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VOLTAGE QUALITY ANALYSIS IN LOW VOLTAGE PUBLIC ELECTRIC DISTRIBUTION NETWORKS OPERATED IN DISTORTED AND UNBALANCED CONDITIONS

BY

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Abstract. According to the Romanian Regulatory Authority for Energy, public low voltage electric distribution networks supply around 9,000,000 final consumers, which are residential or non-residential clients. Usually, these are non-linear consumers, with unbalanced placement on the three active phases. Following a thorough analysis of data and results obtained after an extended measurement campaign with instantaneous and long term recordings made in an important number of LV feeders, it was confirmed that the true operating conditions of these networks are distorted and unbalanced during the whole year, in working and weekend days. Also, the most often encountered voltage and current harmonics were identified and computed in percent from the fundamental wavelength. Instantaneous values have been recorded for line-ground and line-line voltages on LV feeders, relative level of voltage harmonics, the variation of harmonic voltages, THD coefficients for line-ground and line-line voltages, and their variation during a working day.

Key words: distribution network; harmonics; voltage quality.

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1. Introduction

The ‘quality of supply’ includes a high number of heterogenous topics and phenomena, ranging from the continuity of supply, disturbances, sinusoidal and non-sinusoidal waveforms for the state variables (voltages, currents), to economic aspects, which measure quality in free-market economy terms. The increasing demands coming from consumers for a better quality of supply led in many countries to the enforcement of detailed rules and regulations regarding the varoious aspects of electric distribution systems operation.

Low voltage (LV) and medium voltage (MV) networks account for around 85% of all electric networks in Romania. Their development and upgrading becomes of high importance, because of the consumption shift to MV and LV levels happening in the last years, and also because of the tighter regulations regarding the quality of supply. The ‘quality of supply’ means delivering electricity to consumers in a given range of quality requirements, which depends on an adequate operating state of the distribution network, measured through several parameters: voltage and frequency quality, continuity of supply. The quality of supply is of interest for both the consumer and the distribution utility. The continuity of supply component can be considered as an associated problem and is usually analyzed separately, because of its particular aspects. (Eremia *et al.*, 2006; Georgescu *et al.*, 2001; Georgescu *et al.*, 2008).

The AC three-phase electiricity supply is characterized by the following quality parameters: frequency deviation, frequency oscillation amplitude, voltage deviation, short term varioations of RMS voltage values, interruptions and spikes on the fundamental wavelength, the unbalance of the three-phase voltages and currents, content of voltage and current harmonics.

The analysis of the supply indices and parameters falls in the responsibility of the utility, but it must take into account the disturbances caused in the network by the consumers. This is the reason why regional monopoly utilities must ensure a continuous monitoring of the quality of supply parameters.

The public LV distribution networks supply a low number of small industrial consumers, which absorb relatively small powers, and an increasingly higher number of residential consumers. Lately, both consumer types have a growing number of sophisticated receptors, which require improved quality of supply. Also, it should be noted that most consumers supplied from LV networks are non-linear and usually connected on the three phases without taking into account strict balancing criteria.

These are the reasons why the real operation conditions encountered thorought the whole year, both in the warm and cold seasons, in working or weekend days, are distorted and unbalanced, with voltage and current harmonics of different orders and amplitudes (Chicco *et al.*, 2011; Eremia, 2006;

Golovanov *et al.*, 2007; Neagu *et al.*, 2012).

Today, there are many challenges for ensuring the quality of supply in LV distribution networks, and they are of theoretical, tehnical, but also economic nature. This paper is limited to a number of aspects regarding the distortion of voltage and current waves, analyzed in real LV distribution systems monitored the whole yeat in real operating conditions, which are distorted and unbalanced.

2. The Anlysis of Periodic Distorted Signals from LV Electric Power Distribution Networks

Harmonics were first defined by J.B.J. Fourier. This notion is derived from acoustics, where it signifies the vibration of a chord which accompanies the fundamental vibration and has a frequency equal to a multiple integer of the fundamental wave frequency. In a similar manner, in the electricity field, it is defined as voltage and current harmonic any electrical signal which has a frequency equal to a multiple integer of the fundamental 50 Hz sau 60 Hz frequency of the synchronous generator (Chicco *et al.*, 2011; Eremia, 2006; Georgescu *et al.*, 2008; Hanzelka *et al.*, 2004; Georgescu *et al.*, 2016).

