Journal of
Electrical & Electronic Systems

Lugo, J Electr Electron Syst 2019, 8:1
DOI: 10.4172/2332-0796.1000297

Case Report | Open Access

Harmonic Distortion Responsibility Attribution between Utility and Specific Low-Tension Costumer – Case Study

Lugo AJ*

Sankt-Peterburgskij Politehniceskij Universitet Petra Velikogo, Russian Federation

Abstract

The Electric Power Quality studies the electromagnetic phenomena that can cause disturbances in the electrical systems, which can be of permanent regime (steady state voltage, power factor, harmonics, voltage unbalance, voltage fluctuation, frequency variation) or transient voltage variations). With the technological advance in the area of power electronics, an increase and diversification of the amount of appliances that need electric energy for its operation is occurring. These devices (non-linear loads) produce distorted (ie non-sinusoidal) current, even when powered by a sinusoidal source, and can also distort the voltage at the connection point with the utility. These distortions are called harmonic distortions of current and voltage and are classified as permanent regime perturbations. As harmonic distortions cause several problems in the various consumers connected to the electrical system, ranging from noises, vibrations and variations in light intensity, shortening the useful life of the appliances, and in the case of the industrial sector, which can lead to a halt to the production process. Due to the importance of the theme, there are rules with limits for these distortions, and this work has as a proposal to investigate computationally a responsibility assignment between a concessionaire and residential consumer of low voltage in the city of São Paulo, Brazil, through the network model of the concessionaire and possible electro-electronic equipment We will analyze some methodologies found in the literature, such as the Harmonic Power Method, Conformity and Non-Compliant Current Method and Superposition Method. As simulations, they were done in an ATP Draw environment, where the necessary results were generated for the review of methodologies analyzed, thus verifying, as limitations and potentialities of its own.

Keywords: Harmonic distortion; Electric power quality; Harmonic responsibility attribution

Introduction

Electrical power quality, a topic with a lot of discussion in the industry since 1980 is getting more sensitive each year for electrical energy companies and final consumers.

Any disturbance on the tension, current or frequency which results in failure or bad consumer equipment operation is a parameter for the measurement of electrical power quality, which according to 8.1 version of "Procedure of Electrical Energy Distribution of National Electric System – PRODIST – ANEEL (2016), can be divided in:

1. Service Quality: it defines the set of consumers unity, provides the definitions, limits and relative procedures to the continuity indicators and attendance time;

The Service Quality works with the interruption which occurs in the electric energy supply, in other words, faults in the electrical system which can be permanent, demanding corrective maintenance and temporary, which by external influences occurs the arc gap between feeder phases or between phases and the neutral, and by the reset of the electrical system the supply is restored, according to Kagan, Robba and Schmidt (2009).

2. Product Quality: it defines the terminology, characterizes the phenomena and establishes the indicators and limits or reference values related to the voltage compliance at steady state and the disturbances in the voltage waveform

The following phenomena are from product quality in steady state or transitory

a) Steady State

i. Voltage at steady stage

ii. Power factor

iii. Harmonics

iv. Voltage unbalance

v. Voltage fluctuation

vi. Frequency variation

b) Transitory

i. short-term voltage variation;

Electric power quality

The conditions of the electric voltage and current signal are evaluated in the Electrical Power Quality [1-3], so that the operation of equipment, processes, installations and electrical systems can be satisfactory and safe. This rated current or voltage is the one which drives the electric charge and if it is not in certain operating conditions the load may malfunction, causing failures, shortening the life of the system and shutting it down. The quality of electrical energy is a variety of electromagnetic phenomena that in some way distort the waveform of voltage or current. These disturbances can be divided into two categories of disturbances: events and sustained events. The event disturbances are of short duration that occurs occasionally, whereas the

***Corresponding author:** Lugo AJ, Sankt-Peterburgskij Politehniceskij Universitet Petra Velikogo, Russian Federation, Tel: +79992297950; E-mail: afonso.lugo@epowerbay.com

Received January 24, 2019; **Accepted** February 27, 2019; **Published** March 05, 2019

Citation: Lugo AJ (2019) Harmonic Distortion Responsibility Attribution between Utility and Specific Low-Tension Costumer – Case Study. J Electr Electron Syst 8: 297. doi: 10.4172/2332-0796.1000297

Copyright: © 2019 Lugo AJ, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Citation: Lugo AJ (2019) Harmonic Distortion Responsibility Attribution between Utility and Specific Low-Tension Costumer – Case Study. J Electr Electron Syst 8: 297. doi: 10.4172/2332-0796.1000297

sustained disturbances are variations in the tension and steady state current. The presence of some of these phenomena is related to the electric power quality.

