The Analysis of Load Unbalance in Low Voltage Distribution Network of Nis

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Abstract – **This paper presents the results of measurements in transformer stations 10/0.4kV in the area of city of Nis that quantify the load unbalance in low voltage distribution network. The measurements are performed in transformer stations that supply the loads of different load types which are placed in different parts of the city. The inducements of unbalance are identified and concrete actions for unbalance decrease are suggested that will consequently decrease power and energy losses in the network.**

Keyword – **Load unbalance, Losses, Distribution networks**

I. Introduction

By rule, low voltage distribution networks are three-phase four wire networks with three phase wires and one neutral. Neutral is connected with grounded neutral point of the transformer. It is used for connection of single phase consumers and it can have protection function. If the load is balanced there is not neutral current. However, in real conditions, the load is unbalanced that causes the neutral current. The unbalance can be systematic and stochastic. Systematic unbalance is the consequence of single-phase devices that are not equally distributed among the phases. Stochastic unbalance is the consequence of different load diagrams of load devices.

On the other hand, with the increase of usage of nonlinear load devices and apparatus, such are fluorescent lamps, mercury lamps, power converters, computers, TV sets etc., harmonic distortion of load currents increases, too. Therefore, harmonic currents which are multiple of three also flow through neutral, even single-phase nonlinear devices are equally distributed among the phases. Third harmonic currents of different phases (and all other harmonic currents which order is multiple of three) have the same angle, and these are summed in neutral. Thus, neutral current can reach the value 1.73 times greater than phase current values [1].

Therefore, neutral current exists due to two reasons: load unbalance and nonlinearity of load currents. Both reasons cause the increase of real power losses in distribution networks, in lines and in transformers. Regarding the fact that low voltage network is branched, as well as the number of distribution transformers 10/0.4kV is huge, the problem of increase of losses owing to load unbalance and presence of neutral current can be potentially large.

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The aim of this paper is to determine the level of load unbalance by measurements at different locations in low voltage distribution network of city of Nis. Numerous measurements are performed for identification of unbalance load conditions in the area of Nis - measurements of transformer total load and the load of particular feeders. Comprehensive data is collected, hence this paper mostly presents and analyses the results of measurements that are performed at low voltage side of transformers. Also, low voltage feeders with the largest current unbalance are identified. These results provide the basis for concrete actions for load sharing among the phases that will decrease the losses.

In order to obtain the right conclusions connected with the unbalance of low voltage distribution network of city of Nis, transformer stations (TS) in different parts of Nis and its surrounding are selected for measurements. These transformer stations supply different load types:

1. residential load with central heating (TS “Duvaniste 7“, TS “Dom studenata“, TS “Cesalj“, TS “Bore Price 2“),
2. residential load without central heating (TS “Medijana 2“),
3. residential rural load (TS “Selo Gabrovac“),
4. commercial load (TS “Dimitrija Tucovica 3“).

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

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

where index *i* denotes inverse, and index *d* direct component of current [2, 3].

II. Measurement Results

Transformer stations that supply the residential load with central heating are selected in the way to be located in different parts of the city. Thus, TS “Duvaniste 7” and TS “Dom studenata” are in the wider area of Nis, and TS “Cesalj” and TS “Bore Price” are placed in the centre of the city.

Large load unbalance is recorded in TS “Duvaniste 7” (2×630kVA). Phasor diagram of currents and voltages for early afternoon of a working January day (display of power quality analyser C. A 8332) is presented in Fig. 1. The picture shows that the magnitudes of phase currents are different and also it is obvious that angles between currents of two next phases significantly differ from 120° (131°, 106° and 123°).

Measurements in this transformer stations were also performed during a week, from 19th to 26th January 2007. Average values of currents of certain phases in this period confirmed the existence of load unbalance: I_{L1}=271.52A, I_{L2}=239.41A and I_{L3}=224.22A, thus average value of neutral current was I_N=60.27A. Mean value of unbalance factor of currents in considered period was I_{unb}=14.3%, while minimal and maximal recorded values of unbalance factor were 3.4% and 30.8%, respectively.

