https://dx.doi.org/10.22161/ijaers.6745 ISSN: 2349-6495(P) | 2456-1908(O)

Use of Simple Linear Regression Models to Analyze the Contribution of Non-linear Loads in the Harmonic Distortions of Voltage in an Electric System Bus: Case Study

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***Abstract*— *A new harmonic data distribution window was developed, through the collection of data from the distribution network, in a medium voltage substation of level 13.8 kV. The objective of this article is to obtain a study on the energy for the consumer units (UCs), for a minimum period of 7 consecutive days according to the PRODIST, electrical system. The harmonics are not as harmful for firms as for power distribution company. A technique developed of this article is a linear regression technique, which is a construction of parametric models and a mathematical analysis. This is an article published and applied in the practice of case studies of harmonic analysis of electric energy distribution systems through linear regression analysis, obtaining great results in the study, thus validating an applied technique in harmonic analysis of electric power distribution systems.*
***Keywords*— Linear Regression, Quality Power, Harmonic Distortions, Non-linear loads.**

I. INTRODUCTION

It is undisputed that the dispersed use of non-linear electric charges in residential, commercial and industrial class consumers is contributing significantly to the increase in voltage harmonic distortion in electrical systems, as can be seen in electrical systems worldwide. [1] states that worldwide power supply is becoming a source of harmonic currents with pollution caused by modern electronic equipment, causing interference with communication systems, generating extra losses of electrical energy in the wiring, overload in transformers or in the electrical systems themselves, and besides that, causes the conduction of a high level of reactive power, thus adding more charges on electric bills to consumers due to this pollution.

According to [2], with the intention of maintaining a harmonious coexistence between sensitive equipment and equipment, it is necessary to establish limits and standards to control such talents or phenomena. They are: Institute of Electrical and Electronic Engineers (IEEE) in the United States, International Electrotechnical commission (IEC), Europe and Proceedings of Distribution of National Electrical Energy (PRODIST) in Brazil.

The standards cited above define the reference values for the electric power quality indicators, for example, the PRODIST module defines indicators limited for voltage harmonic distortion, which restrict the levels of harmonic distortion of voltage in the electric net within a limit that would not cause damages to the quality of the electric energy, thus not affecting the operation of the electrical devices, electronics and equipment connected to the electric net. A good prevention for possible voltage distortions in the electrical system is make the dealership perform a constant monitoring in the electrical net in order to identify suspect loads that may be contributing significantly to the harmonic distortion of voltage at some points or specific feeders of interest to the electric system. Therefore, the dealership need to use methodologies that help them in identifying which non-linear loads between the loads connected to the grid are most significant for increasing the harmonic distortions of voltage at specific points in the electrical system or PCC. In the case of this article the contribution of a feeder to the harmonic distortion of a busbar system of an electric system is

https://dx.doi.org/10.22161/ijaers.6745 ISSN: 2349-6495(P) | 2456-1908(O)

analyzed, thus allowing the implementation of a specific treatment for the consumers served by this feeder seeking corrective actions to alleviate the problem that the harmonic currents cause in the electrical system, which are the violations of the voltage harmonic distortion indicators in the electrical systems.

It is important to emphasize that although there are documents that contemplate subjects related to reference values, measurement procedures, protocols, etc., there are still few researches with applications of methodologies to quantify the percentage of contribution to harmonic distortions of tension to be attributed to dealership and customer in Brazil, as well as there is no norm for current harmonic distortion in Brazil, and once a violation of the reference values of the current norms has been found, the use of a methodology to identify the percentages of contribution of each of the parties, both of electric power dealership and consumers, thus assigning responsibilities to both. Thus, this paper suggests a methodology of analysis, with the construction of parametric regression models called simple linear regression, using harmonic voltage magnitude at the point of interest and magnitude of harmonic current in each feeder under study. This analysis is performed using the statistical metric R-squared (R^2) to evaluate the relevance of the respective correlation model.

The structure of this article is as follows: in Section 2, the mathematical model of the electric network is formulated and the linear regression method is presented; In Section 3, the methodology proposed to estimate the harmonic contribution of the feeder of the electric system under study is formulated; in Section 4, this methodology is applied in a case study of an actual electrical system; and Section 5, the main conclusions of this article are presented.

II. MATHEMATICAL MODEL OF THE DISTRIBUTION NETWORK

According to [3], a distribution network can be represented by the matrix impedance matrix in (1), such as:

$$\boldsymbol{E^h} = \boldsymbol{Z^h}.\boldsymbol{I^h} \tag{1}$$

where $\boldsymbol{E^h}$ is the n-dimensional complex harmonic voltage vector of order *h*, with magnitude $\boldsymbol{V^h}$ and phase angle θ^h; $\boldsymbol{I^h}$ is the n-dimensional vector of complex harmonic current injections of order *h*, with magnitude I^h and phase angle φ^h; $\boldsymbol{Z^h}$ is the complex matrix of harmonic impedance of order *h*.