A problem in the Electric Power Quality is characterized by any disturbance or occurrence manifested in voltage levels, voltage or current waveforms that cause a failure, decrease efficiency or a defect in electrical system equipment. The purer the sinusoidal waveform, free of distortions, without changes in amplitude, the more quality the electric energy has [2].

The word harmonic has its origin in the study of acoustics to designate a multiple of a tone. The same treatment can be given to a sinusoidal voltage or current. When the periodic wave is distorted, a case commonly found in electric, the result of the distorted wave is the superposition of sine waves having a fundamental sinusoidal component.

Harmonics

When Fourier Analysis is applied in a generic periodic waveform, a summation of infinite sinusoidal terms is obtained, whose respective frequencies are given by kf, (k = 1,2 ...) plus a term equal to the average value presented by the original waveform (continuous component). Any wave that has distortions or frequencies with different amplitude from the fundamental can be decomposed into a component of the same frequency as the resulting distorted wave (fundamental wave) and in other sine waves of fundamental frequencies (harmonics), as can be seen in Figure 1 [4].

The electric energy is usually produced in electric generators in the frequency of 50 or 60 Hz and can be considered as sinusoidal. When a sinusoidal voltage source is applied to a device or non-linear load, the result is distorted and is not perfectly sinusoidal. The non-sinusoidal voltage drop produces a distortion in the voltage at the terminals of the load that contains harmonics. Harmonics in power systems are defined as voltages and sinusoidal currents with frequencies that are integral multiples of the fundamental frequency [1].

As previously mentioned, non-linear loads are the main cause of harmonic distortions. These non-linear loads are present in various devices widely used by industry. These harmonic generating sources can be divided into three categories, according to [3-9]:

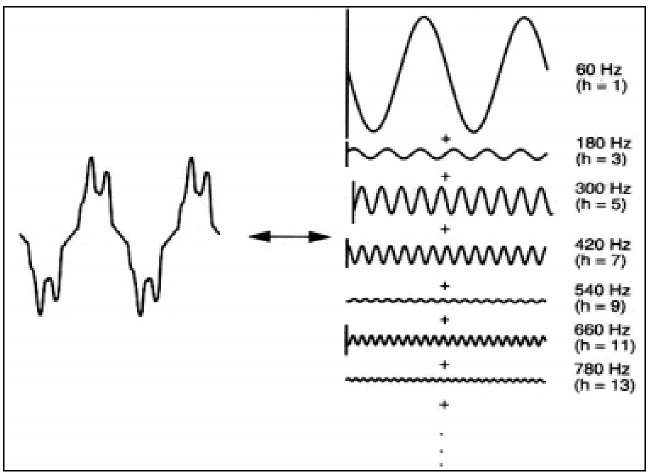


Figure 1: Distorted waveform and harmonic decomposition.

- Electronic power devices: single-phase and three-phase static converters;
- Ferromagnetic devices: transformers and rotary machines;
- Arcing devices: lighting and discharge of electric arc furnaces.

Harmonics can be classified as harmonic characteristics and non-characteristics. When harmonic distortion is predictable, of expected frequency and amplitude, it is said characteristic and is normally generated by static converters represented by rectifiers and inverters. When there is a random harmonic resulting with complex modeling, it is said to be non-characteristic and is normally generated by discharge lamps or electric arc equipment.

Legislation

PRODIST – module 8: According to the Procedures for Distribution of Electric Power in the National Electric System - PRODIST - Module 8, section 8.1 Product Quality, revision 8, which is in force in 2017, deals with the Electric Power Quality, and in item 4 the theme of harmonics is discussed Table 1.

