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MONITORING SYSTEM FOR ELECTRICAL ENERGY PARAMETERS IN A ROMANIAN PRE-UNIVERSITY EDUCATION INSTITUTION

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Abstract. ***A desideratum of the society, not only in Romania, is the efficiency of the electricity consumption and its passage on green energy in a bigger proportion. This can be achieved by research on various topics chosen from different areas of the economy. One of the most widespread public institutions is education, which is why the results obtained from the research of such a subject can bring major benefits to the entire society. In general, the structure of pre-university education institutions is similar, with classrooms, laboratories equipped with the same types of electric consumers, and very close heating systems. This article proposes a method of monitoring the electrical energy and consumption parameters of a pre-university education institution in Romania. The results obtained are compared to the energy quality standards and will be the basis for a PV system that will be designed to ensure the entire energy consumption of the institution.***

Keywords: data acquisition system, energy parameters, power quality, PV system.

1. INTRODUCTION

At the level of each country educational institutions account for a large share of public electricity consumption. For example, in Romania there are 7270 educational units, which represent about 27% of the total public institutions [1]. As can be seen in Table 1, in Romania, the zonal distribution of pre-university education institutions according to the data provided by the National Institute of Statistics (NIS) [1] is not homogeneous, especially as high school education, which is concentrated in the urban area.

Table 1. The zonal distribution of education institutions

	High school education	Pre-university education
Total	1534	5736
Urban	1289	2668
Rural	245	3068
Urban	84.03%	46.51%
Rural	15.97%	53.49%

However, the data provided by the study of an educational institution, even if it is a particular one, can be used in the analysis and modeling of the efficiency of the energy consumption of any institution.

Therefore, many studies are conducted both in Romania [2-3], [21-22] and abroad, [4-7], which compare the data collected under different structural and climatic conditions, in order to find optimal solutions for optimize the energy consumption.

In recent years studies have analyzed the energy quality and have carried out monitoring of non-renewable energy sources utilization, both locally and consortium (consisting of at least two institutions, usually from the same area) and regional [3-4].

Worldwide, substantial funding is allocated to research on renewable energy [10-15], basically not being a country to invest in green energy, and not to harmonize legislation on mandatory its use in increasing proportions [16-19].

Like any consumer of electricity, educational institutions have to fit within the limits of the perturbations imposed by the current standards, and to work together with the suppliers to keep the energy quality.

In Romania, local standards and regulations have been harmonized with European standards.

The standard EN 50160 [9] sets out the main voltage parameters and allowable deviations under normal operating conditions at the common switching point (CSP) of a consumer connected to a public low voltage (LT) and medium voltage (MT).

Thus, the parameters whose values and limits are standardized are:

- Frequency of supply voltage
- Voltage variations
- Fast voltage variations (flicker)
- unbalance of the three-phase voltage system in the network
- voltage harmonics
- interharmonics
- the introduction of other signals through the distribution network.

A minimum of one week is recommended for data collection in the measurement process such that the results of measurements to be representative.

Since the conditions of generation, transport, distribution and consumption of electricity are not ideal, the voltage and current variation in time is not a sinusoidal function, the deviation produced by the nonlinear circuits connected to the network, lead to the distortion of the sinusoidal wave, and so when the real mode of operation of the electrical networks, called deforming regime, appears.

Among the electric receivers that produce the deforming regime we mention:

- gas discharge lamps and tubes;

- electronic components in: automation circuits, televisions, computers, etc.;
- single-phase rectifiers with single or double alternating currents.

This regime has negative effects on the technical performances of both electric grids and electric consumers, by affecting the quality parameters of electric power.

In a node of the electrical network, the degree of energy quality can be described by:
- Voltage quality by fitting the required limits;
- Frequency quality, fit within required limits;
- Degree of symmetry of the three-phase network (voltage / current);
- Deviation from sinewave voltage and current.

Therefore, it was necessary to have some quality indicators, which are the basis of the international and national recommendations for the distribution of electricity, being defined as the ratio between the measured value and the standardized value.

