The Research of Harmonics in Low Voltage Distribution Network of Nis

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Abstract – **This paper presents the results of harmonic analysis in low voltage distribution network in the area of Nis. The research is based on the measurements in transformers stations 10/0.4kV that supply different load classes and that are located in different parts of the city of Nis and its surrounding. Total and individual harmonic distortions are analysed and compared with IEEE Standard 519 and EN 50160 limits. The results are grouped and discussed according to the load classes that considered transformer stations supply.**

Keywords – **Power quality, Distribution networks, Harmonics.**

I. Introduction

Power quality becomes especially up to date with energy market deregulation and competition between power distribution companies. In this environment, electrical energy is treated as ware with the quality that is most frequently specified by its technical quality – the quality of delivery and the quality of delivered energy [1]. The quality of electrical energy delivery comprehends the problems of reliable and safe supply that are the base of every electrical power system operation. The problem of the quality of delivered energy, i.e. power quality, is connected with the power system stability, disturbances and mutual influences system-consumer. This has become especially important with the appearance of so called “sensitive devices” as are computers, processor equipment in the industry, complex devices that are controlled by microprocessors, etc.

Scientists and professionals all around the world regard the power quality. Numerous papers and books concerning this item [1-3], as well as standards and recommendations [4-7] are published. Also, many devices and adequate measurement equipment are produced for the control and power quality improvement.

One of the most discussed topics in power quality studies is the presence of higher harmonics in electrical power networks. Generally, nonsinusoidal currents can appear due to nonsinusoidal generator voltage, nonlinear device operation in the network and nonlinear load devices. Generated voltage which is then transformed on transmission level is commonly very close to sinusoidal and has little distortion. Transmission overhead lines, cables and transformers are quite linear and couse little distortion of voltage and current waveforms.

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However, overall usage of nonlinear devices [2, 3] such are TV sets, fluorescent and mercury lamps, computers, etc., as well as variable speed drives and uninterraptible power supplies can violate power quality and cause serios problems such as increase of power and energy losses in lines and transformers, capacitor failures, inadequate electronic equipment operation and inadvertent circuit breaker tripping. Current waveform and harmonic spectrum for the most frequently used low-voltage nonlinear devices are presented in [3]. Moreover, it is stated that large number of different nonlinear load devices of relatively small rated power hardly influence on the spectrum of currents measured in low voltage distribution network [8].

Therefore, this paper presents the results of one comprehensive survey of current and voltage harmonics in the area of Nis distribution network. The measurements were performed in many transformer stations (TS) 10/0.4kV that supply the load belonging to different load classes. These TS are placed in different parts of the city of Nis and its surrounding and the measurements are performed in different seasons. Thus, overall conclusions about the presence of harmonics in investigated network are made on the basis of comparison of obtained total and individual harmonic distortions of current and voltage ($THDI$, HDI_h, $THDV$ and HDV_h) with IEEE Standard 519 and EN 50160 limits. This study can be very useful, because it provides data for electrical distribution company regarding the presence of harmonics in its low voltage network before the standard that treats the quality of power supply is adopted in Serbia.

The necessary data for this research are obtained by three-phase measurements at low voltage side of transformers 10/0.4kV using power analyser C. A 8332. The measurement in every TS lasted one week and recorded values are averaged and memorized after the periods of ten minutes according to EN 50160.

II. Analysis of Measurement Results

Since twenty one measurements are performed in twenty transformer stations the results are summarized in Table I. This table presents the results of 95% probability values of total and individual harmonic distortions of currents and voltages. Individual harmonic distortions are given for harmonics up to ninth, due to space limitations.

The results in Table I are grouped according to the load class investigated transformer stations supply and according to the season (winter or summer) when the measurements were performed. The values of harmonic distortions obtained for the same load class and the same season are averaged and presented in the table, too.