It is worth noting that the total limits of harmonic distortion correspond to the maximum desirable value to be observed in the distribution system.

IEEE 519-2014: IEEE standards have levels of applicability that are divided into Guiders, guidelines characterized by common examples and solutions, Recommended practices, which are best practices, and Standards, which are codes that are collectively agreed upon by various stakeholders and have the force of law.

The IEEE Standard 519-2014 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems defines acceptable levels of voltage and current harmonics in the CAP to limit the impact of non-linear loads between the utility and the consumer.

IEC 6100-3-2: The IEC 61000-3-2 of 2009 defines current harmonic limits for equipment with rated current less than or equal to 16 A per phase. These limits refer to electrical and electronic equipment connected to public low voltage AC distribution systems (minimum 220 V) operating at 50 or 60 Hz.

Methodology of Responsibilities Attribution on Harmonic Distortions

When the maximum limits of harmonic distortion in force in local and international laws are exceeded, it is necessary to assign responsibility for the violation so that the responsible party, the supplier or the consumer can be penalized in a correct and fair manner and seek solutions to minimize impacts on the quality of electric energy. The methodology initially proposed by Krishnaswamy Srinivasan [10] and later studied by several authors is quite effective and with acceptable results, although it has particularities that distance the result of the precision of a real case. The equivalent harmonic impedance, because

Indicator	Nominal Voltage		
	Vn ≤ 1,0 Kv	1,0 kV < Vn < 69 kV	69 kV ≤ Vn < 230kV
DTT95%	10,0%	8,0%	5,0%
DTT_p95%	2,5%	2,0%	1,0%
DTT_i95%	7,5%	6,0%	4,0%
$DTT_3$95%	6,5%	5,0%	3,0%

Table 1: Limits of total harmonic distortions (% of fundamental voltage).

it is variable and not constant, becomes the main point of difficulty in modeling the circuit between the concessionaire and the consumer at the PAC (Point of Common Coupling).

Harmonic power method

The principle of the direction analysis of the active harmonic power flow in the network and its correlation with the fundamental power flow is employed in the power flow analysis method [8].

The active power is calculated by the combination of the individual components of effective voltage and harmonic current (Vh and Ih) added to the combination of the effective voltage and fundamental effective current (V1 and I1), the index h is referred to the harmonic order, the index s is related to the supplier and the index c is referred to the consumer, according to Figure 2. The angular mismatch between voltage and harmonic current and voltage and fundamental current is represented by Øh and $Ø_1$.

Conform and non-conforming current method

The loads supplied are divided into two groups. Group I refers to the loads that are not distortion-generating and have constant impedance with the variation of the frequency under evaluation. This last condition conflicts with the electrical fundamentals when the load has inductive and capacitive elements [5]. Group II refers to the loads that produce distortions additional to those originally present in the supply voltage. This group is further divided into three classifications [10]:

1. Desirable loads: which attenuate the relative levels of harmonics originally present in the network;

2. Undesirable loads: which amplify the relative levels of the harmonics originally present in the network;

3. Distortion-generating loads: they produce distortion in the current waveform, even when the electrical system supply voltage is a perfect sinusoid.

The schematic representation of this distortion-generating current separation model (Group I) and non-distortion currents (Group II) is illustrated in Figure 3.

In order to attribute the contribution of responsibility, it is enough to associate the proportions between current conform and non-conforming current for each frequency.

Superposition method

The contribution of the supplier and the consumer to the total current (Ipac-h) and to the total voltage (Vpac-h) in the PAC can be found by means of the superposition principle, as shown in Figure 4,

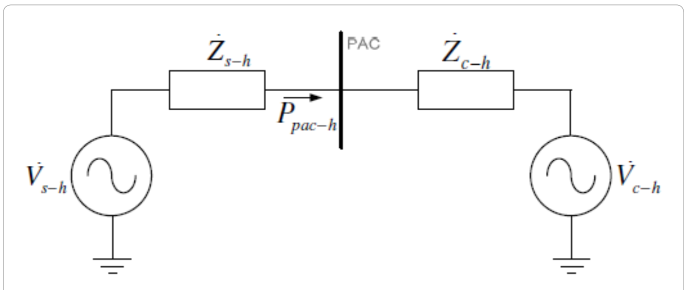


Figure 2: Equivalent harmonic circuit for mathematical evaluation purposes.