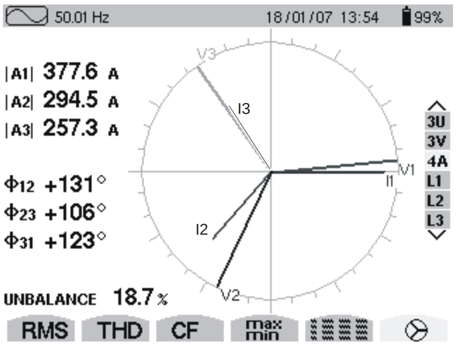

Fig. 1. Phasor diagram of currents and voltages in TS "Duvaniste 7"

In transformer station TS "Dom studenata" (630kVA) the measurements were performed from 19th to 26th December 2007. The changes of phase currents and neutral current during the week are presented in Fig. 2. The figure shows very large current unbalance causing the average value of neutral current to be even 103.56A, and it is 36.67% of the mean value of the smallest phase current. Unbalance factor of currents in consider transformer station changed from the biggest values in early morning (between 5 and 6 o'clock) to the smallest values between 10 and 11 o'clock that is presented in Fig. 3. Mean value of unbalance factor of currents in the period of measurements was 10.18%, and maximum recorded value was 21.7%.

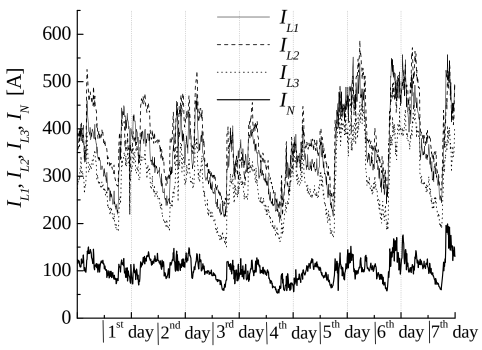

Fig. 2. Phase currents and neutral current in TS "Dom studenata"

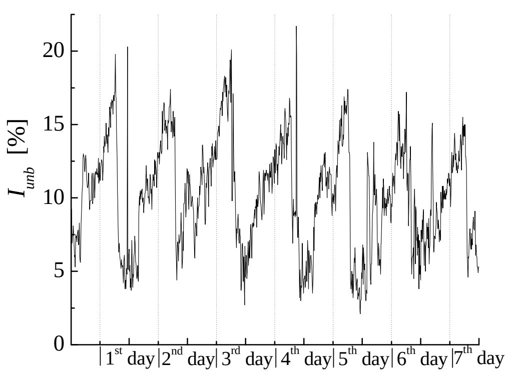

Fig. 3. Unbalance factor of currents in TS "Dom studenata"

TS „Cesalj" (1000MVA) is placed in centre of the city and supplies residential load with central heating as two previously mentioned transformer stations. Phasor diagram of currents and voltages recorded in the afternoon of a working February day is shown in Fig. 4. The currents from the figure are quite different, so unbalance factor of currents is 9.9%. Measurements during a week, from 14th to 21st February 2008, showed that average value of unbalance factor of currents was similar to the value from Fig. 4, it was 9.1%. Mean value of neutral current was I_N=102.63A, that is 28.88% of the mean value of the smallest phase current (I_{L3}=355.34A).