TABLE I

VALUES OF TOTAL AND INDIVIDUAL HARMONIC DISTORTIONS OF CURRENTS AND VOLTAGES OBTAINED WITH 95% PROBABILITY

Load class	Season	TS	$THDI$ [%]	HDI_3 [%]	HDI_5 [%]	HDI_7 [%]	HDI_9 [%]	$THDV$ [%]	HDV_3 [%]	HDV_5 [%]	HDV_7 [%]	HDV_9 [%]
Residential with central heating	Winter	„Bore Price 2”	8.3	7.7	3.2	2.4	1.3	3	0.2	3	0.9	0
		„Cesalj“	5.9	5.5	2.1	1.4	1.3	2.9	0.4	2.7	0.9	0.1
		„Dom studenata“	11.4	9.2	6.5	4.3	1.5	2.9	0.5	2.6	1.2	0
		„Duvaniste 7“	10.6	8.9	5.1	3	3.3	2.7	0.4	2.6	0.9	0
		Average value	**9.05**	**7.82**	**4.22**	**2.77**	**1.85**	**2.87**	**0.90**	**2.72**	**0.97**	**0.02**
Residential without central heating	Winter	„Medijana 2“	9.8	9.4	3.4	2.2	2.3	3	0.3	2.8	1	0
		„Medijana 2“	3.8	3.7	0.8	0.6	0.7	2.9	0.3	2.7	1	0
		„Delijski Vis 1“	4.7	4.6	1.4	1	0.7	2.6	0.5	2.5	0.8	0
		„Vojvode Tankosica 1“	5.8	5.5	2.4	1.4	0.6	3	0.4	2.9	0.9	0
		„Gabrovacki most“	6.2	5.9	1.9	1.5	1	3	0.3	2.9	0.8	0
		Average value	**6.28**	**5.84**	**1.98**	**1.34**	**1.06**	**2.9**	**0.36**	**2.74**	**0.9**	**0**
	Summer	„Knjazevacka 1“	6.5	5.7	3.1	2.4	1.3	3	0.7	2.9	0.8	0.1
		„Marsala Tita 1“	7.4	7	3	2.3	1.2	3.1	0.5	2.9	1	0.1
		„Brace Ignjatovic 2“	8.1	7.6	3.5	2	1.1	3.1	0.4	3	0.8	0
		„Takovska 1“	9.7	8.3	4.8	2.7	1.7	3.1	0.4	3	0.9	0
		„Ledena Stena 2“	11.6	10.7	4.7	2.3	1.6	2.9	0.3	2.8	0.9	0.1
		Average value	**8.66**	**7.86**	**3.82**	**2.34**	**1.38**	**3.04**	**0.46**	**2.92**	**0.88**	**0.06**
Res. with and without cent. heating	Summer	„7. jula“	8.5	7.9	2.8	1.8	1.1	3.2	0.3	3.1	1	0
Rural	Winter	„Selo Gabrovac“	3	2.8	1.5	0.9	0.3	3	0.3	2.9	1	0
		„Selo Gabrovac“	2.9	2.8	1.2	1.1	0.3	3	0.3	2.8	1	0
	Summer	„Popovac 3“	9.9	9.6	3	1.3	1.1	2.8	0.4	2.7	0.9	0
Commercial	Winter	„Dimitrija Tucovica 3“	18.2	16.8	7.3	5.3	1.5	2.7	0.6	2.5	1	0
Commercial and residential	Summer	„Niska banka“	9.8	9.3	4.5	3.1	1.1	3.4	0.4	3.3	1.3	0
Industrial	Winter	„Masinska industrija 2“	5.8	2.7	4.5	2.9	1	3.8	3.3	2.4	1	1.3

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 “Bore Price 2” and TS “Cesalj” are placed in the centre of the city while TS “Duvaniste 7” and TS “Dom studenata” are in the wider area of Nis. The currents measured in TS “Cesalj” are with smallest distortion ($THDI$=5.9%) while the currents of transformer in TS “Dom studenata” are hardly distorted and $THDI$=11.4%.