Analyzing that it is desirable to determine the contribution of the harmonic current $\boldsymbol{I^h_{fAl}}$ of phases A, B and C of three feeders of an actual electric system for harmonic distortion of voltage in a bus ***i*** of the electric system, can be written as:

$$\boldsymbol{E^h_i} = \boldsymbol{Z^h_{ifAl}}.\boldsymbol{I^h_{fAl}} + \sum_{k=1}^{n} \boldsymbol{Z^h_{ik}}.\boldsymbol{I^h_k} \tag{2}$$

In which,
h – harmonic order
Al - Feeder
f – phases of the feeders ***Al***
Or, optionally, as:

$$\boldsymbol{E^h_i} = \boldsymbol{E^h_{ifAl}} + \boldsymbol{E^h_{iB}} \tag{3}$$

In which $\boldsymbol{E^h_{ifAl}} = \boldsymbol{Z^h_{ifAl}}.\boldsymbol{I^h_{fAl}}$ is the harmonic distortion of voltage due to the current of the feeder $\boldsymbol{I^h_{fAl}}$; $\boldsymbol{E^h_{iB}} = \sum_{k=1}^{n} \boldsymbol{Z^h_{ik}}.\boldsymbol{I^h_k}$; The harmonic distortion of background voltage due to other non-linear loads connected to the feeders that are not being monitored. Assuming that the electric net under study can be considered a linear net, then in equation (2) the term $\boldsymbol{Z^h_{ifAl}}.\boldsymbol{I^h_{fAl}}$ represents the harmonic distortion due to the non-linear loads connected to the feeder *Al* monitored, while the term sum represents the background contribution due to other non-linear loads connected in unmonitored feeders. However, in a power grid it is often not valid due to the magnetic saturation of reactors and transformers, which can also introduce harmonic distortions of voltage $\boldsymbol{E^h_i}$.

In equation 2, the contribution of each harmonic current $\boldsymbol{I^h_{fAl}}$ to the harmonic voltage $\boldsymbol{E^h_i}$ can be exactly determined if the transfer impedance $\boldsymbol{Z^h_{ifAl}}$ is known for each operational condition, which is not trivial to obtain this information in electrical systems real. Thus, direct application (2) is not a trivial task since it is necessary to have a detailed description of the connected non-linear elements in the electrical network, requiring simultaneous measurements of voltage and current magnitudes and phases in the feeders under study. Often utilities measure only the harmonic magnitudes of voltage and current, that is, $\boldsymbol{V^h_i}$ and $\boldsymbol{I^h_{fAl}}$ which in this case, the most practical and direct way of obtaining an indication of the contribution to the harmonic distortion of voltage is $\boldsymbol{E^h_i}$ due to the harmonic current injected into the feeder *Al* $(\boldsymbol{I^h_{fAl}})$ is identifying a regression model to express a correlation between $\boldsymbol{V^h_i}$ and $\boldsymbol{I^h_{fAl}}$. It is well known that statistical models do not necessarily represent a causal relationship, but if they present a high correlation between two

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variables, it means that one variable can explain the behavior of the other. Considering this characteristic, statistical model will be developed to evaluate the relationship between E_i^h and I_{fAl}^h of each phase of the electrical system feeder under study using parametric simple linear regression model.

2.1. MODEL OF SIMPLE LINEAR REGRESSION

The simple linear regression model is used to describe the relationship between a response variable (V_i^h) and a quantitative explanatory variable (I_{fAl}^h) and takes the form of a straight line through the scattering of points that arise when the values of variables are plotted in relation to the values of the explanatory variable. This model can be represented by equation (4) [3]. According to [4], the most common method to find the regression line is the least squares. This method calculates the better fit line for the observed data, minimizing the sum of the squares of the vertical distances from each point to the line.

$$V_i^h = \beta I_{f,Al}^h + \alpha + \epsilon \quad (4)$$

Where V_i^h is the magnitude of the harmonic voltage of order h in bus i; I_fAl^h is the magnitude of the harmonic current injection of order h in phase f of the feeder Al; β and α are the first order slope and intercept parameters; ε is the model error, which is characterized by a Gaussian distribution with mean zero and variance equal to σ^2. In equation (4), when the harmonic current I_fAl^h, is zero, α represents the background harmonic voltage, which is considered constant during the analysis period.

The least squares principle uses (5) and (6) to calculate the regression parameters β and α, respectively, as [5].

$$\beta = \frac{\sum_{i=1}^{n}(V_i^h - \bar{V}^h)(I_{fAl}^h - \bar{I}^h)}{\sum_{i=1}^{n}(I_{fAl}^h - \bar{I}^h)^2} \quad (5)$$

$$\alpha = \bar{V}^h - \beta \bar{I}^h \quad (6)$$

Where $\bar{V}^h$ and $\bar{I}^h$ are mean values for V_i^h and I_{fAl}^h.

Once the regression model is constructed using simple linear regression, it is necessary to evaluate this model through the analysis of the variance, in order to certify if the regression model obtained is adequate to explain the relation between the dependent variable and the independent variables. The analysis of variance is a statistical tool that, through statistical inference techniques, analyzes two main assumptions: the null assumption, which means the possibility of the parameter β (slope of the line) is null; and the alternative assumption, which means that the same parameter can not be null [6].

