THE INFLUENCE OF THE DEFORMANT AND NON SIMETRIC PROCEDURE ON THE NULL CONDUCTOR IN THE LOW VOLTAGE INSTALLATIONS

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Abstract - The paper presents general aspects regarding the nature of loads that are generated and circulate in low voltage networks, the influence on the null conductor and the calculation of the actual value of the current on the null. The paper considers the measured values of null current in networks with deforming and unbalanced loads related to transformer stations. The calculation of power and energy losses in symmetrical and non-symmetrical balanced three-phase networks allows the determination of the CPT growth rate (own technological consumption) and its comparison with that determined from the graphs given by the standards. Balancing measures of phase loading and reduction of deforming regime are analyzed.

Keywords: transformer station, null conductor, harmonics, imbalance, loading.

1. GENERAL INFORMATION

In the last decade including in our country, due to the evolution of electricity consumption, the role of low-voltage networks in ensuring an adequate quality has become increasingly important.

Thus, this network must be made to reach the terminals of any consumer (receiver), regardless the location, the time of day and night, and provide all the required power and energy at a voltage and frequency as close as possible to the nominal ones, ensuring the appropriate degree of safety throughout the operation.

An element that increasingly disturbs the long-term normal functioning is the occurrence and intensification of the deforming and unbalanced regime. The causes that lead to the deformation, especially of the current curves, but also of the voltage curves (to a much lesser extent) belong firstly to the consumers, the rest of the component elements of the system contributing to a small extent as sources of deformation or to its amplification.

It is necessary to carry out a theoretical and practical analysis of the phenomena occurring in the low-voltage networks, but also to make measurements to know the real situation, as well as the causes that determine it, in order to take appropriate measures to mitigate the existing negative aspects.

Examination of the phenomena which occur in the low voltage networks can not be complete unless the situation in the null conductor is also taken into account. The succession of the phenomena taking place in these installations begins with the direct influence of single phase computerized receivers (computers, televisions, etc.) which pollute the curves of the absorbed current and are the sources disturbance of the entire network: indoor electrical installations inside the households that make up the low voltage network, mainly three-phase, starting from the electrical boxes/panels and connecting to the low voltage bars of the 20/0.4 kV transformers in the transformer stations.

The main focus will be monitoring of the null conductor in single-phase areas and especially in three-phase areas, considering the totally different behavior of the null during operation.

To the conditions of the existing single phase, unbalanced consumption, which in fact has existed until now and did not pose any special problems, the non-sinusoidal regime appeared and expanded, which is accentuated as the number of receivers with static converters increase.

Their area of spreading is very broad and we find it in households, in all state and private institutions, in large, medium and small enterprises, in banks and computing centers and in any other contemporary human activity. Their nominal powers start from a few W, kW. The control installations of major industrial consumers (pumps, fans, conveyors) can reach several hundred thousand kilowatts. A main feature is that they are found practically in all areas of the power system, their number and weight being very high.

2. SUPPLEMENTARY CHARGING OF THE NULL CONDUCTOR

2.1. Theoretical notions

Considering the above mentioned, we note the great stresses that occur in the active lines of three-phase low-voltage circuits. In a much worse situation and in most cases, even worrying, are the null conductors of the low-voltage networks. In single phase circuits, the null conductor condition is, on each section, similar to that of the active line, the load similar to the phase of the single phase (three-phase) circuit.

Due to the fact that the null is mandatory in three-phase circuits, its load becomes particularly challenging. The neutral takes over all the consequences resulted from deviation from normal functioning regime of consumers', in which case its presence would not even be necessary.

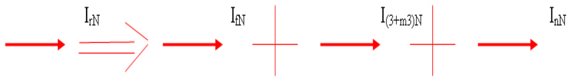

Fig. 1. The symmetrical components that circulate through the null conductor

In order to determine the currents flowing through the null conductor, it mst be taken into account the property of the positive and negative component systems in the three-phase circuits, which symmetric and balanced have the resultant, in the neutral low voltage point of the transformer station, equal to zero and will not circulate in the null conductor, [3]. This situation occurs both for the fundamental and harmonic current systems.

Consequently, the null conductor will also circulate the zero-sequence components of the fundamental current and the imbalanced systems of the harmonic currents with frequencies different from those of harmonics 3 and multiple of 3; also the sum of all currents corresponding to harmonics 3 and multiples of 3 of the three phases will be circulated (figure 1).

