Measurement and Analysis of the Neutral Conductor Current in Low Voltage Distribution Network of Nis

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Abstract – **This paper presents measurement results of neutral conductor current in low voltage network in the region of city of Nis, Serbia. The influence of load unbalance and nonlinear loads on neutral conductor current is analysed. Load current harmonics have strong influence on rms value of neutral conductor current in the network that supply commercial load.**

Keywords – **Neutral current, Load unbalance, Distribution networks, Power quality.**

I. Introduction

Low voltage distribution networks are three-phase four wire networks, by rule, with three phase wires and one neutral. If the load is balanced there is not neutral current. However, in real conditions, the load is unbalanced because the network mostly supplies a set of single-phase load devices. The unbalance can be systematic due to no equally distributed single-phase devices among the phases and stochastic owing to different load diagrams of load devices. As the consequence of unbalance the current flows trough neutral conductor and the losses in the network increase [1].

The modern phase of distribution network development is characterized by the usage of large number of nonlinear devices. With the increase of the number of nonlinear devices and apparatus, there is harmonic distortion of load currents and this causes the increase of losses in lines and transformers. Harmonic currents, which are multiple of three, flow through neutral, even single-phase nonlinear load devices are equally distributed among the phases [1, 2, 3]. These harmonic components are in phase, and therefore are summed arithmetically. Therefore, there are two reasons of the presence of neutral current: load unbalance and nonlinearity of load currents. Both reasons cause the increase of real power losses in lines and in transformers.

In specific cases third harmonic current can increase up to the value that is 1.73 times larger than phase current. Excessive neutral conductor currents can cause overloading or even burning of neutral, voltage distortion and faults of distribution transformers.

The main aim of this paper is to determine the level of load unbalance and neutral currents by measurements at different locations in distribution network of PD “Jugoistok” (Economic Association for Electric Energy Distribution “Jugoistok”) that comprehends the region of city of Nis. Special attention is given to the analysis of harmonics in load currents and in the neutral.

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II. The Analysis of Field Measurements

In order to obtain the right conclusions connected with neutral current values 30 transformer stations (TS) are selected, 16 in Nis and 14 in town Leskovac. These transformer stations are located in different parts of towns and supply different load classes:

- residential load with central heating,
- residential load without central heating,
- residential load with and without central heating,
- rural,
- commercial,
- administrative,
- industrial and
- composite load.

In every transformer station measurements of transformer total load and the load of particular feeder supplying characteristic loads are performed during seven days according to standard EN 50160.

Load unbalance is quantified by unbalance factor of currents that is calculated according to formula

$$I_{unb} = \frac{|I_i|}{|I_d|} \cdot 100, \qquad (1)$$

where index i denotes inverse, and index d direct component of current.

Comprehensive data based on two years long research is collected, but here are especially presented and analysed the results obtained in three transformer stations due to space limitation. These transformer stations supply: residential, commercial and rural load. For other transformer stations only the most important variables are specified and discussed.

For illustration of the circumstances in transformer station that supplies residential load with central heating, TS „Dom studenata“ is considered. The measurements in this transformer station are performed during one week, from 19th to 26th December in 2007. The large unbalance of load currents is recorded that can be seen from Fig. 1. This figure presents phasor diagram of currents and voltages recorded at one moment. It is obvious that currents differ from each other regarding both magnitudes and phases. Unbalance factor at the moment of measurement was 7.4%. In the period of seven days the currents of transforme, I_1, I_2 and I_3 varied depending on day period, and their average values were 353.15A, 377.91A and 288.94A, respectively. Unbalance factor of currents is presented on Fig. 2 and it varies in the range from 2.3% to 21.7%. Due to the unbalance of load, neutral conductor current varies in the range from 53.4A to 199.2A. Average value of neutral conductor current is 103.6A that is 35.85% of the average value of the smallest phase current.