For comparison, Figs. 1 and 2 present $THDI$ and harmonic spectrum of the currents (maximum and 95% probability values) in TS “Cesalj” and TS “Dom studenata”, respectively. These figures also show IEEE standard 519 limits for $THDI$ and HDI_h up to 15th harmonic according to the ratio I_{SC}/I_L, the ratio of short-circuit current at the point of common coupling to the maximum fundamental load current. For TS “Cesalj” this ratio belongs to the interval 50<100, and for TS “Dom studenata” it is in the range 20<50. Even harmonics of currents and harmonics greater than 15th one are not presented on figures because they are negligible in all investigated transformer stations.

Third harmonic is dominant in both transformer stations, in TS “Cesalj” HDI_3=5.5%, and in TS “Dom studenata” is 8.9%. High presence of harmonics in TS “Dom studenata” that is above IEEE standard limit, can be primarily explained by large number of computers in Students’ Hall that is consumer of considered TS.

Although the levels of higher harmonics of currents measured in transformer stations that supply residential load with central heating are different, the presence of harmonics in voltages is very similar in investigated transformer stations and does not depend on the location of TS (see Table I). Therefore, Fig. 4 presents maximum and 95% probability values of $THDV$ and HDV_h of supply voltage for one of considered transformer stations - TS “Dom studenata”. It is ascertained that voltage harmonics higher than 9th are not present in this and other transformer stations, so these are omitted from Fig. 4 and other figures considering voltage harmonics. On this figure $THDV$ and HDV_h limits according to EN 50160 are also presented and these are higher then 95% probability values of $THDV$ and HDV_h .

Further, the results of harmonic analysis for residential load without central heating are presented in Table I for the measurements in five transformer stations during the winter and in five during summer. Harmonic presence is generally lower in transformer stations where the measurements are performed during winter season.

Certain differences in the results obtained for the transformer stations which supply the same load class in the same season appear due to differences in weather conditions for the periods belonging to the same, winter or summer season. For example, in TS “Medijana 2” measurements are performed two times - from 27th October to 3rd November 2006 and from 6th to 13th December 2006. From Table I it is obvious that in the first period, in autumn, the presence of harmonics is much lower than in the second one.

However, the results from the table regarding the measurements in transformer stations supplying residential load without central heating in winter season can be averaged: $THDI$=6.28%, HDI_3=5.84%, HDI_5=1.98%, HDI_7=1.34%, HDI_9=1.06%. These values are lower than those obtained for the same season but in transformer stations that supply residential load with central heating: $THDI$=9.05%, HDI_3=7.82%, HDI_5=4.22%, HDI_7=2.77%, HDI_9=1.85%. This is because the usage of resistive load devices is larger when there is not central heating.

