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HARMONICS IN PUBLIC DISTRIBUTION NETWORKS

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Abstract - *The growth of the number of the non-linear elements in public distribution networks, leads to an ascent of the harmonic pollution. Economically, the presence of the harmonics determines a growth of the operating costs. Unanimously is accepted the fact that the disturbing state in urban distribution networks can not be avoid because most of the appliances, public lighting, a.s.o use non-linear elements of circuit. In present, with the help of the Alpha Power Plus meters the non-sinusoidal state in public distribution networks can be identified and thus can be substantiated the solutions to diminish its effects.*

Keywords – *non-symmetry, unbalance*

1. INTRODUCTION

In an energetic system that operates in ideal conditions the energy is produced, transmitted and used under a single and constant frequency, the voltage and current waves being sinusoidal. Because of physical, constructive, technological or economical reasons the permanent sinusoidal steady state, as it is strictly defined, is not the real operating state in high current electrical engineering, being an ideal state, of study and analysis. In practice, the real operating state is that non-sinusoidal, consisting, in essence, of the deviation of the voltage and current waves from the sinusoidal shape, which is expressed, usually, under harmonic components.

In reference to the three-phase networks the appearance of the non-sinusoidal (disturbing) state is inevitably in the actual technological conditions, because any non-linear or parametric circuit element represents a source of harmonics, being, so, a disturbing element of circuit. The response of a such element of circuit excited by a sinusoidal signal is non-sinusoidal. In the future, it is expected a growth of the number and power of the disturbing elements and a large diversity of the points of connection for the small power disturbing receivers, which, in our days, already represent 30% of the low voltage receivers, having an annual growth ratio of 0.5% in economically developable countries.

In present days the main harmonic sources in the urban distribution networks are the lighting, generically named fluorescent, the TV-sets and computers. The main problems belong to the diversity of the points of connection in the network with implications on the harmonic current flow. The problem with the contribution of every disturbing element at the current flow is actual, trying to establish certain rules that take into account the complexity of the phenomenon. The elaboration of too strict rules can lead to unjustly economically costs paid to adapt the receivers. When the amount of the disturbing receivers in the whole network is not very large the connection of a new one doesn't implies big problems because the electric system is strong enough. The growth of the disturbing elements lead to a weakness of the system and this determined the present standards to establish more severe rules.

The medium and low voltage distribution networks represent about 85% from the total transport and distribution networks from Romania, in the conditions in which the expenditure of the electric energy shifted, in the past years, to medium and low voltage. In present, about 70% from the electric energy is sold at medium or low voltage, in comparison with the year of 1989, when it represented about 51%. Referring to the electrical energy, the aim of the supplier is that to provide to the consumer a sinusoidal voltage, symmetrical on the three phases, of values and frequency maintained between contractually defined limits. Through the term of quality of the electric energy, usually, it is understand the quality of the production, transformation and transmission, distribution and utilization process of the electromagnetic energy in the electromagnetic power systems. From the quantitative point of view, the quality of the electrical energy may be watched after some parameters that express the non-symmetrical powers, the global power factor, the non-symmetry factors for voltage and current, the harmonics' contents, the THD coefficients, a.s.o. The analysis of the parameters or indicators of the quality of the electric energy, as an obligation of the supplier, must be performed in close connection with the perturbations that might be introduced in the distribution network by the consumers during their operation. In Romania, there are defined and standardized a series of parameters that are susceptible to present interest in the definition of the quality of the electric energy. The noncompliance of the PE 142/80 (regarding the flicker), PE 143/94 (regarding the disturbing and non-symmetrical states), PE 124/95, RFUEE (both with a general character) or STAS (regarding normal and admitted voltages' deviations) lead to a depreciation of the quality of the electric energy.

The growth of the number of the non-linear elements in public distribution networks, leads to an ascent of the harmonic pollution. Economically, the presence of the harmonics determines a growth of the operating costs. The main effects of the operation under a non-sinusoidal state are: the growth of active power losses, the appearance of overvoltages in the nodes of the electric network and at the terminals of the equipments, high currents, bad operation of the instruments, of the devices for automation and control, of the electric meters, of the transformer meters, of the devices for distant control, the rise of the noise made by electric machines, phone perturbation, a.s.o.