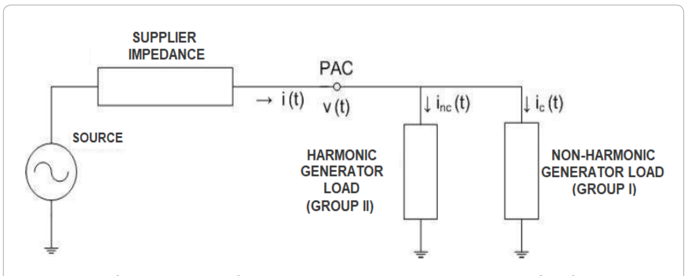


Figure 3: Composition of a typical charge according to the Conformity and Nonconforming Current Method.

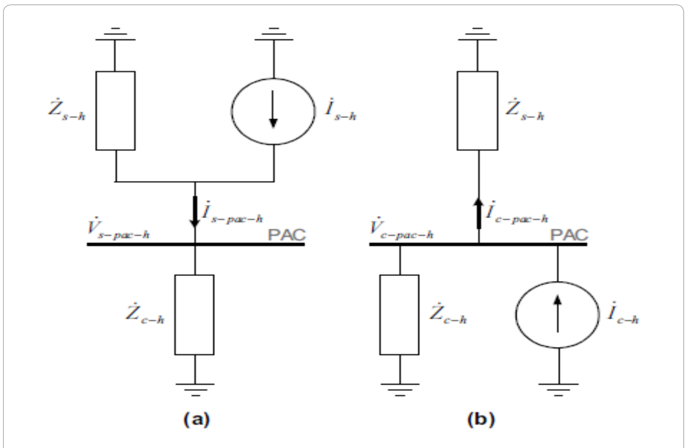


Figure 4: Schematic representation of an electric power system at the electric power delivery point in the frequency domain.

where the original circuit is decomposed in two distinct circuits that interact with each other. Part (a) corresponds to the determination of the concessionaire's contributions and part (b) corresponds to the determination of the consumer's contributions [9].

The projections of the voltages in the harmonic current in the PAC indicated in Figure 5 are considered as the portions of responsibility of injection of harmonic voltage in the system.

System for Methodology Application

Assumptions adopted

The simulations were carried out by subjecting the electric grid formed by the utility and the low voltage residential consumer according to the following situations:

- Case A0: the applied voltage will be pure sinusoidal, with linear and non-linear loads;
- Case A1: the applied voltage will have a predefined distortion pattern, with linear loads;
- Case A2: the applied voltage will have a predefined distortion pattern, with linear and non-linear loads;

The voltage with predefined distortion will be applied according to Table 2.

For all cases the following configuration was used in ATP Draw:

- Integration step = 125 µs
- Study time = 1 s

Citation: Lugo AJ (2019) Harmonic Distortion Responsibility Attribution between Utility and Specific Low-Tension Costumer – Case Study. J Electr Electron Syst 8: 297. doi: 10.4172/2332-0796.1000297

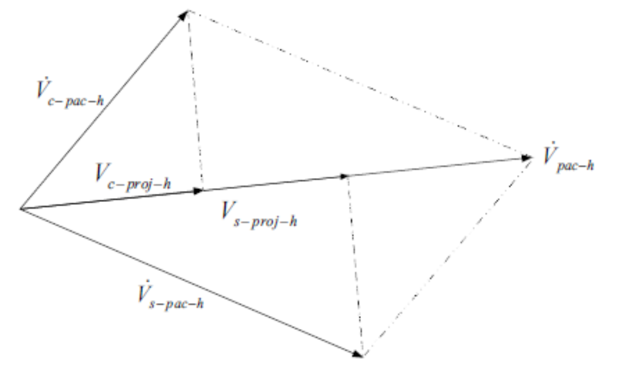


Figure 5: Projection of the harmonic tensions of the utility and the consumer in the PAC.