In the literature (Eremia, 2006; Georgescu *et al.*, 2008), for studying steady distorted states, harmonic analysis is used, which computes the amplitudes and phases for THE fundamental wavelengths and higher order harmonics which propagate through an electrical line.

If a periodic function $s(t)$ can be represented as a piecewise smooth function over a period, then it can be decomposed in a Fourier series written as:

$$s(t) = S_0 + \sum_h S_h \sin(h\omega t + \varphi_h). \tag{1}$$

For analyzing a periodic non-sinusoidal signal written with (1), several quantities must be determined, the most important of which are its RMS value, distortion residue, harmonic level, total harmonic distortion (THD), average value, form factor etc.

The RMS value S of a periodic non-sinusoidal signal $s(t)$ is defined as the square root of the arithmetic mean of the squares of the harmonic values S_h, including the constant factor (0 order harmonic), and can be computed with:

$$S = \sqrt{\sum_{h=0}^{\infty} S_h^2}. \tag{2}$$

The order h of a harmonic is defined as ratio of the frequency of that wave to the frequency of the fundamental wave.

The distortion residue of a periodic non-sinusoidal signal $s(t)$ is computed by removing the fundamental wave from the trigonometric series attached to the signal, with the equation:

$$S_d = \sqrt{S^2 - S_1^2} = \sqrt{S_0^2 + \sum_{h=2}^{\infty} S_h^2}. \tag{3}$$

The total harmonic distortion (THD) is the ratio of all harmonic components of the voltage or current waveform to the fundamental voltage or current component. THD is always a positive and less than 1 value, and it can be computed in percent using one of the following equations:

$$\mathrm{THD} = \sqrt{\sum_{h=2}^{\infty} S_h^2 \Big/ \sum_{h=1}^{\infty} S_h^2} \cdot 100 = \frac{1}{S_1}\sqrt{\sum_{h=2}^{\infty} S_h^2} \cdot 100, \ \ [\%]. \tag{4}$$

The average value of the signal is the arithmetic mean of the periodic non-sinusoidal signal $s(t)$ over a period or for another time interval, being computed with:

$$S_{\mathrm{med}} = \frac{1}{T}\int_0^T s(t)\mathrm{d}t \tag{5}$$

For computing the amplitude factor k_a and the form factor k_f of the signal, the following equations can be used:

$$k_a = \frac{S_{\max}}{S}; \qquad k_f = \frac{S}{S_{\mathrm{med}}}, \tag{6}$$

where: $S_{\max}$ is the maximum value of the signal.

The advantage of decomposing a non-sinusoidal periodic signal in a Fourier series (1) is that, in a linear system, each harmonic component can be considered on its own, and the total distortion can be assessed by overlaying the components. For such a representation, it is interesting to note that, while in the acoustics field the addition of the harmonics over the fundamental wave changes the sound quality, but the audible effect is not affected by the difference in phase between the fundamental wave and the harmonics, in the electric field the effect is contrary, because the phase difference between the harmonics and the fundamental wave can be of major importance (Neagu *et al.*, 2016a). Depending on the phase angle, a harmonic can increase the peak value of the wave, while another harmonic can decrease it.

It follows that, when different harmonic sources are combined, the phase angle of the harmonics can differ considerably, and the resulting total distortion can be increased or reduced. Based on this discussion, the state variables of an electric distribution network (voltage and current) can be computed in periodic non-sinusoidal conditions with the following equations:

$$u(t) = U_0 + \sum_{h=1}^{+\infty} U_{hm} \sin(h\omega t + \gamma_{uh}); \quad i(t) = I_0 + \sum_{h=1}^{+\infty} I_{hm} \sin(h\omega t + \gamma_{ih}). \quad (7)$$

3. General Characteristics for Public LV Distribution Systems and Regulations for Limiting Distorting Operation States

In today's free market economic conditions, the development and upgrading of electric distribution systems is of essential importance, because in the recent year's consumption shifted to MV and LV levels. An estimate number for the final consumers supplied through the public distribution networks from Romania is impressive, of around 9,000,000, according to the Romanian Regulatory Authority for Energy (ANRE): 8,380,000 residential users, 20,000 public or big non-residential users, 600.000 small and medium non-residential users (Eremia, 2006; Georgescu *et al.*, 2001; Georgescu *et al.*, 2008). At the same time, the requiements for service quality, power transfer capacity, loss reduction and efficiency have significantly increased.

