RESEARCH ARTICLE OPEN ACCESS

Analysis of Harmonic Impacts on an Electric System Bus Using Artificial Neural Networks

Jayne do Nascimento Souza*, Jandecy Cabral Leite**, Rivanildo Duarte Almeida***

**(Post-Graduation Program in Process Engineering of the Institute of Technology of the Federal University of Pará, Federal University of Pará (UFPA), Belém-Pará, Brazil*
*** (Institute of Technology and Education Galileo of the Amazon (ITEGAM), Manaus-Amazonas, Brazil*
**** (Institute of Technology and Education Galileo of the Amazon (ITEGAM), Manaus-Amazonas, Brazil*

ABSTRACT

In this article is presented a methodology to investigate the influence on non-linear charges on the harmonic voltage distortion (THDV) in electric system and to estimate the contribution of non-linear charges on the voltage distortion of a bus of interest of the electric system of force studied in the article. This estimation was accomplished through the construction of a model based on the Artificial Neural Networks (ANN), using the software AAQEE dedicated to electricity quality (EQ) analysis, which the entrance of the model is constituted by the harmonic current deriving from the non-linear charges connected to two feeders which compose the actual system and the exit relating to the values of the harmonic voltage in the bus of interest. This study was fulfilled to the following harmonic currents 5th and 7th individually, and the necessary data to the construction of the model as well as to the validation of the results was acquired from a measurement campaign. The ANN identified the feeder DIAL2-19 as most responsible for the THDV in the studied bus of the electric system, then showing the percentage of the harmonic contribution of each feeder to the THDV in the bus.

Keywords - Electricity quality, Harmonic impacts on electric power systems, Non-linear loads, Computational Intelligence, Neural Networks.

Date of Submission: 22-01-2021 Date of Acceptance: 06-02-2021

I. INTRODUCTION

Through the transformations and discoveries in the new technologies of electronics, which are more and more present on business fields, domestics and industrials, providing more efficiency and speed to the diary activities, we can take as example: microcomputers, laptops, electronic equipment chargers, electric cars, microwaves and other non-linear waves (non-linear relation between voltage and network current) [1-2].

The non-linear charges are sources of harmonic currents which contaminate the electric system with disturbance as distortion on the form of voltage wave [3-4].

Accordingly [5-9], what can lead to impacts on networks are:

a) Low power factor;

b) Distortion of the network voltage on the commune connecting point due to the impedance of the circuit or installation;

c) Overcharge on the neuter conductors due to the sum of the harmonics of third order generated by the single phase charges;

d) Low efficiency;

e) Interference on some instruments and equipments;

f) Over dimensioning of the distributing systems.

g) Overheating on alternating current apparatus due to the skin effect (increase of the copper resistance with frequency), to hysteresis and to parasite currents.

On the long term the presence of harmonics can also cause economic damage. We can take as example: the premature aging of cables and electronic components, being necessary the replacement of the materials before the intended time on the project, overload on the network and untimely discharges leading to stops on the production sectors [10], and besides all this, accordingly [11], the harmonics of the electric networks have negative effects as increase of active force loss, on resonance voltage, increase of the neuter point force of the alternating current apparatus, on the current of three phase networks which can lead to difficulties whereas the selectivity of the production relays and capacitor banks with excessive stress.

For the prevention of disturbances on the electric system it's necessary to monitor periodically the system, so it can be possible to identify which are the suspicious chargers that are injecting significantly harmonic currents on the electric network, causing a increase on the harmonic voltage distortion on some parts of the electric system. The dealerships need to use techniques or methodologies that can assist them to identify which non-linear charges among the charges connected to the network possess a bigger portion of contribution to increase the harmonic voltage distortion on specific parts of the electric system. This research suggests a methodology of analysis, with the construction of models using the technique of computational intelligence Neural Networks. Through this technique it's analyzed the contribution of three feeders to the harmonic voltage distortion in an electric system bus, making it possible a diagnose and specific treatment to the served consumers by this feeder, seeking correcting actions to minimize the violations of the harmonic voltage distortion indicators on the electric systems.

The objective is to estimate and to quantify the harmonic contribution of three feeders to a bus of an electric system using the ANN technique.

The structure of this article is as it follows: on section 2 is accomplished the revising of the literature; on section 3, the purposed methodology to estimate the electric system's feeder's harmonic contribution at study is formulated; on section 4, this methodology is applied on a case study of a real electric system; and on section 5, the main conclusions of this article are presented.

II. LITERATURE REVIEW

2.1 Electricity quality

Nowadays, suddenly, part of the variable charge and the non-linear charge increased significantly, what is more, changes were occurred on the charge compositions, consequently changes were occurred on the EQ indicators' deviation, therefore to monitor and to improve the quality indicators of electricity is of fundamental importance so as to the dealerships as to the consumers, since the efficiency of the electric and electronic devices depend on this [12].

The diffused use of non-linear electric charges on residential consumers, business and industrials is significantly contributing to the harmonic voltage distortion increase on electric systems, as it can be noticed on electric systems all over the world.

The world power supply is transforming into a harmonic currents supply with the pollution caused by modern electronic equipments, generating interference on the communication systems, leading to extra loss of electricity on the cables, overload on the alternating current apparatus or on the electric systems themselves, and besides this, it causes the conduction of a high level reactive power, adding more fees to the electricity bills for the clients due to this pollution [13].

With the purpose of maintaining a mild coexistence between sensitive equipments and equipments, it is necessary to determine limits and norms to control such phenomenons. They are: IEEE 519:2014, G5/4-1, EN 50160:2008, IEC/TR 61000-3-6 and PRODIST (Module 8) [14].

The proceedings of electricity distribution on the national electric system (Procedimentos de Distribuição de Energia Elétrica no Sistema Elétrico Nacional (PRODIST)), were created in Brazil by Agência Nacional de Energia Elétrica (ANEEL). Among the main objectives of the PRODIST there is one responsible to guarantee that the distribution systems operate with safety, efficiency, and reliability. The PRODIST module 8 regulate the power quality on electricity distribution networks and the actual revision of the PRODIST module 8 started to work on January 1st 2018 [15].

The cited norms above have as objective to establish harmonic measurement proceedings and acceptable levels of distortion on the electric networks, as example, In Brazil it was defined in the PRODIST module 8 the indicators that make possible characterize the power quality and establish acceptable levels of these indicators on the electricity distribution systems, which can be highlighted the individual harmonic distortion tax and the voltage total [16].

It is necessary to emphasize that in spite of existing documents which consider themes related to reference limit values, measurement proceedings, protocols etc., yet there are few researches with methodology applications to quantify the contribution percentage to harmonic voltage distortions to be attributed to the dealerships and consumers in Brazil, just as there is no norm for the actual harmonic distortion in Brazil, and once found a violation on the reference values of the actual norms, the use of a methodology to identify the contribution percentage of each part as of the dealerships as of the consumers, attributing responsibility to both.

2.2 Harmonics generating supply

The concern with the EQ and consequently with the harmonics have become frequent for there was a big rise on the non-linear charges (harmonics generating supplies) on the network, since the 90's decade, due to the equipments based on electronics of power [17].

On the electric systems, harmonics is defined as the signal's content in a specific frequency, which is multiple of fundamental frequency of the electric system or the main frequency produced by the generators [18].

The harmonic distortion is caused by non-linear charges on the power system; a non-linear device is that in which the current is not proportional to the applied voltage, that is, having an applied sinusoidal voltage to a simple non-linear resistance with the voltage and current changing while the applied voltage is perfectly sinusoidal, the resulting current is distorted [19].

The Figs. 1 and 2 clarify the relation between voltage and current in a circuit formed by linear and non-linear elements, respectively.

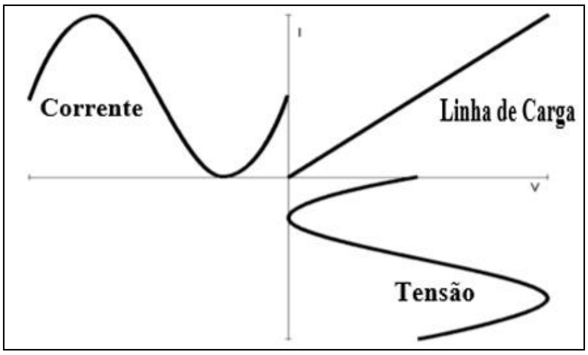

Fig 1. Relationship between voltage and current in a circuit formed by linear elements [14].