2. THE ESTIMATION OF THE DISTURBING STATE

To estimate the disturbing state, for Romania, it was elaborated the PE 143/1994 standard that specifies the allowed limits of the quantities that characterize it.
The harmonic content is estimated with the help of the γ_{uk} and γ_{ik} coefficients defined as follows:

$$\gamma_{uk} = \frac{U_k}{U_1} \cdot 100 \ [\%] \, , \quad \gamma_{ik} = \frac{I_k}{I_1} \cdot 100 \ [\%] \, . \qquad (1)$$

where, U_k, I_k : the r.m.s. value of the k order harmonic for voltage, respectively current; U_1, I_1: the r.m.s. value of the first order harmonic (the fundamental) for voltage, respectively current.
The Total Harmonic Distortion (THD) for voltage - subscript u - and current - subscript i – are defined as follows:

$$THD_u = \frac{\sqrt{\sum_{k=2}^{\infty} U_k^2}}{U_1} \cdot 100 \ [\%] \qquad (2)$$

$$THD_i = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \cdot 100 \ [\%] \qquad (3)$$

The root mean square (r.m.s.) value for voltage and current are computed with the help of the expressions:

$$U = \sqrt{\sum_{k=0}^{\infty} U_k^2} \quad [\mathrm{V}] \qquad (4)$$

$$I = \sqrt{\sum_{k=0}^{\infty} I_k^2} \quad [\mathrm{A}] \qquad (5)$$

Table 1. The allowed limits for the quantities that estimate the disturbing state (from PE 143/1994)

		The voltage of the supply network (kV)		
		<1	1-35	>110
THD_U		2%	4%	3%
The harmonic content(γ_u); of order	3	0.85%	1%	0.8%
	5	0.65%	2.5%	2%
	7	0.60%	2.5%	2%
	9	0.40%	1%	0.8%
	11	0.40%	1.5%	1%
	13	0.30%	1.5%	1%
odd order from 15 to 25 (each)		0.25%	1%	0.8%
even order from 2 to 24 (each)		0.20%	0.6%	0.5%

Experience proved that THD_U (Total Harmonic Distortion for voltage) can be an useful quantity than can appreciate the possible consequences of the exposition, for a long period of time, of the equipments at non-sinusoidal voltages. The information contained in Table 2 are based on the observation provided from the exploitation of the equipments in disturbing conditions.
Unanimously is accepted the fact that the disturbing state in urban distribution networks can not be avoid because most of the appliances, public lighting, a.s.o use non-linear elements of circuit. In the near future, when the electric cars will, probably, replace the actual ones, a lot of rectifiers will be necessary and, so, the disturbing state will rise.

Table 2. The possible consequences of the exposition for a long period of time of the equipments at non-sinusoidal voltages

THD_U	Possible consequences of the exposition for a long period of time
$THD_U \le 5\%$	Do not appear any problems in many of the cases
$5\% \le THD_U \le 7\%$	There can appear some problems for the very sensitive elements
$7\% \le THD_U \le 10\%$	There can appear some problems for many of the equipments
$10\% \le THD_U$	For sure, will appear effects for a long time

3. THE DISTURBING STATE IN A PUBLIC DISTRIBUTION NETWORK

It is meritorious that electric companies are preoccupied by the disturbing state and try to identify the problem and to take measures against it. But before taking measures one must know the real level of the harmonic pollution in different kinds of networks. With the help of the Alpha Power Plus meters there can be measured, on every of the three phases, on the 0.4 kV side of every point of supply of a public distribution network, the γ_{uk} and γ_{ik} coefficients (up to the 15^{th} harmonics), the r.m.s. values of the voltages and currents, the THD_U and THD_I coefficients. The records of the Alpha Power Plus meters look like in Fig.1.