The indicators are influenced and determined by the type and size of the consumer's burden.

In Table 2 are presented the main quality parameters extracted from the norm 28.1.013.0.00.30.08.2007 issued by ANRE [8]:

Table 2. Quality of the voltage curve

Phenomenon	**Permissible limits**
Limits for contract voltage to LT, MT and HT	Uc contract tension in the limits ± 10% of nominal voltage ± 5 % of nominal voltage
Flicker	$P_{lt} \le 1$, for 95% of the week
Fast voltage variations in normal mode	± 5 % of nominal voltage U_n to LT ± 4 % of U_c to MT and HT
Non-symmetry (negative component) – Kn	To LT and MT, $K_n \le 2\%$, for 95% of the week; in some areas it can reach 3 %; To HT, $K_n \le 1$ %, for 95% of the week
Frequency*	50 Hz ± 1 % (interconnected network) 50 Hz + 4/- 6 % (isolated network)

According to the normative PE 143/1994 issued by ANRE [8], the following are standardized:
- The level of harmonic stresses at the LT and MT delimiting points must not be greater than the maximum limits in Table 3, measured for at least 95% of a week.

The factor

$$k_{hvs} = 1{,}3 + \frac{0{,}7}{45} \cdot (h - 5) \quad (1)$$

is used for the THD_U analysis over an intranet time that does not exceed 3s, with the THD_{Uh} compatibility level (which is 11%), multiplying it by the values in Table 3.

Table 3. THD_U levels

Odd range not multiple of 3		**Odd range multiple of 3**		**Even range**	
Rang *h*	Harmonic voltage U_h, [%]	Rang *h*	Harmonic voltage U_h, [%]	Rang *h*	Harmonic voltage U_h, [%]
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	0,4	6	0,5
13	3	21	0,3	8	0,5
$17 \le h \le 49$	$2{,}27 \cdot \frac{17}{h} - 0{,}27$	$21 < h \le 45$	0,2	$10 \le h \le 50$	$0{,}25 \cdot \frac{10}{h} + 0{,}25$
Note: Compatibility level for total harmonic distortion factor THD_U = 8%.					

- Because they do not have the standardized values in the EU, the maximum harmonic electrical currents in relation to the maximum electric current of the I_S of the LT and MT networks have the levels recommended in Table 4.

Consumer THD_I level analysis is required to provide the power bars at the connection points (CPOs), depending on the maximum short-circuit power P_{SC} and the peak load current I_L, for a period of one year.

Table 4. THD_I levels

Ratio I_{sc}/I_L	**Report Ih/I_L [%] depending on the rang of the harmonics**					
	$h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$h \ge 35$	*TDD*
<20	4,0	2,0	1,5	0,6	0,3	5,0
20... <50	7,0	3,5	2,5	1,0	0,5	8,0
50... <100	10,0	4,5	4,0	1,5	0,7	12,0
100.. <1000	12,0	5,5	5,0	2,0	1,0	15,0
≥ 1000	15,0	7,0	6,0	2,5	1,4	20,0
Note 1: The harmonics appear to be limited to 25% of the limit values of odd harmonics. Note 2: Harmonic currents that are caused by continuous voltage deviations (eg: in semipontage rectifiers) are not allowed. Note 3: All power generation equipment has the admissible limits corresponding to these values.						

The results obtained by monitoring the parameters and the consumption of electricity from a pre-university education institution in Romania are compared with the energy quality standards. Thus the input parameters of PV system installation that will ensure the entire electricity consumption of the institution will be know.