In the value of the resulting current in the null conductor (figure 1) an important weigh is related to the fundamental frequency current, but a very significant, sometimes even greater weight, is given by the harmonic currents of the order 3 and the multiple of 3, respectively the current (3+m3) N (figure 1), to which are added the zero sequence components of the other currents' harmonics.

As a consequence, under the actual conditions of three-phase low-voltage current networks, the additional load, above the one related to the 50 Hz frequency of the neutral conductor may be very high, reaching and in some cases even exceeding the permissible load limit for its section.In this case, the question arises whether it is not necessary to adopt for the null conductor a superior, equal or even higher section than that of the active phase conductors.

This would in fact lead to a deviation from the principle of manufacturing three-phase cables with the sections of the three active conductors larger with one or two steps than the null conductor section, with a load resulting as the sum of the currents in the three phases, smaller than the smallest value of the currents in the active conductors.

At the same time, however, the very important problem can be raised in the technical-economic aspect if by increasing the section of the null conductor the current situation is solved and in the future the conductor's load.

It is noted that there is no question of changing or adopting larger sections for active conductors. It follows that the additional load level and the increased power losses in these conductors will not change.

Consequently, what will also result for the new null conductor with increased section, in terms of the value of the current components, will not change. The loading rate will remain higher than that of the fundamental component, with only a partial reduction in active power losses due to the increase of the section.

The phenomenon remains virtually unchanged, with all the mentioned disadvantages, to which one can still add one with unpredictable consequences, for now, on the issue of electromagnetic compatibility due to the unlimited circulation of a wide spectrum of current harmonics, which can have frequencies up to 2.5 kHz, through the entire low-voltage network and especially through the null conductor.

A consequence with serious consequences, which may occur, is the increase in the number of interruptions of the null conductor due to local overheating, and as a result of the film phenomenon, at its joining points.

Of course, the phenomena that are happening nowadays and with greater intensification, even in the near future, are complex and they will still require, in addition to taking mitigation measures, further analyzes taking into account the events that occur throughout the whole period operation of low-voltage installations.

2.2. Measurements made on the null conductor in the transformer stations

Following the measurements made with the network analyzers on the phase conductors and the neutral conductor connected to the secondary terminals of the transformers analyzed in some PTs, Figures 2 ÷ 10 show the curve of the actual deformed current, the distortion factor of these transformer stations as well as the value harmonics of the order 3, 5, 7, 9, 11, which appear on the null conductor.

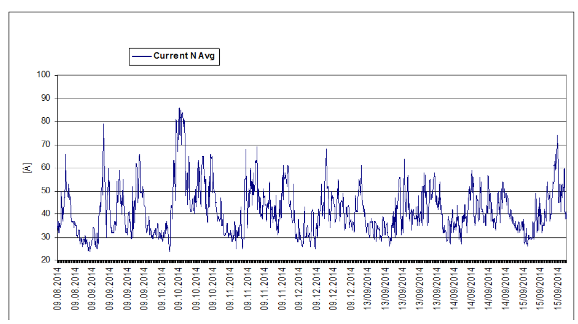

Fig. 2. The shape of the current through the neutral conductor in PTab 1 - 20 / 0.4 kV

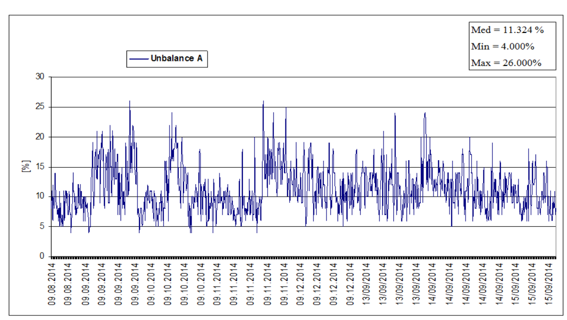

Fig. 3. Variation of the distortion factor through the neutral conductor in PTab 1 - 20 / 0.4 kV