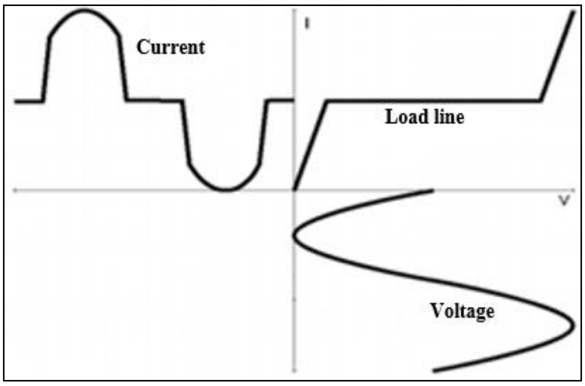

Fig 2. Relationship between voltage and current in a circuit formed by nonlinear elements [14].

2.3 Harmonic distortions

The ideal electricity delivery must invariably provide a voltage signal with wave form perfectly sinusoidal at each delivery point. However, because of several reasons the dealerships cannot maintain such desirable conditions.

The concept of electricity quality is arising as a "basic right" of the electricity user, providing a well functioning of the equipments. The residential or industrial electricity users need free of failure, distortions, scintillation, noise and

interruption electricity. The electricity dealerships desire the users to use equipments of good quality so that there is no abnormality to the electric system. The use of electronic devices in the industrial environment brought flexibility and electricity economy, but on the other hand it caused problems due to the harmonics generating. Both the industrial and residential users use electronic devices based on power commutation that generate harmonic currents. This current is a dominant factor on the production of the harmonic distortion of voltage [22].

The anomalies of the sinusoidal current and voltage wave forms are described in terms of distortion of the wave form, which is mostly manifested as harmonic distortion [23]. The Figs. 3 and 4 show a form of wave without harmonic content and another with harmonic content, respectively.

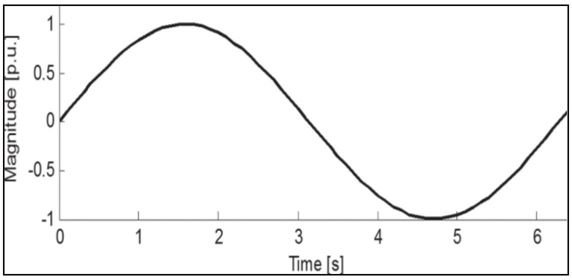

Fig 3. Waveform without harmonic content [18].

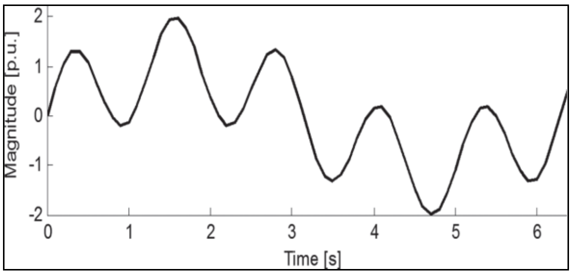

Fig 4. Waveform with harmonic content [18].

To analyze a voltage wave form or current with harmonic content it relies on Fourier's analysis. The Fourier's analysis is the process of time domination wave form transformation into frequency domination wave form, which make possible to institute a simple relation between a time domination function and a frequency domination function [24].

The general representation of Fourier's series with coefficients *a*, b_n, c_n is given as:

$$x(t) = \frac{a}{2} + \sum_{n=1}^{\infty}[b_n \cos(nt) + c_n \sin(nt)] \quad (1)$$

The representation of Fourier's series as a harmonic function is given as:

$$x(t) = \frac{a}{2} + \sum_{n=1}^{\infty}[b_n \cos(2\pi n f_0 t) + c_n \sin(2\pi n f_0 t)] \quad (2)$$

Being:

a = is the DC signal;

a_n e b_n = are Fourier coefficients;

N = is the value of the harmonic order which compose the signal, compounded by integer and positive values.

The evaluation of the harmonic distortion level on transmission and distribution networks is accomplished by indicators denominated total harmonic distortion (THD) and individual harmonic distortion (IHD). THD is designated to current distortion and total voltage distortion. THD to current distortion (THDI) and voltage (THDV) are expressed by the Eqs. (3) and (4), respectively [25]:

$$THDI = \frac{1}{I_1}\sqrt{\sum_{h=2}^{\infty} I_h^2} \quad (3)$$

$$THDV = \frac{1}{V_1}\sqrt{\sum_{h=2}^{\infty} V_h^2} \quad (4)$$

The index of individual harmonic distortion (IHD) presents the percentage of current ratio or voltage in the harmonic order h in relation to the fundamental value. IHDI and IHDV are the IHD to current and voltage, respectively. IHDI and IHDV are expressed by the Eqs. (5) and (6).

$$IHDI = \frac{I_h}{I_1} \times 100 \quad (5)$$

$$IHDV = \frac{V_h}{V_1} \times 100 \quad (6)$$

The consumers of electricity with non-linear characteristics are especially potential on the installation of converters, semiconductor devices, gas discharge light sources, electronics etc., and to analyze the harmonic current influence on the high and low voltage electricity networks which a huge amount of electricity consumers own non-linear characteristics is very much relevant [26]. Fig. 5 presents a force system with sinusoidal voltage supply (V_s) operating with a linear and non-linear charge. The current of the non-linear charge (I_{L1}) contains harmonics. The harmonics in the current of line (I_s) produce a fall of non-linear voltage (Δv) on the impedance of the line which distort the charge voltage (V_L). As the charge voltage is distorted, until the current in the linear charge (I_{L2}) it becomes non-sinusoidal.

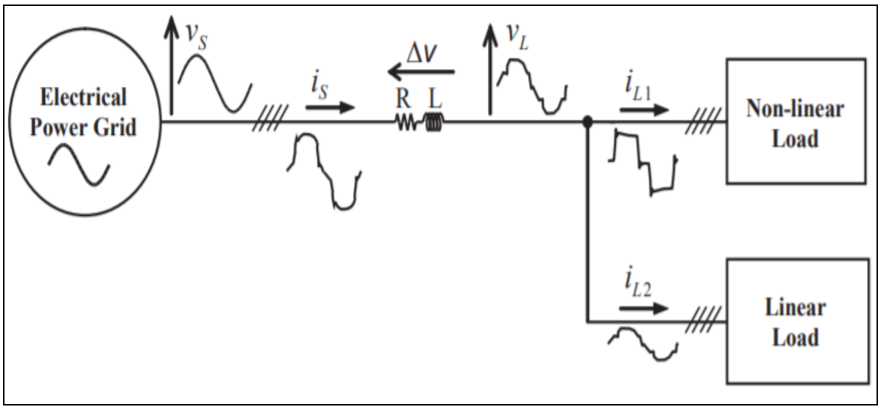

Fig 5. Block diagram of an electrical system with nonlinear loads [27].

2.4 Simetric components

In the three phased force electric systems, the amount of energy is composed by voltage and current, and according to the simetric component theory it can be decomposed in component of positive, negative and zero sequence [28].

When the force system is at normal operating conditions, the phase amplitude and angle of every amount of energy is measured and then, according the simetric component theory, these three components of the sequence can be calculated, for example with voltage, at (7) are introduced simetric components of positive, negative and zero sequence [29].

$$\begin{array}{llll} \text{Pos.seq:} & \dot{U}_{a1} & \dot{U}_{b1} = e^{\frac{j4\pi}{3}}\dot{U}_{a1} & \dot{U}_{c1} = e^{\frac{j4\pi}{3}}\dot{U}_{a1} \\ \text{Neg.seq:} & \dot{U}_{a2} & \dot{U}_{b2} = e^{\frac{j2\pi}{3}}\dot{U}_{a2} & \dot{U}_{c2} = e^{\frac{j4\pi}{3}}\dot{U}_{a2} \\ \text{Zero.seq:} & \dot{U}_{a0} & \dot{U}_{b0} = \dot{U}_{a0} & \dot{U}_{c0} = \dot{U}_{a0} \end{array} \tag{7}$$

Every component or harmonic order presents a proper sequence, that can be positive, negative or zero sequence, and each harmonic sequence produce a distinct effect on electric installations and equipments. They are [30]:

a) Positive sequence: they tend to make the motors spin to the same direction as the fundamental component, causing, then, an overcurrent on their windings;

b) Negative sequence: they tend to make the motors spin on opposite ways to that of the fundamental component, then braking the motor and also causing undesired overheating;

c) Zero sequence: rising of a current of neuter 3 (three) times larger than the phase current, leading to excessive heating of the neuter conductor.