The LV distribution systerms are mainly built with the three-phase AC technology, with cable or aerial lines, using gernerally three active wires and one neutral wire. The used connection is the star type, with grounded neutral. In Romania, LV distribution systems are built in meshed configuration, but usually operated in radial or tree configuration, the disconnected sections being used as reserve for fault scenarios that can occur unexpectedly (Neagu *et al.*, 2016b).

By considering simplifying assumptions, in most theoretical and practical studies it is considered that the power systems are operated in perfect conditions, the electrictricity being generated and used everywhere at the same constant frequency, and the voltage and current waves being considered perfectly sinusoidal. However, because of physical, material, technological or economical reasons, the ideal balanced operating conditions cannot be achieved in reality. The real operating state is always a distorted state, where the current and voltage waveforms contain also some harmonic components (Chicco *et al.*, 2011; Golovanov *et al.*, 2003; Georgescu *et al.*, 2016; Hanzelka *et al.*, 2004).

Also, LV distribution networks supply a considerable number of unbalanced three-phase and two-phase receptors, with realtively high consumption, together with a very high number of single-phase small receptors which have an unbalanced placement on the three active phases of the network.

Taking into account all these aspects, the obvious conclusion is that distribution systems or networks are operated in real distorted conditions and, at the same time, are unbalanced. For these reasons, in daily normal operating conditions, the currents and voltages system on the three phases is distorted and unbalanced, and there is a current flow on the neutral wire. Actually, the neutral wire current is the phasor sum of the three active phase currents.

In Romania, the standards which define the rules for limiting the distorted states in electric networks are PE 143/1994, and 143/2012, where the parameters which describe the distorted state in a given location of the power system or electric network are specified: the total harmonic distortion THD_U and the relative level of voltage harmonics k_{hU}, computed as the ratio of the effective value of the *h*-th order harmonic to the fundamental wave RMS value. These parameters must not exceed the ranges given in Table 1, according to PE 143/2012, written in the form of compatibility levels computed in relative units U_h/U_1, where U_h is the RMS aplitude of the h-th order harmonic, and U_1 is the RMS value of the fundamental voltage wave for MV and LV networks.

The regulations regarding the establishment of a quality system and of a norm for the voltage used for supplying different consumer categories from the public distribution networks can be used for enforcing comparative performance assessments, encouraging competition, creating performance standards and sanctioning with penalties when these standards are not met. The costs associated with such a quality systems refer to investments for implementing the system itself and costs for inspections carried out throrought the year.

Table 1

Compatibility Levels for Individual Harmonic Voltages in MV and LV Electric Distribution Networks

Odd order, not multiple of three		Odd order, multiple of three		Even order	
Order *h*	Harmonic voltage, U_h, [%]	Order *h*	Harmonic voltage, U_h, [%]	Order *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 THD_U = 8%.					

The compatibility levels for harmonic voltages used in LV and MV networks are given in detail in Table 1, with the note that there are no such values defined for HV and UHV networks. For very short term distortion effects, the compatibility level is obtained in practice by multiplying the values from Table 1 with the k_{hVs}, coefficient, as in the following equation:

$$k_{hVs} = 1.3 + \frac{0.7}{45}\left(h - 5\right). \tag{7}$$

The rules must define the quality indices, together with their allowed range, to clarify the required procedures for measurements and recordings, and to specify the economic responsibilities for exceeding the allowed ranges.

4. Case Study

The urban public JT distribution networks are in a continuous gradual upgrading process, and they supply a reduced number of small industrial consumers, with low consumptions, and an increasing number of residential consumers. Both small industrial and residential consumers increasingly use sophisticated electric receptors which, among others, cause distorted operating states and current and voltage harmonics for the entire duration of the year, in cold and warm seasons, in working or weekend days.

In order to analyze the quality of the electricity delivered through the public LV distribution systems and the voltage quality at the consumers' end, and also to identify the consumers' distorted and unbalanced operating states, a significant number of measurements and recordings has been made in several LV distribution networks, in multiple network locations and on the feeder sections. For direct measurements, the CA8334 (Chauvin Arnaux) power analyzers have been used, which allow a complete and thorough analysis of the quality of supply, according to the SR EN 50160 and IEC 6100–4–30 standards.

