utility and another consumer connected to the same feeder (9).

Table 3. Planning levels for individual harmonic voltages in average networks

Odd-numbered non-multiple of 3			Odd multiplesof 3			Pairs		
Harmonic Order h	Harmonic Voltage %		Harmonic Order h	Harmonic Voltage %		Harmonic Order h	Harmonic Voltage %	
	MT	AT-EHT		MT	AT-EHT		MT	AT-EHT
5	5	2	3	4	2	2	1.8.	1.4
7	4	2	9	1.2	1	4	1	0.8
11	3	1.5	15	0.3	0.3	6	0.5	0.4
13	2.5	1.5	21	0.2	0.2	8	0.5	0.4
17≤h≤49	1.9(17/h)-0.2	1.2(17/h)	21≤h≤45	0.2	0.2	0.25≤10/h≤50	0.25(10/h)+0.22	0.19(10/h)+0.16

Source: (10).

In PAC, system owners or operators should limit line-to-neutral voltage harmonics as follows (9):

- 99th percentile daily period, very short time values (3s) should be less than 1.5 times the values given in Table 4 (9).
- 95th percentile, weekly percentile values (10 min) should be less than the values given in Table 4 (9).

All values should be in percent of the rated power frequency voltage at the PAC. Table 4 applies to voltage harmonics whose frequencies are integer multiples of the power frequency (9). All values should be in percent of the rated power frequency voltage in the PAC. Table 4 applies to voltage harmonics whose frequencies are integer multiples of the power frequency (9).

Table 4. Voltagedistortionlimits

Bus Voltage V at PCC	Individual Harmonic (%)	Total Harmonic Distortion THD (%)
V ≤ 1.0 kV	5.0	8.0
1 kV < V ≤ 69 kV	3.0	5.0
69 kV < V ≤ 161kV	1.5	2.5
161 kV < V	1.0	1.5[a]

Source (3)(9).

High voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

Table 5. Current distortion limits for 120 V to 69 KV systems

Maximum harmonic current distortion in percent I_L						
Individual harmonic order (odd harmonics) [a, b]						
*I*sc/*I*L	3≤ *h* <11	11≤ *h* < 17	17≤ *h* < 23	23 ≤ *h* < 35	35≤ *h* ≤50	TDD
< 20[C]	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

Source: (3)(9).

- Harmonics are limited to 25% of the odd harmonic limits above.
- Current distortions that result in a dc shift, e.g., half-wave converters, are not allowed.
- All power generation equipment is limited to these current distortion values, regardless of the actual Isc/IL.

Where:

Isc = maximum short-circuit current in the PAC
IL = maximum demand load current (fundamental frequency component) in the PAC under normal load operating conditions.

Table 6. Current distortion limits for systems rated above 69 kV.

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics) [a, b]						
*I*sc/*I*L	3≤ *h* <11	11≤ *h* < 17	17≤ *h* < 23	23 ≤ *h* < 35	35≤ *h* ≤50	TDD
< 20[C]	2.0	1.0	0.75	0.3	0.15	2.5
20 < 50	3.5	1.75	1.25	0.5	0.25	4.0
50 < 100	5.0	2.25	2.0	0.75	0.35	6.0
100 < 1000	6.0	2.75	2.5	1.0	0.5	7.5
> 1000	7.5	3.5	3.0	1.25	0.7	10.0

Source: (3)(9).

- Even harmonics are limited to 25% of the odd harmonic limits above.
- Current distortions that result in a dc shift, e.g., half-wave converters, are not allowed.
- All power generation equipment is limited to these current distortion values, regardless of actual Isc/IL.

Where
Isc = maximum short-circuit current in the PAC.

IL = maximum demand load current (fundamental frequency component) in the PAC under normal load operating conditions.

Table 7. Current distortion limits for rated systems > 161 Kv

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics) [a, b]						
*I*sc/*I*L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
$< 25^C$	1.0	0.5	0.38	0.15	0.1	1.5
25 < 50	2.0	1.0	0.75	0.3	0.15	2.5
≥ 50	3.0	1.5	1.15	0.45	0.22	3.75

Source: (9).

- Harmonics are limited to 25% of the odd harmonic limits above.
- Current distortions that result in a dc shift, e.g., half-wave converters, are not allowed.
- All power generation equipment is limited to these current distortion values, regardless of the actual Isc / IL.

Where

Isc = maximum short-circuit current in the PAC
IL = maximum demand load current (fundamental frequency component) in the PAC under normal load operating conditions

ANEEL Standard - Procedures for the Distribution of Electric Energy in the National Electric System - PRODIST - Module 8

Module 8 addresses both service and product quality, in this paper we are interested in product quality. For product quality, this module defines the terminology and indicators, characterizes the phenomena, establishes the limits or reference values, the measurement methodology, the management of complaints regarding voltage compliance in permanent regime and voltage waveform disturbances, and the specific power quality studies for the purpose of access to distribution systems (13). The electric power quality procedures defined in this module must be observed by (13):

(a) Consumers with installations connected in any distribution voltage class; (b) generating plants; (c) distributors; (d) agents importing or exporting electric power; (e) transmitters holding DemaisInstalações de Transmissão - DIT; (f) National Electric System Operator - NOS. Os (13) defines the terminologies, characterizes the phenomena, and establishes the indicators and limits or reference values concerning permanent regime voltage compliance and voltage waveform disturbances. It addresses the following permanent regime product quality phenomena: i. permanent regime voltage; ii. Power factor; iii. Harmonics; iv. Voltage unbalance; v. voltage fluctuation; vi. frequency variation. There are many other relevant factors besides the Product Quality defined and standardized through (13), but the aspect that will be treated with more relevance in the current work will be the harmonic distortions, which will serve us as the main analysis variables in the decision making process. Harmonic distortions are phenomena associated with deformations in the waveforms of voltages and currents in relation to the sine wave of the fundamental frequency (13). Table 8 presents the terminologies applicable to the calculation of harmonic distortions.