2. STUDY OF THE CONSUMER CHARACTERISITCS

As a case study was chosen the building A of "Goga Ionescu" Technological High School Titu - Dambovita, where consumers are installed with the active powers declared by the manufacturers, visible in Table 5:

Table 5. Consumers in the Building A and their active powers

CONSUMERS	GROUND FLOOR		FIRST FLOOR		SECOND FLOOR	
	Pieces	Power	Pieces	Power	Pieces	Power
Laptop 45W	26	1170W				
Computer 600W	1	600W	2	1200W		
Multifunctional 400W	3	1200W				
Projector 300W	1	300W				
Fluorecent tube 18W	32	576W	46	828W	44	792W
Fluorecent tube 36W	10	360W	10	360W	8	288W
Neon 250W			1	250W		
Pump 70W	4	280W				
Pump 380W	2	760W				
Pump 1020W	1	1020W				
Keston C55 heating station 262W	6	1572W				
Total	**7838W**		**2638W**		**1080W**	
Total Building A	**11556W**					

The distribution of classrooms in the Building A, the types of consumers and their number, which are installed in each room are presented respectively in Tables 6, 7, and 8.

Table 9 shows the symbols used to represent the types of consumers and the active power declared by the manufacturer, which were used in the distribution on each floor in Building A.