The instantaneous electrical state variables provided by these analyzers, which are of interest in LV distribution networks, are the following: frequency, [Hz], line-line and line-ground RMS voltages U_{rms} and V_{rms}, [V]; the phase RMS currents on the active and neutral wires A_{rms}, [A]; the phase active powers P_{L1}, P_{L2}, P_{L3} and the three-phase active power P_{tot}, [W]; similar values for the reactive powers, [VAr] and apparent powers, [VA]; the power factor (PF) and tangent (tan), values on each phase and three-phase; the unbalance coefficient for voltage V_{unb} and current $A_{un\text{b}}$; the RMS fundamental wave voltages Vh01, [V]; the 2^{nd} up to 50^{th} order voltage harmonics (Vh02…Vh50), in percent from the fundamental wave; similar for the current fundamental wave Ah01, [A] and harmonics (Ah02…Ah50); the total distortion coefficient for line-line voltages U_{thd}, and line-ground voltages V_{thd} and similarly for currents, A_{thd}.

The research carried out for this paper began with the analysis of a real LV distribution system connected in a MV/LV substation, whose one-line diagram is given in Fig. 1, together with the physical data of its feeders (cable types, cross-sections and lengths). The LV distribution network has six feeders, which are operated in radial configuration and supply residential building blocks, a food store, an office building and a GSM antenna. The locations used for installing the power quality analyzers for taking measurements are marked on the one-line diagram, namely at the LV side of the substation transformer (1) and at the beginning of the main LV feeders (2,…,7).

After analyzing the results obtained during an extensive measurement campaign performed on-site in the distribution networks belonging to E.ON Romania Distributie, using the previously mentioned power quality analyzers, together with the data presented in the paper, the obvious conclusion was that the operating conditions of these public distribution networks are distorted and unbalanced, on all the LV feeders tested during the campaign. In the particular case of the test system presented in Fig. 1, recordings have been made in

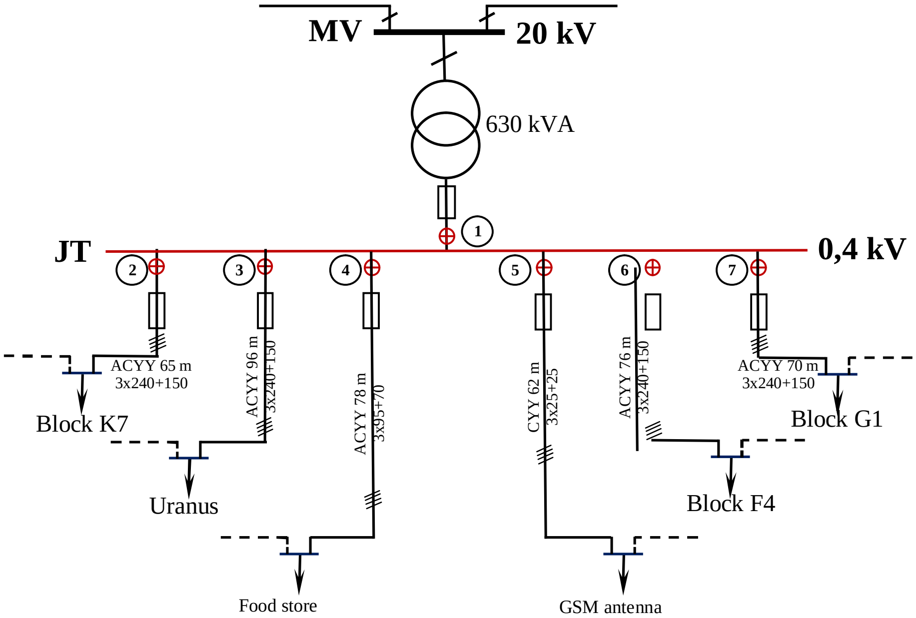

Fig. 1 – The one-line diagram for the public JT distribution system connected in a MV/LV substation.

different day time intervals in summer time (warm season conditions). As examples, in Figs. 2 and 3 are given the third order phase-ground voltage harmonics variation at the LV substation busbar (measurement point 1 from the one-line diagram), for a daytime interval and for the peak load interval (21.00 – 23.00 hours), measurements taken during a working day. Similarly, in Figs. 4,…,7 are given the third and seventh order voltage harmonics, for the same measurement point.