In the analysis of variance, three essential parameters are obtained: the total sum of squares (SS_{Total}), the sum of squares of error (SS_{Res}) and the sum of squares of regression (SS_{Reg}). These parameters are calculated by equations (7), (8) and (9), respectively.

$$SS_{Total} = \sum_{i=1}^{n}(V_i^h - \bar{V}^h)^2 \quad (7)$$

$$SS_{Reg} = \sum_{i=1}^{n}(\hat{V}_i^h - \bar{V}^h)^2 \quad (8)$$

$$SS_{Res} = \sum_{i=1}^{n}(V_i^h - \hat{V}_i^h)^2 \quad (9)$$

In which:

$\hat{V}_i^h$ – is the estimated value of the variable V_i^h by the regression model;

$\bar{V}^h$ – is the hope of the variable V^h;

V_i^h – is the value of the variable V^h used to construct the regression model.

III. MATERIALS AND METHODS

As mentioned briefly in the introduction, the main objective of this work is to present a parametric regression model applied in the analysis of the contribution of harmonic currents injected into a feeder of an electric system for harmonic distortions of voltage in the electric network. The technique used in the methodology of this article is the simple linear regression technique, which has as a characteristic the construction of parametric models and simple mathematical calculation. The metric used to validate the models is the coefficient of determination R^2. With the parameters, SS_{Total}, SS_{Res}, SS_{Reg}, the value of the reliability indicator of the constructed model, known as the determination coefficient R^2, is calculated. According to [7], the coefficient of determination R^2 is the ratio of the total sum of the squares of the dependent variable to the independent variables in the model, according to equation 10. The coefficient of determination R^2 is used to measure the correlation intensity between the response and the independent variables in a regression model and based on the R^2 value, one can reject the regression model or not.

$$R^2 = \frac{SS_{Reg}}{SS_{Total}} = \frac{\sum_{i=1}^{n}(\hat{V}_i^h - \bar{V}^h)^2}{\sum_{i=1}^{n}(V_i^h - \bar{V}^h)^2} = 1 - \frac{SS_{Res}}{SS_{Total}} \quad (10)$$

Where $\hat{V}_i^h$ is the estimated value obtained by the linear method V_i^h while $\bar{V}^h$ is the mean value for the time series of measurements. The correlation intensity associated

https://dx.doi.org/10.22161/ijaers.6745 ISSN: 2349-6495(P) | 2456-1908(O)

with the R^2 value is presented in table 1. [8] explains, if R^2 = 0%, indicates that the model does not explain any variability of the response around its average, while R^2 = 100% means that the model explains all the variability of the response data around its average.

Table 1. Correlation Intensity R^2.

Value of R^2	Correlation intensity
0,00	Null
(0,00 – 0,09)	Low
0,09 – 0,36)	Moderate
(0,36 – 0,81)	High
(0,81 – 0,98)	Very high
1,00	Perfect

Source: Authors, (2019).

As can be seen in Table 1, the higher the R^2, the stronger the correlation intensity and the more adequate the regression model to represent the data. The use of R^2 can identify where the main harmonics are, but can not quantify the harmonic contribution of these harmonic sources. This calculation can be obtained by calculating the harmonic percentage impact for each harmonic source and the respective precedents as in [9]. The use of the linear regression technique is justified by the computational simplicity in the creation of the models, since the simplicity of such models helps to ensure that the constructed regression models are easy to interpret, thus obtaining a faster response time. The procedures adopted to collect data from the electric system are shown in figure (1).

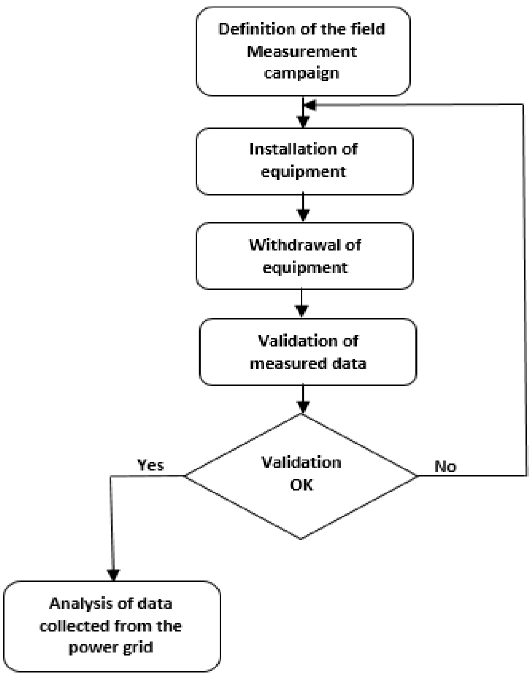

Fig.1: Design the search.

Source: Authors, (2019).

3.1. DEFINITION OF THE FIELD MEASUREMENT CAMPAIGN

This paper was based on field-synchronized measurement campaigns on a feeder and bus of the electrical power system under study, using a properly calibrated DHT Energy Quality Analyzer, which will measure the levels of harmonic distortions present in the signal. The objective is to analyze the impacts of the harmonic currents injected in this feeder to the harmonic distortions of voltage in a bus of the electric system. Measuring time: 7 days. Intervals of each measurement: 10 minutes.