Table 6. Ground Floor

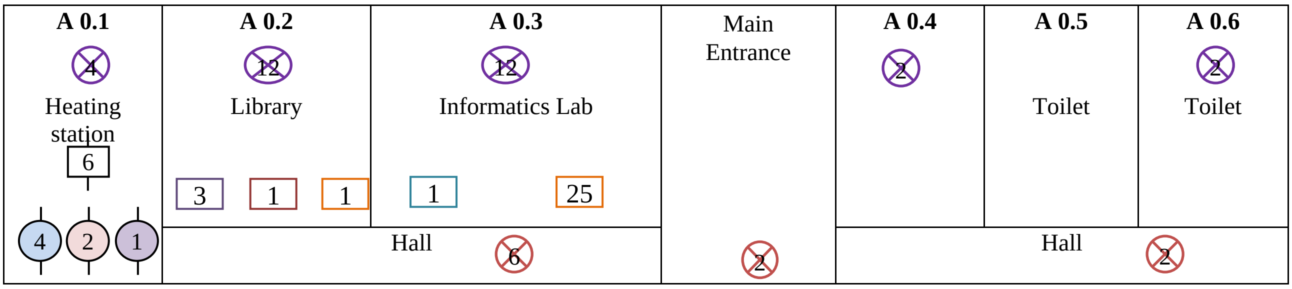


Table 7. First Floor

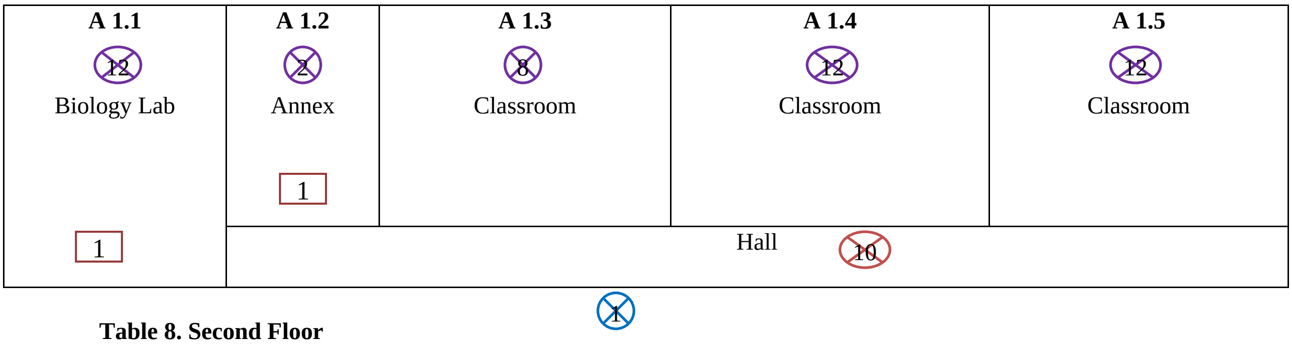


Table 8. Second Floor

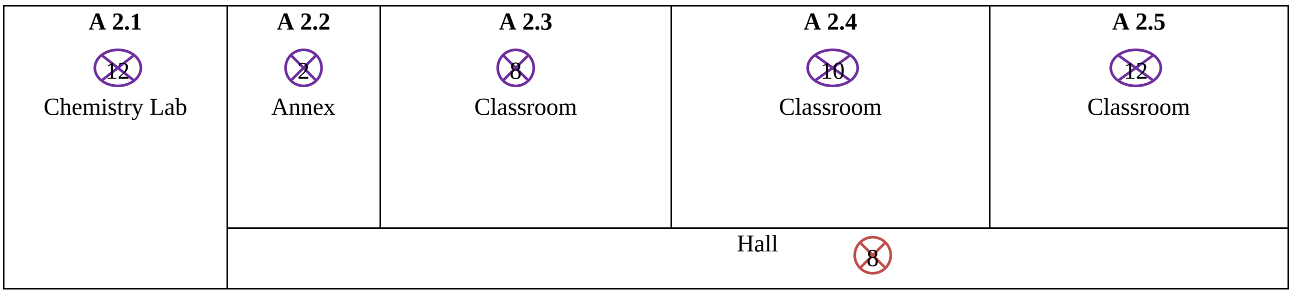
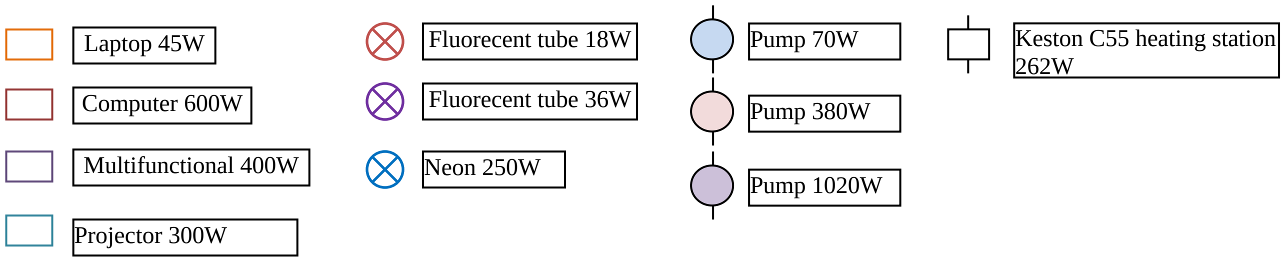


Table 9. Active symbols and powers of consumers.



The measurements were made with the Janitza UMG 96RM electric energy analyzer with the following general technical data:

- AC 20 ... 250 V AC supply voltage;
- DC 20 ... 300 V DC supply voltage;
- Used in low and medium voltage networks;
- Accuracy of voltage measurement 0.2%;
- Accuracy of current measurement 0.5%;
- Actual energy measurement accuracy (kWh, ... / 5A) Class 0.5;
- Number of points for the measurement period 426;
- Continuous measurement.

and by using current transformers from Lumel LCTS 93 / 30SC 250A / 5A, as can be seen in Figure 1.

Figure 1. The electric energy analyzer

Figure 2 illustrates the electrical energy analyzer which was connected to the power supply installation of building A.

