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ANALYSIS OF A LOW VOLTAGE DISTRIBUTION NETWORK THAT OPERATES IN A NONSINUSOIDAL REGIME AND THE ADDITIONAL ACTIVE POWER LOSSES IN THIS NETWORK

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Abstract. In a distribution network that supplies energy towards diverse consumers, there are recorded the nonsinusoidal voltages and the nonsinusoidal currents, with the help of an ALPHA-meter. Thus, can be calculated the parameters that characterize the nonsinusoidal operating regime. This regime can be evaluated, with the help of the Regulation for Limitation of the Deforming Regime in Unbalanced Electric Networks. Conclusions are drawn regarding the causes of the appearance of the nonsinusoidal operating regimes. Also, there are calculated the additional active power losses which appear in the networks operating in nonsinusoidal regime.

Key words: nonsinusoidal regime; active powers in nonsinusoidal regime.

1. Introduction

At a distribution network there are connected various consumers, some of them being linear, others, nonlinear. In the latter case, when the number is high or their installed power is high, the operating regime can become nonsinusoidal. In such a operating regime, the waveforms of the voltages and

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currents deviate from sinusoidal. Beside the fundamental frequency component, the signals contain higher frequency components which are integer multiple of 50 Hz, called harmonics.

The types of the consumers connected at a distribution network have changed much in the last 20 years. Almost all consumers have devices that contain parametric or nonlinear circuit elements that represent sources of harmonics for the network at which they are connected (Rosman & Savin, 1974). Now, the consumers that prevail contain low power converters. The control of the flow of the harmonic current can become a problem because of the diversity of places where the converters are connected, the moments when they are turned on, together with their operating time.

2. The Analysis of a Low Voltage Distribution Network that Operates in Nonsinusoidal Regime

It is analysed a urban 20 kV distribution network. There are various types of consumers connected at the substation: residential buildings, office buildings, street lighting, hotels, restaurants, schools a.s.o.

There can be registered the harmonic levels, up to the 15-th, together with the r.m.s values of voltages and currents, with the help of a Alpha-meter placed on every phase, on the 0.4 kV side. The level of each harmonic voltage and current is given as a percentage [2], [3]:

$$H_{U_k} = \frac{U_k}{U_1}\cdot 100 \quad [\%]\, , H_{I_k} = \frac{I_k}{I_1}\cdot 100 \quad [\%]. \tag{1}$$

where: U_k, I_k are the r.m.s. value of the voltage, respectively the r.m.s. value of the current, on k harmonic order; U_1, I_1 – the r.m.s. value of the voltage, respectively the r.m.s. value of the current, which correspond to the fundamental frequency of 50 Hz.

The total harmonic distortion, *THD*, for voltage (subscript U) and current (subscript I) are calculated, for each phase, with the help of the expressions:

$$THD_U = \frac{\sqrt{\sum_{k=2}^{\infty} U_k^2}}{U_1} \times 100, \ [\%]\, , \ THD_I = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \times 100. \ [\%]\, . \tag{2}$$

The r.m.s. values of a nonsinusoidal signal, U and I, are calculated with the help of the expressions:

$$U = \sqrt{\sum_{k=0}^{\infty} U_k^2}\ , \ [\mathrm{V}], \qquad I = \sqrt{\sum_{k=0}^{\infty} I_k^2}\ , \ [\mathrm{A}]. \tag{3}$$

Thus, on each phase, there can be calculated:

a) the r.m.s. value of the voltage, respectively the r.m.s. value of the current on fundamental frequency, U_1 and I_1:

$$U_1 = \frac{100U}{\sqrt{100^2 + \sum_{k=2}^{15} H_{U_k}^2}}, \text{[V]}; \qquad I_1 = \frac{100I}{\sqrt{100^2 + \sum_{k=2}^{15} H_{I_k}^2}}, \quad \text{[A]}. \tag{4}$$

b) the r.m.s. value of the voltage, respectively the r.m.s. value of the current on each harmonic, U_k, I_k, $k \in [2, 15]$:

$$U_k = \frac{1}{100} H_{U_k} U_1, \text{[V]}; \qquad I_k = \frac{1}{100} H_{I_k} I_1, \quad \text{[A]}. \tag{5}$$

c) the deforming residue for voltage and current, U_d, respectively, I_d:

$$U_d = \sqrt{\sum_{k=2}^{15} U_k^2}, \quad \text{[V]}; \qquad I_d = \sqrt{\sum_{k=2}^{15} I_k^2}, \quad \text{[A]}. \tag{6}$$