3.2. INSTALLATION OF EQUIPMENT

The energy quality analyzers were installed in medium voltage.

The power quality analyzers were installed in the medium voltage substation booth using the secondary CT and TPS. The power quality analyzer remained installed for a minimum of 7 continuous days, according to PRODIST module 8 / ANEEL.

3.3. WITHDRAWAL OF EQUIPMENT

The removal of the equipment was always performed on the eighth day of monitoring, so the energy quality analyzer monitored for 7 (seven) complete days and at least up to the 25th harmonic order according to the [10].

3.4. ANALYSIS OF DATA COLLECTED FROM THE POWER GRID

The analyzes of the data collected were performed respecting the limits for total and individual harmonic distortions described in [10], [11] and [12], and applying the simple linear regression technique, seeking the correlation between the harmonic currents injected into the feeders and the distortion harmonic in a bus of the electric system under study. In the next sections, the proposed methodology is applied to the data of a feeder and a bus of an actual electrical system, presented as case study. A case study will be performed, which consists of analyzing the harmonic impacts of the feeder under study for harmonic distortion of voltage in the bus. The analysis to be presented will focus on the third, fifth and seventh harmonics only thus covering the three harmonic sequences, positive, negative and zero.

IV. RESULTS

The results were obtained through a case study carried out in the electric system of an electric power utility. In order to evaluate the methodology proposed previously, a study was made in a feeder and a bus of the electrical system in order to determine the influence of some nonlinear loads on the harmonic distortion of the busbar under study, as shown in figure (2).

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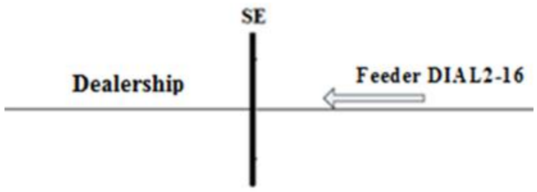

Fig.2: Identification of the harmonic impact of the feeder under study in a common bus of a substation.

Source: Authors, (2019).

During the studies in the system, tensions and harmonic currents were obtained in the study feeder, which allowed the construction of regression models that described the relationship between these quantities.

The analyzes were carried out with measurements collected in the period from May 15, 2017 to May 22, 2017. During this period a measurement campaign was carried out in the substation of voltage level 13.8 kV of the power distribution company under study, in which two QEE analyzers to perform simultaneous measurements at the following measuring points: DITF4-04 transformer; and DIAL2-16 feeder.

Figure (3) shows the single line diagram of the substation under study and the location of the energy quality analyzer installation points (blue circle points) for this measurement campaign, totaling two simultaneous measurement points. The purpose of installing the QEE analyzer on the DITF4-04 transformer is to monitor the harmonic voltage on the DIBR2-03 (green circle) bar. These analyzes sought to evaluate the correlation between the harmonic currents of order 3a, 5a and 7a of the DIAL2-16 feeder and the harmonic voltages of the same order in the DIBR2-03 (13.8 kV) bar of this substation and thus covering the three sequences, zero (3rd), negative (5th) e positive (7th).