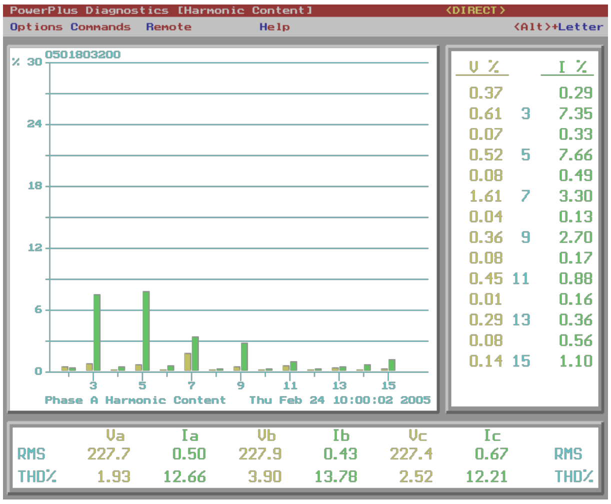

Fig. 1.- The record, on a phase, of an Alpha Power Plus meter installed on the 0.4 kV side of a supply point of a public distribution network

With these data provided by the records the following quantities where computed:
- the r.m.s. value of the fundamental for voltage and current on every of the $m=a,b,c$ phases:

$$U_{1m} = \frac{100U_m}{\sqrt{100^2 + \sum_{k=2}^{15} \gamma_{ukm}^2}} \quad [\mathrm{V}] \tag{6}$$

$$I_{1m} = \frac{100I_m}{\sqrt{100^2 + \sum_{k=2}^{15} \gamma_{ikm}^2}} \quad [\mathrm{A}] \tag{7}$$

- the r.m.s. value of every harmonic:

$$U_{km} = \gamma_{ukm} \cdot U_{1m} \quad [\mathrm{V}]\,,\ I_{km} = \gamma_{ikm} \cdot I_{1m} \quad [\mathrm{A}]$$
$$m = a, b, c\,, \qquad k = 2, 3, \ldots 15 \tag{8}$$

- the disturbing residue for voltage, U_d and current, I_d:

$$U_d = \sqrt{\sum_{k=2}^{15} U_k^2} \quad [\mathrm{V}]\,, I_d = \sqrt{\sum_{k=2}^{15} I_k^2} \quad [\mathrm{A}]\ . \tag{9}$$

The data measured or computed in some of the points of supply of the network are presented in Tables 3 and 4.

Table 3. Voltage harmonics and THD coefficients with marks for those quantities that do not respect the PE 143/1994 standard

	Point of measure 11			Point of measure 270			Point of measure 271		
	phase a	phase b	phase c	phase a	phase b	phase c	phase a	phase b	phase c
U (V)	225.4	225.6	225.4	221.7	221.7	221.0	222.3	221.6	222.0
U_1 (V)	225.37	225.55	225.35	221.65	221.61	220.90	221.52	2 2 1 . 9 3	0 . 2 6
U_2 (%)	0 . 2 6	0.6	0.6	0.36	0.62	0.12	0.32	0.57	0.66
U_3	0.72	0.42	0.42	0.37	0.29	1.18	0.59	1.25	0.72
U_4	0.06	0.44	0.44	0.12	0.43	0.44	0.07	0.54	0.43
U_5	1.31	0.64	0.64	1.77	1.67	2.07	1.51	1.6	1.46
U_6	0.06	0.37	0.37	0.07	0.63	0.4	0.04	0.61	0.18
U_7	0.84	1.01	1.01	1.05	1.41	0.96	0.96	0.23	0.97
U_8	0.08	0.25	0.25	0.05	0.74	0.5	0.09	0.24	0.64
U_9	0.06	0.4	0.4	0.21	0.45	0.31	0.14	0.41	0.16
U_{10}	0.06	0.58	0.58	0.06	0.48	0.5	0.04	0.48	0.5
U_{11}	0.16	0.45	0.45	0.07	0.73	0.23	0.03	0.31	0.7
U_{12}	0.01	0.45	0.45	0.02	0.42	0.55	0.02	0.43	0.59
U_{13}	0.2	0.67	0.67	0.43	0.43	0.53	0.13	0.64	0.62
U_{14}	0.09	0.42	0.42	0.08	0.41	0.48	0.1	0.67	0.3
U_{15}	0.04	0.7	0.7	0.1	0.47	0.5	0.09	0.42	0.72
THD_U	1.78	3.34	3.5	2.23	3.13	3.87	1.93	3.48	3.16

In tables 3 and 4 the following notations were used:
- U(V): the r.m.s. value of the voltage expressed in Volts; U1 (V): the r.m.s. value of the voltage on the 1st harmonic, expressed in Volts; Uk: the voltage on the kth harmonic expressed in % (which is identically with the γ_{uk} coefficient, as it is given by (1)).
- there are marked with light gray the even harmonics, with gray the odd harmonics and with dark gray the THD_U coefficients that do not respect the PE 143/1994 standard.