Once there have been collected the values provided by the Alpha-meter, there can be calculated the values for U_1, I_1, U_k, I_k, U_d and I_d, with (4)...(6). With the help of the Regulation for Limitation of the Deforming Regime in Unbalanced Electric Networks, the nonsinusoidal regime in the analyzed network can be appreciated. In our network there was observed a powerful deforming regime on most of the harmonics, especially during the evening and the night time (from 8 p.m. to 12. p.m.), period during which most of the devices that have nonlinear elements of circuit in their construction are turned on (street lighting, personal computers, TVs a.s.o.). Very early in the morning (2 a.m.), the deforming regime becomes softer, mainly because all the devices are turned off and only the street lighting is on. During the morning (7 a.m), when street lighting is also turned off, the network operating mode is almost sinusoidal (see Table 1).

In all the situations when the network operates in nonsinusoidal regime, on all of the three phases, the values which characterize the regime were higher than the limits specified by the Regulation, indicating a structural problem of the network. The main deforming consumer in the network is the street lighting. The unbalance of the network is also observed, the deforming regime being stronger on two phases (see Table 2). A global improvement of the operating mode can be achieved by installing a filter for the 5-th harmonic on the main bars. Another solution, but that does not take into account the underlying causes of the existence of the nonsinusoidal regime, is the increase of the power short circuit on the substation bars, solution that requires investments.

Table 1
Parameters that Characterize the Deforming Regime Regarding Voltage - Temporal Evolution

	Hour: 2 am			Hour: 8 am			Hour: 8 pm			Hour: 12 pm		
Phase	a	b	c	a	b	c	a	b	c	a	b	c
U, [V]	233.5	232.0	235.4	227.2	226.0	225.5	229.5	228.8	232.0	225.0	224.4	227.2
U_1, [V]	233.5	232.0	235.4	227.1	225.9	227.5	229.0	228.7	232.0	224.94	224.3	227.2
U_2, [V]	0.81	0.766	0.329	0.501	0.232	0.159	1.606	1.761	0.41	1.575	1.727	0.409
U_3, [V]	1.003	2.018	0.941	1.003	1.355	1.638	0.826	2.562	2.155	0.810	2.512	2.113
U_4, [V]	1.05	0.975	0.143	0.318	0.066	0.022	1.05	0.962	0.138	1.035	0.942	0.136
U_5, [V]	1.936	1.647	1.392	1.493	1.244	1.857	2.409	2.674	1.738	2.362	2.624	1.704
U_6, [V]	0.881	1.395	0.259	0.411	0.564	0.295	0.826	1.168	0.0928	0.810	1.144	0.091
U_7, [V]	1.741	1.066	0.869	0.477	0.836	0.91	0.879	1.027	1.065	0.877	1.077	1.045
U_8, [V]	1.723	0.674	0.260	0.179	0.431	0.159	0.617	1.074	0.116	0.607	1.054	0.114
U_9, [V]	1.073	0.556	0.495	0.911	0.228	0.773	1.537	2.126	0.950	1.507	2.086	0.931
U_{10}, [V]	1.403	1.159	0.138	2.159	0.50	0.134	1.169	1.168	0.091	1.147	1.144	0.091
U_{11}, [V]	1.145	0.698	0.282	0.385	1.635	0.523	2.019	2.000	1.065	1.979	1.862	1.045
U_{12}, [V]	1.012	0.975	0.115	0.045	0.288	0.067	1.055	1.119	0.069	1.035	1.099	0.068
U_{13}, [V]	1.838	1.044	0.069	0.500	1.130	0.612	1.212	1.847	0.974	1.192	1.817	0.954
U_{14}, [V]	1.586	1.599	0.162	0.134	0.511	0.089	1.582	1.376	0.045	1.552	1.346	0.045
U_{15}, [V]	0.862	1.413	0.259	2.159	0.3776	0.362	1.002	1.529	0.627	0.990	1.525	0.613
THD_U	1.67	3.5	2.97	0.958	2.8	3.26	1.33	2.04	2.3	1.31	2	2.26
U_d, [V]	5.04	4.53	2.06	3.826	2.998	3.05	5.097	6.322	3.523	4.997	6.199	3.453