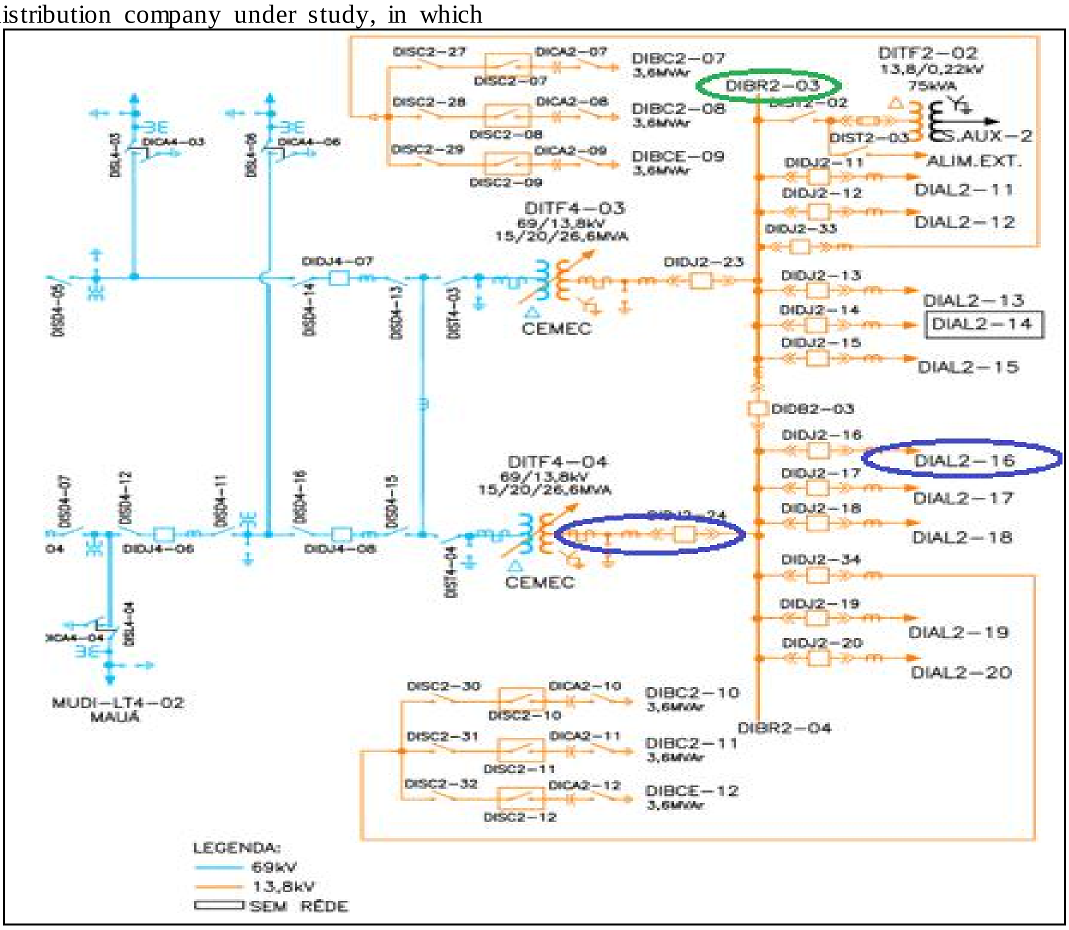

Fig.3: Single-line diagram of substation points under study.

Source: Authors, (2019).

4.1. CASE STUDY

The case study presents the harmonic impact study between the harmonic current of orders 3rd, 5th e 7th of the DIAL2-16 feeder and the same order harmonic voltage of the DIBR2-O3 bar, see figure 3.

4.1.1. IMPACT ANALYSIS BETWEEN THE HARMONIC CURRENT OF THE 3RD ORDER OF THE DIAL2-16 FEEDER AND THE HARMONIC VOLTAGE IN THE SAME ORDER ON THE DIBR2-03 BAR

https://dx.doi.org/10.22161/ijaers.6745 ISSN: 2349-6495(P) | 2456-1908(O)

Based on the field measurement data, Table 2 shows the percentage impact of the 3rd order harmonic current on the DIBR2-03 bar of phases A, B and C of the DIAL2-16 feeder in relation to the background (VBG - unmeasured feeders) using the linear regression technique. Analyzing the values of the metric R^2, it is observed that the phases A and B present high intensity of correlation and low intensity of correlation in phase C whose R^2 is 0,043. Table 2 indicates that phase A is responsible for about 37% of the harmonic distortion impact on the DIBR2-03 bar caused by the harmonic currents injected into the DIAL2-16 feeder in relation to the VBG, phase B is responsible for about 100% in relation to VBG and phase C is responsible for about 12% in relation to VBG.

Table 2. Load Porch, Coefficient of determination and Impact factor.

Load Porch - Morning and Afternoon			
STARTING TIME		FINAL TIME	
00:00:00		14:00:00	
METRICS	PHASE A	PHASE B	PHASE C
R^2	00,526	00,385	00,043
Impact Factor (%)			
VOLTAGE	PHASE A	PHASE B	PHASE C
VT	37,225	104,527	12,367
VBG	62,775	-04,527	87,633

Source: Authors, (2019).

The simple linear regression models between the harmonic currents of the 3rd order and the same order of harmonic voltage of the DIBR2-03 bar in phases A, B and C are shown in Figures 4, 5 and 6, respectively.

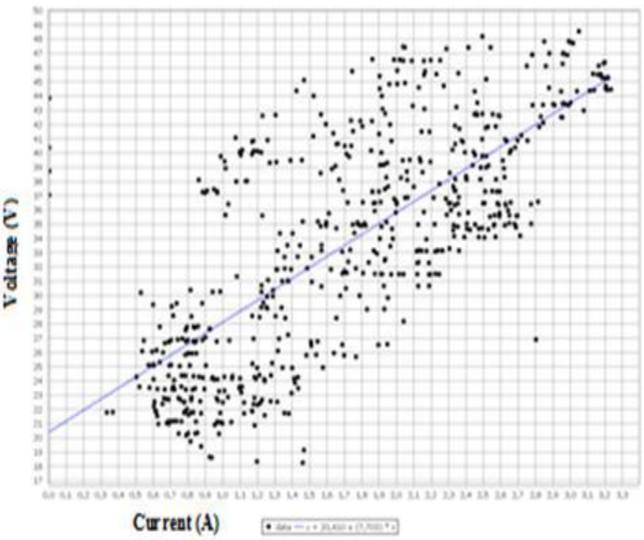

Fig.4: 3rd harmonic of PHASE A.
Source: Authors, (2019).