On Table 1 are catalogued the order, frequency and sequence of the harmonics [31].

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: [31].

2.5 Artificial neural networks

ANNs are defined as computational mathematic models inspired on the human brain behavior. The human brain possess a information processing system extremely complex, non-linear and parallel; whereas the artificial neural networks possess a parallel processing that is distributed by its processing units, that is, the neurons, which are favorable to knowledge storing to a posterior use [32].

According to [33], among the different tasks that can be implemented using ANNs are:

a) Pattern classification and recognition: process in which a received signal (input) is attributed to a certain group or category;

b) Categorization: class or category discover well defined on the input data. On the contrary to classification, the classes are not known before;

c) Prediction: estimation of a numeric answer based on input values, also called calibration;

d) Optimization: characterized by the minimization or maximization of a function of cost;

e) Noise filtration: information extraction about a certain response of interest of a noisy data ensemble.

2.5.1 Multi-Layer-Perceptron neural network (MLP)

A MLP is a feedforward network, formed by the perceptron neurons type, disposed by layers, one being input layers, one or more hidden layers and one output layer [34]. The learning of a MLP happens often by the Back Propagation (BP) algorithm, and with this learning the MLP can be applied to a pattern learning, data mining and so forth [35].

Fig. 6 presents a MLP network type (Multi-Layer-Perceptron) with two intermediate or hidden layers.

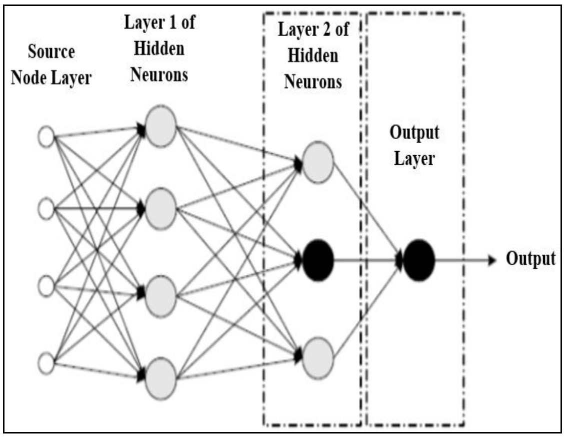

Fig 6. MLP network with two hidden layers [36].

The intern configuration selection of a neural network with hidden capacity and a sufficient number of neurons is able to approximate the precision of a continuous function at a compact domain, on the other hand a small number of neurons means that the network cannot learn properly the relations on the data, meanwhile a larger number makes the network memorize the data with a bad generalization and little utility to precision [37].

III. METHODOLOGY

Consider the Fig. 7 to illustrate a typical electric power system, where it's represented part of the distribution network, a bus of interest and three feeders.

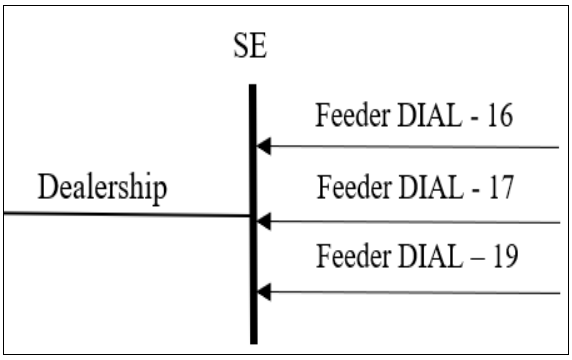

Fig 7. Typical electrical power system.

The objective is to determine how the non-linear charges connected in the feeders at study (see Fig. 7) are influencing on the harmonic distortion in a certain bus of interest.

To this study is suggested a neural network model which has as purpose to capture and replicate the typical particularities of the electric system under study, more specifically the impedance of this system, since as input of the neural network we have the harmonic currents I_n originating from the non-linear charges connected to the feeders under study at a certain frequency, and as output, the harmonic voltage V_n at the same frequency as of the bus of interest. Fig. 8 presents a brief scheme of the suggested model.

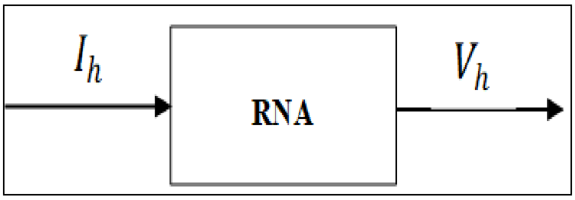

Fig 8. Summary scheme of the proposed model.

3.1 Neural Model to Determining the Harmonic Influence

3.1.1 Learning Process

Because of the particularities of the exposed set of problems in which it's desired to replicate a certain value, that is, to determine the harmonic voltage in function of the harmonic currents originated from the non-linear charges connected to the feeders under study of the electric system, being the input data (I_h) and output (V_h) of the neural network obtained through measurement campaign, it was adopted a neural network of the Multi-Layers-Perceptron Neural Network (MLP) type such as the learning is supervised, that is, the learning of the unknown environment is granted by the comparisons between the desired responses with the responses provided from the output neural network at each repetition until the error is minimized. Fig. 9 shows the diagram in blocks that clarifies the learning manner to the suggested study.

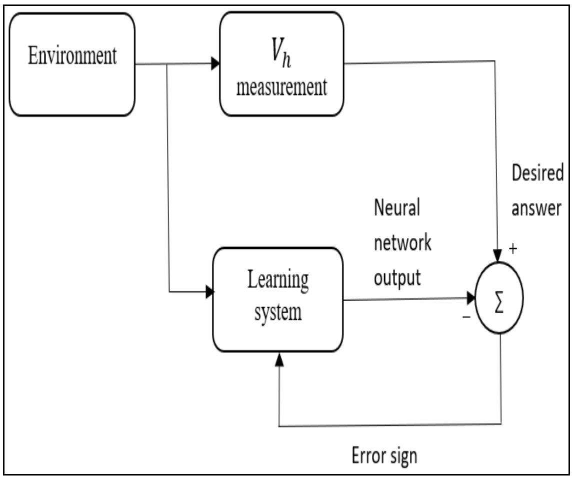

Fig 9. Block diagram showing the way of learning.

The ANN learning is achieved by means of the data collected during the measurement campaign, such data are inserted as on the input (I_h provided from every non-linear charge) as on the output (V_h at a determined bus of interest) of the neural network to each frequency of interest. It is important to highlight that the data collecting realization must be synchronized, that means that they must be realized at the same time instant.

3.1.2 Estimation Process

In this stage it is achieved the estimation process of V_h (harmonic voltage) on the bus of interest from the acquired knowledge in the learning process of the suggested ANN model, and at this stage the input data is unknown to the developed neural model.

Fig. 10 illustrates the diagram of the suggested model to the estimation of V_h at a determined bus of interest in which the input of the ANN is composed by the harmonic currents originated from the non-linear charges that compose the system at study.

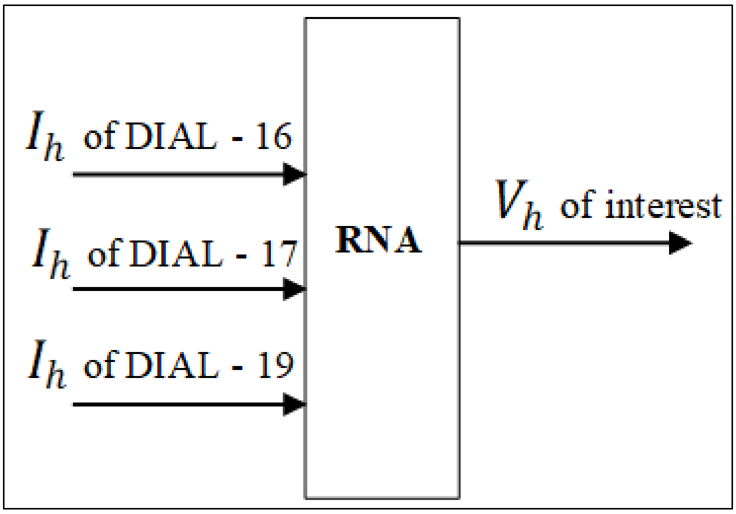

Fig 10. General scheme of the proposed model for estimating V_h in a bus of interest.