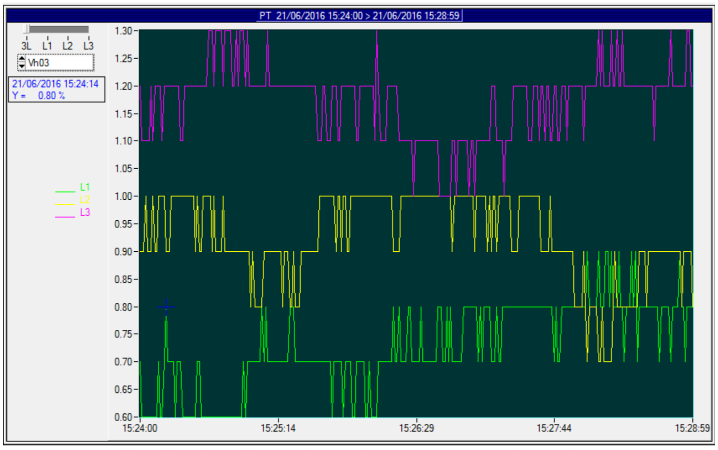

Fig. 2 – The third order voltage harmonics at the substation LV busbar, in a daytime interval, on a working day.

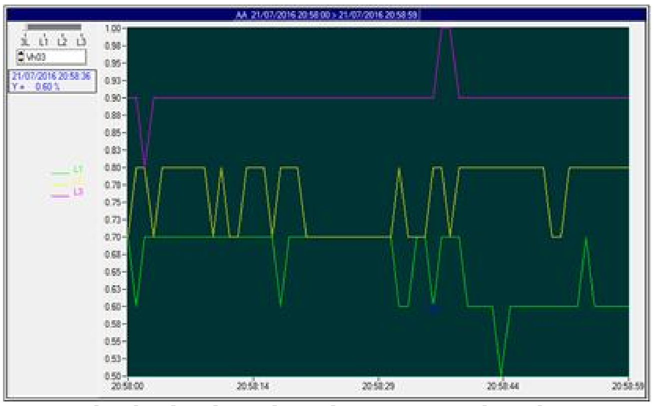

Fig. 3 – The third order voltage harmonics at the substation LV busbar, in the peak load interval, on a working day.

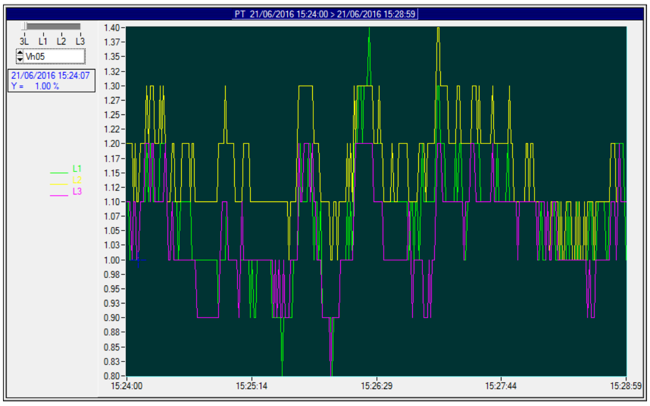

Fig. 4 – The fifth order voltage harmonics at the substation LV busbar, in a daytime interval, on a working day.

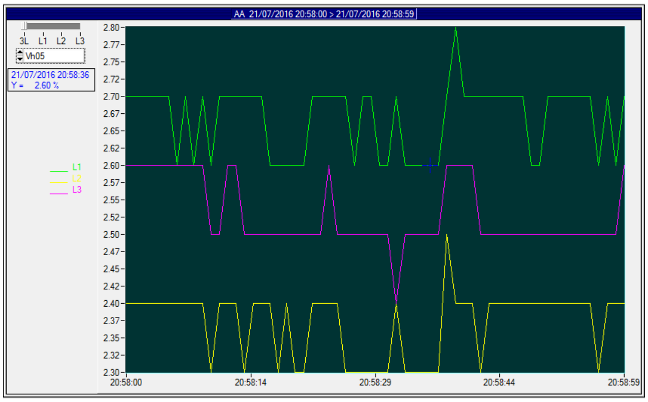

Fig. 5 – The fifth order voltage harmonics at the substation LV busbar, in the peak load interval, on a working day.