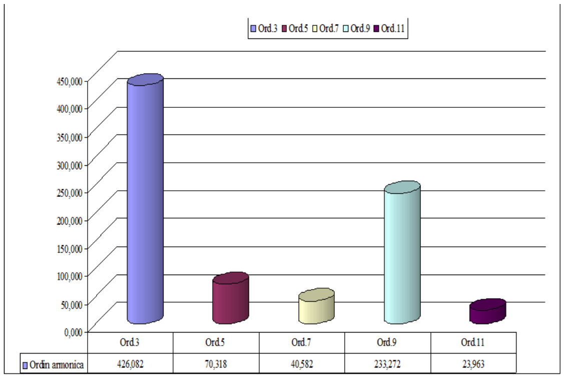

Fig. 4. Spectrum of harmonics through the null conductor in PTab 1 - 20 / 0.4 kV

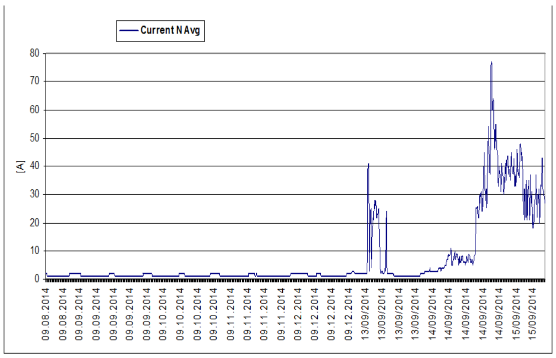

Fig. 5. Current variation through neutral conductor in PTab 2 - 20 / 0.4 kV

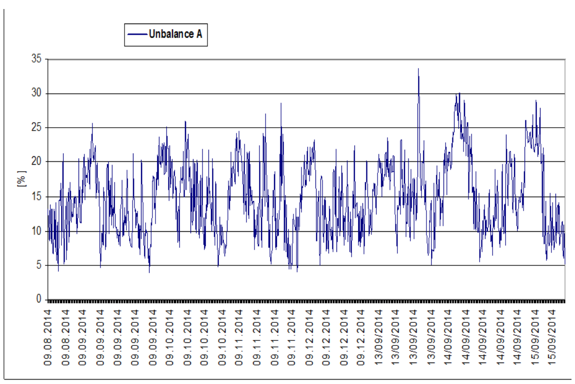

Fig. 6. The variation of the distortion factor through the null conductor in PTab 2 - 20 / 0,4 kV

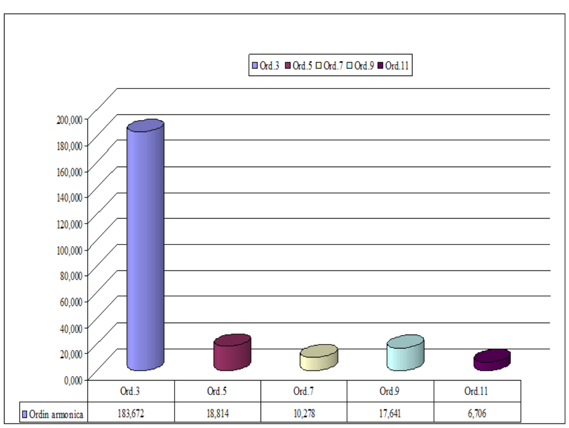

Fig. 7. Spectrum of harmonics through the null conductor in PTab 2 - 20 / 0.4 kV

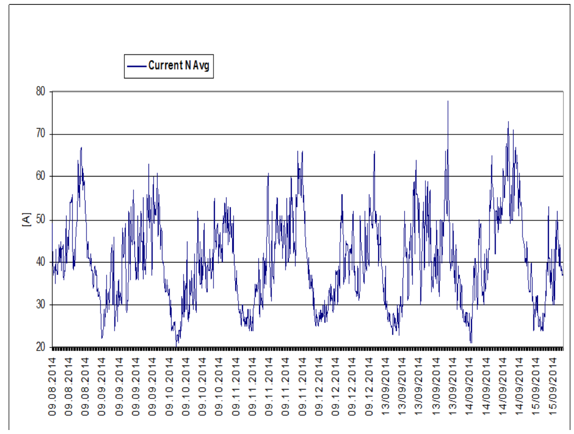

Fig. 8. Current variation through neutral conductor in PTab 3 - 20 / 0.4 kV

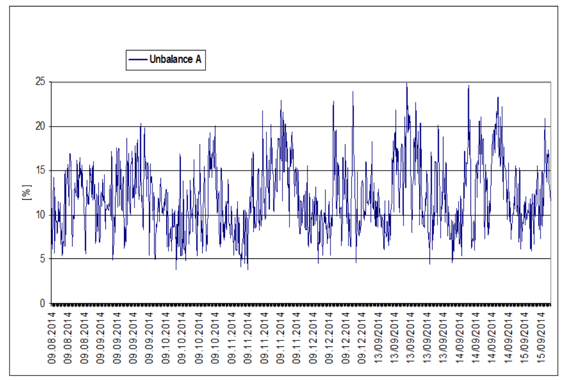

Fig. 1. The variation of the distortion factor through the null conductor in PTab 3 - 20 / 0.4 kV