3.1.3 Individual Contribution of the feeders to harmonic voltage distortion on the bus

The determination of which feeder presents larger contribution on the harmonic voltage distortion at a bus of interest happens by means of the following procedure: consider the vector X as the input of the estimated ANN patterns, which to the suggested study are the harmonic current values (I_h) of each non-linear charge connected to the investigated feeders, and the vector Y corresponds to the output of the ANN, represented by the harmonic voltage (V_n) of the bus of interest. In which the values I_h and V_n are time series sizable to the considered measurement.

$$\begin{bmatrix} I_h \text{ DIAL} - 16 \\ I_h \text{ DIAL} - 17 \\ I_h \text{ DIAL} - 19 \end{bmatrix} \tag{8}$$

$$Y = [V_h] \tag{9}$$

Which h is the harmonic order.

Once the ANN is trained, it starts the estimation process with a satisfying error as mentioned previously, that is, the ANN has "learnt" the characteristics of the system at study, any input is chosen, that means that any feeder is chosen on the test ensemble, zeroing the other inputs of the test ensemble, to analyze separately the contribution of this referred input or feeder. That said, we have to I_h DIAL − 16:

$$Xnovo = \begin{bmatrix} I_h \text{ DIAL} - 16 = - \\ I_h \text{ DIAL} - 17 = 0 \\ I_h \text{ DIAL} - 19 = 0 \end{bmatrix} \tag{10}$$

$$Ynovo = [V_h novo] \tag{11}$$

Hence, the input or feeder which presents a output voltage time series ($V_n novo$) more similar to that of the original series (V_n), that is, revealing a tendency to follow the original harmonic voltage curve profile (V_n), theoretically presents a bigger influence on the THDV of a bus of interest, due to the ANN to attribute more importance to this input during the training phase.

The analysis sought to evaluate the contribution of the harmonic currents of order 3a, 5a and 7a of the feeders DIAL2-16, DIAL2-17 and DIAL2-19 to THDV on the bus DIBR2-03 (13.8 kV) of the electric system being studied and enclosing so the harmonic sequences, zero (3^a), negative (5^a) and positive (7^a). These feeders serve the Polo Industrial de Manaus (PIM) industry which possess a huge quantity of non-linear charges installed, as for example the CNC machines, electric arc furnaces, plastic and aluminum injection machines and others, therefore, great harmonics supply.

IV. ANALYSIS OF THE RESULTS

The analysis were performed through a field measurement campaign achieved on the period between May 15th 2017 and May 22nd 2017 at a power station of voltage level 13,8 kV of the enterprise denominated A in this work for ethic reasons, in which it was installed 4 EQ analyzers of PW 3198 model from HIOKI for the realization of simultaneous measurements on the following measuring points: alternating current supply DITF4-04; and feeders DIAL2-16, DIAL2-17 and DIAL2-19. Fig. 11 shows the single-line diagram of the enterprise A's power station and the location of the installation points of the electricity quality analyzers (blue circled points), for this measurement campaign, totaling 4 points of simultaneous measuring. The objective of the EQ analyzers installation on the DITF4-04 alternating current supply is to monitor the harmonic voltage at the bus DIBR2-03 (green circled). Fig. 11 presents part of the single-line diagram of the electric system at study with the installation points.

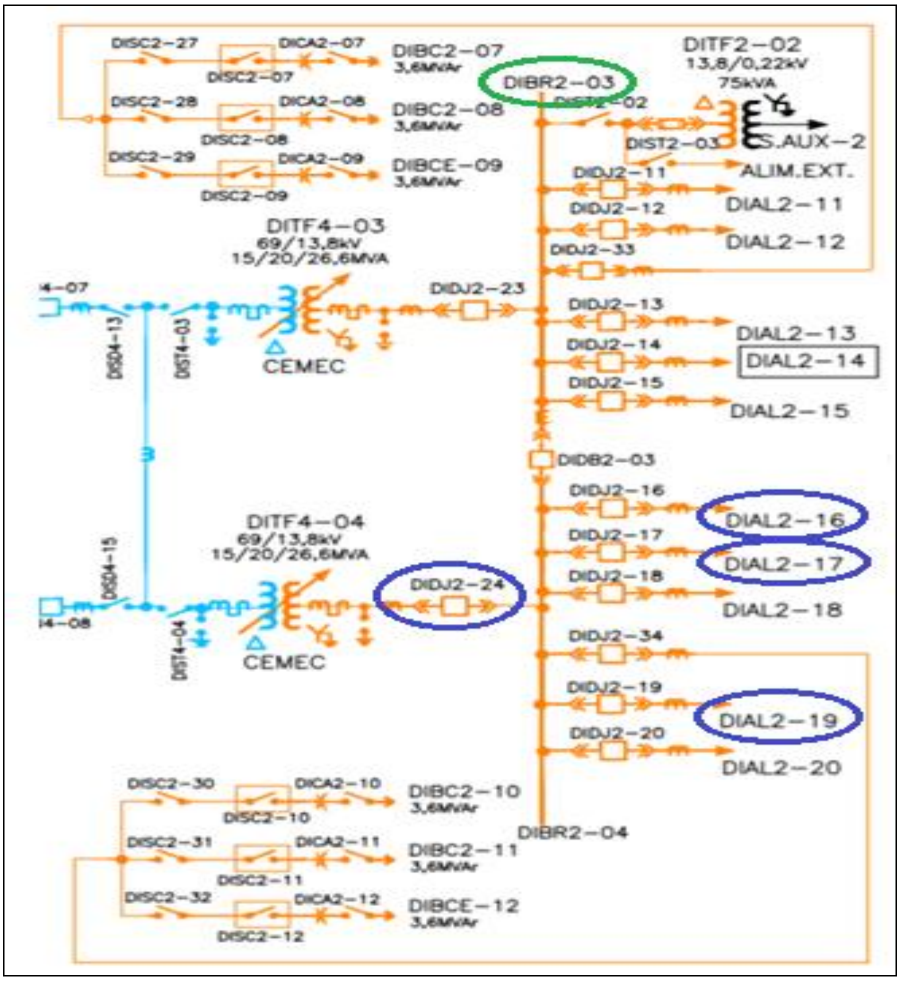

Fig 11. Single-line diagram of the substation under study.

For the realization of such study it was used a neural network of the type MLP with 3 neurons on the input layer, that correspond to the currents of the feeders DIAL2- 16, DIAL2-17 and DIAL2-19, a hidden layer containing 5 neurons and 1 neuron on the output layer, which correspond to the voltage of the alternating current supply DITF4-04. The structure of the final ANN was obtained by experimental procedure, being chosen that one structure with acceptable error.

4.1 Harmonic impact corresponding to 3ª order

In this subtopic are presented the results referring to the analysis of the harmonic contribution of the feeders DIAL2-16, DIAL2-17, DIAL2-19 on the 3ª order of the harmonic voltage of the bus located at the alternating current supply DITF4-04 (13,8 kV) low voltage side using artificial neural networks.

As we can see on the Table 2, that contains the impact factors calculated considering the whole measurement period, the feeder DIAL-2-16 showed a bigger impact factor in the B stage, reaching a value equal to 55,803%. However, in the A and C stages, the feeder which presented bigger influence on the voltage distortion in the bus DIBR2-O3 was DIAL2-19, presenting a value equal to 67,895% in the A stage and 38,229% in the C stage. In relation to the contribution quota of the background, the impact factor values were equal to 08,094% in the A stage, 17,147% in the B stage and 11,682% in the C stage, not significantly impacting on the distortion of the bus DIBR2-O3.

Table 2. Impact (%) calculated on the bus DIBR2-O3 (13,8 kv) of the alternating current supply ditf4-04 (3º harmonics).

BASE	STAGE A	STAGE B	STAGE C
DIAL2-16	07,135	55,803	16,344
DIAL2-17	16,876	12,938	33,746
DIAL2-19	67,895	14,112	38,229
BACKGROUND	08,094	17,147	11,682

The Fig. 12, 13 and 14 show the ANN output voltage as well as the measured voltage values on the bus DIBR2-03. Analyzing these figures we notice that the ANN presented a good development because there was a good approximation between the estimated signal by the ANN considering the three feeders and the signal measured on the system. As it can be observed in the Figs. 12, 13, and 14 it is difficult to identify a dominant feeder to contribution of the harmonic voltage distortion in the bus DIBR2-03 along all the measurement period, that is, on certain moments a specific feeder presents a larger variation on the ANN output (bigger sensibility), while at another moment another feeder is responsible for presenting a bigger sensibility. But when the impact is analyzed on a general way, as show on table 2, it is possible to identify the feeder DIAL2-19 as most responsible for the harmonic distortion in the bus at study.

