International Conference on Renewable Energies and Power Quality (ICREPQ'20)

Consumption Prediction and Evaluation of Harmonic Distortion in a Hospital using Neural Networks

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I - Introduction

It is clear how dependence on electricity and its demand has increased in recent decades. Therefore, the electric energy issue, in its different segments of generation, transmission, distribution and use, has stimulated discussions involving researchers, energy concessionaires and regulatory agents from the electric sector to society in general.

This is because, although electricity is of paramount importance for economic development, the assessment of the social and environmental impacts of countries' energy policies on the population and the environment has become as valuable as the broad and secure supply of energy.

This article aims to present a proposal for a methodology to analyze the energy efficiency of a hospital according to the current consumption obtained through field measurements. In addition, it aims to present the prediction of the increase in consumption over the years and correlate it with the possible increase in the harmonic distortion of stress. This analysis is essential for the studies of the connection impacts, allowing the estimation and evaluation of the energy quality through the harmonic voltage distortions over the years. The study is validated by comparing the consumption prediction curve obtained by Neural Network training with the data extracted from measurements and analysis of energy bills. The results show that the model generates the best prediction performance.

II – Methodology

The UFTM School Hospital is a university hospital, where, in addition to care, teaching and research activities are performed. Its service covers 27 municipalities that make up the southern triangle macro-region of the state of Minas Gerais. It accounts for 73% of all medium and high complexity in the macro-region and 100% of high complexity in the same area, with the exception of cancer treatment.

Regarding the structure, it has more than 302 active beds in an area of 26.000 m², distributed among hospitalization environments, outpatient clinics, emergency room and diagnostic services and specialized treatments [12].

The simplified diagram shown in Figure 1 shows the 6 transformers present in the substation (SS) studied, as well as the main parameters that characterize the elements that make up the system.

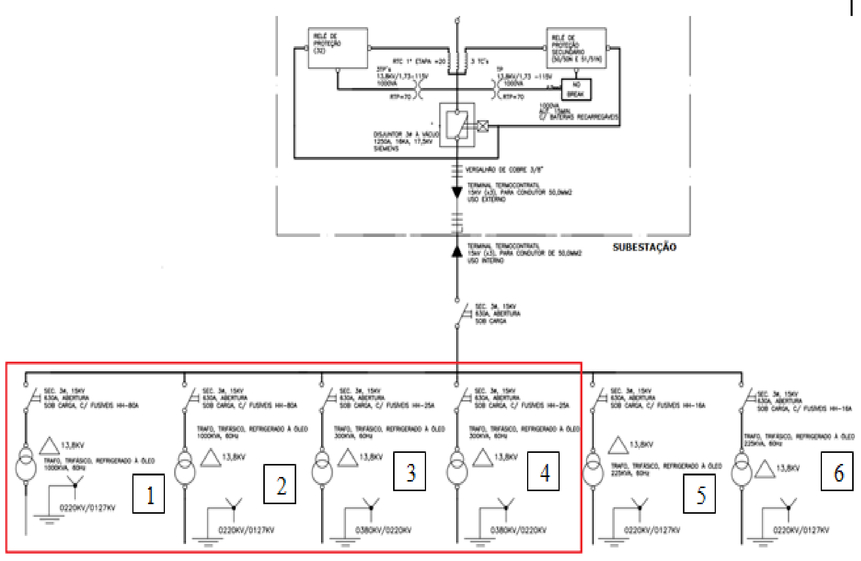

Fig.1. Simplified HU single-line diagram from UFTM.

Fig. 1 – Simplified HU single-line from UFTM

A. Diagnosis of energy efficiency

1) THD and THDi

The degree of harmonic distortion present in the voltage and/or current can be expressed mathematically based on the study of non-periodic waves by means of the Fourier series.

Fourie's Theorem guarantees that every periodic non-sine function can be represented by a sum of expressions composed by a sine expression in fundamental frequency and by sine expressions whose frequencies are multiple integers of fundamental, that is, harmonics [13].

Equation 1 presents, in a mathematical form, a sign f non-periodic sinusoidal tension.

$$v(t) = V_o + V_{max1}sin(1\omega t + \varphi_1) + V_{max2}sin(2\omega t + \varphi_2) + \cdots + V_{maxh}sin(h\omega t + \varphi_h) \qquad (1)$$

Thus, knowing the values of harmonic voltages or currents present in the system, we tried to analyze the influence of the harmonic content for this study.