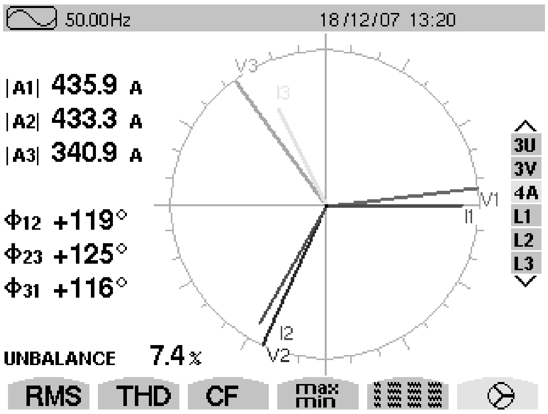

Fig. 1. Phasor diagram in TS „Dom studenata”

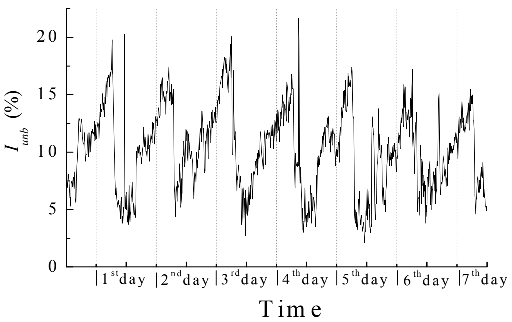

Fig. 2. Unbalance factor of currents in TS “Dom studenata”

As mentioned before, neutral conductor current flows due to two reasons: load unbalance and higher harmonics which are multiple of three (that are the consequence of nonlinear load). A question arises what is harmonic spectrum of neutral conductor current, i. e. what is participation of higher harmonics in total neutral conductor current? To answer the question properly, Fig. 3 is considered. On this figure waveforms of load currents, I_1, I_2 and I_3, and neutral conductor current, I_N, are presented. Corresponding current spectrums of currents I_3 and I_N are presented in Fig. 4.

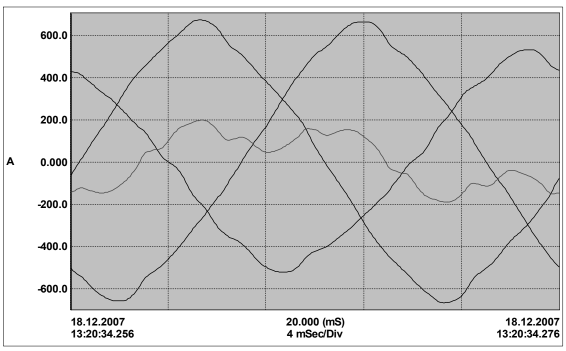

Fig. 3. Waveform of phase and neutral conductor currents in TS “Dom studenata“

It can be noticed that all load currents from Fig. 3 are distorted. Quantified with total harmonic distortion of currents (*THDI*) these distortions are 5.74%, 5.65% and 6.37% for I_1, I_2 and I_3, respectively. There is remarkable presence of third, fifth, seventh and ninth harmonics in load currents. For example, third, fifth, seventh and ninth harmonic of third phase current are 5.2%, 1.9%, 2.3% and 1.3%, respectively.

The presence of third and ninth harmonic in load phase currents causes the increase of neutral conductor current because these harmonics are summed. This is explicitly seen on Fig. 4 where harmonic spectrum of neutral conductor current is presented. In this example, rms value of neutral conductor current is 121A, and the currents of the first, third and ninth harmonics are: 104.1A (100%), 59.4A (57%) and 13.6A (13.1%), respectively.