Table 8. Terminology

Magnitude Identification	Symbol
Individual voltage harmonic distortion of order h	$DIT_h\%$
Total harmonicdistortion	DTT%
Total harmonic voltage distortion for even-numbered components not multiple of 3	DTTP%
Total harmonic distortion for odd-numbered non-multiple-3 components	DTTi%
Total harmonic voltage distortion for multiples of 3	$DTT_3\%$
Voltageharmonicorder h	V_h
Harmonicorder	h
Maximumharmonicorder	hmáx
Minimumharmonicorder	hmin
Measured fundamental voltage	V_1
DTT% indicator value exceeded in only 5% of the 1008 valid readings	DTT95%
DTTP% indicator value exceeded in only 5% of 1008 valid readings	$DTT_p95\%$
DTTI% indicator value exceeded for only 5% of the 1008 valid readings	$DTT_i95\%$
DTT3% indicator value exceeded for only 5% of the 1008 valid readings	$DTT_395\%$

Source (13).

Table 9. Expressions for the calculation of the magnitudes $DIT_h\%$, DTT%, DTTp%, DTTi% and DTT 3% Are

Where: h = individual harmonicorder.	$DIT_h\% = \frac{V_h}{V_1} X100$
Where: h = all harmonic orders from 2 to hmax. hmax = according to class A or S.	$DTT\% = \frac{\sqrt{\sum_{h=2}^{h_{máx}} V_h^2}}{V_1} X100$
where: h = all even harmonic orders, not multiple of 3 (h = 2, 4, 8, 10, 14, 16, 20, 22, 26,28, 32, 34, 38, ...). hp = maximum even harmonic order, not multiple of 3.	$DTT_p\% = \frac{\sqrt{\sum_{h=2}^{h_p} V_h^2}}{V_1} X100$
where: h = all odd harmonic orders, not multiple of 3 (h = 5, 7, 11, 13, 17, 19, 23, 25, 29, 31, 35, 37,...). hi = maximum odd harmonic order, not multiple of 3.	$DTT_1\% = \frac{\sqrt{\sum_{h=5}^{Pet} V_h^2}}{V_1} X100$
where: h = all harmonic orders multiple of 3 (h = 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36,39,...). h3 = maximum harmonic order multiple of 3.	$DTT_3\% = \frac{\sqrt{\sum_{h=3}^{h3} V_h^2}}{V_1} X100$

Source: (42)(43).

Table 10. The limits for the total harmonic distortions

Indicator	Ratedvoltage		
	Vn ≤ 1,0 kV	1,0 kV <Vn< 69 kV	69 kV <Vn< 230 kV
DTT95%	10,0 %	8,0 %	5,0 %
DTT$_P$95%	2,5 %	2,0 %	1,0 %
DTT$_I$95%	7,5 %	6,0 %	4,0 %
DTT$_3$95%	6,5 %	5,0 %	3,0 %

Source: (13).

The limits correspond to the maximum desirable value to be observed in the distribution system. In case of measurements made using TPs with V-type or open delta connection, the allowed limits for the DTT$_3$ 95% indicator shall correspond to 50% of the respective values indicated in Table 8. The Basic Grid accessors must follow what is determined in the Network Procedures or in specific regulations.

MATERIALS AND METHODS

Company Profile: For ethical reasons the company under study will be called KDW Engineering. The industry is aimed at the manufacturing of electronic equipment, digital devices, telecommunications and television signal retransmission areas, civil construction, and real estate investments. Relying on a modern industrial park, state-of-the-art equipment, and skilled professionals, company A provides superior quality services, outsourcing the production of circuit boards to large companies in the Manaus Industrial Pole. Industry A is a local company that offers effective and cost competitive solutions in Contract Manufacturing (CM) in various technology segments such as audio and video products, computers, telecommunications, and others. We manufacture the following equipment: barebones, cell phones, desktop, notebooks, receivers, motherboard.

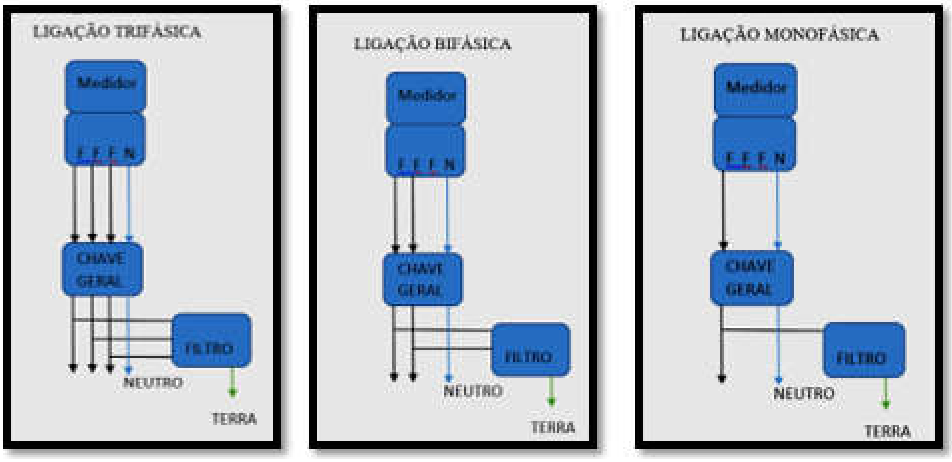
Quality Policy: The management of KDW Engineering industry, in compliance with requirements of the standard, NBR ISO 9001: 2015 are committed to maintain continuous improvement of its QMS (Quality Management System), which means a set of interconnected elements, integrated into the organization, which works as a gear to meet the Quality Policy and the company's objectives, making visible in the products and services and meeting customer expectations, through service in:

- Ensuring excellence in customer service through rigorous quality control in our processes, products and services;
- b) Meeting the requirements of our customers, legal and other associates;
- c) Manage the risks and opportunities that may impact the organization.