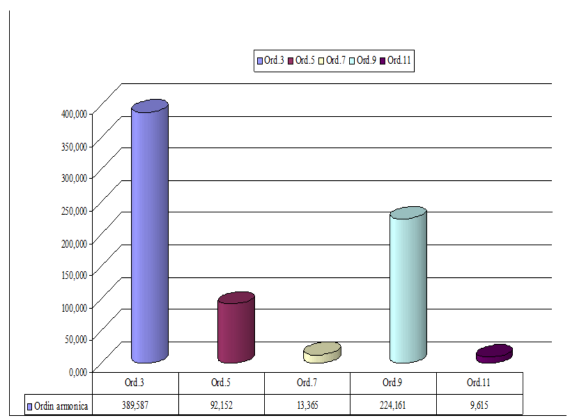

Fig. 2. Spectrum of harmonics through the null conductor in PTab 3 - 20 / 0.4 kV

The data on the parameters of the transformers analyzed are presented in Table 1, and the data on the monitored currents in the transformer stations analyzed are shown in Table 2.

Table 1. Monitored PT parameters

Nr. crt.	Denumire PT	S_n [kVA]	$S_{masurat}$		Încarcare trafo			Cos φ mediu	P_{med} [kW]	Q_{med} [kVAr]	PC 95%			PC 95% k_u [%]
			S_{med} [kVA]	S_{max} [kVA]	k_{med} [%]	k_{max} [%]	$k_{utilizare}$ [%]				U1 [V]	U2 [V]	U3 [V]	
1.	PTab 1	160	72,85	104,10	0,455	0,651	0,70	0,953	70,07	19,26	243,85	241,81	241,37	0,776
2.	PTab 2	400	43,53	88,10	0,109	0,220	0,50	0,909	39,56	17,35	237,83	238,34	238,40	0,288
3.	PTab 3	630	64,59	108,50	0,103	0,172	0,59	0,923	60,74	-18,79	238,25	238,35	238,82	0,213

Table 2. Current values monitored

Denumire	Valoare	I_1 [A]	I_2 [A]	I_3 [A]	I_N [A]
PTab 1	Med.	94,587	111,670	104,832	41,448
	Min.	55,000	73,000	63,000	24,000
	Max.	153,000	166,000	162,000	86,000
PTab 2	Med.	73,666	60,988	52,836	7,100
	Min.	30,000	28,000	27,000	1,000
	Max.	170,000	141,000	115,000	77,000
PTab 3	Med.	98,757	99,00	73,450	40,389
	Min.	50,000	59,000	41,000	20,000
	Max.	179,000	182,000	129,000	78,000

3. CALCULATION OF THE EFFECTIVE VALUE OF THE NULL CURRENT

We consider a simplified system, consisting of a balanced three-phase source and three identical single-phase loads, connected between phases and neutral (Figure 11), [8].

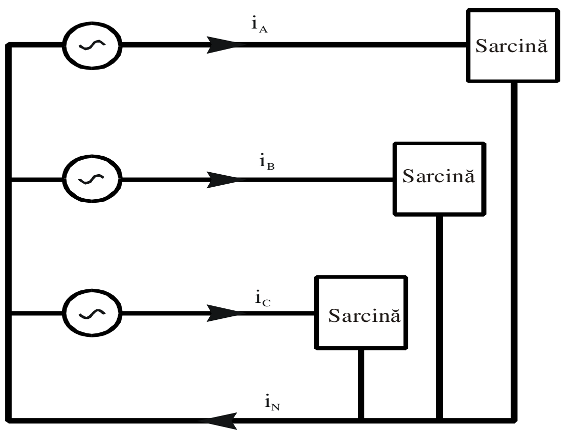

Fig. 3. Balanced single-phase loads

If the three phase currents do not overlap, the actual value of the phase current is calculated using the formula:

$$I_L = \sqrt{\frac{1}{T}\int_0^T i_L^2 dt} \quad (1)$$

The effective value of the null current over a range equal to T / 3 is:

$$I_N = \sqrt{\frac{1}{T/3}\int_0^{T/3} i_N^2 dt} = \sqrt{3}\cdot\sqrt{\frac{1}{T}\int_0^{T/3} i_N^2 dt} = \sqrt{3}\cdot\sqrt{\frac{1}{T}\int_0^{T} i_L^2 dt} = \sqrt{3}\cdot I_L \quad (2)$$

As a consequence the current on the null has a $\sqrt{3}$ times greater value than the phase current.