Vh	%	Vrms [V]	Vpeak [V]
V1	100	127.000	179.61
V3	10	12.700	17.96
V5	7,5	9.525	13.47
V7	5,0	6.350	8.98
V11	2,5	3.175	4.49
V13	1,25	1.588	2.25

Table 2: Tension Distortions Applied in Case A1 And A2.

Network configuration

The electrical network to be simulated is shown in Figure 6, with the utility data shown in Table 3, and the modeled electrical and electronic equipment shown in Table 4.

The technical characteristics of this equipment are real data from a residence in São Paulo city, Brazil.

Results and Discussions

Case A0

Initially, a simulation was made with the utility voltage being purely sinusoidal, and the consumer being represented by its linear and non-linear loads. In order to simplify this study, a single-phase 127| 0º Vrms.

It is possible to notice a high distortion on the voltage according to Graphic 1 and a smaller distortion on the current, according to Graphic 2.

The harmonic current and voltage signals were extracted from the ATP while the analysis for harmonic extraction was done through a MATLAB simulation and are noted in Table 5.

Harmonic power method

In order to determine the harmonic responsibility of the cases according to the Harmonic Power Method, as presented in item 4.1 of chapter 4, an analysis of the angular or phase difference between the voltage and the current is made, where φh is the power phase harmonic and $\phi h = \phi v - \phi i$.

Analyzing Table 6, it is observed that the 1st harmonic is assigned to the utility, since the angle between the voltage and the current is in the 1st quadrant, resulting in a positive active power. All other harmonics have phase in the 2nd and 3rd quadrant and consequently the power value is negative, which according to the Harmonic Power Method, the responsibility to the consumer must be attributed.

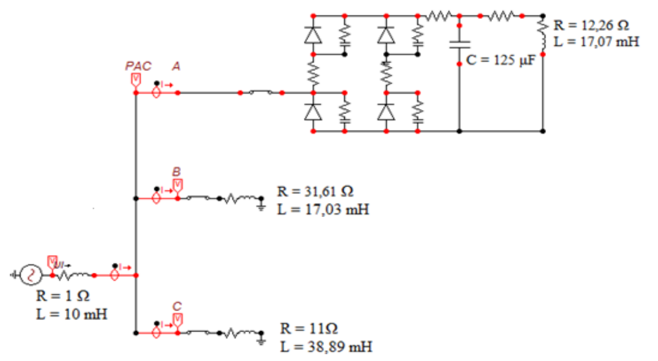


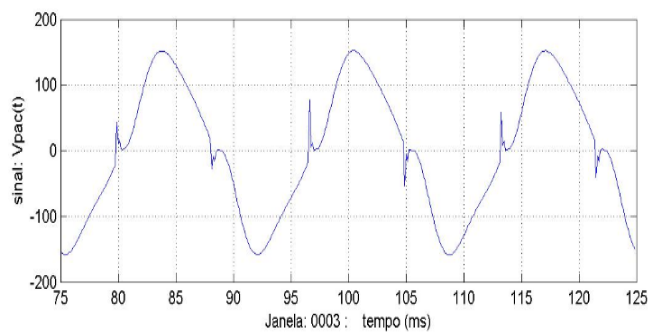
Figure 6: Representation of simulated electrical network in ATPDraw.

Parameters	
Feed tension	127 V
Resistance	1 Ω
Inductance	10 mH

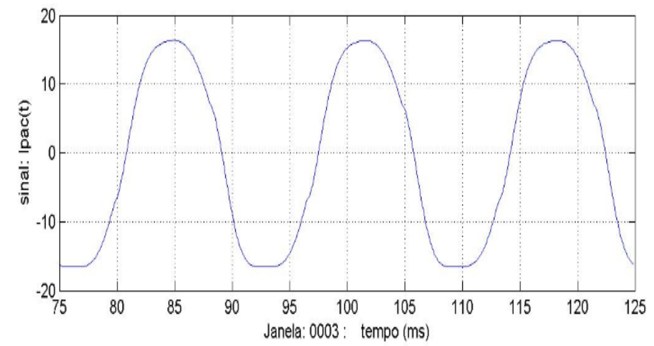
Table 3: Data of the Utility.