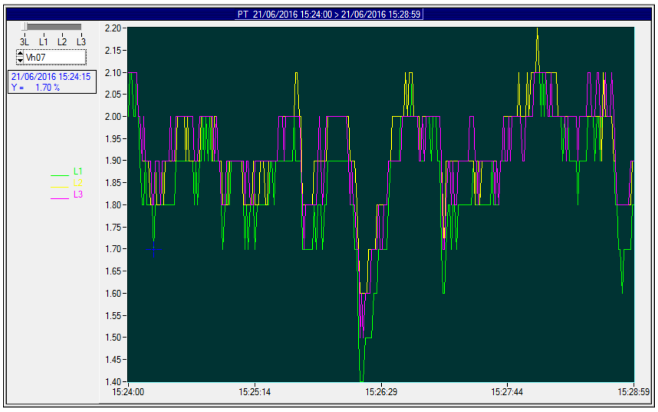

Fig. 6 – The seventh order voltage harmonics at the substation LV busbar, in a daytime interval, on a working day.

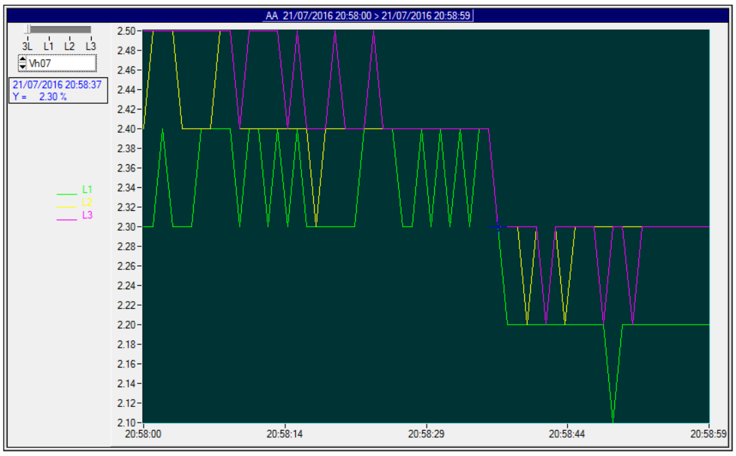

Fig. 7 – The seventh order voltage harmonics at the substation LV busbar, in the peak load interval, on a working day.

From the measurement/recording campaign carried out as described above, it was emphasized that the most frequently encountered current and voltage harmonics, having also the highest relative amplitude, are the odd 3, 5 and 7th order for voltages, together with the even 2 and 4th and odd 3, 5, 7 and 11th order harmonics for current.

As examples for the distribution network from Fig. 1, in Tables 2 and 3 are given the daily variations for two periods in a working day, daytime and peak load time, of the total harmonic distortion for line-ground voltages THD_V and line-line voltages THD_U, together with their average values over the measured time intervals. These values are given for all 7 measured locations.

Table 2

The Average Total Distortion Indices for Line-Ground Voltages, THD_V for the Measured Interval, in Daytime and Peak Load Time, at the Seven Measured Locations

Time interval	LV busbar	At the beginning of the LV feeders					
	Position (1)	Position (2)	Position (3)	Position (4)	Position (5)	Position (6)	Position (7)
Daytime	2.43	2.51	2.40	2.47	2.18	2.16	2.15
Peak load time	3.52	3.46	3.35	3.48	3.28	3.14	3.23

Table 3

The Average Total Distortion Indices for Line-Ground Voltages, THD_U for the Measured Interval, in Daytime and Peak Load Time, at the Seven Measured Locations

Time interval	LV busbar	At the beginning of the LV feeders					
	Position (1)	Position (2)	Position (3)	Position (4)	Position (5)	Position (6)	Position (7)
Daytime	2.23	2.34	2.20	2.29	2.02	1.99	1.96
Peak load time	3.41	3.32	3.29	3.42	3.04	3.06	3.13

Also, for the same test distribution network and same measurement locations, in Table 4 are presented the variations of the average compatibility levels, over the measured intervals, for the individual harmonic voltages. In Table 5 are summarized the maximum, minimum and average instantaneous neutral wire currents generated by the 3rd order harmonic (distortion) and zero sequence components (unbalance), measured on the first sections of the six LV feeders, in daytime and peak load intervals, warm season, working day, while in Table 6 are given the values of the unbalance coefficients for the currents at the LV busbar and at the beginning of the six feeders. Also, in Fig. 8 and 9 are depicted the variations of the neutral currents measured on the LV busbar of the substation, during daytime and peak load time respectively.