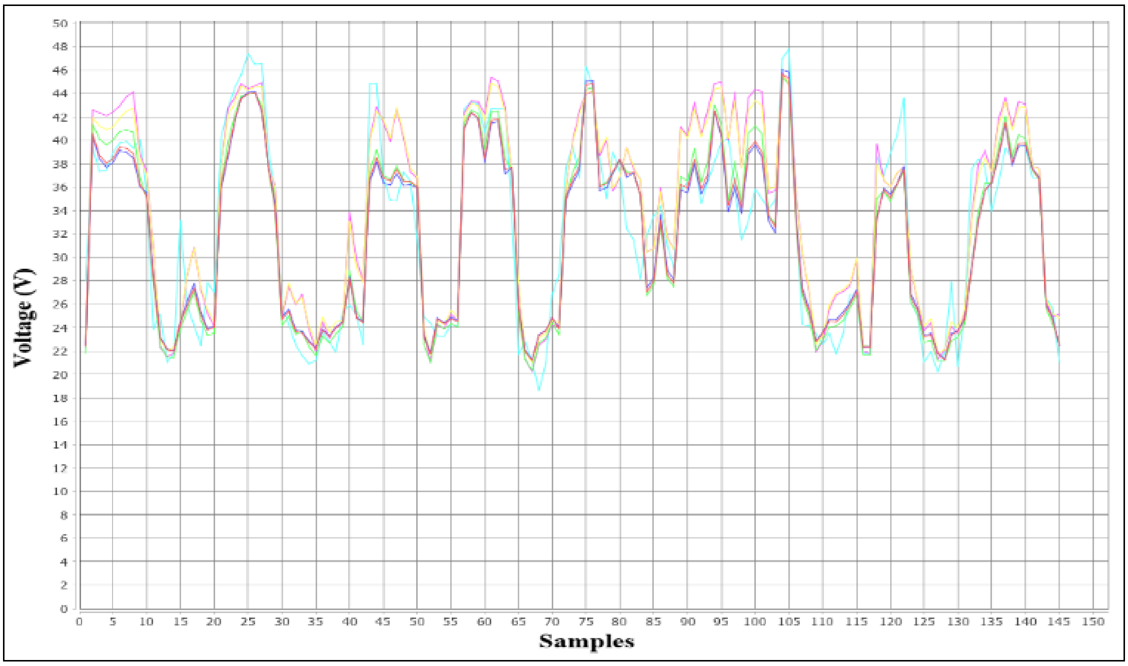

Fig 12. Analysis of the ANN output voltages of 3rd harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage A).

Caption:
Blue: Contribution considering only DIAL2-16;
Green: Contribution considering only DIAL2-17;
Yellow: Contribution considering only DIAL2-19;
Purple: Contribution considering the three feeders;
Light blue: Measured value in the electric system bus.

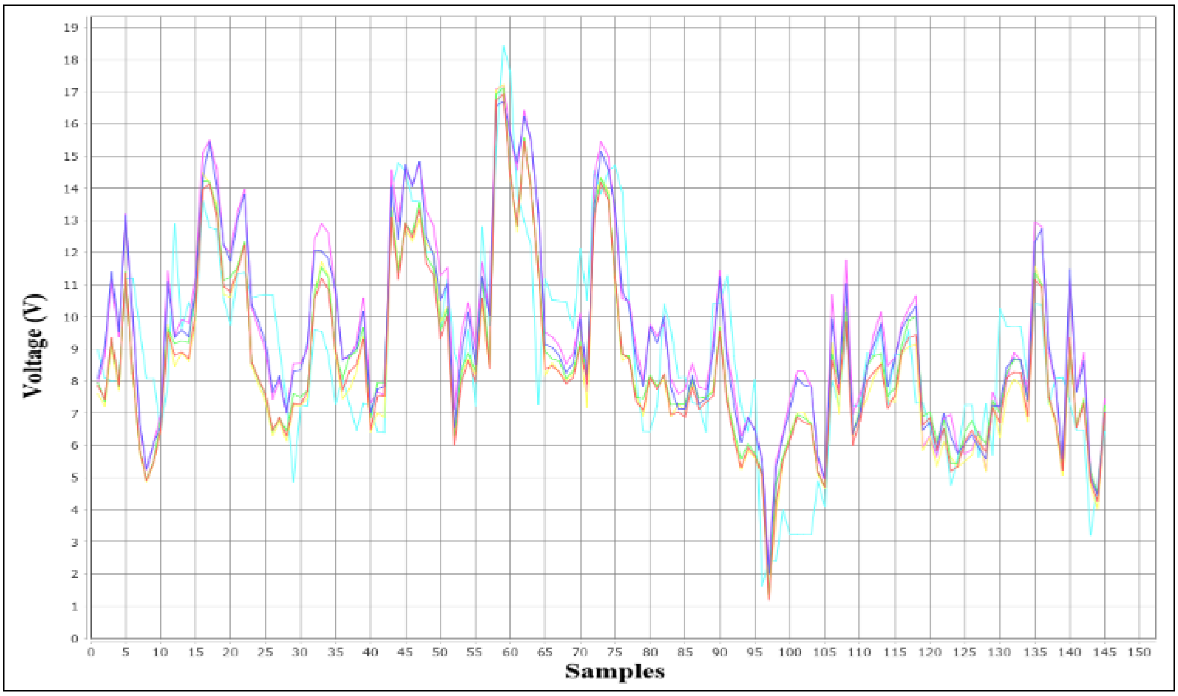

Fig 13. Analysis of the ANN output voltages of 3rd harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage B).

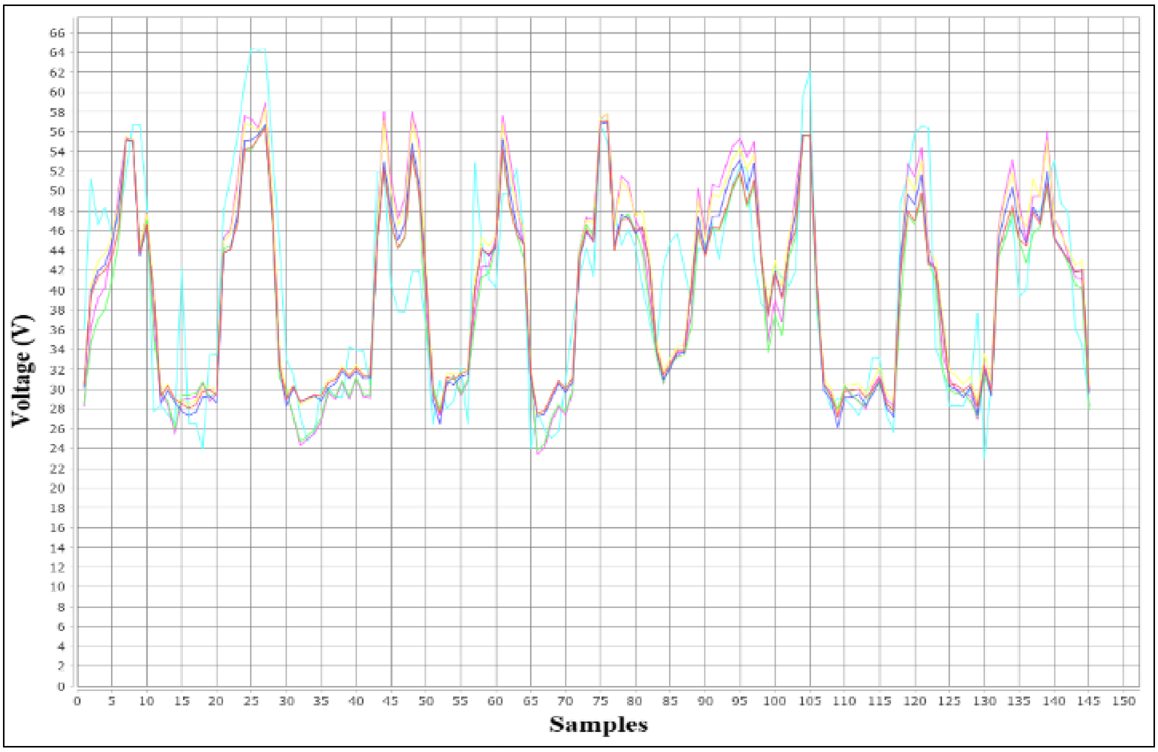

Fig 14. Analysis of the ANN output voltages of 3rd harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage C).