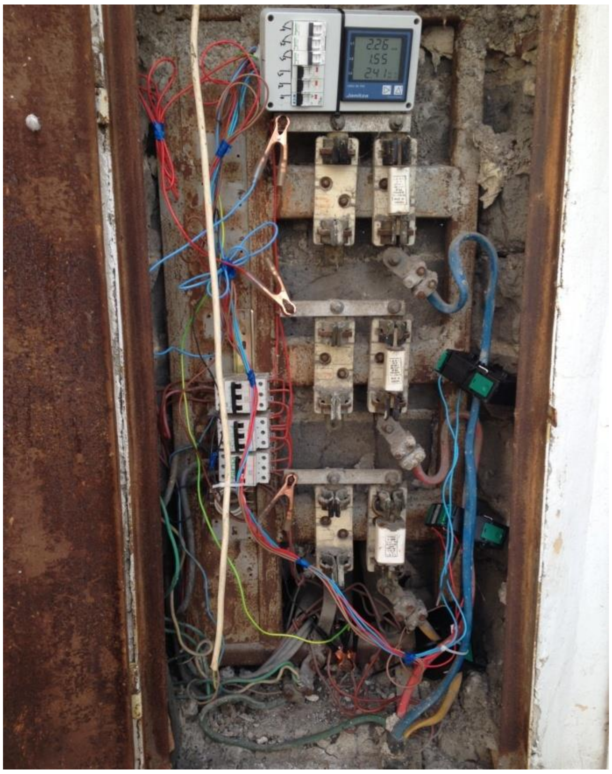


Figure 2. Connecting the electric energy analyzer

The weather conditions [20], which were measured between October 19 and 25, 2017, are shown in Table 10 and are a major factor in the power consumption along with the night time of the Sun raises (07:38), respectively sets (18:21), as well as the program of high school running between 08:00 and 20:00.

Table 10. The wather conditions

Thru. 19.10	Fri. 20.10	Sat. 21.10	Sun. 22.10	Mon. 23.10	Tue. 24.10	Wed. 25.10
Effective Temp. Day/Night 26° /5°	Effective Temp. Day/Night 25° /6°	Effective Temp. Day/Night 22° /5°	Effective Temp. Day/Night 19° /6°	Effective Temp. Day/Night 17° /10°	Effective Temp. Day/Night 14° /7°	Effective Temp. Day/Night 13° /4°
Medium Temp. Day/Night 17°/6°	Medium Temp. Day/Night 17°/6°	Medium Temp. Day/Night 17°/6°	Medium Temp. Day/Night 16°/6°	Medium Temp. Day/Night 16°/5°	Medium Temp. Day/Night 16°/5°	Medium Temp. Day/Night 16°/5°

3. RESULTS

The UMG 96RM Measurement Tool uses calculation formulas to obtain the energy parameters. For each power supply line the actual instantaneous voltages measured over a time interval are geometrically mediated to obtain an average effective value with the relation:

$$U_{1N} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(U_{1N})_i^2} \qquad (2)$$

where n is the number of measurement points, and U_{1N} is the value of the voltage on line 1 in a measurement period N. The values of the effective voltages for the 3-phases are shown respectively in Figures 3, 4 and 5. In these figures, different colors were chosen for representing the measured voltage values on each day of the monitoring interval.

Knowing that the standardized lower and upper limits for the voltage are ± 10% of the nominal voltage Un = 230V, U_l = 207V and U_u = 253V, it is observed that the voltage values, for the most of the measurement period, are closed to the upper limit for all the three voltage lines.

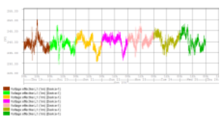


Figure 3. Line 1

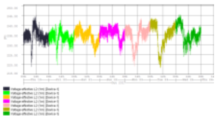


Figure 4. Line 2

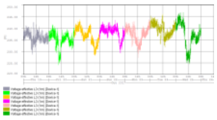


Figure 5. Line 3

Using a similar relationship, the values of currents absorbed by the consumer on each line were obtained. Thus, for line 1, over a N measurement period:

$$I_1 = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(I_1)_i^2} \qquad (3)$$

Current values for the three lines are shown in Figures 6, 7 and 8.

We can see large differences in current absorbed from the network:

i) on line 1(L1) it reaches a maximum consumption of 10A in a period of the day between 7-14 hours and during the rest of the day the consumption is zero;

ii) on line 2 (L2) the consumption is on average 4A / day, only during the period 6-11 there are increases that can reach up to 15A;

iii) on line 3 (L3), the consumption reaches a maximum of 14A in the 7-15 period, then drops to about 4A to 17 o'clock, the remaining 24 hours is a few hundred mA.

The unbalance between the three lines is due to their faulty load with consumers.