Table 2
Voltage Harmonics and Distortion Coefficients Calculated at Transformation Stations, the Deviations from Normative are Marked

	PT12			PT65			PT69			PT294			PT415		
Phase	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
U, [V]	229,9	230.1	229.9	236.6	235.9	235.6	218.4	212.8	217.0	215.8	212.5	216.7	228.0	227.9	228.5
U_1, [V]	229.8	230.0	236.5	231.9	236.5	235.5	218.3	216.9	217.3	215.7	216.6	217.3	227.9	227.8	228.4
U_2, [V]	0.26	0.61	0.61	0.05	0.29	0.07	0.31	0.71	0.73	0.19	**0.77**	0.74	0.21	0.27	0.75
U_3, [V]	0.73	0.44	0.43	0.21	**1.19**	0.42	0.42	0.73	**1.02**	0.28	**1.27**	0.82	0.58	**1.12**	0.26
U_4, [V]	0.07	0.45	0.45	0.02	0.43	0.02	0.28	0.52	0.47	0.09	0.42	0.47	0.13	0.42	0.46
U_5, [V]	**1.33**	0.65	0.65	**1.12**	0.58	0.40	**1.78**	**1.99**	**2.61**	**1.90**	**1.69**	**1.48**	**0.66**	**1.19**	**0.88**
U_6, [V]	0.06	0.39	0.39	0.13	0.38	0.68	0.11	0.39	0.36	0.1	0.67	0.41	0.14	0.34	0.54
U_7, [V]	**0.85**	**1.03**	**1.03**	0.52	**1.02**	0.52	0.58	0.25	**0.82**	0.07	0.44	0.46	0.15	0.53	**0.72**
U_8, [V]	0.08	0.25	0.25	0.09	0.26	0.19	0.11	0.57	0.47	0.08	0.52	0.51	0.06	0.58	0.49
U_9, [V]	0.06	0.4	0.4	0.16	**0.73**	0.24	0.23	**0.50**	**0.47**	0.1	0.41	**0.55**	0.35	**0.79**	**0.70**
U_{10}, [V]	0.06	0.59	0.59	0.03	0.49	0.2	0.07	0.74	0.32	0.05	0.58	0.49	0.01	0.57	0.49
U_{11}, [V]	0.16	0.46	0.46	0.27	0.79	0.33	0.37	0.44	0.65	0.44	0.64	0.87	0.92	0.99	1.24
U_{12}, [V]	0.01	0.46	0.46	0.02	0.43	0.18	0.03	0.44	0.74	**0.01**	0.66	0.49	0.03	0.53	0.53
U_{13}, [V]	0.2	**0.68**	**0.68**	0.08	**0.21**	0.30	**0.43**	**0.85**	**0.62**	0.11	**0.65**	**0.55**	**0.37**	**0.85**	**0.95**
U_{14}, [V]	0.09	0.43	0.43	0.03	0.69	0.21	0.03	0.59	0.53	0.01	0.63	0.57	0.06	0.61	0.49
U_{15}, [V]	0.04	**0.71**	**0.71**	0.16	**0.34**	0.17	0.08	**0.84**	**0.48**	0.03	**0.55**	**0.56**	0.19	**0.52**	**0.65**
THD_U	1.79	*3.37*	*3.52*	1.65	*2.88*	*2.93*	1.99	*4.7*	*3.9*	*2.19*	*3.91*	*3.64*	1.79	*3.68*	*4.15*

3. The Flow of the Active Powers in Networks which Operate in Nonsinusoidal Regime

It is considered a network operating in a nonsinusoidal and balanced regime. A generator (*G*) supplies active power for a linear consumer (*LC*) and to a nonlinear one (*NC*), through a distribution line (*L*). All of them are symmetrical, so the operating regime is balanced and, because of the nonlinear consumer, is also nonsinusoidal.

In what follows there are used the notations: P_{G1} – the active power delivered by generator on the first harmonic (fundamental frequency), P_{L1} – the active power consumed on the distribution line on the first harmonic, P_{LC1} – the active power consumed by the linear consumer on the first harmonic, P_{NC1} – the active power consumed by the nonlinear consumer on the first harmonic, P_{NCh} – the harmonic active power generated by the nonlinear consumer which is reinjected in the network, P_{Lh} – the harmonic active power which is injected in the distribution line by the nonlinear consumer, P_{LCh} – the harmonic active power which is injected at the linear consumer by the nonlinear consumer.