ATP	Equipment	Voltage [V]	Power [W]	Power Factor
A	Fluorescent lamps + Microwaves + TV + Notebook + Cell phone charger	127	1,165	0.89
B	Fridge	127	500	0.98
C	Washing machine	127	880	0.60

Table 4: List of Equipment and Their Technical Characteristics.



GRAPHIC 1. Voltage Wave Form on the Pac for the Case A0.



GRAPHIC 2. Current wave form on the Pac for the case A0.

Citation: Lugo AJ (2019) Harmonic Distortion Responsibility Attribution between Utility and Specific Low-Tension Costumer – Case Study. J Electr Electron Syst 8: 297. doi: 10.4172/2332-0796.1000297

Harmonic	Voltage		Current	
	Amplitude [Vrms]	Phase [º]	Amplitude [Arms]	Phase [º]
1	96,4103	-20,52	12,7895	-32,51
3	13,9395	-31,56	1,2257	63,48
5	7,0605	18,09	0,3723	111,11
7	3,9425	146,97	0,1479	-120,87
11	2,3174	74,19	0,0546	165,54
13	1,9864	-138,44	0,0392	-47,31
	THDv%	**18,29%**	**THDi%**	**10,02%**

Table 5: Results of Harmonic Distortions on the Pac for the Case A0.

Harmonic	S = V*I	ϕh = θv-θi	P
	[VA]	Phase [º]	[W]
1	1233,0377	12,00	1.206,1096
3	17,0856	-95,04	-1,5023
5	2,6287	-93,02	-0,1386
7	0,5832	267,85	-0,0219
11	0,1266	-91,35	-0,0030
13	0,0780	-91,13	-0,0015

Table 6: Ase A0 – Avaliation of The Assignment of Responsibilities By The Method of the Harmonic Power Flow.

The Harmonic Power Method is effective to analyze the resulted harmonic distortion, providing from which side it mainly come from, but it does not attribute responsibility for the supplier or for the consumer.

Case A1

For this case, a simulation was made with the utility voltage presenting a predefined distortion pattern, and with the consumer being represented only by its linear loads Figure 7.

According to the established assumptions, the calculations and analyzes for this case were made according to the voltages and harmonic currents in the PAC, according to Table 7.

Conform and non-conforming current method

In this method, the current is separated into conform (loads that do not generate harmonics) and non-conforming (harmonic generating loads) [4]. Table 8 shows the results obtained for harmonic currents and voltages and Table 9 shows the results of assigning responsibility for this method.

The Table 2 shows that conform current (not distorted) is higher than the non-conform current (distorted) for all evaluated harmonic levels, but it does not attribute responsibility for the supplier or for the consumer.

Case A2

For this case, a simulation was made with the utility voltage showing a predefined distortion pattern, as shown in Table 10, and with the consumer being represented by its linear and non-linear loads.

Figure 8 shows the simulated electrical network for this case.

With the insertion of the equipment with wave rectifier, it is expected that there will be harmonic distortions of responsibility of the concessionaire and the consumer. The results are in Table 10.

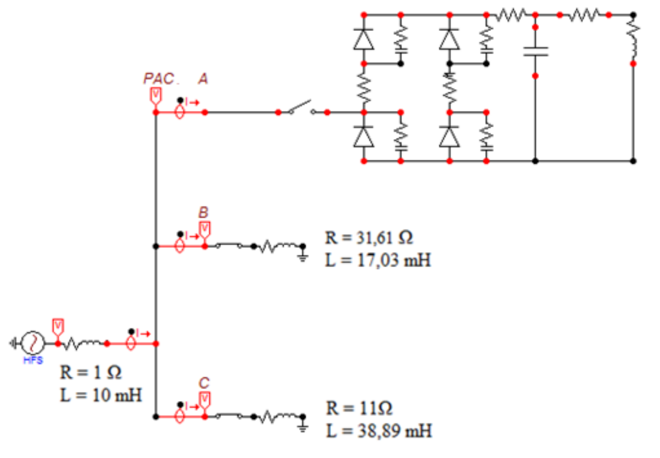


Figure 7: Electrical network representation studied at ATPDraw for the A1 Case.