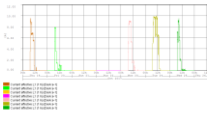


Figure 6. Line 1

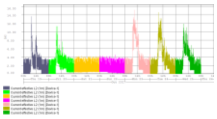


Figure 7. Line 2

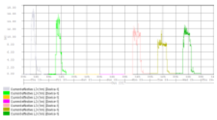


Figure 8. Line 3

Active, reactive and instantaneous powers measured over time N for line 1 were obtained with the following relationships:

$$P_1 = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(U_{1N})_i(I_1)_i} \qquad (4)$$

$$Q_1 = \sqrt{(S_1)^2 - (P_1)^2} \qquad (5)$$

$$S_1 = U_{1N} \cdot I_1 \qquad (6)$$

The active, reactive and apparent powers on line 1 are shown respectively in Figures 9, 10 and 11.

It can be seen that the power absorbed by the network has the following limit values: the active power does not exceed 1.5 kW, the reactive power is less than 2 kVAR and the apparent one does not exceed 2.4 kVA, during the day 7-14, the rest of the 24 the hours of consumption (ie active, reactive and apparent absorbed powers) being zero.

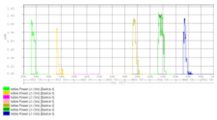


Figure 9. **Active Power Line 1**

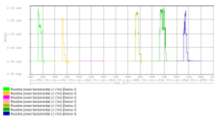


Figure 10. **Reactive Power Line 1**

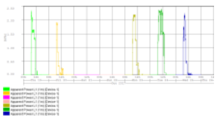


Figure 11. **Apparent power Line 1**

Active, reactive and apparent powers on line 2 are shown in Figures 12, 13 and 14.

In this case can be notice that the powers absorbed by the network have their limit values as follows: the active power has values that do not exceed 3kW in the 7-14th day of the day, the rest of the consumption being at the limit of 1kW (the limit that is maintained and on weekends), the inductive reactive does not exceed 15VAR during the 17-6: 30 and weekends, the reactive capacitive is less than 0.4kVAR in the 6: 30-17 hour period, with a peak consumption of 1.8kVAR in the period 7-8, and the apparent one does not exceed 3.4kVA, during the day 7-14, the remaining 24 hours of power absorbed by 1kVA.

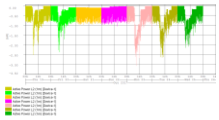


Figure 12. **Active Power Line 2**

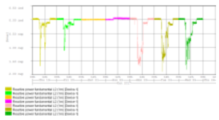


Figure 13. **Reactive Power Line 2**

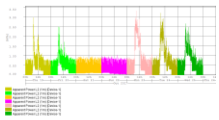


Figure 14. **Apparent power Line 2**

Active, reactive and apparent powers on line 3 are shown in Figures 15, 16 and 17.

We notice that the power absorbed by the network has the limit values as follows: the active power has values that do not exceed 4kW at the beginning of the 7-10th day of the day, then the consumption is about 1kW, the consumption slope drops below 0.5kW from 13am to 17, the rest of the consumption being zero (the weekend limit), the inductive reactive does not exceed 630VAR during the 7: 30-12: 30 working day period, the reactive capacitive is less than 50VAR during the time period 17 - 6: 30, with a peak consumption of 300VAR during 6: 30-8, but the weekend is zero, and the apparent one does not pass 4 kVA during day 7-11, then the slope drops from 1kVA to 0.2kVA by 17 o'clock, the remaining 24 hours the absorbed power not equal to 0.1kVA, except for the wekends when the absorbed powers are zero.

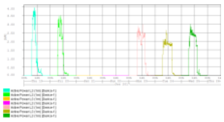


Figure 15. Active Power Line 3

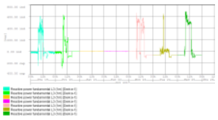


Figure 16. Reactive Power Line 3

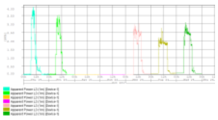


Figure 17. Apparent power Line 3

The power factor measured over a time interval N for phase 1 was obtained with the relation:

$$cos\varphi_1 = \frac{P_1}{Q_1} \quad (7)$$

and is shown for all three lines respectively in Figures 18, 19 and 20.