In networks, currents flow on fundamental frequency and on harmonics, the active power being conservative on fundamental frequency and on every harmonic. The voltage at generator is sinusoidal but, because the harmonic currents flow in the whole network, the voltages become nonsinusoidal. Regarding the conservation of the active power, the following relations can be written:

$$P_{G1} = P_{L1} + P_{LC1} + P_{NC1}\,,\; 0 = P_{Lk} + P_{LCk} + P_{NCk}\,, \forall k = \overline{1,\infty}\,. \tag{7}$$

Even if the generator provides active power only on fundamental frequency ($P_{G1} > 0$, $P_{Gh} = 0$), because of the nonlinear consumer which behaves as a consumer for the active power on fundamental frequency supplied by the generator ($P_{NC1} > 0$) and as a generator of active power on harmonics ($P_{NCh} > > 0$), in the line and at the linear consumer, beside active power on fundamental ($P_{L1} > 0$, $P_{LC1} > 0$) there exist active powers on harmonics ($P_{Lh} > 0$, $P_{LCh} > 0$).

Generally, the conservation of active powers may be expressed as:

$$\begin{aligned} P_G = P_{G1} = P_L + P_{LC} + P_{NC} = P_{L1} + P_{Lh} + P_{LC1} + P_{LCh} + P_{NC1} + P_{NCh} = \\ = (P_{L1} + P_{LC1} + P_{NC1}) + (P_{Lh} + P_{LCh} + P_{NCh}) \end{aligned} \tag{8}$$

The additional losses because of the nonsinusoidal regime are:

$$P_{NCh} = P_{Lh} + P_{LCh} \tag{9}$$

Beside the values of H_{U_k}, H_{I_k} (values for $k \in [2, 15]$), *U*, *I*, THD_U and THD_I, an alpha-meter gives, on every phase *m*, *m* = *a*, *b*, *c*, the values of the phase difference between voltage and current, φ, and the active and apparent powers on every phase.

The additional loss of active power in a network operating in an unbalanced and nonsinusoidal regime is calculated with the expression (Varvara & Cârţină Gh., 2001):

$$\Delta P = \sum_{m=a,b,c} \sum_{k=2}^{\infty} U_{km} I_{km} \cos\varphi_{km} = P - \sum_{m=a,b,c} U_{1m} I_{1m} \cos\varphi_{1km} \,, \qquad (10)$$

where: P is the total three-phase active power.

In the analyzed network, for all the measurements taken in different moments of day and in different moments of the year, the additional loss of active power is less than 1% of the total active power transmitted.

4. Conclusions

The main element deforming in a low-voltage distribution network is street lighting. During the day, when street lighting is turned off, the deforming regime is present, mainly because of computers and so called “fluorescent” lamps.

Nonlinear elements of circuit behave as generators for harmonic active power, which is injected in network.

In low voltage distribution networks, even if the nonsinusoidal regime is strong, the additional loss of active power because of the nonsinusoidal regime is very small compared with the total active power transmitted.

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ANALIZA UNEI REŢELE DE DISTRIBUŢIE DE JOASĂ TENSIUNE CARE FUNCŢIONEAZĂ ÎNTR-UN REGIM NESINUSOIDAL ŞI PIERDERILE SUPLIMENTARE DE PUTERE ACTIVĂ ÎN ACEASTĂ REŢEA

(Rezumat)

Într-o reţea de distribuţie care furnizează energie către diverşi consumatori, sunt înregistrate tensiunile nesinusoidale şi curenţii nesinusoidali cu ajutorul unui Alpha-metru. Astfel, pot fi calculaţi parametrii care caracterizează regimul de funcționare nesinusoidal. Acest regim poate fi evaluat cu ajutorul Normativului de limitare a regimului nesimetric şi deformant în rețelele electrice. Sunt trase concluzii privind cauzele apariției regimului de funcționare nesinusoidal. De asemenea, sunt calculate pierderile suplimentare de putere activă care apar in rețelele care funcționează in regim nesinusoidal.