Promote the engagement of all employees, contributing to an excellent result.

Data survey: This research presents a study of the electric power quality diagnosis of the company KDW DA AMAZÔNIA. The requirements for electric power quality analyzed were: Voltage Harmonic Distortions (DHTv), Power Factor, Reactive Power in Permanent Regime, Active Power in Permanent Regime, Voltage Analysis in Permanent Regime and Current Analysis in Permanent Regime.

Measurement Campaign: The data was obtained from measurement campaigns conducted at the substation of the company KDW DA AMAZÔNIA in the month of December 2017. At the 13.8 kV substation, the modules of the 3rd, 5th, and 7th order harmonic voltages and currents were measured at the industrial consumer, the modules of the 3rd, 5th, and 7th order harmonic currents, respectively, were measured at each. The electric power substation of the company under study, is installed with a medium voltage input of 13,800V per phase, and low voltage transformers of 1000kva (220v), and another of 500kva (380v), and a 500kva electric power generator, for power supply only in the office sectors and IT room, according to these data from the company's facilities a load survey of all machines and installed equipment was done, such as: SMD machines, compressors, electromechanical motors. Due to the different connections of this equipment, the consumption of reactive power was verified, reaching a power factor of 0.75 kVAr, therefore a study was developed in its electric power bill and the consumption of reactive power above the average was verified. According to the installed power a capacitor bank was created in the low voltage with 2 capacitors of 50 kVAr, to meet the corrections of reactive energy according to the standards of the electric energy concessionary, which is 0.92 FP at minimum.



Source: Authors, (2018).

Figure 2. The forms of filter installations and models

The QGBT power supply boards are made up of low voltage circuit breakers with a capacity of 2000A in 220v and another of 500A in 380v. The substation is feeding two factories, each one has two 1000A circuit breakers, therefore the electric energy bill is only one. To measure the electric power consumption it was necessary to install a powerNET M200 IMS meter, which is used to analyze the main electric power quality parameters with SCADA management and software.The electricity consumption of the company under study in kWh is on average 280,000 kWh per month, according to this consumption was made a survey for installation of capacitive filters. The industrial automated filters of 380/440v have a total power of 14,000 kW, so 14,000 x 20 filters = 280,000 kW, with this result 20 industrial automated 380/440 filters were installed. To attend to both types of voltage, two tables were made: one table with 15 filters in 220v and another with five capacitive filters in 380v, one in each existing QGBT. Below are the capacitive filter models with their main information: Single-phase residential 380/440v automated filter; Two-phase residential 380/440v automated filter; Three-phase residential 380/440v automated filter; Three-phase commercial 380/440v automated filter; Three-phase industrial 380/440v automated filter.

The main damage caused in industry 'A' studied

Power Failures: In the industry studied it was verified that the failure in the electrical system occurred mainly due to the events cited: lightning, downed power lines, network over-demand, accidents, blackouts. According to the failure a 500kva electrical energy generator was installed, and two panels with 20 filters and parallel to the general QGBT.

Voltage Peak or Power Surge: Industry 'A' is located in an area with a higher rate of atmospheric discharges, and had an improvement in equipment burns, due to the presence of SPD's - surge protectors - up to 680V of peak voltage, in conjunction with RLC circuitry. The high voltage short term surge matches that above 110% of the nominal value can be caused by lightning and can send line voltages to levels above 6,000 volts. A short duration surge (spike) almost always results in data loss or damage.

Excessive Voltage or Overvoltage: Line Voltage was observed to rise for prolonged periods, from a few minutes to a few days, which was caused by a rapid reduction in power loads, heavy equipment being switched off, or network switching, overloading the voltage of equipment remaining on the network. One of the automation components that make up the RLC system of capacitive filters is the varistor, which is a component responsible for protection by cutting and diverting surges to the proper ground.

Line Noise: In industry 'A' it was observed the magnetic interference generated by welding devices, and SCR printers, which are high frequency waves. Through these problems pointed out, we identified that in the capacitive filters are formed by electrolytic capacitors, with exclusive responsibility for capturing noise, in other words, avoiding waste of electrical energy.

Switching Transient: Instantaneous voltage and undervoltage (node) in the nanosecond interval Cause: The normal duration is shorter than a short duration surge (spike) and usually falls in the nanosecond range.

Harmonic Distortion: Distortion of the normal line waveform, usually transmitted by non-linear loads Cause: Switched power supplies, variable speed motors and drives, copiers and fax machines are examples of non-linear loads. They can cause communication errors, overheating, and hardware damage. Here are some examples of filter applications to solve numerous problems that exist within the electrical network. These solutions are called filters, be it line filter, harmonic filter, high voltage filter, among others. But analyzing the cost benefit of the applications we conclude that the Capacitive Filter fits in all these solutions.

Values: Efficiency with the best operation of the equipment; Sustainability, because the equipment reduces the emission of **CO_2** - increasing the useful life of engines and electronic boards and Technology used in the production process of the capacitive filter.

Protection benefits: Protection in the local electrical network against distortions caused by surges; Protection against the burning of motors and equipment up to 680V; Increased useful life of motors and electro-electronic equipment and Decreased equipment downtime due to circuit breaker tripping and fuse blowouts.