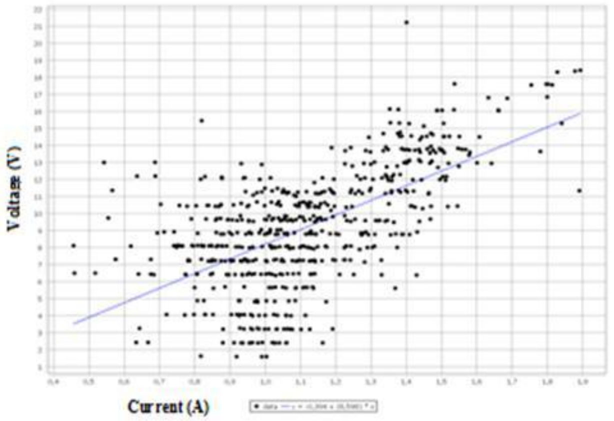

Fig.5: 3rd harmonic of PHASE B.
Source: Authors, (2019).

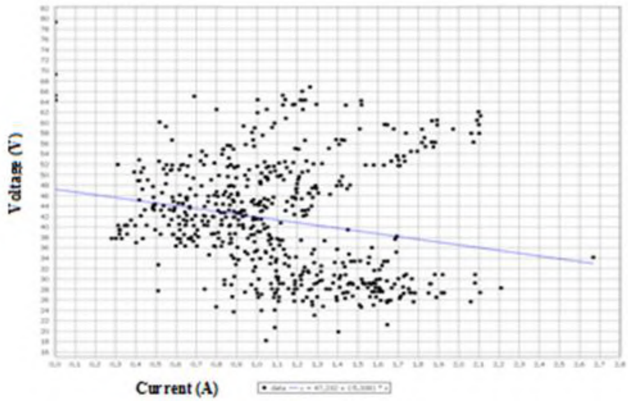

Fig.6: 3rd harmonic of PHASE C.
Source: Authors, (2019).

The regression models of Figures 4, 5 and 6 are represented by equations 11, 12 and 13 respectively.

$$V^{3h}_{A,16} = 20{,}410 + (7{,}703).I^{3h}_{A,16} \quad (11)$$

$$V^{3h}_{B,16} = -0{,}394 + (8{,}598).I^{3h}_{B,16} \quad (12)$$

$$V^{3h}_{C,16} = 47{,}232 + (-5{,}338).I^{3h}_{C,16} \quad (13)$$

4.1.2. ANALYSIS OF IMPACT BETWEEN THE HARMONIC CURRENT OF THE 5TH ORDER OF THE DIAL 2-16 AND THE HARMONIC VOLTAGE OF THE SAME ORDER IN THE DIBR2-03 BAR

Based on the field measurement data, Table 3 presents the percent impact of the 5th order harmonic current on the DIBR2-03 bar of phases A, B and C of the DIAL2-16 feeder in relation to the VBG using the linear regression technique. Analyzing the values of the R^2 metric, it can be observed that the phases A and C have zero correlation intensity and very high correlation intensity in phase B whose R^2 is 0.875. Table 3 indicates that phase B is responsible for about 72% of the harmonic distortion impact on the DIBR2 - 03 bar caused by the harmonic

https://dx.doi.org/10.22161/ijaers.6745 ISSN: 2349-6495(P) | 2456-1908(O)

currents injected into the DIAL2 - 16 feeder in relation to the VBG and the impacts of phases A and C are lows close to zero.

Table 3. Load Porch, Coefficient of determination and Impact factor.

Load Porch - Morning and Afternoon			
STARTING TIME		FINAL TIME	
00:00:00		14:00:00	
METRICS	PHASE A	PHASE B	PHASE C
R^2	00,000	00,875	00,000
Impact Factor (%)			
VOLTAGE	PHASE A	PHASE B	PHASE C
VT	00,575	72,239	00,619
VBG	99,425	27,761	99,381

The simple linear regression models between the 5th order harmonic currents and the same order of harmonic voltage of the DIBR2-03 bar in phases A, B and C are shown in Figures 7, 8 and 9, respectively.

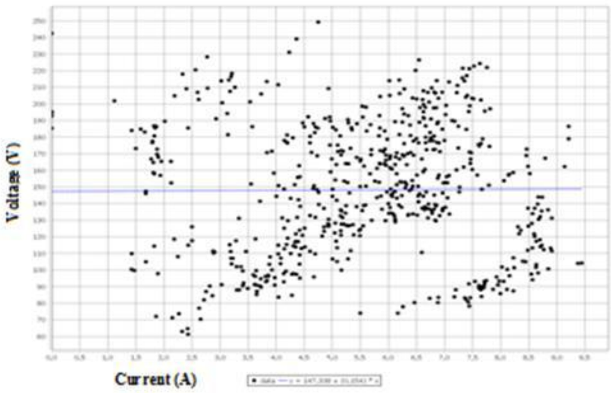

Fig.7: 5th harmonic of PHASE A.
Source: Authors, (2019).

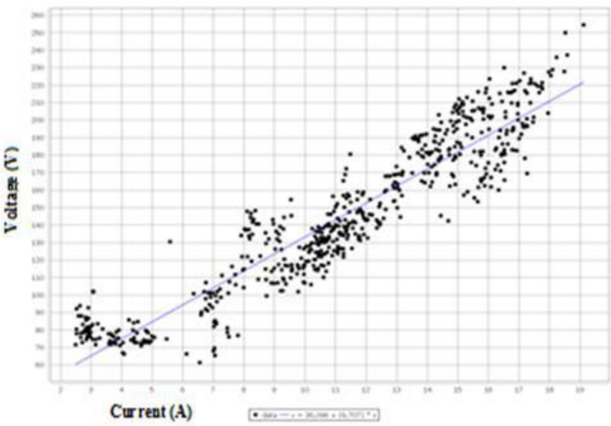

Fig.8: 5th harmonic of PHASE B.
Source: Authors, (2019).