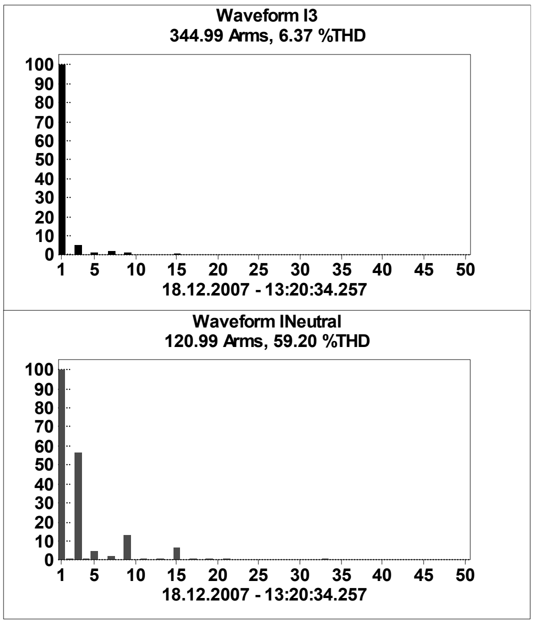

Fig. 4. Harmonic spectrums of current I_3 and neutral conductor current I_N

In Fig. 5 the variations of neutral conductor current and its third and ninth harmonic during one week are presented. Third harmonic current values change periodically during every day from the smallest values in the morning hours (between 7 and 10h) to the biggest ones during the evening (between 18 and 23h). Participation of third harmonic in neutral conductor current in per cents varies from 11 to 89%, and average value is 59.7%. Only in short morning intervals (7 to 9h) the participation of third harmonic is below 20%.

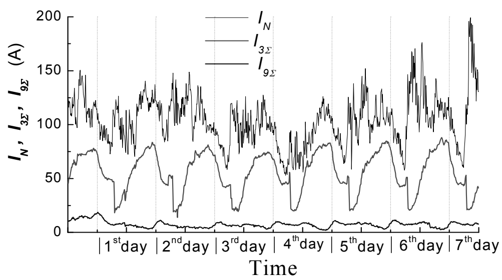

Fig. 5. Neutral conductor current (I_N), sum of third harmonic currents ($I_{3\Sigma}$) and sum of ninth harmonic currents ($I_{9\Sigma}$) in TS „Dom studenata“

For the illustration of circumstances in one transformer station that supplies commercial load, the results of measurements in TS „Robna kuca“ in Leskovac are analysed. These results are obtained in the period from 16th to 23rd July in 2007. In Fig. 6 waveforms of load currents and neutral conductor current are presented at one moment before the noon.

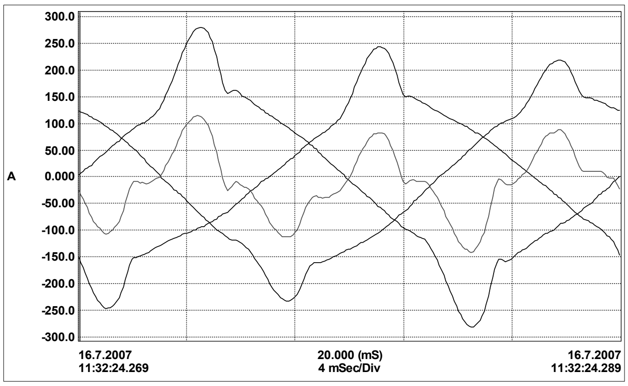

Fig. 6. Waveform of phase and neutral conductor currents in TS „Robna kuca“

Harmonic spectrums of currents I_1 and I_N recorded at the same moment are presented in Fig. 7. Total harmonic distortion (*THDI*) of phase currents I_1, I_2 and I_3, is 25.91%, 24.61% and 15.18%, respectively. Third, fifth, seventh and ninth harmonics in the load of the first phase are: 19.1%, 13.5%, 8.7% and 5.5%, respectively. High values of third and ninth harmonic in load phase currents cause the increase on neutral conductor current, and these higher harmonics are dominant ones in the neutral conductor of considered transformer station (Fig. 7).