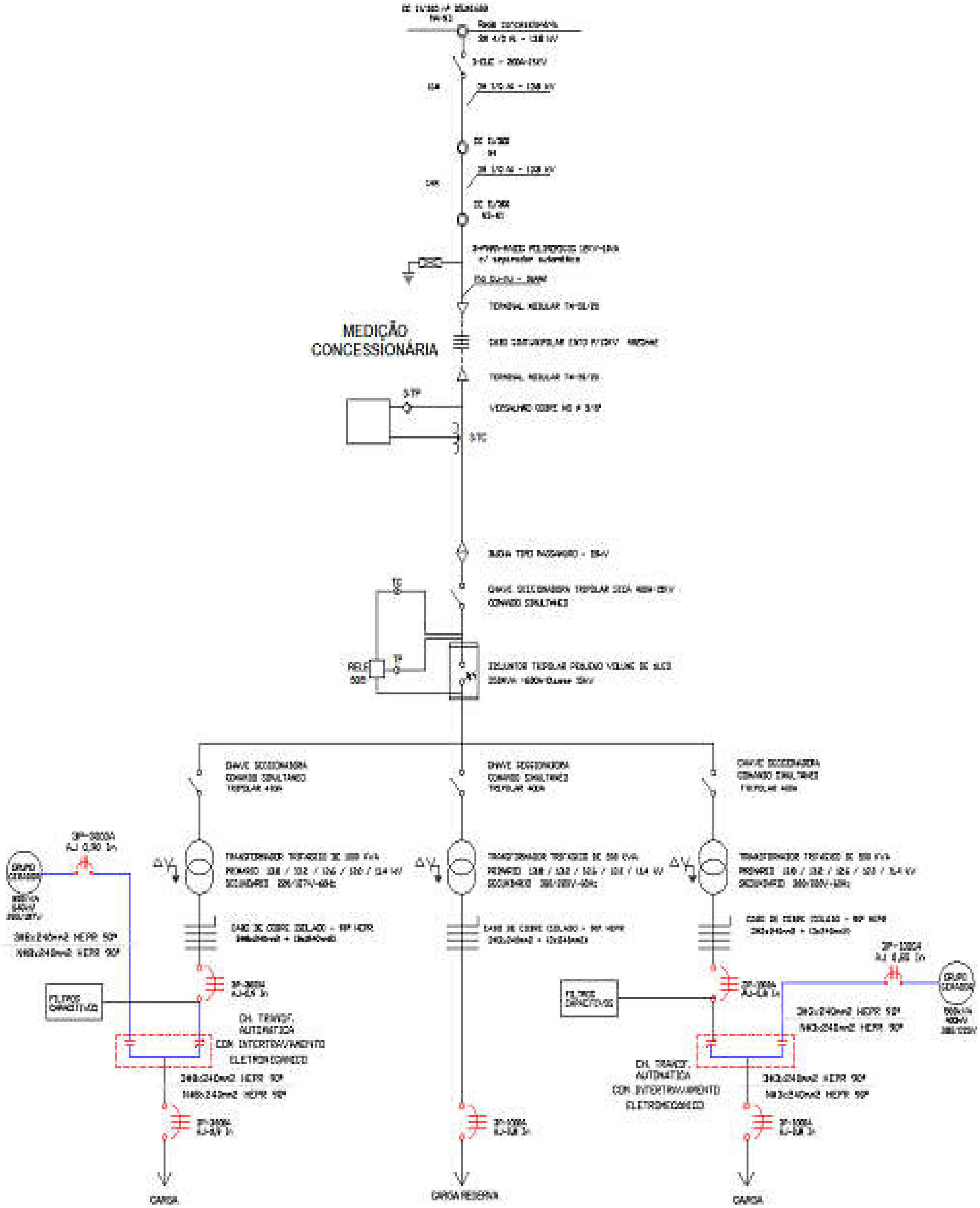
Efficiency benefit: Performance and durability of equipment and Direct gains of 8 to 20% in registered energy consumption.

Unifilar Diagram for the Application of Filters: Figure 10 shows the wiring diagram of the company where the capacitive filters were installed aiming to improve the power quality performance in the industry. In the power supply of the electric utility company we have the poles 11/300kg/f - M4/N3 with switch CUC 200A- 15 KVA, interconnecting 3#1/0 in the voltage of 13.8 KV, deriving to supply the 'SE' of the industry KDW da Amazonia, we have the entrance poles 11/300 kg/f -N4 in the voltage 13. 8 KV, with a protection of three Polymeric Lightning Arresters 12KV-10KA with automatic separators, from the internal post to the substation we have the external mouflas, that is, (Modular Terminal 15KV TM 50/20), with 25mm² 15KV cables, branching to the TP (Potential Transformer) and CT (current transformer) of 500/5, this equipment is supplied by the energy concessionaire for its measurements. Continuing in the medium voltage, following by the punched bushing, arriving at the maneuver device (Dry three-pole switch of 400A-15kv simultaneous command), feeding the three-pole circuit breaker of 350MVA-630A class 15KV, the medium voltage oil, this equipment is responsible for the maneuver and protection of the whole system, This equipment is responsible for the maneuver and protection of the whole system, through the PEXTRON URPE 7104T relay with overcurrent + under/overvoltage and continuity of coil and capacitive trip, thus leading to the 1000KVA transformer, lowering the voltage to 220V, up to the distribution QGBT, where the panel with Capacitive Filters is located in parallel**.** This research presents a study of the diagnosis of the electric power quality at the company KDW da Amazônia S.A. The requirements for the electric power quality analyzed were: Voltage Harmonic Distortions (DHTv), Power Factor, Reactive Power in permanent regime, Active Power in permanent regime, Voltage Analysis in permanent regime and Current Analysis in permanent regime.

Measurementwith HIOKI analyzer: The data were obtained from measurement campaigns carried out at the substation of the company KDW da Amazonia in the month of November 2018. In the 13.8 kV substation, the modules of the 3rd, 5th and 7th order harmonic voltages and currents were measured in the industrial consumer, the modules of the 3rd, 5th and 7th order harmonic currents were measured in each, respectively. The equipment used was the power quality analyzer, model PW3198 HIOKI, with the following characteristics:

- 1P2W to 3P4W
- 50, 60 and 400 Hz measurements
- GPS clock synchronization (optional)
- Power factor, SAGS, SWELLS, FLICKER, transients

- Harmonics up to the 50th order
- Accurate high-speed transient capture with 2MHz sampling
- Waveform detection and display
- Four voltage channels and four current channels
- Advanced PC software
- Higherorderharmonics



Source: Authors, (2019).