Harmonic	Voltage		Current	
	Amplitude [Vrms]	Phase [º]	Amplitude [Arms]	Phase [º]
1	100,6173	-8,55	8,0908	-46,83
3	8,7313	-11,31	0,3968	-62,60
5	5,9810	-10,91	0,2036	-69,83
7	3,7910	-9,55	0,1027	-74,42
11	1,8034	-7,11	0,0340	-79,51
13	0,8915	-6,23	0,0145	-81,02
	THDv%	11,35 %	**THDi%**	5,67 %

Table 7: Results of Harmonic Distortions in The Pac For Case A1.

Harmonic	Module [rms]	Angule [°]
V1	100,6173	-8,55
I1	8,0908	-46,83
V3	8,7313	-11,31
I3	0,3968	-62,60
V5	5,9810	-10,91
I5	0,2036	-69,83
V7	3,7910	-9,55
I7	0,1027	-74,42
V11	1,8034	-7,11
I11	0,0340	-79,51
V13	0,8915	-6,23
I13	0,0145	-81,02

Table 8: Case A1 Current Results and Harmonic Voltages by the Current Method of Conformity and Non-Conforming Current.

Superposition method

As already mentioned, in this case where the simulated electrical system has harmonic generation on both sides of the PAC, it was expected that the attribution of responsibility would be balanced, with the supplier and the consumer being held responsible in a similar way. Table 11 shows the results obtained by this method.

The results presented in Table 11 are according to the expectations with the distortions being assigned for parties, supplier and consumer, as the system has injection of harmonic are loads which are considered harmonic generators.

Citation: Lugo AJ (2019) Harmonic Distortion Responsibility Attribution between Utility and Specific Low-Tension Costumer – Case Study. J Electr Electron Syst 8: 297. doi: 10.4172/2332-0796.1000297

Har-mo-nic	I conform			I non-conform		
	Module [Arms]	Angule [°]	%	Module [Arms]	Angule [º]	%
V1 / I1	8,090	-46,8	8,09	-	-	-
V3 / I3	1,164	-23,3	56,6	0,893	172,9	43,4
V5 / I5	0,797	-22,9	54,2	0,675	169,7	45,8
V7 / I7	0,505	-21,5	52,9	0,451	168,8	47,1
V11 / I11	0,240	-19,1	51,6	0,225	168,3	48,4
V13 / I13	0,118	-18,2	51,3	0,113	168,2	48,7

Table 9: Case A1 – Evaluation of the attribution of responsibilities by the current method of conformity and current non-conforming.

Harmonic	Voltage		Current	
	Amplitude [Vrms]	Phase [º]	Amplitude [Arms]	Phase [º]
1	100,617	-8,55	8,090	-46,83
3	8,731	-11,31	0,396	-62,60
5	5,981	-10,91	0,203	-69,83
7	3,783	-9,55	0,102	-74,42
11	1,803	-7,11	0,034	-79,51
13	0,891	-6,23	0,014	-81,02
	DHTv	**10,70 %**	**DHTi**	**7,80 %**

Table 10: Results of Harmonic Distortions on the PAC of case A2.

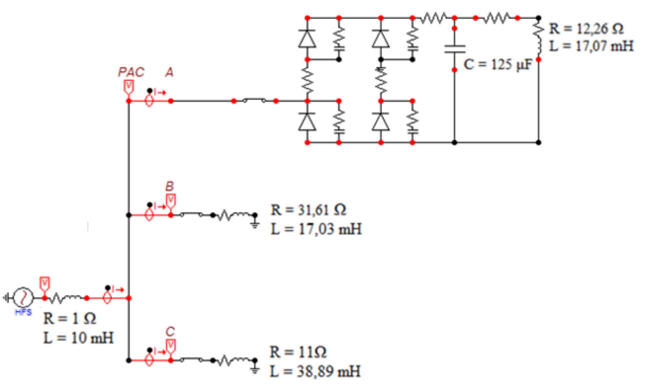


Figure 8: Electrical network representation studied at ATPDraw for case A2.