Table 4. Voltage harmonics and THD coefficients with marks for those quantities that do not respect the PE 143/1994 standard

	Point of measure 294			Point of measure 301			Point of measure 413		
	phase a	phase b	phase c	phase a	phase b	phase c	phase a	phase b	phase c
U (V)	211.60	212.50	213.20	214.90	213.80	214.50	223.60	223.50	224.10
U_1 (V)	211.56	212.41	213.13	214.85	213.75	214.43	223.58	223.42	224.03
U_2	0.18	0.76	0.73	0.08	0.08	0.32	0.21	0.27	0.74
U_3	0.27	1.25	0.81	1.16	1.16	0.49	0.57	1.09	0.25
U_4	0.09	0.41	0.47	0.06	0.06	0.12	0.13	0.41	0.45
U_5	1.86	1.66	1.45	1.54	1.54	1.88	0.65	1.16	0.84
U_6	0.09	0.65	0.4	0.11	0.11	0.19	0.13	0.32	0.51
U_7	0.07	0.42	0.45	0.58	0.58	0.34	0.14	0.51	0.69
U_8	0.08	0.51	0.5	0.05	0.05	0.18	0.06	0.57	0.48
U_9	0.1	0.41	0.54	0.33	0.33	0.24	0.34	0.78	0.69
U_{10}	0.05	0.57	0.48	0	0	0.05	0.01	0.56	0.48
U_{11}	0.43	0.63	0.85	0.25	0.25	1.37	0.9	0.97	1.2
U_{12}	0.01	0.65	0.48	0.03	0.03	0.05	0.03	0.52	0.52
U_{13}	0.11	0.64	0.54	0.58	0.58	0.28	0.36	0.83	0.93
U_{14}	0.01	0.62	0.56	0.05	0.05	0.03	0.06	0.6	0.48
U_{15}	0.03	0.54	0.55	0.11	0.11	0.09	0.19	0.51	0.64
THD_U	2.17	3.84	3.59	2.06	3.46	3.11	1.78	3.64	4.04

Analyzing the data one can affirm that the harmonic charge is unequal on the three phases, which is a normal situation, as the operating state is non-symmetrical. It is well known that is very difficult to achieve a perfect balance of the charges on the three phases of a public distribution network. From the very beginning we knew that the operating state of the analyzed network is non-symmetrical and the harmonic measurements provided the confirmation. This is another reason why it is recommended, in a non-sinusoidal and non-symmetrical operating state, to start the measures of the limitation of the negative effects by balancing the receivers on the three phases.

It is to be observed that the even harmonics are lower than the narrow odd ones. As the consumers are restaurants, hotels, hospitals, public lighting and of domestic and commercial types it is normal situation. What is to be remembered is that the non-sinusoidal state is very firm installed in the network. There are a lot of marked quantities, which show that must be taken measures fast against this situation. Even if the highest THD_U is lower that 5%, which is a value of reference, (see Table 2), if there are not taken measures against this situation now, in the near future they will become stringent. The harmonic pollution is not an acute disease, but induces the development of others. You can live a long time with it, but in the whole network may appear different problems. It is not well known the mechanism but experience proved this. The diagnostic, the causes and the eventually measures that can be taken are presented in Table 5.

Table 5. The diagnostic, the causes and the eventually measures that can be taken to diminish the non-sinusoidal state