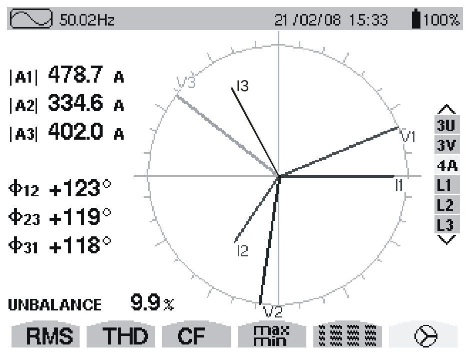

Fig. 4. Phasor diagram of currents and voltages in TS "Cesalj"

Larger unbalance of currents was recorded in TS "Bore Price 2" (630kVA) in the centre of the city, that can be noticed from Fig. 5. This picture presents phase currents and neutral current during the measurements from 22sc to 29th February 2008. Average neutral current value in considered period was 76.6A, that is even 55.82% of the average value of the smallest phase current (I_{L1}=140.15A). Average value of unbalance factor of currents in the same period of time was 14.1%, similarly as in TS "Duvaniste 7" that is placed in wider area of the city.

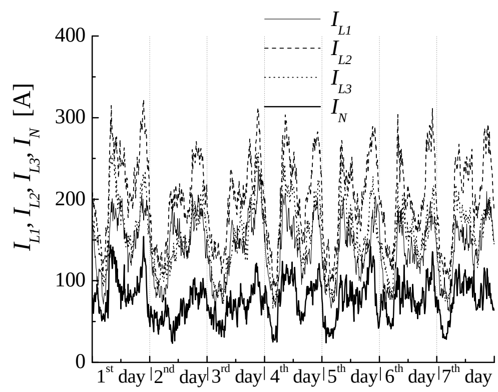

Fig. 5. Phase currents and neutral current in TS "Bore Price 2"

In transformer station TS "Medijana 2" (2×400kVA) that supplies residential load without central heating, the measurements were performed in autumn and in winter 2006. During the autumn (27.10-3.11.2006.) mean value of neutral current was 65.07A. Mean value of unbalance factor of currents was 13.8%, while maximum recorded value was even 25.5%. During the winter (6-13.12.2006) the unbalance was smaller, thus average neutral current was 22.68A. Mean value of unbalance factor of currents in this period was 8.5%, that is less than arithmetic mean value of unbalance factor of currents in four mentioned transformer stations that supply residential load with central heating in the same - winter season (11.9%).

The measurements in rural settlement, in „Selo Gabrovac“ (250kVA), were performed two times - in the first and in the second half of November 2006, from 4th to 11th and from 15th to 22nd . Both measurements showed that values of currents and unbalance factor were similar: in the first half of November mean values of these variables were I_{L1}=334.88A, I_{L2}=306.81A, I_{L3}=324.22A and I_{unb}=6.06%, and in the second half I_{L1}=317.96, I_{L2}=282.35A, I_{L3}=303.48A and I_{unb}=6.70%. It means that the load of the network supplied by this TS is more equally distributed among the phases than the load supplied by all other previously mentioned transformer stations. The values of unbalance factor of currents in time domain are presented in Fig. 6. This figure shows that unbalance factor varies in the wide range, from 1.3 to 18.2% with large changes in all day periods.

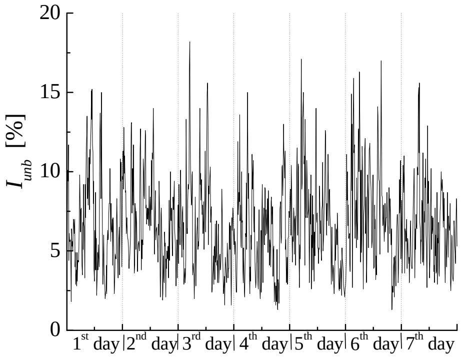

Fig. 6. Unbalance factor of currents in TS “Selo Gabrovac”

Phasor diagram of currents and voltages in TS “Selo Gabrovac” from Fig. 7 presents, among other things, that the angle between phase voltage and corresponding current is very small, i.e. the load in rural settlement is mostly composed of resistive load devices.