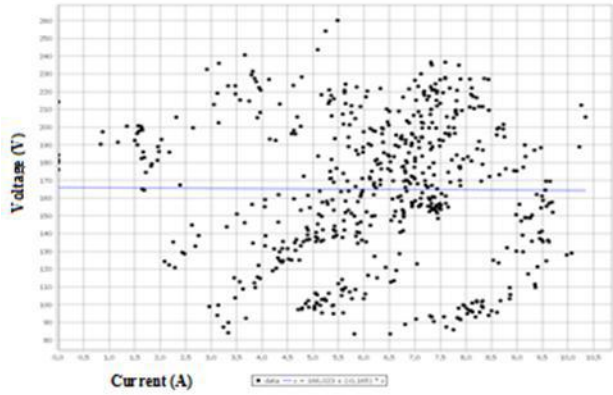

Fig.9: 5th harmonic o f PHASE C.
Source: Authors, (2019).

The regression models of Figures (7), (8) and (9) are represented by equations 14, 15 and 16 respectively.

$$V_{A,16}^{5h} = 147{,}338 + (0{,}154).I_{A,16}^{5h} \quad (14)$$

$$V_{B,16}^{5h} = 36{,}096 + (9{,}707).I_{B,16}^{5h} \quad (15)$$

$$V_{C,16}^{5h} = 166{,}023 + (-0{,}165).I_{C,16}^{5h} \quad (16)$$

4.1.3. ANALYSIS OF IMPACT BETWEEN THE HARMONIC CURRENT OF THE 7TH ORDER OF THE DIAL2-16 AND THE HARMONIC VOLTAGE OF THE SAME ORDER IN THE DIBR2-03 BAR

Based on the field measurement data, Table 4 presents the percentage impact of the 7th order harmonic current on the DIBR2-03 bar of phases A, B and C of the DIAL2-16 feeder in relation to the VBG using the linear regression technique. Analyzing the values of the R^2 metric, it is observed that the phases A have low correlation intensity, phase B presents very high correlation intensity whose R^2 is 0.896 and in phase C it presents high intensity of correlation. Table 4 indicates that phase A accounts for about 12% of the harmonic distortion impact on the DIBR2-03 busbar caused by the harmonic currents injected into the DIAL2-16 feeder in relation to the VBG, phase B is responsible for about 96% in relation to VBG and phase C is responsible for about 56% in relation to VBG.

Table 4. Load Porch, Coefficient of determination and Impact factor.

Load Porch – Morning and Afternoon			
STARTING TIME		FINAL TIME	
00:00:00		14:00:00	
METRICS	PHASE A	PHASE B	PHASE C
R^2	00,057	00,896	00,581
Impact Factor (%)			
VOLTAGE	PHASE A	PHASE B	PHASE C
VT	12,307	96,059	56,726
VBG	87,693	03,941	43,274

Source: Authors, (2019).

https://dx.doi.org/10.22161/ijaers.6745 ISSN: 2349-6495(P) | 2456-1908(O)

The simple linear regression models between the harmonic currents of the 7th order and the same order of harmonic voltage of the DIBR2-03 bar in phases A, B and C are shown in Figures 16, 17 and 18, respectively.

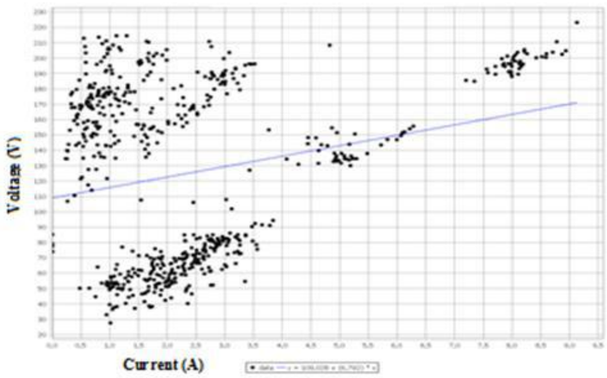

Fig.10: 7th harmonic of PHASE A.
Source: Authors, (2019).

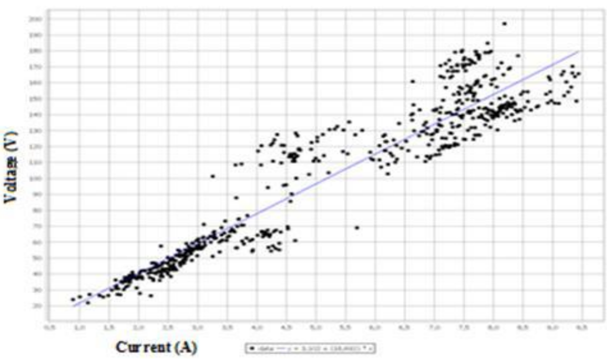

Fig.11: 7th harmonic of PHASE B.
Source: Authors, (2019).