If the current curves of the three phases overlap, the actual value of the current on the neutral is less than $\sqrt{3}$ times the value of the phase current [2, 5].

In installations where a large number of non-linear loads are present, the null current may exceed the phase current value. Protection and control devices (circuit breakers, breakers, contactors) must be dimensioned according to the null current.

3.1. Additional charging of the null conductor to balanced and unbalanced loads

To begin with, the additional charge of the null conductor will be calculated based on the degree of current distortion for balanced loads.

Considering the harmonic 3 as predominant, the current in the null will be:

$$I_N \approx 3 \cdot I_3 \quad (3)$$

It can be written:

$$I_N \approx 3 \cdot \delta_I \cdot I_I \quad (4)$$

where $\delta_I \equiv \text{THD}$ is the distortion factor.

The phase current is determined with the relation:

$$I_I = \frac{I_L}{\sqrt{1+\delta_I^2}} \quad (5)$$

is obtained:

$$I_I = 3 \cdot \delta_I \frac{I_L}{\sqrt{1+\delta_I^2}} \quad (6)$$

Analyzing relations 4 and 6 results:

$$\frac{I_N}{I_L} = \frac{3 \cdot \delta_I}{\sqrt{1+\delta_I^2}} \quad (7)$$

The degree of loading of the null conductor according to the current distortion factor is given in figure 12, [5].

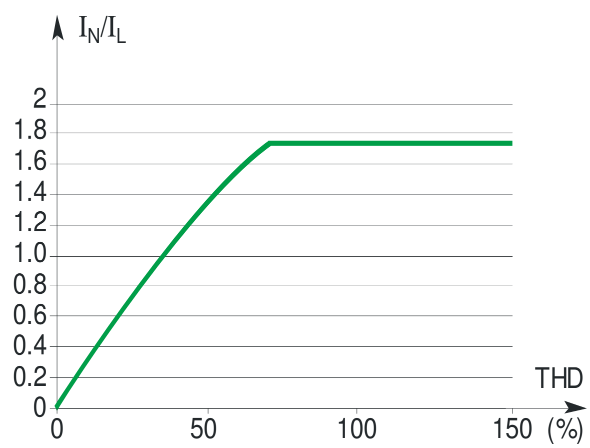

Fig. 4 Load null conductor at balanced loads

Next we will study the case of imbalanced tasks. Figure 13 is a balanced three-phase source and two single-phase loads [6].

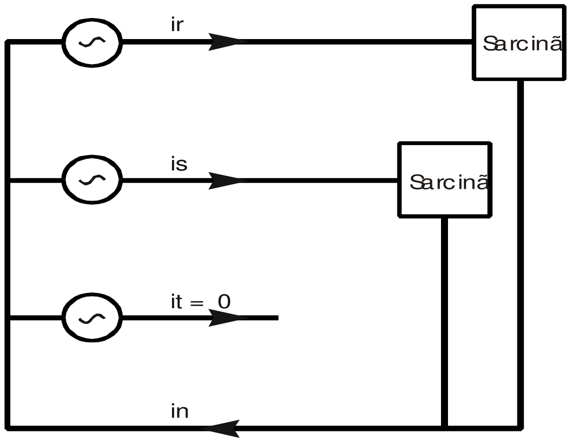

Fig. 5. The case of unbalanced tasks

It can be demonstrated in the same way that the maximum value of the current in the null conductor can not exceed $\sqrt{2}$ times the current in each phase.

Considering only the fundamental and harmonic component of the 3rd order of each load, the current in the null conductor is the sum of the fundamental and the harmonic 3. The fundamental component is the phasor sum of the fundamental components of the two loads. As these currents are equal and out of phase with $\frac{2\pi}{3}$, the resulting current equals the fundamental component of each load.

The harmonic current 3 of the null conductor is the sum of the harmonic load currents 3 (in phase).