Figure 3. depicts the SE single-line diagram, and indicates the exact installation point of the capacitive filters

Source: ITEGAM Electric Power Quality Laboratory, (2018).

Figure 4. HIOKI PW 3198-90 Power Quality Analyzer

Precaution with the company's electrical system

- Cabling
- Path related to power and low current cables - control and automation systems
- Positioning of equipment in relation to sources of disturbance
- Grounding system

Changes in the waveform

- Waveform variation
- Amplitude and frequency variation

Change in waveform

- Harmonic, Surge, Transient, Notching, Noise.

Electric power disturbance mitigation technique

- Evaluation of the electrical installation (Substation, control loops and user) - NR-10
- Identification of PQ problems by meter installation. In PCC - request with the concessionaire.
- Understanding of the production process (production report, maintenance, quality)
- History of occurrence of problems with suspected PQ disturbances
- List of equipment and critical loads
- Statistical data survey of shutdowns
- Simulation of the disturbances in the laboratory (if possible), with implementation of solutions and analysis of results
- Evaluation of results
- Proposed solutions
- Implementation of the proposed solutions and Evaluation of the results.

ANEEL- PRODIST- Module 8

The considered aspects of the product quality in permanent or transient regime are: a) voltage in permanent regime; b) power factor; c) harmonics; d) voltage unbalance; e) voltage fluctuation; f) short duration voltage variations; g) frequency variation.

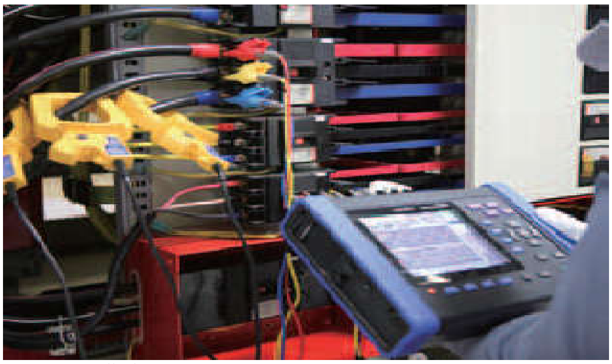
Takingcareofpowerquality

- Security
- Information
- Accidentprevention

Power Quality Analysis of the Measurement Campaign at the Company

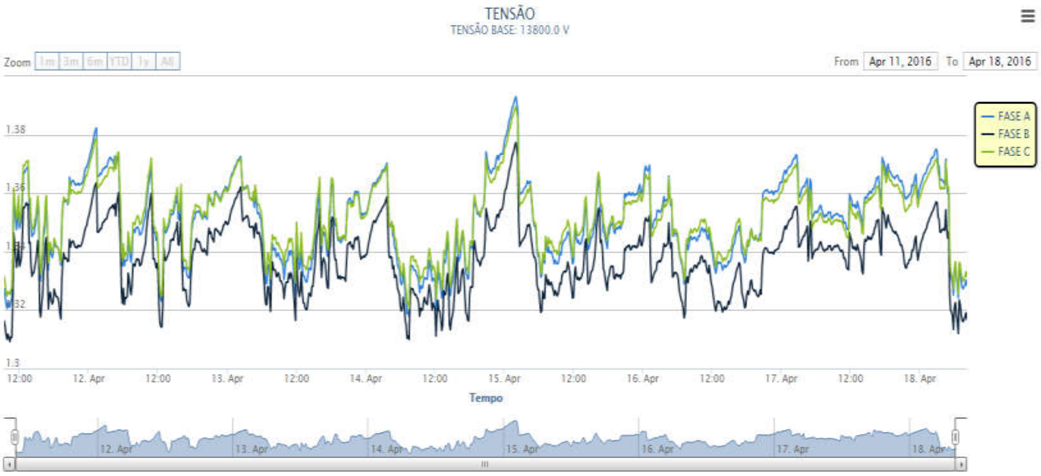
Steady-State Voltage Analysis

Figures 6 shows, respectively, the voltage profiles in phases A-B-C, recorded in the substation cabin in the secondary of the transformer of the Company KDW da Amazonia S.A. Analyzing the records in Figure 1, it was found that the RMS voltage value violated the appropriate level (0.95 TR $\leq$ TL $\leq$1.05 TR), as established in module 8 of PRODIST, considering that the minimum values of the RMS voltage values in phases A, B, C were 1.3178 pu, 1.3093 pu and 1.3206 pu, respectively; while the maximum values of the RMS voltage values were 1.3930 pu, 1.3773 pu and 1.3896 pu, respectively, as presented in Table 1.



Source: studied company.

Figure 5. HIOKI equipment installed, (2018). in the studied company.



Source: Authors, (2018).

Figure 6. Voltage profile in phases A B and C of the Amazon KDW Company

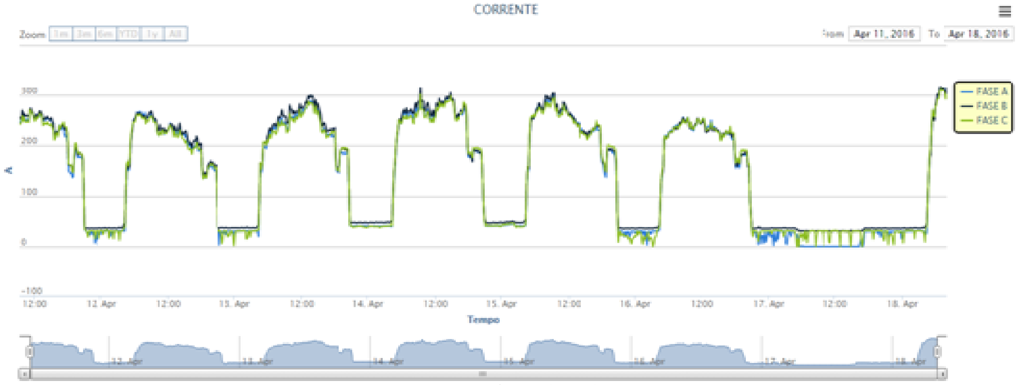
Table 11. Minimum, Maximum and Average RMS voltage values measured on phases A, B, C.