It can observe that the power factor for line 1 (L1) in the 7-11 hour period is between 0.6-0.8%, then decreases to an average of 0.3% until 16 o'clock, the remainder of the 24-hour period and the weekends being zero. For L2, the power factor in the 6-17 hour period is between -0.6% and -1%, and between 17-6 on working days he is between 0% and -0.6%, and the weekend is between -0.68 % and -0.97%, except Sunday between 7:00 and 7:00 when we have a power factor between -0.1% and -0.72%. For L3 the power factor has only positive values, between 0% and 0.05% in the weekend, during the 7: 30-12 hour period it is close to 1%, then gradually decreases to 0.3% by 17, after which is limited to not more than 0.1%.

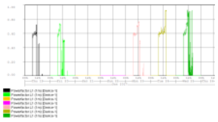


Figure 18. Line 1

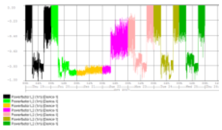


Figure 19. Line 2

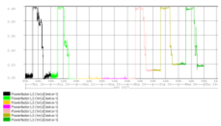


Figure 20. Line 3

The total distortion factor of the voltage measured over a time interval N for each line was obtained with the relation:

$$THD_v = \frac{1}{|U_1|}\sqrt{\sum_{n=2}^{M}|U_n|^2} \quad (8)$$

where U_1 is the value of the fundamental voltage, U_n values of the voltage harmonics, starting with the second one up to the order M. The total distortion factor of the voltage for the three lines is shown respectively in Figures 21, 22 and 23.

It can observe in these three Figures that the distribution of the total distortion factor of the voltage is similar, the percentage being in the range of 0.6% and 2.3%.

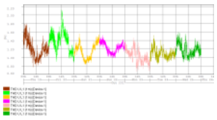


Figure 21. Line 1

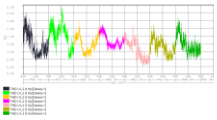


Figure 22. Line 2

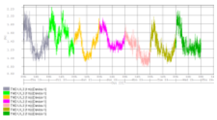


Figure 23. Line 3

The total distortion factor of the current measured over a time interval N for each line was obtained with the relation:

$$THD_I = \frac{1}{|I_1|}\sqrt{\sum_{n=2}^{M}|I_n|^2} \qquad (9)$$

where I_1 is the value of the current on the fundamental, I_n the values of the current harmonics, starting from the second to the order M. The total distortion factor of the current for the three lines is shown in Figures 21, 22 and 23, respectively.

In this case it can observe that the distributions of THD_I for L1 is about 9% during the day 7-14, with jumps of up to 160% between 30'-1h at the end of this interval, the rest of the day and the weekend being 100%. For L2 the percentage is between 55-100% per working day, during the 6-17 hour period there are decreases, the percentage reaching between 5-50%, and in the weekend it is in the range 30-75%, except the period between Sunday 7 am and Monday 7 o'clock when the percentage is between 55-120%. On L3, the percentage is between 6-30% in the 7-15 business day period, reaching 55-100% for the rest of the 24 hours except for Friday between 12:14 when the percentage is between 78 to 120%. The weekend is characterized by a 100% THD_I.

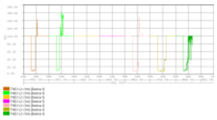


Figure 24. Line 1

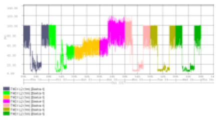


Figure 25. Line 2

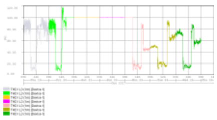


Figure 26. Line 3

4. CONCLUSIONS

Analyzing the energy quality parameters it can be seen the unbalance in the consumer load on the three lines. It is therefore necessary to balance them by moving consumers, both from the point of view of their influence on the network and the consumption periods. Since the minimum power factor provided by the payee in order not to pay reactive energy is normalized to 0.92, it is necessary to bring it from the measured values to the normal ones by reducing the reactive energy consumers, by increasing the network conductor section, or by compensating, thus reducing negative effects on the network, such as increased voltage losses, reduced network distribution capacities, etc.

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