4.2 Harmonic impact corresponding to the 5th order

In this subtopic are presented the results referring to the analysis of the harmonic contribution of the feeders DIAL2-16, DIAL2-17, DIAL2-19 on the 5th order of harmonic voltage in the bus located in the side of low voltage of the alternating current supply DITF4-04 (13,8 kV) using artificial neural networks.

As it can be noticed on Table 3, which contains the impact factors calculated considering all the measurement period, the feeder DIAL2-16 presented a value equal to 36,176%. However, in the stages A, B and C, the feeder which presented most influence in the voltage distortion on the bus was the one DIAL2-17, presenting a value equal to 70,232% in the stage A, 52,599 in the stage B and 69,025% in the stage C. In relation to the contribution quota of the background, the impact factor values were equal to 06,847% in the stage A, 05,447% in the stage B and 06,389% in the stage C.

Table3. Impact (%) calculated on the bus DIBR2-O3 (13,8 kv) of the alternating current supply DITF4-04 (5º harmonics).

BASE	STAGE A	STAGE B	STAGE C
DIAL2-16	14,386	36,176	13,197
DIAL2-17	70,232	52,599	69,025
DIAL2-19	08,535	05,778	11,389
BACKGROUND	06,847	05,447	06,389

The Figs. 15, 16 and 17, show the ANN output voltages as well as the voltage values measured on the bus DIBR2-03. Analyzing these figures, we notice that the ANN showed a good development, because there was a good approximation between the estimated signal by the ANN considering the three feeders and the signal measured on the system. As we can observe on the Figs. 15, 16 and 17, it is not possible to identify a dominant feeder to contribution of the harmonic distortion on the bus DIBR2-03 along the whole period of measuring, that means, at certain moments a specific feeder shows larger variation on the ANN output (bigger sensibility), meanwhile at another moment another feeder is responsible for presenting bigger sensibility. But when the impact is analyzed in a general way, as presented on table 3, it is possible to identify the feeder DIAL2-17 as most responsible for the harmonic distortion on the bus at study.

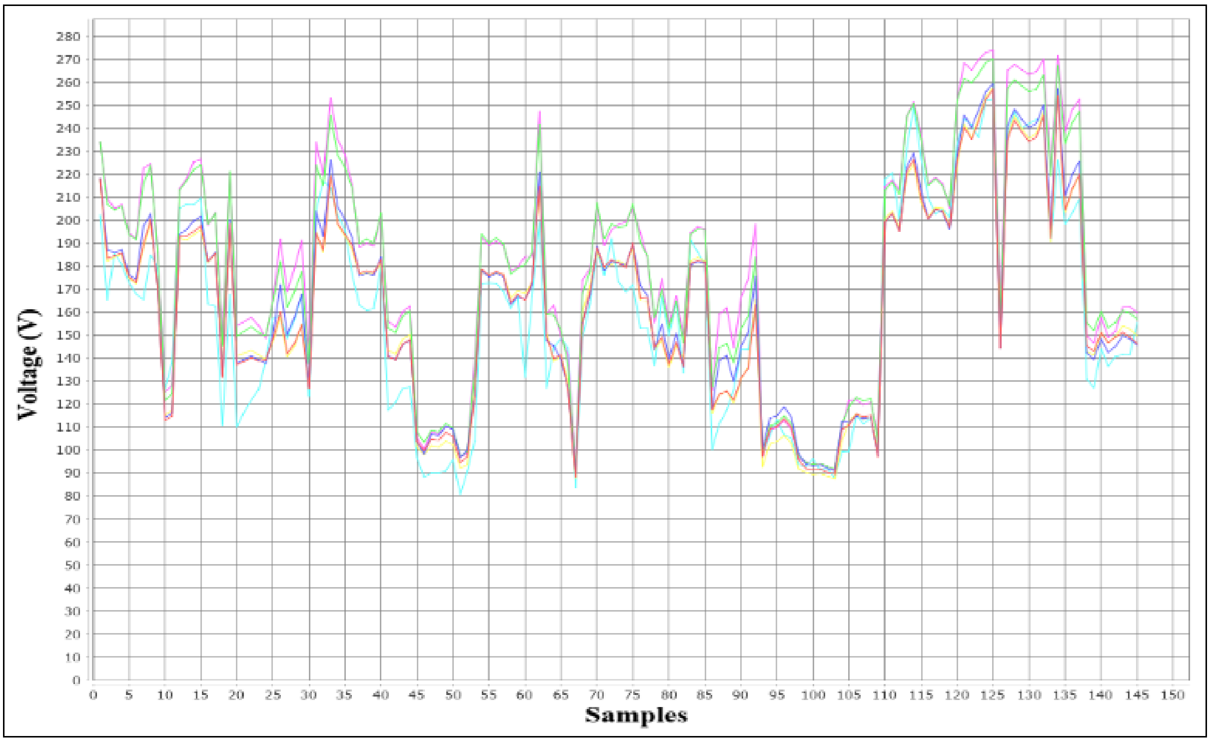

Fig 15. Analysis of the ANN output voltage of 5th harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage A).

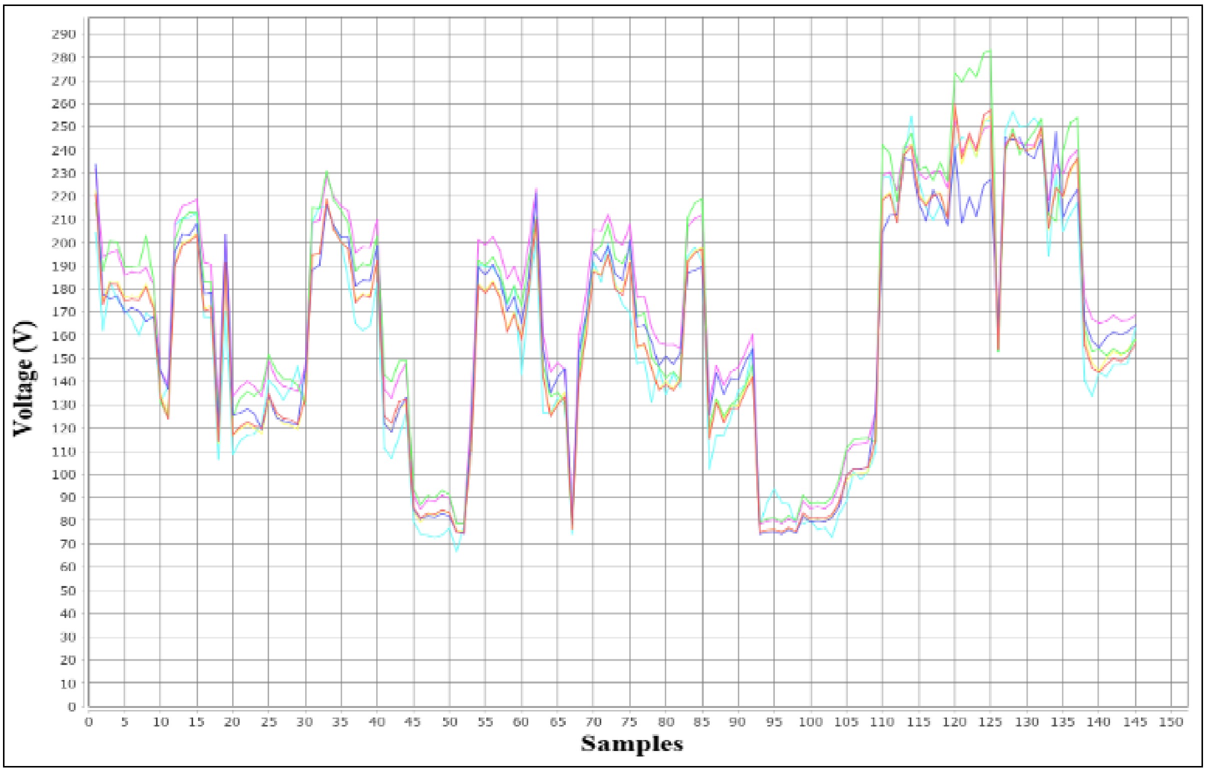

Fig 16. Analysis of the ANN output voltage of 5th harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage B).