	Minimum values	Maximum values	Average values
PHASE A	1,3178	1,3930	1,3514
PHASE B	1,3093	1,3773	1,3378
PHASE C	1,3206	1,3896	1,3518

Source: Authors, (2018).

Analysis of the Current in Steady Regime: Analyzing Figure 2, it can be seen that the registered current, presented a behavior in phase C that zeroed during the night and the current phases A and C zeroed in the day, presenting similar values in all other periods, reaching maximum values in phase A = 315.6300A, phase B = 317.8100 A and phase C = 312.2100 A

Analysis of the Active Power and Reactive Power in permanent regime: Figure 3, presents a weekly cycle of the consumption of KDW Engineering Company. According to this figure, it was verified that the weekdays presented similar consumption patterns, reaching maximum values around 321kW. During the weekend, the measurement records show that the registered values found were 0kW (zero), as shown in Table 3.



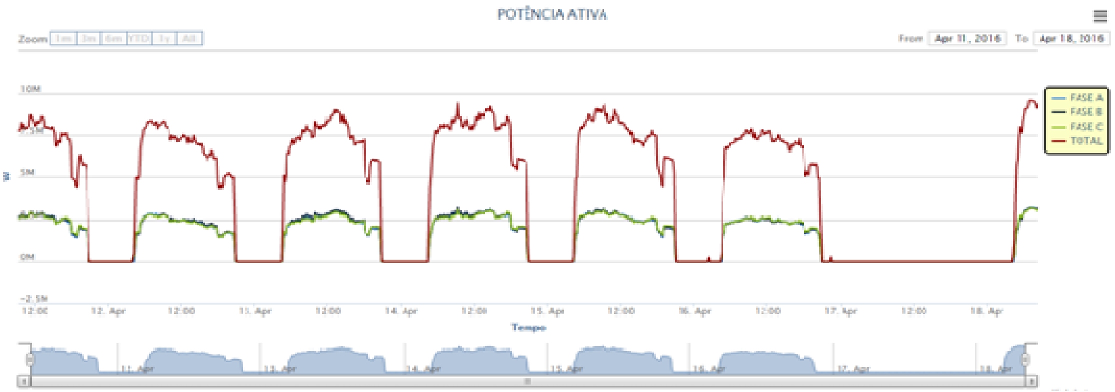
Source: Authors, (2018).

Figure 7. RMS current recorded in phases A, B and C.

Table 12. Minimum, Maximum and Average RMS voltage values measured on phases A, B, C.

	Minimum values	Maximum values	Average values
PHASE A	0,0000	315,6300	144,8602
PHASE B	30,5000	317,8100	152,5440
PHASE C	0,0000	312,2100	146,1779

Source: Authors, (2018).



Source: Authors, (2018).

Figure 8. Active power recorded in phases A B and C of the Amazon KDW Company

Table 13. Minimum, Maximum and Average RMS voltage values measured on phases A, B, C

	Minimum values	Maximum values	Average values
PHASE A	0,0000	3212000,0000	1395213,0739
PHASE B	0,0000	3214000,0000	1413372,7545
PHASE C	0,0000	3171000,0000	1396921,9062
TOTAL	0,0000	9570000,0000	4205127,2455

Source: Authors, (2018).

As can be seen in Figure 4, where the recorded values of reactive power are illustrated, it can be seen that phase A B, C presented inductive characteristics during the commercial period and capacitive during the evening hours. The data is also presented in Table 4 with minimum values around -96kVar and maximum values around 109.6kVar. Table 4 presents the data Minimum, Maximum and Average values obtained in phases A B and C. Figure 9 of the reactive power recorded in phases A B and C of the Company KDW da Amazônia.

Source: Authors, (2018).

Figure 9. Reactive power recorded in phases A, B and C of the Diffusora radio

Table 14. Minimum, Maximum and Average Values obtained in phases A,B,C.

	Minimum values	Maximum values	Average values
PHASE A	-966000,0000	1064000,0000	107647,4551
PHASE B	-961000,0000	1096000,0000	30406,4371
PHASE C	-950000,0000	1079000,0000	90753,4930
TOTAL	-287000,0000	3240000,0000	225194,6108

Source: Authors, (2018).

Power FactorAnalysis: As can be seen in Figure 10, where the power factor values for the referred measuring point are presented, it presented values below 0.92 (inductive) in the (de) period and values above 0.92 (capacitive) during the period.

Source: Authors, (2018).

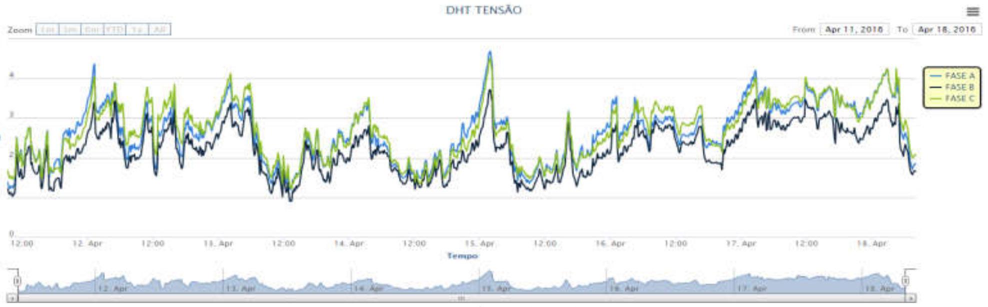
Figure 10. Power Factor recorded in phases A, B and C of the Amazon KDW Company

Table 15. Minimum, Maximum and Average values obtained in phases A B, C

	Minimum values	Maximum values	Average values
PHASE A	-0,9980	0,9978	0,4324
PHASE B	-0,9985	0,9979	0,3746
PHASE C	-0,9983	0,9985	0,4284
TOTAL	-0,9983	0,9974	0,4103

Source: Authors, (2018).