This analysis was performed using the method of Total Harmonic Distortion (THD) and Individual Harmonic Distortion (THDi), which can be calculated according to equation 2. According to module 8 of Prodist, in addition to THD, some specific cases must be calculated:

- h = all even harmonic orders, not multiple of 3;
- h = all odd harmonic orders, not multiple of 3;
- h = all multiple harmonic orders of 3.

$$THD = \sqrt{\frac{\sum_{h>1}^{hmax} V^2{}_h}{V^2{}_1}} \qquad (2)$$

2) On-site measurements

Measurements were performed on the buses of transformers 1, 2, 3 and 4. Given the limitations of equipment, each transformer was measured for 24 hours in two consecutive weeks in October, since it is one of the hottest months of the year and consequently of higher consumption. To enable these records, the Fluke 1735 portable PQ recorder with 4 MB Flash memory, sampling rate of 10.24 kHz, 50 Hz/60 Hz, precision class S and manufactured according to the DIN ISO 9D01 standard was used [14]. At this stage of measurement, during the first week, the consumption data in kWh and the THD of each transformer were obtained, with measurements performed every 15 minutes.

B. Artificial Neural Networks (ANN)

ANNs are computational algorithms that present a mathematical model, which allows simplified insertion of the functioning of the human brain into computers. In this way, like the human brain, ANN is able to learn and make decisions based on its own learning. For multi-layered network training, the back propagation algorithm (Backpropagation) is used, which is based on the learning rule by error correction [15]. Therefore, ANN was used to predict, through data from mass memory, the typical H.S. consumption curve in the coming years. The analysis of the load curve allows us to know the behavior of consumption over a period of time [19], to know the months of higher and lower consumption and correlate the variation in consumption with another magnitude, such as THD.

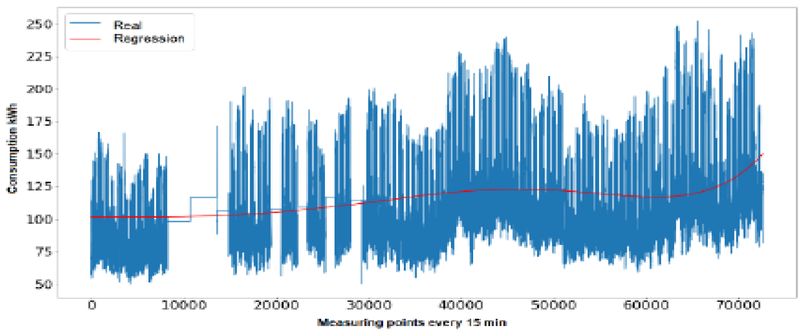

Fig 2. Energy consumption (kWh).

However, each type of consumer has a standard consumption curve type, that is, the shape of these curves depends on the consumption habits of the population [19].

To model the typical monthly consumption curve of the facility, its revenue mass memory of the second half of 2016, 1st semester of 2017 and the full year of 2018, provided by the local concessionaire, in which the active power of all this is recorded period with aggregation times of 15 minutes.

Thus, the first ANN received the concatenated consumption data (kWh) from the billing mass memory. With this, it was possible to determine the typical consumption profile of H.E, which is presented in Figure 2.

III – Results

C. THD e THDi

According to the limits established by Prodist Module 8, the total and individual harmonic distortions of maximum voltage recorded in a system with rated voltage of 220V/380V must be equal to or less than 10% [20]. However, the statistical values of total harmonic distortion of tension were lower than the reference value of 10% indicated by Prodist, more specifically, were below 2.5%.

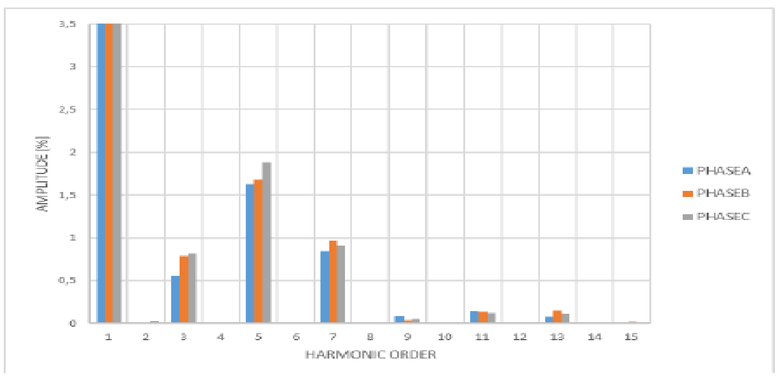

Fig. 3. THDi 1,000 kVA transformer.