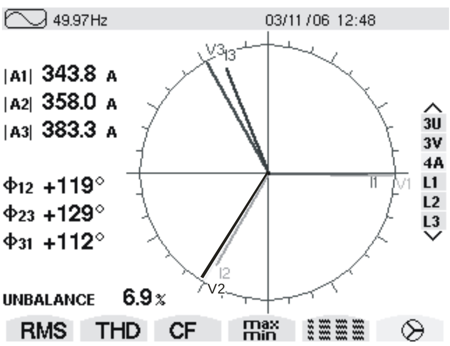

Fig. 7. Phasor diagram in TS “Selo Gabrovac”

TS “Dimitrija Tucovica 3” (400kVA) supplies commercial load and one gas station. Phasor diagram of currents and voltages that is recorded before noon of one working December day is presented in Fig. 8. Then the load was rather equally distributed among the phases (I_{L1}=101.0A, I_{L2}=97.0A, I_{L3}=107.6A) and unbalance factor was only 4.8%. However, the measurements during the week, in the period from 8th to 15th December 2007, showed that mean value of unbalance factor of currents was 8.14% and that this factor varied in wide ranges, from 1.6% to 17.9%.

Fig. 9 presents phase currents and neutral current during the same week, 8-15.12.2007. Then the average value of neutral current was 40.61A, that is 33.38% of the mean value of the smallest phase current.

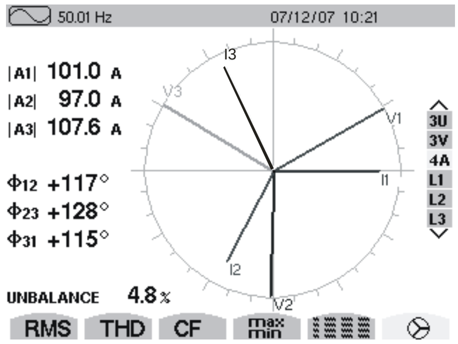

Fig. 8. Phasor diagram in TS “Dimitrija Tucovica 3”

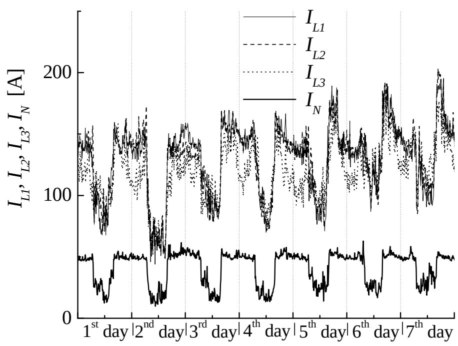

Fig. 9. Phase currents and neutral current in TS “Dimitrija Tucovica 3”

III. Analysis of the Results

All the results from Section 2, that are obtained on the basis of measurements during the week, show that the parts of low voltage distribution network supplied by considered transformer stations have significant load unbalance. This unbalance exists in all day periods, in all days of the week and varies in wide ranges for all investigated parts of low voltage distribution network of city of Nis.

It is obtained that the mean value of unbalance factor of currents for the half of measurements was greater than 10% (see Table I): for TS “Duvaniste 7”, for “Dom studenata”, for “Bore Price 2” and for TS “Medijana 2” in October. In all considered parts of low voltage distribution network that supply residential load with central heating, mean values of unbalance factor were greater than 9%, and arithmetic mean value of this factor for these four transformer stations was 11.9%. It is established that unbalance factor does not depend on the location of TS, whether it supplies consumers far from the centre or in the centre of the city.