Table 4

The Variation of the Average Compatibility Level, on the Measured Interval, of the Individual Harmonic Voltages, in Daytime and Peak Load Time, at the Seven Measured Locations

Time interval	Harmonic order	The harmonic voltage Uh, [%]						
		Position (1)	Position (2)	Position (3)	Position (4)	Position (5)	Position (6)	Position (7)
Daytime	3	0.69	0.95	0.96	0.94	0.83	0.85	0.86
	5	1.09	1.09	1.01	1.04	0.86	0.88	0.85
	7	1.90	2.01	1.91	2.00	1.77	1.74	1.71
Peak load time	3	0.82	0.88	0.75	0.74	0.86	0.78	0.78
	5	2.63	2.56	2.42	1.84	2.42	2.24	2.27
	7	2.34	2.17	2.21	2.47	1.96	2.08	2.21

Table 5

The Instantaneous Neutral Current Values on the Six LV Feeders

Time interval	The neutral wire current I_N (A)																	
	Position (2)			Position (3)			Position (4)			Position (5)			Position (6)			Position (7)		
	min	avg	max	min	avg	max	min	avg	max	min	avg	max	min	avg	max	min	avg	max
Daytime	18.02	23.95	43.78	57.14	72.81	86.22	75.41	78.44	86.92	9.72	9.94	10.16	13.84	14.76	15.82	8.07	8.60	9.32
Peak load time	8.81	9.79	11.32	50.80	55.17	58.72	66.82	68.64	74.04	13.22	13.49	13.76	18.71	20.03	20.76	9.92	10.75	11.45

Table 6

The Values of the Unbalance Coefficients at the LV Busbar and at the Beginning of the Six Feeders

Time interval	The unbalance coefficient for the currents																				
	Position (1)			Position (2)			Position (3)			Position (4)			Position (5)			Position (6)			Position (7)		
	min	avg	max	min	avg	max	min	avg	max	min	avg	max	min	avg	max	min	avg	max	min	avg	max
Daytime	1.52	1.58	1.67	1.51	1.68	2.58	1.48	1.54	1.79	1.57	1.65	1.63	1.43	1.48	1.63	1.41	1.51	1.72	1.43	1.58	1.92
Peak load time	1.55	1.59	1.64	1.49	1.82	2.25	1.54	1.60	1.68	1.61	1.83	2.14	1.44	1.50	1.61	1.43	1.84	2.35	1.63	2.11	2.58

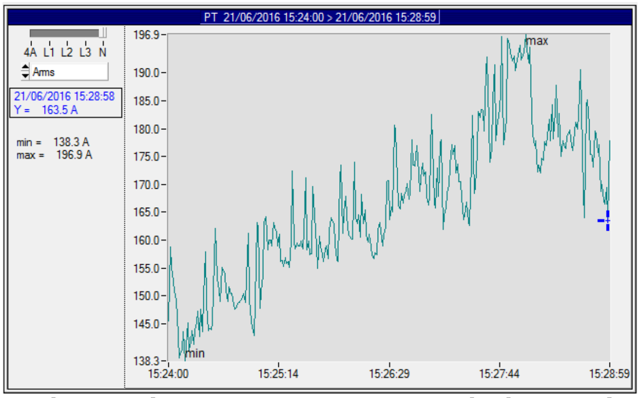

Fig. 8 – The neutral wire current variation at LV busbar, in a daytime interval, on a working day.

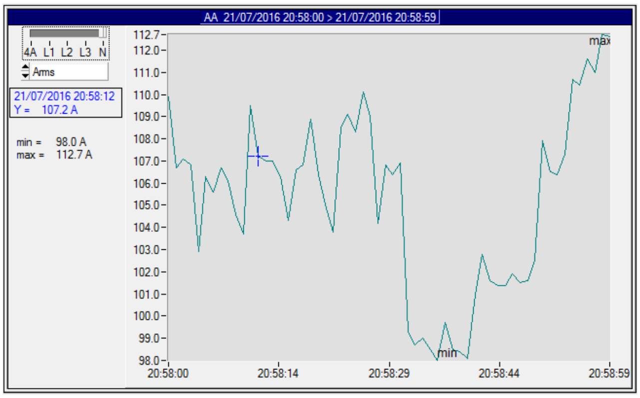

Fig. 9 – The neutral wire current variation at the LV busbar, in the peak load time interval, on a working day.