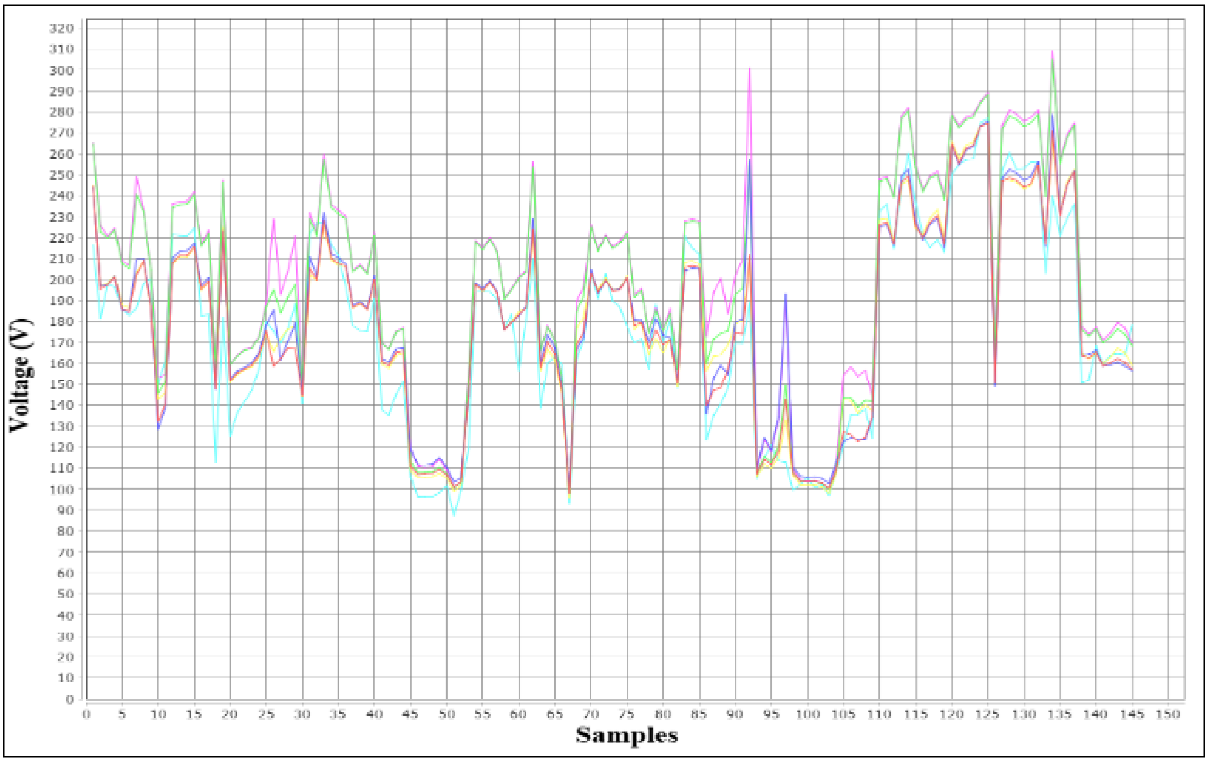

Fig 17. Analysis of the ANN output voltage of 5th harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage C).

4.3 Harmonic impact corresponding to 7th order

In this subtopic are presented the results referring to the analysis of the harmonic contribution of the feeders DIAL2-16, DIAL2-17, DIAL2-19 on the 7th order of harmonic voltage in the bus located in the side of low voltage of the alternating current supply DITF4-04 (13,8 kV) using artificial neural networks

As we can notice on table 4, which contains the impact factors calculated considering the whole period of measurement, the feeder DIAL2-16 presented a larger impact factor on the stage B, reaching a value equal to 41,971%. However, on the stages A and C the feeder that showed most influence on the voltage distortion in the bus DIBR2-O3 was DIAL2-17, presenting a value equal to 62,785% on the stage A and 49,618% on the stage C, and with significant impact factor on the stage B. In relation to the background contribution quota (impact factor), the calculated values were equal to 09,574% on the stage A, 05,543% on the stage B and 09,799% on the stage C.

Table 4. Impact (%) calculated on the bus DIBR2-O3 (13,8 kv) of the alternating current supply DITF4-04 (7º harmonics).

BASE	STAGE A	STAGE B	STAGE C
DIAL2-16	09,381	41,971	05,461
DIAL2-17	62,785	38,145	49,618
DIAL2-19	18,261	14,342	35,123
BACKGROUND	09,574	05,543	09,799

The Figs. 18, 19 and 20 present the ANN output voltages as well as the measured values on the bus DIBR2-03. Analyzing these figures, it has been verified that the ANN showed a good development, similarly to the of the of case 2, because there was a good approximation between the estimated signal by the ANN considering the three feeders and the signal measured on the system. As it can be noticed in the Figs. 18, 19 and 20 it is not possible to identify a dominant feeder to contribution of the harmonic voltage distortion on the bus DIBR2-03 along the whole period of measuring, that is, at certain moments a specific feeder presents larger variation on the ANN output (bigger sensibility), meanwhile at another moment another feeder is responsible for presenting bigger sensibility. But when the impact is analyzed in a general way, as show on table 4, it is possible to identify the feeder DIAL2-16 with a significant impact factor on the stage B, however the feeder DIAL2-17 was identified as being most responsible for the harmonic distortion on the bus at study.

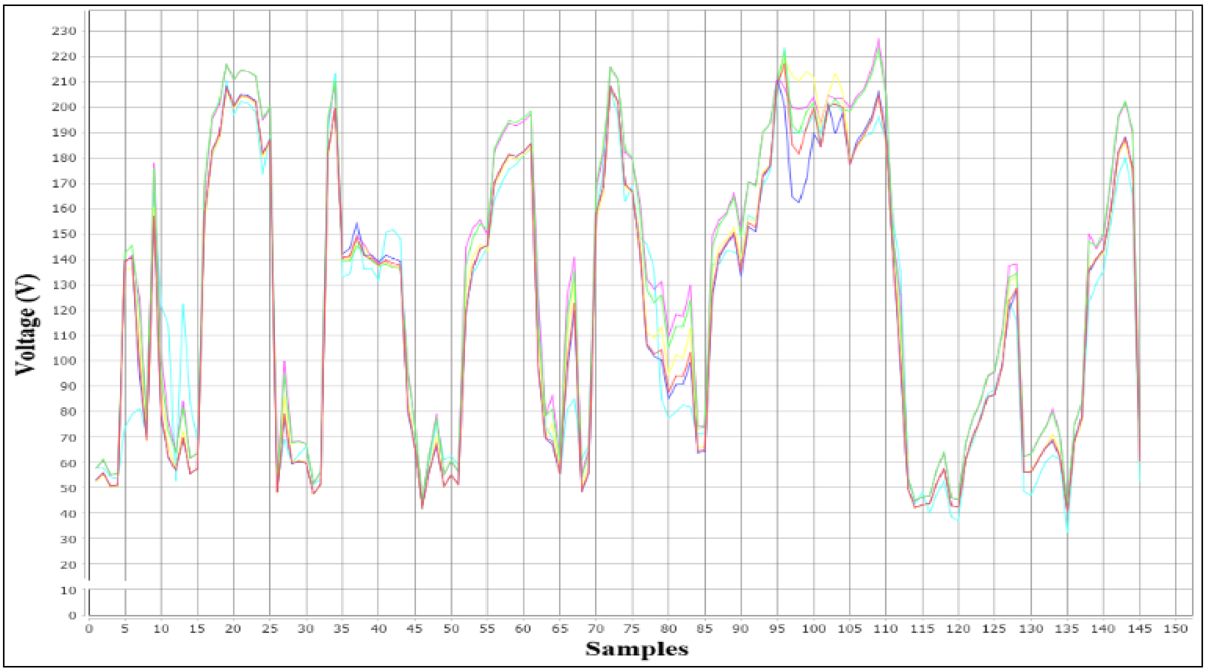

Fig 18. Analysis of the ANN output voltage of the 7th harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage A).