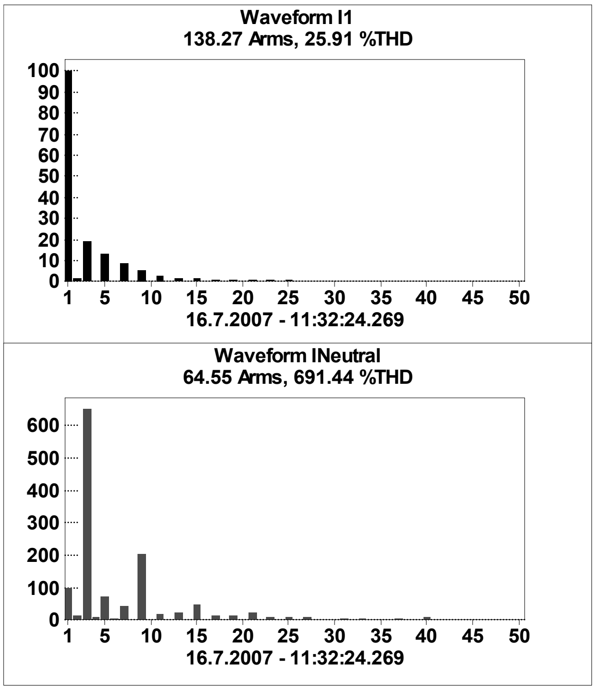

Fig. 7. Harmonic spectrums of current I_3 and neutral conductor current I_N

In the period of seven days, *THDI* varies in the ranges: from 11.3 to 29.1% for the current of the first phase I_1, from 16.7 to 44% for the current I_2 and from 7.8 to 23.1% for I_3. Maximum values of *THDI* and the values of individual harmonics (HDI_h) are beyond IEEE 519 standard limits, that for the networks such concerned network is (where $50 < Ik / In < 100$) allows *THDI*=12% and *HDI*=10% for $h \leq 11$. For weaker networks ($20 < Ik / In < 50$) these limits are *THDI*=10% and *HDI*=8% for $h \leq 11$.

Respecting high *THDI* value of load currents, through neutral conductor flows the current that is practically the consequence of third and ninth harmonic that can be seen from Fig. 8.

Third harmonic of current (and neutral conductor current at the same time) changes during every day from the smallest values, around 11A in the hours after the midnight (between 2 and 6h) to the largest values during the night (between 23 and 24h). It should be emphasized that participation of the third harmonic in neutral conductor current varies from 35% to 89.6%. Its average value is 65%.

As the consequence of load unbalance and nonlinear load, significant current flows through neutral conductor and its value varies from 40.8 to 107.5% of the smallest phase current (see Fig. 9). Average value of neutral conductor current is 40.7% of the average value of the smallest phase current. Unbalance factor of currents I_{unb} varies in the range from 3.8 to 26.9%, and its average value is 13.42%.

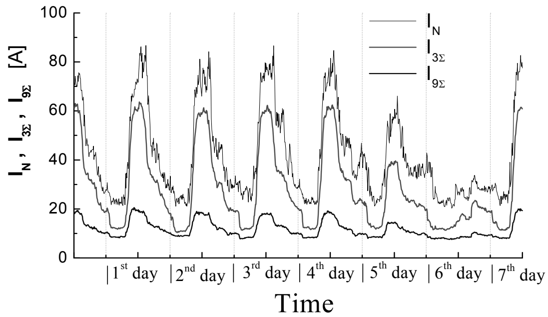

Fig. 8. Neutral conductor current (I_N), sum of third harmonic currents ($I_{3\Sigma}$) and sum of ninth harmonic currents ($I_{9\Sigma}$) in TS „Robna kuca“

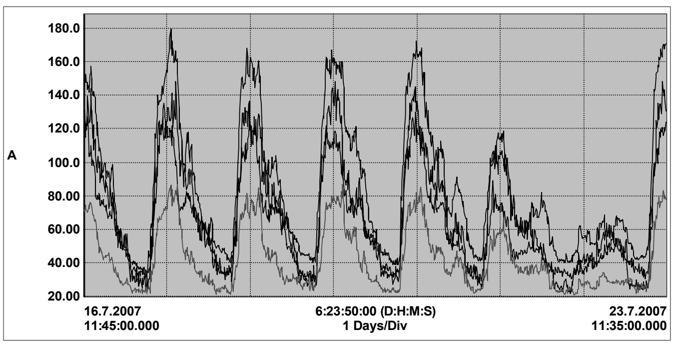

Fig. 9. Phase and neutral conductor currents in TS „Robna kuca“

Third harmonic of current (and neutral conductor current at the same time) changes during every day from the smallest values, around 11A in the hours after the midnight (between 2 and 6h) to the largest values during the night (between 23 and 24h). It should be emphasized that participation of the third harmonic in neutral conductor current varies from 35% to 89.6%. Its average value is 65%.