The current in the null conductor:

$$I_N \approx \sqrt{I_I^2 + (2I_3)^2} \tag{8}$$

sau:

$$I_N \approx \sqrt{I_I^2 + (2\cdot\delta_I \cdot I_I)^2} = I_I\sqrt{1+4\cdot\delta_I^2}$$
$$I_N \approx \frac{I_L}{\sqrt{1+\delta_I^2}}\cdot\sqrt{1+4\cdot\delta_I^2} \tag{9}$$

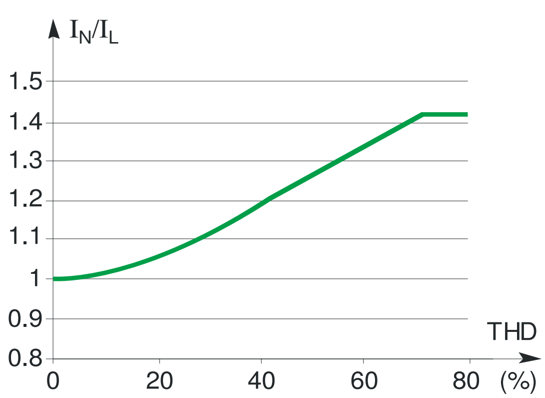

Fig. 6. Charging of the null conductor for unbalanced loads

From relationship 9 follows:

$$\frac{I_N}{I_L} \approx \frac{\sqrt{1+4\cdot\delta_I^2}}{\sqrt{1+\delta_I^2}} \tag{10}$$

This formula is valid if the result is less than $\sqrt{2}$.

The variation in the null conductor load according to the distortion factor for unbalanced loads is given in Figure 14, [2, 5].

4. CALCULATION OF POWER AND ENERGY LOSS IN BALANCED AND UNBALANCED SYMMETRICAL THREE-PHASE NETWORKS

In order to determine the technical losses of electric energy in the elements of the networks it is necessary to know the electric schemes, the characteristic parameters of the sources, the network and the consumers [1, 4, 7].

4.1. Concentrated load at the end of the network

$$\underline{I}_1 = \underline{I}_2 = \underline{I}_3 = 40\text{A}$$

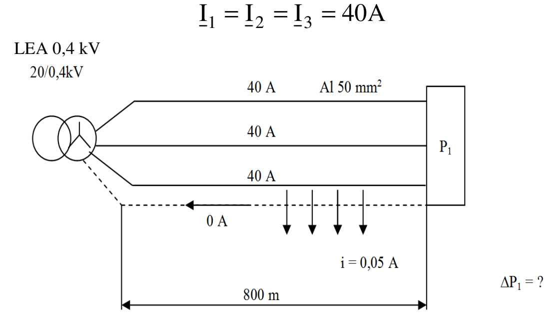

Fig. 7 Symmetric and balanced network

for l = 0,8 km ⇒

$$\Delta P = 3RI^2 = 3\cdot 0{,}61\cdot 0{,}8\cdot 40^2 = 2342{,}4\ \text{W/h}$$
$$\Delta P = 2{,}342\ \text{kW/km/h}$$

for l = 1 km ⇒

$$\Delta P = 3RI^2 = 3\cdot 0{,}61\cdot 1\cdot 40^2 = 2928\ \text{W/h}$$
$$\Delta P = 2{,}928\ \text{kW/km/h}$$

4.2. Unbalanced current network

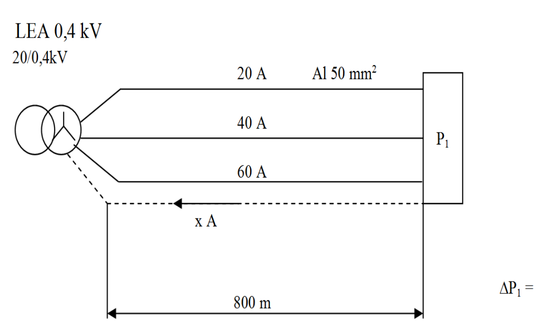

Fig. 8 Unbalanced current network

For the network of figure 16, the phasor diagram of the currents was drawn up.