5. Conclusions

The comprehensive information regarding the instantaneous state values, currents and voltages, obtained during the extensive measurement campaingn performed with the CA 8334 power quality analyzer in several public electricity low voltage distribution networks from which non-residential and residential consumers are supplied, confirmed the presence of both current and voltage harmonics and the fact that all these networks are operated thorought the year in distorted and heavily unbalanced conditions. There were confirmed the most frequently found harmonics, with the highest amplitutes relative to the fundamental wave, as follows:

a) the odd order harmonics: 3, 5 and 7, for voltage;

b) the even order harmonics: 3, 5, 7, 11 and odd order harmonics: 2 and 4, for current.

In the test LV distribution system, the phase voltages measured in several locations, on a working day, is heavily distorted and unbalanced, being charcterized by the following indices:

1º The medium variation of the total line-ground voltage distortion, THD_V:

a) in a daytime interval, in the 2.15,…,2.43 range;

b) in the peak load interval, in the 3.14,…,3.52 range.

2º The medium variation of the total line-line voltage distortion THD_U:

a) in a daytime interval in the 1.96,…,2.34 range;

b) in the peak load interval, in the 3.04,…,3.41 range.

3º The variation of the average harmonic voltage compatibility level for:

a) the third order harmonic, in the 0.69,…,0.96 range;

b) the fifth order harmonic, in the 0.85,…,2.63 range;

c) the seventh order harmonic, in the 1.71,…,2.47 range.

4º The average variation of the unbalance coefficient for the current:

a) in a daytime interval, in the 1.41,…,2.58 range;

b) in the peak load interval, in the 1.43,…,2.58 range.

Taking into account the previous discussion about the average THD values and the found average values of the third, fifth and seventh voltage harmonics, it results that the test network is in the allowed range for harmonic pollution established in Romania. However, knowing that the public LV distribution networks supply a very large number of residential and non-residential consumers, the distortion of the voltage system can incur damages for both consumers and utilities. The most significant of these damages, along with the increase of losses generated by the harmonic pollution, appear because of the third order harmonic current flows through the neutral wires. These currents have characteristics similar to those of the zero sequence currents, which can lead do wire overheating and failure, potentially affecting severely other equipment connected in the LV network.

In the analyzed test network, the load is also heavily unbalanced, adding to the effects of the harmonic distortion. In this case, the use of 3 ½ three-phase cables is justified only in the scenarios in which a balanced loading of the phases can be achieved.

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CALITATEA TENSIUNII ÎN REŢELELE PUBLICE DE DISTRIBUŢIE DE JOASĂ TENSIUNE ÎN REGIM NESINUSOIDAL ŞI NESIMETRIC

(Rezumat)

Prin intermediul reţelelor publice de distribuţie de joasă tensiune sunt alimentaţi cu energie electrică, conform datelor publicate de ANRE, circa 9000000 de consumatori finali, respectiv utilizatori rezidenţiali, publici sau non rezidenţiali. În general, toţi aceşti consumatori sunt neliniari, fiind repartizaţi nesimetric pe cele trei faze ale reţelelor de joasă tensiune. Din analiza datelor sau rezultatelor obţinute în urma unei campanii extinse de măsurători/înregistrări instantanee şi de durată, a unui număr mare de distribuitori de JT, s-a confirmat că, în aceste reţele, regimurile reale de funcţionare sunt regimuri nesinusoidale şi nesimetrice, pe tot parcursul unui an calendaristic, atât în regimurile de vară şi iarnă, cât şi în zilele lucrătoare şi de repaus. De asemenea, a fost pusă în evidenţă prezenţa armonicilor de tensiune şi curent cel mai des întâlnite şi cu cele mai mari amplitudini, în procente prin raportare la armonica fundamentală. Au fost înregistrate totodată, mărimile instantanee privind valorile efective ale tensiunilor de linie şi de fază pe distribuitorii de JT, nivelul relativ al armonicilor de tensiune khU, variaţia tensiunilor armonice, coeficienţii totali de distorsiune THD pentru tensiunile de linie şi de fază etc., precum şi evoluţiile acestora în timp pe parcursul unei zile lucrătoare.