Mea-sure	Phase	Diag-nostic	Causes	Eventually measures
11	a	On limit	Especially the 5^{th} harmonic	Filter on the 5^{th} harmonic
	b	Significant exceed of the standard	Almost all harmonics and especially the even ones, the 5^{th} and the 7^{th}	Must be exactly established the sources of the even harmonics -filters for the 5^{th} and the 7^{th} harmonics
	c	Significant exceed of the standard	Almost all harmonics and especially the even ones	Must be exactly established the sources of the even harmonics -filters for the 5^{th} and the 7^{th} harmonics
270	a	Exceed of the standard	Especially the 5^{th} and the 7^{th} harmonics	Filters for the 5^{th} and the 7^{th} harmonics
	b	Exceed of the standard	Almost all harmonics but especially the 5^{th} and the 7^{th}	Filters for the 5^{th} and the 7^{th} harmonics
	c	Exceed of the standard	Almost all harmonics but especially the 5^{th} and the 7^{th}	Filters for the 5^{th} and the 7^{th} harmonics
271	a	On limit	The 5^{th} and the 7^{th} harmonics	Filters for the 5^{th} and the 7^{th} harmonics
	b	Significant exceed of the standard	Almost all harmonics	A deeper study of the consumers' nature and after that the substantiation of the solutions
	c	Significant exceed of the standard	Almost all harmonics	A deeper study of the nature of the consumers and after that the substantiation of the solutions
294	a	Exceed of the standard	Especially the 5^{th} harmonic	Filter on the 5^{th} harmonic
	b	Exceed of the standard	Almost all harmonics	A deeper study of the consumers' nature and after that the substantiation of the solutions
	c	Exceed of the standard	Almost all harmonics	A deeper study of the consumers' nature and after that the substantiation of the solutions
301	a	Exceed of the standard	Especially the3^{rd} and the 5^{th} harmonics	Filters for the 3^{rd} and the 5^{th} harmonics
	b	Exceed of the standard	Especially the3^{rd} and the 5^{th} harmonics	Filters for the 3^{rd} and the 5^{th} harmonics
	c	Exceed of the standard	Especially the 5^{th} harmonic	Filter on the 5^{th} harmonic
413	a	On limit	Especially the 5^{th} harmonic	Filter on the 5^{th} harmonic
	b	Significant exceed of the standard	Almost all harmonics are very high	A deeper study of the consumers' nature and after that the substantiation of the solutions
	c	Significant exceed of the standard	Almost all harmonics are very high	A deeper study of the consumers' nature and after that the substantiation of the solutions

In present, the most economic and efficient method used to diminish the harmonic pollution is that based on the installation of filters tuned on the harmonics that exceed the limits. In this way the harmonic content and the THD_U coefficient become lower and fulfil the requested criteria. Because any filter contains a capacitor, the problem of filtering must be appreciated in close connection with the improvement of the power factor.

4. CONCLUSIONS

- In the present structure of the low voltage distribution networks, the main distortion load is represented by the public lighting, generally named as fluorescence type, an important source of harmonics being also the colour TV sets and personal computers.
- The existence of an important number of low power non-linear loads, which act as harmonic generators, connected in various points of the network, determines the dependence of the distorting state magnitude on the load curve.
- In the study of the harmonic current flow, in the distribution network, a number of distributed non-linear loads can not be estimated as a concentrated single distorting element.
- In present, the harmonic pollution in public distribution networks can be measured and appreciated with the help of the Alpha Power Plus meters.

REFERENCES

[1] Gretsch R., *Harmonics in Low and Medium Voltage Systems Analysis of Disturbing Sources and Measures for a Limitation of the Emission.* 11th Internat. Conf. on Electricity Distribution, 1991, 1732-1739

[2] Deflandre T., Courty S., Greiveldinger C., Javerzac J.L., *Impact Of Harmonics On French Public Networks: State of Play, Studies, Future Trends,* EDF 1996

[3] Deflandre T., Arson S., Rioual P., *Working Out A Rule For Connecting Industrial Costumers Generating Harmonics* EDF 1995

[4] Kaendler G., *Voltage Distortion in High Voltage Networks Caused by Switched Mode Power Supplies.* Power Quality Conference, Bremen 1995, 117-125.

[5] Mielczarski W., *Quality of Electricity Supply.* 4-th Internat. Conf. on Electrical Power Quality and Utilisation. Cracow, 1997, 15-23.

[6] Ţugulea, A., *Consideraţii privind efectele energetice în regimuri armonice ale sistemelor trifazate* , Energetica XXXIV, 3 (1986), 121-130. [1]

[7] Varvara V., *The Non-sinusoidal State in the Urban Distribution Networks*, Bul. Inst. Polit Iasi, Tom XLVIII, (LII), fasc. 5, 2002, 227-232.

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