Analysis of Harmonic Distortion of Amazon KDW Industry: Analyzing Figure 11 shows the total harmonic voltage distortion rate (DHTv) of the three phases A, B, C of KDW da Amazônia, it was observed that the voltage DHT values were below the limit value of 8%, therefore, in compliance with the reference values defined by module 8 of PRODIST/ANEEL, since the maximum value registered was equal to approximately 4.68%.



Source: Authors, (2018).

Figure 11. Average DHTv values obtained for phases A-B-C

Table 16. Minimum, Maximum and Average DHTv values obtained in phases A,B,C

	Minimum values	Maximum values	Average values	Minimum values
PHASE A	1,2000	4,6870	2,6564	3,7746
PHASE B	0,9040	3,7190	2,2249	3,1649
PHASE C	1,2180	4,5100	2,6971	3,7897

Source: Authors, (2018).

Analyzing Figure 12, which shows the THDi rate of the three phases A, B and C of the substation (13.8 kV) of the Amazon KDW company, it was observed that the THDi values obtained maximum in phase A with 50.7460, phase B with 33.8970 and phase C with 54.5370). Verifying the average THDi values, for the ratio of ICC/Io = 110.4 as established in the recommendation of the IEEE 519-92 standard, it was observed that phases A and C were violated above the limits established by the aforementioned standard. To start a successful installation we first start the technical inspection that comes with the intention of closing the budget with the values referring to the installation and the materials to be used. It is of utmost importance that in each and every industry this technical inspection is carried out, no matter how simple the installation may be. Since each industry is different, in other words, has different installations, such as grounding, where the application will be made, and other specific details in each case. It is essential that the professional teams are equipped with PPE materials. Below is a list of materials used by electricians, for low and high voltage electrical installations:

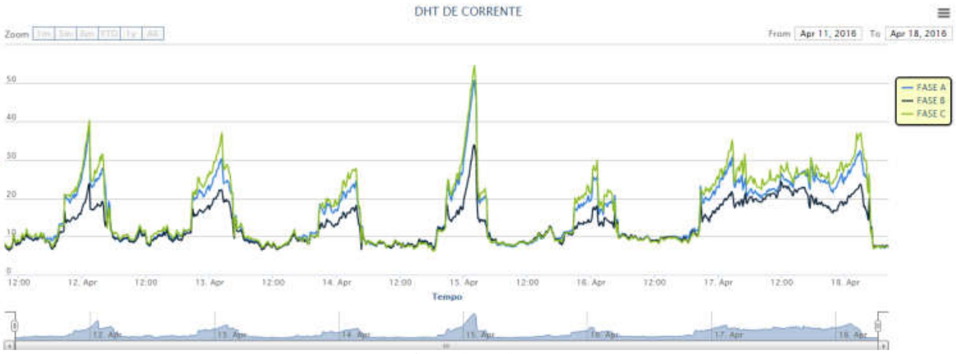
- Safety helmet with insulation for electricity with insulated sock and boot.
- Colorless safety glasses with protection against ultraviolet rays.
- Cottonclothing.
- BT and AT insulating rubber gloves.
- Pelica gloves to protect the rubber gloves.
- Scrap gloves for rough work.
- Safety harness with lanyard for working at great heights.
- Minipa earth meter with case for measuring ohmic resistance.

Materials for installation: In general the installations are very easy, you could say it is the simplest of the whole business. The standard materials for installations are: Control board. 4.0 mm flex cables. Circuit breaker of 10 amperes (according to the amount of filters that make the module). Connectors. Spiral or electro duct. Electrical conduit (if necessary). Bushings, screws and nuts. Rod with GTDU connector for grounding, grounding cable 50mm², conventional and high-fusion insulating tape. In figure 11 you can see the capacitive filters assembled to act in the three-phase 220V QGBT, which will be in parallel with the general low voltage circuit breakers of 3000A with Aj 0,9 In with the following equipment: 10A three-phase circuit breakers, 50A circuit breaker, din circuit breaker rail, 50x50 perforated PVC channel, 6mm² flexible cables, 40x40x3/8 epoxy spacer insulator for copper bus, electrolytic copper flat bar 25, 40mm x 12,70mm of 394A, insulated male terminal 6,3mm for wire from 4mm² to 6mm², flanged self-drilling screw 4,2 by 13mm for fixing the gutters and rails, when the command is 120cm x 80cm x 35cm.

Table 17. Minimum, Maximum and Average DHTi values obtained in phases A,B,C.

	Minimum values	Maximum values	Average values	Minimum values
PHASE A	6,8260	50,7460	15,4909	27,5982
PHASE B	6,4130	33,8970	12,9254	21,8608
PHASE C	6,2300	54,5370	16,4409	30,7349

Source: Authors, (2018).



Source: Authors, (2018).

Figure 12. Average DHTi values obtained for phases A-B-C

Figure 12 shows the start of the assembly of the command board for the capacitive filters at 380V, which will be in parallel with the 1000A Aj 0.8 In low voltage circuit breaker. Only 05 units are installed, because the current consumed in the 380V QGBT is lower than the current consumed in the 220V QGBT. Figure 14 shows the panel being assembled with the 5 Capacitive Filters applied in the QGBT/Substation/380V. Figure 15 shows the electrician making the ends of the cables with tin solder, for better performance and passage of electric current, without losses. In Figure 16 we can see the electrician making the tips of the cables with tin welding, for better performance and passage of electric current, without losses. Figures 17 and 18 show the capacitive filter panel in full operation and with its LEDs all on, informing the good performance of the same. For future maintenance or equipment breakdowns.