Harmo-nic	Vc-proj-h			Vs-proj-h		
	Modu-le	Angule [°]	%	Modu-le	Angule [°]	%
3	3,230	-11,31	36,8	5,538	-11,31	63,2
5	3,987	-10,91	47,2	4,459	-10,91	52,8
7	3,024	-9,55	50,1	3,014	-9,55	49,9
9	1,429	-7,11	52,5	1,291	-7,11	47,5
11	0,686	-6,23	55,2	0,556	-6,23	44,8

Table 11: Case A2 - evaluation of the attribution of responsibilities by the surplus method.

Conclusion

In order to evaluate the attribution of harmonic distortion in the Common Coupling Point (PAC), this monograph sought to apply three methodologies known in the literature: Harmonic Power Method, the Nonconforming and Conforming Current Method and Superposition Method.

The Harmonic Power Method proved to be sensitive in certain situations, where any variation in the harmonic measurement as problems in the accuracy of the measuring devices could lead to a misattribution. The calculated harmonic power angle is a very delicate parameter in this method, which leads to inaccurate results in regions of + 90°. This method is not used to attribute harmonic liability, since it does not separate the parcels, but is effective in assessing the predominant origin of the distortions.

The Conform and Non-conforming Current Method was evaluated from the point of view of its fundamentals, applicability and finally, attribution of responsibility for harmonic distortions. For the application of this method, it was initially considered a premise that what we know does not match the theory of electric circuits. Charges that do not produce harmonics, by simplification, are considered with constant impedance for any frequency, which is not true in inductive and capacitive elements. In addition, this method separates what is distorted current from non-distorted current, but it does not assign responsibility for the parties involved.

The Superposition Method seeks to clearly evaluate the attribution of harmonic responsibility. For this, the equivalent impedance of the consumer and the supplier (concessionaire) is calculated first by calculating the parameters R, L and C for the consumer. At this point the method is very sensitive, since the determination of the exact parameters of the consumer is very difficult, since the loads are constantly changing. The results obtained are consistent with the expected results for all three cases.

Acknowledgement

I thank everyone who fought for the idealization and implementation of the Universidade Federal do ABC in Santo André, an important work center and now of scientific production for Brazil. I thank Dr. Celso Setsuo Kurashima for his contribution to the analysis of the data worked on this project. I thank in particular my counselor Dr. Fabiana Aparecida de Toledo Silva for having guided me, charged me and helped me throughout this work.

References

1. Arrillaga J, Watson NR (1985) Power System Harmonics. 2nd Edition, Christchurch, New Zeland, John Wiley & Sons.
2. Ciurro N (2009) Harmonics in Industrial Power Systems. Qual-Tech Engineers.
3. Leão RPS, Sampaio RF, Antunes FLM (2014) Harmônicos em sistemas 3elétricos. Rio de Janeiro: Elsevir.
4. Pires FA de C (1991) A contribution to the study of harmonics in power systems. Thesis (Doctorate) Electrical Engineering Course, Department of Control and Energy Systems, University State of Campinas, Campinas.
5. Santos AC dos (2015) A contribution to the process of sharing responsibilities over harmonic distortions via the switching of capacitive units. Federal University of Uberlândia, Uberlândia.
6. Santos IN (2011) Modified superposition method as a new proposal for assigning responsibilities over harmonic distortions. Federal University of Uberlândia, Uberlândia.
7. Santos IN (2007) A contribution to the performance evaluation of the main methods for assigning responsibilities over harmonic distortions 95 f. Dissertation (Master in Engineering) - Federal University of Uberlândia, Uberlândia.

8. Silva LCE da (2008) Effects of harmonic distortions (voltages and currents) and imbalances (voltages) on three-phase active electric metersDissertation (Master) – Electrical Engineering Course, University of São Paulo, Ilha Solteira.

9. Silva SF de P (2007) A proposal for sharing responsibilities over harmonic distortions. 106 f. Thesis, Federal University of Uberlândia, Uberlândia.

10. Srinivasan K (1996) On Separating Customer and Supply Side Harmonic Contribution. IEEE Trans Power Deliv 11: 1003-1012.