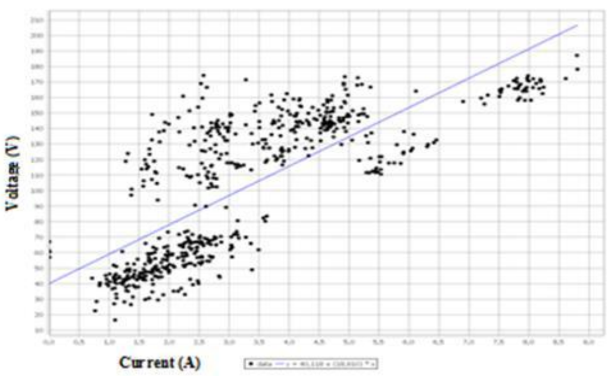

Fig.12: 7th harmonic of PHASE C.
Source: Authors, (2019).

The regression models of Figures 10, 11 and 12 are represented by equations 17, 18 and 19 respectively.

$$V_{A,16}^{7h} = 109{,}028 + (6{,}792).I_{A,16}^{7h} \quad (17)$$

$$V_{B,16}^{7h} = 3{,}102 + (18{,}692).I_{B,16}^{7h} \quad (18)$$

$$V_{C,16}^{7h} = 40{,}118 + (18{,}910).I_{C,16}^{7h} \quad (19)$$

V. RESULTS AND DISCUSSION

In this topic it is measured out the contributions of the feeder studied for the increase of harmonic distortion of voltage in the DIBR2-O3 bar. In the case study 1, the contribution of the DIAL2-16 power supply to the harmonic distortion of the DIBR2-03 bar was analyzed during the analysis, and it was verified that the phases A and B of the 3rd order harmonic current are strong contributors to the voltage harmonic distortion in the DIBR2-03 bar and phase C of the 3rd harmonic has low contribution, phase B of the 5th harmonic is a very strong contributor to the increase in distortion in the DIBR2-03 bar, phases A and C of the 5th harmonic has very low contribution close to zero, and that phases B and C of the 7th harmonic are strong contributors to voltage harmonic distortion in the DIBR2-03 bar and phase A of the 7th harmonic has very low contribution close to zero.

Table 5 presents the occurrence of the contribution in the increase of the voltage harmonic distortion in the busbar DIBR2-03 in the orders 3a, 5a and 7a caused by the phases A, B and C of the feeder DIAL2-16. In red the repetition of occurrences in the three harmonic orders.

As can be seen in table 8, the contribution of phase B of the feeder 16 occurs in the three harmonic orders analyzed with strong contributions, causing malfunction in the loads sensitive to the three harmonic sequences in phase B.

Table 5. Contribution in the increase of the voltage harmonic distortion in the busbar DIBR2-03.

Contribution to the harmonic distortion of the voltage in the busbar DIBR2-03	AL 16		
	PHASES		
3rd harmonic	A	B	C
MF			
F	X	X	
M			
B			X
MB			
NC			
5th harmonic	A	B	C
MF		X	
F			
M			
B			
MB	X		X
NC			
7th harmonic	A	B	C
MF			
F		X	X
M			

B			
MB	X		
NC			

Where:
MF – Very Strong
F – Strong
M – Moderate
B – Low
MB – Very Low
NC – No Contribution

VI. CONCLUSION

This paper presents a study on the investigation of harmonic sources in electric power distribution systems through the application of simple linear regression analysis in feeders of an electrical system under study.

Using the simple linear regression technique, the harmonic impacts of nonlinear loads of a feeder on a bus of the electric system were analyzed. The analyzes were carried out through field measurement campaigns for a period of 7 consecutive days. With the data collected from this measurement campaign it was possible to perform a correlation analysis between the harmonic currents injected at the feeder and the harmonic distortion of voltage in the bar of the electric system under study through the simple linear regression technique.

The models constructed were satisfactory for the analysis of the harmonic impacts in the chosen feeder and when the model did not indicate harmonic impacts generated by the harmonic currents injected in the feeder under study, but indicated harmonic impacts generated by the background.

With these analyzes it was possible to create a profile of the DIAL2 - 16 feeder to then mitigate the harmonic distortion of voltage in the DIBR2-03 bus under study, caused by the impacts of the harmonic currents of this feeder, and, in addition, a report of the analysis of the harmonic impacts performed, which serves as a diagnostic document of the feeder studied; thus obtaining a better management of the electric system, motivating the inclusion in energy pricing of the effects of the harmonic content of the nonlinear loads that pollute the power system.

In this way, this article presented and applied in the practice with case study actions for analysis of harmonic impacts in electric energy distribution systems through the construction of mathematical models using simple linear regression analysis, obtaining excellent results in the studies carried out, thus validating the technique applied in analysis of harmonic impacts in electric energy distribution systems.

VII. ACKNOWLEDGEMENTS

We thank for the support and encouragement of the Institute of Technology and Galileo Education of the Amazon - ITEGAM.

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