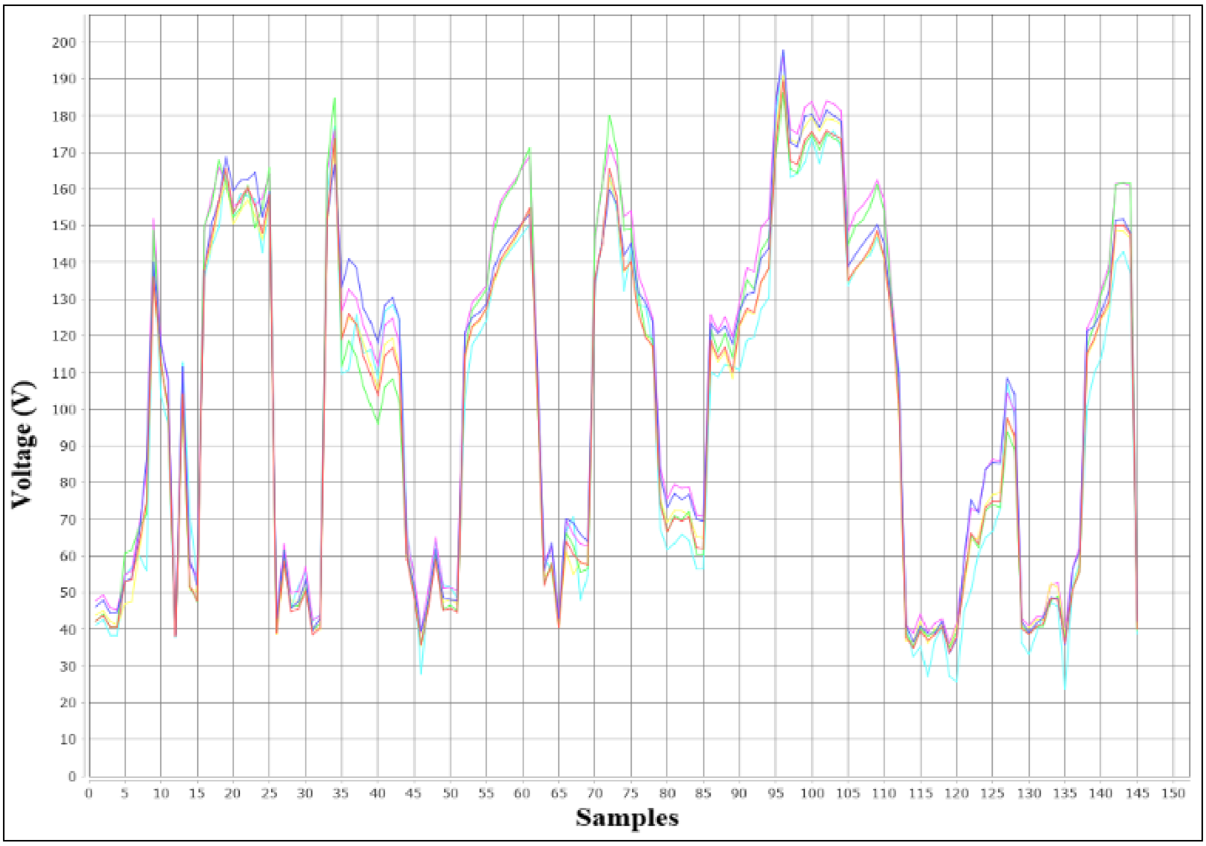

Fig19. Analysis of the ANN output voltage of the 7th harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage B).

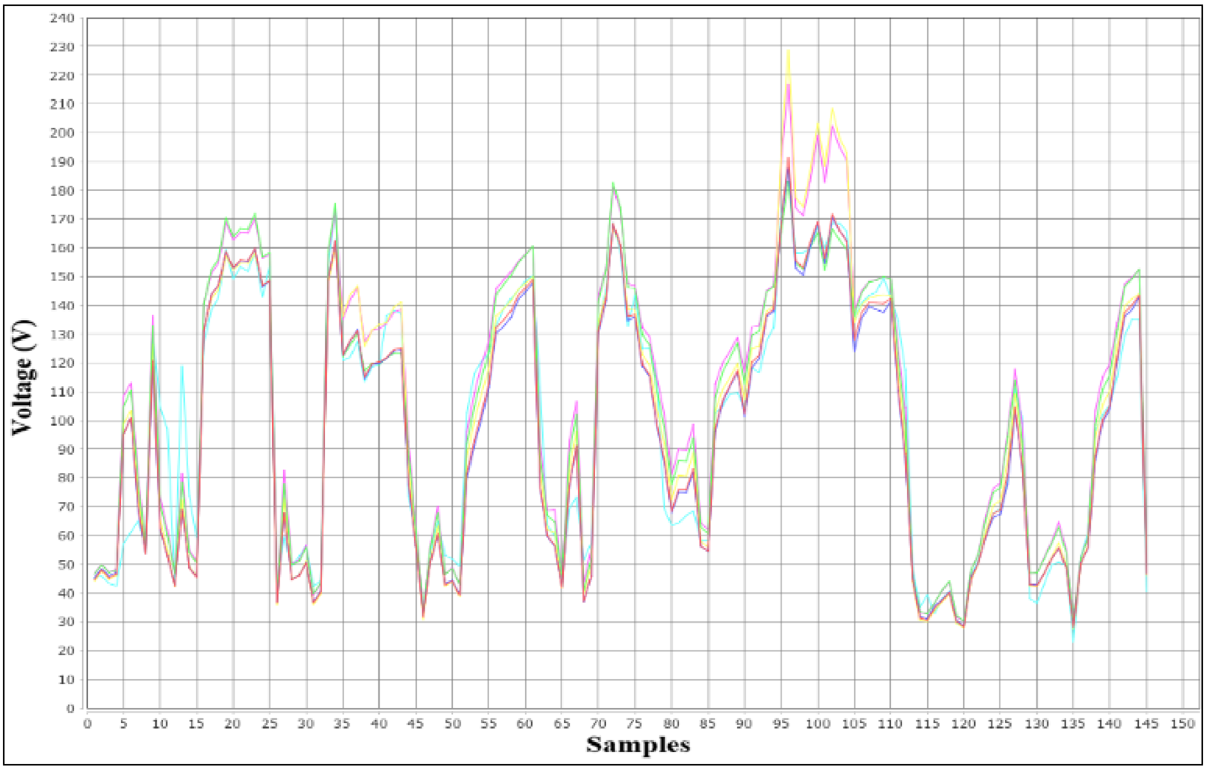

Fig 20. Analysis of the ANN output voltage of the 7th harmonics on the bus DIBR2-03 (13,8 kV) of the alternating current supply DITF4-04 (stage C).

V. CONCLUSION

Using the ANNs technique it was analyzed the impacts occurred by harmonic currents on three feeders on the bus of the electric system, which are 16, DIAL2-17 e DIAL2-19. The analyses were accomplished by means of field measurement campaigns on 7-days period according to PRODIST's module 8. With the collected data on this measurement campaign it was made possible to investigate what is the influence of the harmonic current generated by the non-linear charges in the harmonic voltage distortion on the studied bus of interest (DIBR2-03).

The ANN presented a good development, since there was a good approximation between the ANN estimated signal considering the three feeder and the signal measured on the electric system. The individual estimation of each feeder also presented a good development because there was a good approximation between the estimated signals of each feeder and the ANN estimated signal considering the three feeders. Such fact was awaited due to these feeders are directly connected on this bus.

Because of these analyses, it was made possible to create a profile of the feeders DIAL2-16, DIAL2-17, DIAL2-19 to then mitigate the THDV on the bus DIBR2-03, originated by the impacts of the harmonic currents of these feeders.

In this way it was presented and applied in action with case study the actions to analyses the harmonic impacts on electricity distribution systems through the construction of mathematic models using the ANN technique. The ANN identified the feeder DIAL2-19 as most responsible for THDV on the bus DIBR2-03 in the 3rd order, the feeder DIAL2-17 as most responsible for THDV in the 5th and 7th orders, and the feeder DIAL2-16 with a significant impact factor only on stage B in the 3rd, 5th and 7th orders, demonstrating then the efficiency of the analysis technique application of harmonic impacts on electric systems.

ACKNOWLEDGMENT

To the Post-Graduate Program in Process Engineering of the Institute of Technology of the Federal University of Pará (PPGEP/ITEC/UFPA) and to Institute of Technology and Education Galileo of the Amazon (ITEGAM).

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