D. Correlation of THD and consumption

As stated earlier, maintaining the PQ is paramount in hospital environments due to the continuous characteristic of operation. In addition, logistics is needed focused on effective consumption, since hospitals are large consumers of energy. From Figure 4, it is possible to notice that, although they are different data, the way consumption and THD scans of each phase are similar. In this image, aiming at a greater detail of the chart, only 96 points were plotted, which are equivalent to the period of one month.

With this, it can be affirmed that consumption is directly related to THD.

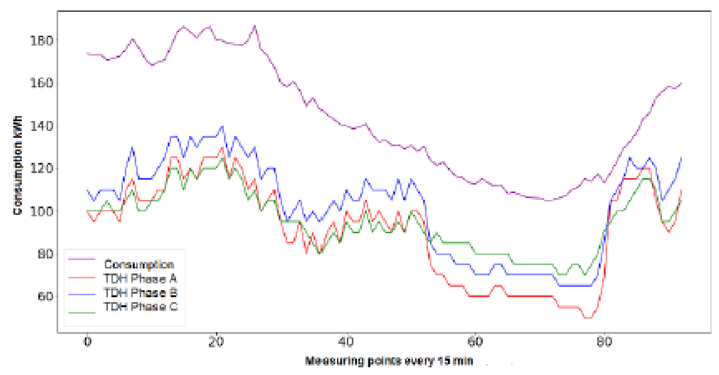

Fig 4. Consumption and THD curve profile of each phase.

The first part of the algorithm, which corresponds to one of the four ANNs used, was able to understand the profile of the load curve presented to neurons of its first layer, perceiving the months of higher and lower consumption, besides identifying the increase that occurred to each year.

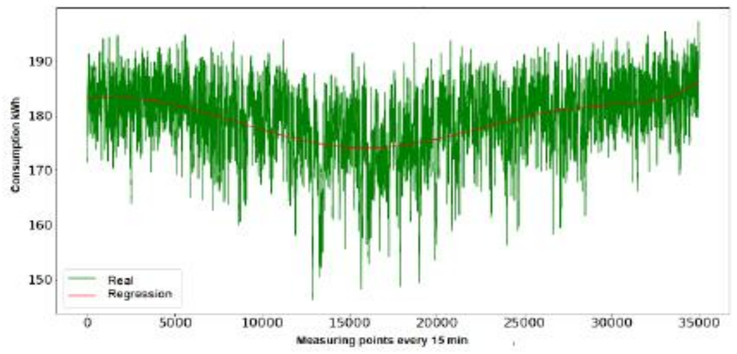

Fig. 5 Predicting consumption for the year 2019..

The maximum peak of prediction was 196.16 kWh and polynomial regression peak, 185.52 kWh. These values are acceptable, since the consumption estimate was made according to the average consumption provided by mass memory. As in Figure 5, the maximum predictive and regression values are acceptable, they are, respectively, 196.69 kWh and 190.13 kWh.

IV - Conclusions

This paper presented an alternative for predicting consumption and THD based on measurements made by the concessionaire and field measurements. For this, the methodology used was presented, where four ANNs were implemented. Thus, through the consumption profile extracted from S.H. mass memory, the proposal was applied.

Finally, the computational models were validated through the analysis of the plotted profiles and the average quadratic error obtained at the end of the net training. The analyses show that the method is very effective, despite the limitations, both in the on-site measurements and in the machines used for the prediction, since they are consistent between the results presented by the implemented ANN model and the actual values used.

Thus, this proposal proves to be an important tool for hospitals and large energy consumers, allowing a deeper analysis of consumption and preventive decisions regarding the insertion of disturbing loads in the installations and, consequently, the possible exceeding of the limits determines by Prodist.

This work was supported by:

CAPES

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