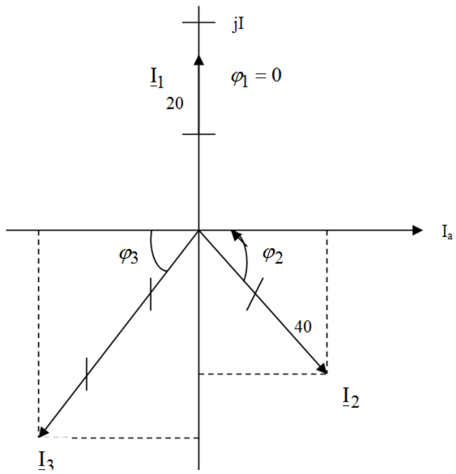

Fig. 9. Phasor diagram of the unbalanced network

From the figure results
$\varphi_1 = 0$; $\varphi_1 = \varphi_1 = 30°$ C

$$I = \underline{I} \cdot e^{j\alpha},\ \text{for}\ \alpha = 0,\ \underline{I} = I \cdot e^{j0}$$
$$20(\cos\varphi + j\sin\varphi),\ \ \varphi = 0,\ \underline{I}_1 = 20 \cdot e^{j0}$$
$$\underline{I}_1 = j20 \Rightarrow I_1 = 20\text{A}$$
$$\underline{I}_2 = 40\left(\cos 30^\circ + j\sin 30^\circ\right) =$$
$$= 40\left(0{,}865 - j \cdot 0{,}5\right) = 34{,}6 - j \cdot 20$$

$$\underline{I}_2 = \sqrt{34{,}6^2 + 20^2} = 39{,}96 = 40\text{A}$$

$$\underline{I}_3 = 6 \cdot \left(\cos 30^\circ + j\sin 30^\circ\right) =$$
$$= 60(-0{,}865 - j \cdot 0{,}5) = -51{,}9 - j \cdot 30{,}0$$
$$\underline{I}_3 = \sqrt{(-51{,}9)^2 + (-30)^2} = 59{,}9 \approx 60\ \text{A}$$
$$\underline{I}_N = \underline{I}_1 + \underline{I}_2 + \underline{I}_3 =$$
$$= j \cdot 20 + (34{,}6 - j \cdot 20) - (51{,}9 - j \cdot 30) = 17{,}3 - j \cdot 30$$
$$\Rightarrow \underline{I}_N = \sqrt{17{,}3^2 + 30^2} = 34{,}63\text{A}$$

4.3. Calculation of power losses

$$s_n = s_f = 50\ \text{mm}^2 \Rightarrow R_{0N} = 0{,}61\ /\text{km}$$

$$\Delta P_t = \left(I_1^2 + I_2^2 + I_3^2\right)R_f + I_N^2 R_N =$$
$$= \left(20^2 + 40^2 + 60^2\right) \cdot 0{,}579 \cdot 0{,}8 + 34{,}63^2 \cdot 0{,}61 \cdot 0{,}8 =$$
$$= 5600 \cdot 0{,}432 + 1199{,}237 \cdot 0{,}488$$

$$\Delta P_t = \Delta P_f + \Delta P_N = 2419{,}2 + 585{,}23 =$$
$$= 3004{,}427\ \ \text{W/h} = 3{,}004\text{kW/h}$$
$$\Delta P_f = 2419{,}2\text{W}/\text{h}$$
$$\Delta P_N = 1199{,}237 \cdot 0{,}488 = 585{,}23\text{W}/\text{h}$$

$$\frac{\Delta P_N}{\Delta P_f} \cdot 100\% = \frac{585{,}23}{2419{,}2} \cdot 100 = 24{,}19\%$$

4.4. Calculation of energy losses

- for maximum unsymmetrical regime:

$$\Delta W_{t/an} = \Delta p_t \cdot \tau = 3{,}004 \cdot 1156 =$$
$$= 3472{,}6\ \text{kWh}\ /\text{an}\ /0{,}8\text{km}$$
$$\Delta W_{t/an}\ \text{for}\ \Delta PW_N = 0{,}585 \cdot 1156 = 676{,}26$$
$$\text{kWh}/\text{an}/0{,}8\text{km}$$

- for medium regime:

$$\Delta W_{N/km} = \frac{\Delta W_{t/an}}{0{,}8} = \frac{676{,}26}{0{,}8} = 845{,}32\ \text{kWh}/\text{km}/\text{an}$$
$$\Delta W_{t/an/1km} = \frac{\Delta W_t}{0{,}8} = 4034{,}75\ \ \text{kWh}/\text{an}/\text{km}$$

- for symmetrical regime:

$$\underline{I}_N = \underline{I}_1 + \underline{I}_2 + \underline{I}_3 = 0$$
$$\Delta P = \left(I_1^2 + I_2^2 + I_3^2\right) \cdot R_f = 3R_f \cdot I_f^2 =$$
$$= 3 \cdot 0{,}579 \cdot 0{,}8 \cdot 40^2 = 2073{,}6\text{W}/\text{h} =$$
$$= 2{,}0736\ \ \text{kW}\ /\text{h}$$
$$\Delta W_{tech} = 2{,}0736 \cdot 1156 = 2{,}397\ \text{kWh}/\text{an}$$
$$\Delta W_{tech}/\text{km} = \frac{2397{,}08}{0{,}8} = 2996{,}35\,\text{kWh}/\text{an}/\text{km}$$
$$k_s = \frac{\Delta W_{tdez/an/h}}{\Delta W_{tech}} = \frac{4034{,}75}{2996{,}35} = 1{,}346$$

ks – losses increase coefficient.