TABLE I

AVERAGE VALUES OF UNBALANCE FACTOR OF CURRENTS AND NEUTRAL CURRENT, OF THE PART OF THE NETWORK SUPPLIED BY TS AND THE FEEDER

Load class	TS	Month	I_{unb} (T) [%]	I_N (T) [A]	Feeder	I_{unb} (feeder) [%]	I_N (feeder) [A]
Residential with central heating	„Duvaniste 7”	January	14.3	60.27	6	19.7	15.26
	„Dom studenata”	December	10.2	103.56	0	41.6	35.53
	„Cesalj”	February	9.1	102.63	0	31.9	16.25
	„Bore Price 2”	February	14.1	76.6	8	15.1	19.22
Residential without central heating	„Medijana 2”	October	13.8	65.07	1	54.2	34.3
		December	8.5	22.68	1	-	13.9
Residential rural	„Selo Gabrovac”	November	6.7	81.19	2	40.0	40.2
Commercial	„Dimitrija Tucovica 3”	December	8.1	40.61	0	6.1	12.29

For the measurements in TS that supplies residential load without central heating, TS “Medijana 2”, similar average value of unbalance factor is obtained (11.1%) as in the transformer stations that supply residential load with central heating. Transformer station TS “Dimitrija Tucovica 3” supplies commercial load that is more equally distributed among the phases (I_{unb}=8.1%). Mean value of unbalance factor of the currents measured in transformer station that supplies residential rural load, TS “Selo Gabrovac”, is the smallest one, 6.7%, but neutral current that causes additional losses in the network and in the transformer is large (81.19A), since this transformer station is pretty loaded.

Regarding the fact that for all measurements in transformer stations unbalance factor of currents is greater than 6%, and for most of them is greater than 10%, it is necessary to identify the reasons of such unbalance and undertake concrete actions of load sharing among the phases for decrease of power and energy losses in the network. This sharing can be performed on the basis of measurements of the load of the feeders supplied by mentioned transformer stations.

Many measurements are performed, but here are selected and presented the results of measurements only for the feeders with the largest load unbalances and the largest load currents. The measurements are performed simultaneously with the measurements of total load supplied by transformers. Since unbalance factor of currents varies in very wide range, average values of this factor obtained by measurements during one week are analyzed and presented in Table I together with average neutral currents of the feeders.

It is shown that for six of seven considered feeders, unbalance factor of currents is greater than 10%, and for four of them this factor is greater than 20%. The largest unbalance is identified for feeder 1 in TS “Medijana 2” (54.2%), then for feeder 0 supplying outdoor lighting in TS “Dom studenata” (41.6%), and for feeder 2 in TS “Selo Gabrovac” (40%). Large unbalance of currents is recorded for feeders in transformer stations that supply residential load with central heating where arithmetic mean value of unbalance factor is 27%, while arithmetic mean of neutral currents of this feeders is 21.56A. Therefore, it is suggested to share the load of mentioned feeders in order to decrease the unbalance of their currents and transformer currents, too. This will reduce neutral currents in considered parts of low distribution network and reduce additional power and energy losses.

IV. CONCLUSION

This paper presents the results of measurements in low voltage distribution network of city of Nis connected with load unbalance. The measurements at low voltage side of transformers 10/0.4kV that supply different load classes and at the begging of low voltage feeders, show that load unbalance exists in all periods of day and week. Average value of unbalance factor of currents during the week is greater than 10% for the half of measurements of total transformer load and for almost all measurements of feeder load. This fact shows the necessity of sharing of phase currents for the feeders with the largest load unbalance and the largest neutral current that are identified in the paper. This sharing, together with the sharing on the basis of other numerous measurements in distribution network of Nis, would reduce the losses in low voltage distribution network of the city.

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REFERENCES

[1] J. C. Balda, A. R. Oliva, D. W. McNabb and R.D. Richardson, “Measurements of Neutral Currents and Voltages on a Distribution Feeder”, *IEEE Trans., Power Delivery*, vol. 12, no. 4. pp. 1799-1804, 1997.

[2] L. Korunovic, D. Stojanovic, “Power Quality Indices of Some Nonlinear Loads in the Area of JP “Elektrodistribucija” Nis”, *Elektroprivreda*, no. 1, pp. 46-57, 2005. (in Serbian)

[3] V. Katic, *Power quality - higher harmonics*, memoir, Novi Sad: Faculty of Technical Sciences, 2002. (in Serbian)