As the representative of rural load TS „Selo Gabrovac" (250kVA), that is in the area of city of Nis, is considered. The measurements were performed two times - in the first and in the second half of November, from 4th to 11th and from 15th to 22nd November 2006.

Both measurements are characterized by similar current values and unbalance factors: in the first half of November average values of these variables were: I_1=334.88A, I_2 =306.81A, I_3=324.22A and I_{unb}=6.06% and in the second half I_1=317.96A, I_2=282.35A, I_3=303.48A and I_{unb}=6.70%. It means that the load of considered TS is averagely more equally shared between phases in comparison with previously mentioned transformer stations. Unbalance factor of currents varies in the wide range, from 1.3 to 18.2% and has large changes in every day period.

Fig. 10 presents the changes of total current and third and ninth harmonic of neutral conductor current in the period of one week. Third harmonic current is averagely 21.9% of total neutral current, and the ninth is only 1.57% of this current. These percentiles are reasonable because rural settlement load is in question, and resistive load devices are dominant load component.

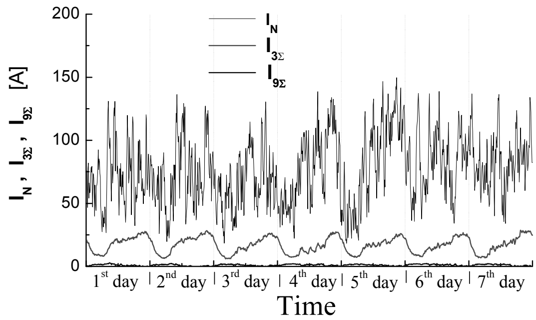

Fig. 10. Neutral conductor current (I_N), sum of third harmonic currents ($I_{3\Sigma}$) and sum of ninth harmonic currents ($I_{9\Sigma}$) in TS „Selo Gabrovac"

The results obtained on the basis of measurements during one week, show that all 30 considered transformers have significant load unbalance. This unbalance exists in all day periods, every day of the week and varies in wide ranges for all transformer stations. Maximum values of unbalance factors of currents are always greater than 10%, and in three transformer stations are greater than 30%. Average values of unbalance factor vary from 3.64 to 14.3%. Only in two TS average value of unbalance factor is less than 5%, while in eight TS is greater than 10%. Average value of unbalance factor of currents is 8.76% in town Leskovac and 9.60% in Nis. These values of unbalance factor regarding total transformer load. Load unbalance of some feeders is greater than specified maximum values, and the largest average value of unbalance factor for one of the feeders is 32%.

As the consequence of unbalance and nonlinear loads, neutral conductor current has large values. Relative value of neutral conductor current regarding average load current of all three phases varies from 0.1421 (14.21%) in TS „Moravska 2" to 0.6685 (66.85%) in TS „Robna kuca". Only in three transformer stations neutral conductor current is less than 20% of phase currents, in five is greater than 50%, and in two („Bore Price 2" and „Medijana 2") is even greater than 60%.

III. Conclusion

This paper presents the results of measurements in transformer stations 10/0.4kV in the area of Nis and Leskovac in order to determine the values of neutral conductor currents and load unbalance of low voltage distribution network and distribution transformers. It is stated that load unbalance exists in all days of the week and day periods. For the most of measurements of total transformer load and almost all measurements of low voltage feeder loads, average value of unbalance factor of currents in the period of one week is greater than 10%. This fact shows the necessity of sharing of phase currents for the feeders with the largest load unbalance and the largest neutral current.

It is stated that nonlinear devices in transformer stations that supply commercial and administrative load significantly contribute to the increase of neutral conductor current.

Load unbalance and higher harmonics should be taken into account in calculations of losses in distribution networks.

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