There is a 34.6% increase in imbalanced losses for the case study.

5. BALANCING THE CHARGING OF THE NETWORK PHASES

A characteristic of the electrical network with a voltage of up to 1000 V is the uneven load of the phases, which leads to increased power and energy losses.

The degree of phase imbalance can be evaluated by the current imbalance coefficient N_i^2 (relation 11).

When increasing the phase load imbalance coefficient, the power losses also increase (figure 18).

For a network segment the imbalance coefficient (non-symmetry) is determined with the relation:

$$N_i^2 = \frac{1}{3}\left[\left(\frac{I_{Ai}}{I_{mede}}\right)^2 + \left(\frac{I_{Bi}}{I_{mede}}\right)^2 + \left(\frac{I_{Ci}}{I_{mede}}\right)^2\right]$$
$$N_i^2 = \frac{1}{3}\left[\left(\frac{20}{40}\right)^2 + \left(\frac{40}{40}\right)^2 + \left(\frac{60}{40}\right)^2\right] \Rightarrow N_i^2 = 1{,}167 \qquad (11)$$

for the unbalanced network (figure 16),

where: I_{Ai}, I_{Bi}, I_{Ci}, are currents in phases.

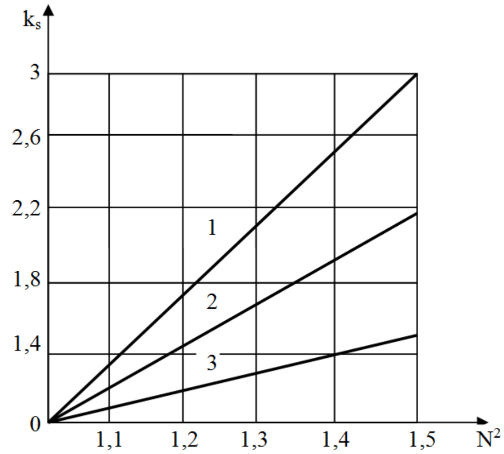

Fig. 10. Variation of the technological power consumption in networks with a voltage below 1 kV depending on the load imbalance coefficient on the line phases:
1 - line with four null conductors; $R_N = 2 \cdot R_f$; 2 - four-conductor line with null conductor $R_N = R_f$; 3 - Line with three conductors without null conductor

The increase in power losses according to the imbalance coefficient is determined by the coefficient ks which has the expression:

- for 2-wire lines: $k_s = 1$;
- for 3-wire lines: $k_s = N^2$;
- for four-conductor lines:

$$k_{si} = N_i^2 \cdot \left(1 + 1{,}5 \cdot \frac{R_{0i}}{R_{fi}}\right) - 1{,}5 \cdot \frac{R_{0i}}{R_{fi}} \qquad (12)$$

where R_{0i} şi R_{fi} are the resistances of the null and phase conductors of section i.

Loss of power on the l section will be:

$$\Delta P_i = k_i \cdot k_{si} \cdot l_{medi}^2 \cdot R_i \qquad (13)$$

where: k_i is the number of phase conductors on section 1; R_i – phase resistance.

From the diagram (figure 18) for a three-phase null conductor (3F + N, $s_N = s_f$), for $N_i^2 = 1{,}167$ a CPT growth coefficient results of $k_i \approx 1{,}35$, corresponding to the value obtained from the calculations performed. For a network with $R_N = 2 \cdot R_f$, the loss coefficient $k_s = 1{,}5$ for the same imbalance coefficient. There is a decrease in loss in the increase of the null conductor section.

6. CONCLUSIONS

In order to reduce power and energy losses in electrical networks due to imbalance it is necessary to systematically control the current and voltage asymmetry in operation and to redistribute the loads on phases if the current on the neutral conductor of the four conductor line on the first portion, exceeds 15 - 20 A. It is also important to balance loads in three-phase networks without a neutral conductor although its efficiency is lower.

It is not necessary to follow a complete symmetry of the load, since the load imbalance coefficient varies with the operation of the network.

The measure of symmetry of the distribution network load has to be considered since its design. For this purpose it is indicated to provide the transformer with the triangle / zigzag connection.

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