Source: Authors, (2018).

Figure 13. Panel with the 15 Capacitive Filters Assembled for application in the QGBT/220V

This application was performed according to the current standards, and with qualified employees, however after all the capacitive filters survey, and the most important step of this installation is the grounding, follows some grounding tips for its best performance. According to NBR-5410 (1990), you should achieve a ground resistance of about 10Ω, since more important than the resistance itself is a perfect equipotentialization of all local grounding in order to avoid potential differences, i.e. all grounding systems must be interconnected. Thus, the value recommended by the standard is based on a lightning rod grounding system, because if it is present, it will be connected to the system and will be adopted as the standard, since it requires a lower value of grounding resistance.

Source: Authors, (2018).

Figure 14: Installation of filters at 380V voltage

Source: Authors, (2018).

Figure 16: Cable points with tin solder of the panel

Source: Authors, (2018).

Figure 17: Filters placed in the QGBT/220V.

Source: Authors, (2018).

Figure18: Filtersplaced in the QGBT/380V

It is worth remembering here that there is no point in concentrating many electrodes in a small area, it is better to get a grounding with 20Ω and low impedance than one with 15Ω and very high impedance, not to mention the high cost of the project as this brings. Of all the types of grounding, the best recommendation for capacitive filter installations is the TT grounding scheme, which in comparison to a direct, phase-mass fault current is lower than a short-circuit current, but may nevertheless be sufficient to cause dangerous voltages to arise. The TT scheme has a directly grounded supply point, with the installation's masses connected to grounding electrodes that are electrically distinct from the supply's grounding electrode. Thus after the filters perform the dissipation of harmonics to ground, they will not be able to return to the neutral conductor.

APPLICATION RESULTS

This topic contains graphs and tables of the results found. Demostrating all consumption parameters, being an industrial connection, group A in high voltage, with green flag contract and contracted demand of 600 KW, and peak consumption between 20:00 and 23:00 hours, increasing the Kw/h price to R$ 1.197799.

Table 18. Statement of Before Accounts

Energy bill before installation of capacitive filters				
BilledItems	**Consumption KW/h**	**Fee per consumption KW/h**	**Tax-Free Rate**	**Value**
Peak Demand	31.080	1,197799	0,898350	37.227,59
Demand	775	9,946664	7,460000	7.708,66
Off-peak consumption	273.840	0,488533	0,366400	133.779,87
Excess reactive energy off-peak	2.520	0,347706	0,260780	876,21
Exceeded Demand	175	19,893328	14,920000	3.481,33
Contribution for Public Lighting (COSIP)				5.890,56
Total ofthisinvoice				188.964,22

Source: Authors, (2018).

Table 19. Statement of Accounts After

Energy bill after installation of capacitive filters				
BilledItems	**Consumption KW/h**	**Fee per consumption KW/h**	**Tax-Free Rate**	**Value**
Peak Demand	24.400	1,197799	0,898350	29.226,29
Demand	794	9,946664	7,460000	7.897,65
Off-peak consumption	209.800	0,488533	0,366400	102.494,22
Excess reactive energy off-peak	840	0,347706	0,260780	292,07
Exceeded Demand	194	19,893328	14,920000	3.859,30
Contribution for Public Lighting (COSIP)				5.890,56
Total ofthisinvoice				149.660,09

Source: Authors, (2018).

The graph in Figure 19, shows the equalization of consumption in the industry KDW da Amazônia LTDA, where the survey was made from the installation of capacitor banks, which was paying surplus reactive power, and capacitive filters in order to obtain power quality, thus generating savings.

CONCLUSION

In a simple system, where the six-pulse drive system loads are 77% of the total load. When the non-linear load is greater than 30% of the total load demand, careful analysis is required for total demand distortion (TDD) control. The two 115 kV busbars are the common coupling point (CCP). In the industrial application methodology the following situations were analyzed:

1. Harmonic current injectionestimation - Estimating the correct harmonic emission from nonlinear loads is important, the first step in the analyses:

- It varies with the operation and load of the drive system, and the short-circuit level at the utility source has a profound effect. Harmonic analysis can be performed with the maximum and minimum levels of the short-circuit currents.
- In this example, since there is only one harmonic source, the harmonic angle does not need to be considered. Where more than one source is present, the angle of each harmonic must be modeled.
- The worst case study scenario is chosen for the analysis. For the example, an angle of $\alpha = 15°$ and the overlap angle is 12.25°.

Conducting load flow and establishing the need for reactive power compensation - To conduct the load flow study, an estimate of the power factor of linear and nonlinear loads is required. Computer-based fundamental frequency load flow calculations show that the operating power factor is 0.82. It is necessary to control the power factor at PCC to > 0.9 and also the TDD at PCC within the limits of IEEE 519-2014, Revision of IEEE 519-1992. The load flow shows a demand of 5,279MW and 3,676Mvar from the 115 kV Source, including system losses. A 1200 kVAr capacitor bank with 115 kV busbar will reduce the reactive power input from the 115 kV source to 2.44Mvar and provide an overall power factor of 0.92 established by the PRODIST/ANEEL Standard.

Determine the short circuit level and load demand at the PCC - To calculate the allowable TDD, a short circuit level at the PCC and the load demand over a 15min or 30min period is required. The short circuit level at the 4.16 kV bus, PCC, is 36.1 kA, the load demand = 800 A, the ratio Is / Ir = 45, and the allowable TDD limits through IEEE 519-2014, Revision of IEEE 519-1992.

ACKNOWLEDGMENTS

To the Postgraduate Program Master, in Engineering, Process the Institute of Technology from Federal University of Para (PPGEP/ITEC/UFPA) and Institute of Technology and Education Galileo from Amazon (ITEGAM) for their support to search.

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