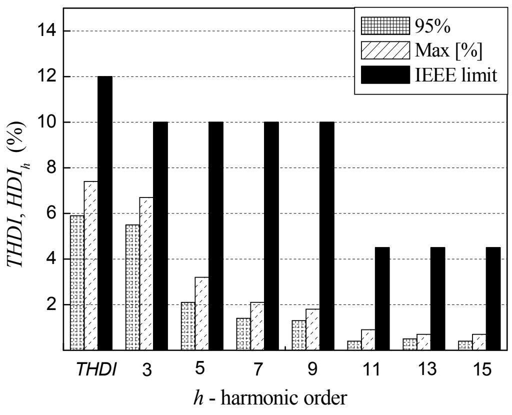

Fig. 1. *THDI* and harmonic spectrum of TS "Cesalj" total current

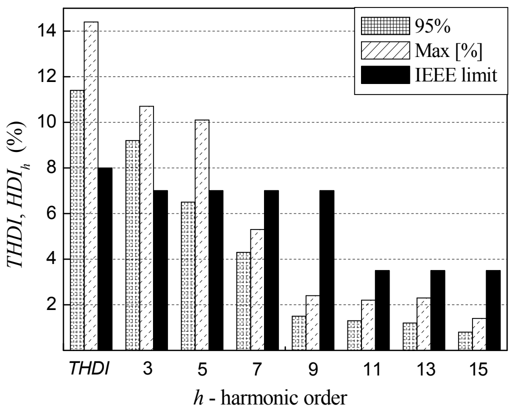

Fig. 2. *THDI* and harmonic spectrum of TS "Dom studenata" total current

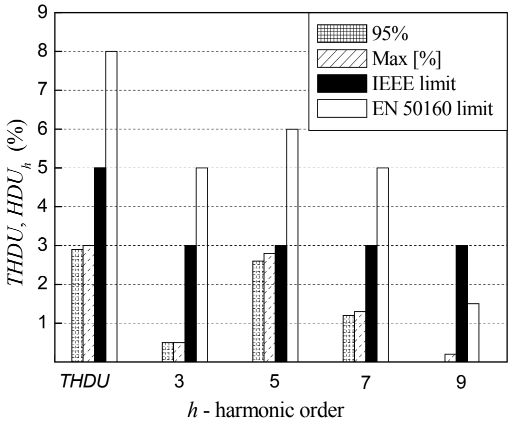

Fig. 3. *THDV* and harmonic spectrum of TS "Dom studenata" supply voltage

In summer season the load composition changes, and the usage of resistive load devices decreases. Therefore, the presence of higher harmonics in currents is higher than in the winter season. Average values of power quality indices *THDI*, HDI_3, HDI_5, HDI_7 and HDI_9 are 8.66%, 7.86%, 3.82%, 2.34% and 1.38%, respectively. These values are similar to average values obtained in winter season for transformer stations that supply resistive load with central heating because the load composition is similar.

Also, average values of total and individual harmonic distortion for TS supplying residential load without central heating are very close to the values measured in TS "7. jula" in the same, summer season This TS supplies residential load with and without central heating and 95% probability values of the indices are: *THDI*=8.5%, HDI_3=7.9%, HDI_5=2.8%, HDI_7=1.8% and HDI_9=1.1%.

In TS "7. jula" larger 95% probability value of *THDV* is recorded in comparison with all other 95% probability values of *THDV* obtained for residential load. It is 3.2%, but still much lower than 8% that is EN 50160 limit. Individual harmonic distortions of voltage are also lower than EN 50160 limits, and are: HDI_3=0.3%, HDI_5=3.1%, HDI_7=1.0% and HDI_9=0%.

Measurements are performed two times in rural settlement, in TS "Selo Gabrovac". Both measurements were in winter season and therefore similar values of power quality indices were obtained. For example, from second measurement 95% probability values are *THDI*=2.9%, HDI_3=2.8%, HDI_5=1.2%, HDI_7=1.1% and HDI_9=0.3%. It means that the presence of higher harmonics in TS "Selo Gabrovac" is the lowest one comparing with all other transformer stations. For illustration, 95% probability values and maximum values of total and individual harmonic distortions of current are presented in Fig. 4. On the same figure IEEE Standard 519 limits are presented. In this case the limits are smaller because the ratio I_{SC}/I_L at the point of common coupling is <20, but still are greater than 95% probability values of *THDI* and HDI_h.

Fig. 5 presents total and individual harmonic distortions of voltage obtained from the same measurement in TS "Selo Gabrovac" and IEEE 519 and EN 50160 limits. The values of total and individual harmonic distortions are almost the same as those obtained for the majority of other transformer stations. It means that voltage distortions are not explicitly dependent on the load class that particular transformer station supplies.

It is most obvious for transformer station "Dimitrija Tucovica 3" that supplies commercial load. In this TS 95% probability values of *THDI*, HDI_3, HDI_5, HDI_7 and HDI_9 are 18.2%, 16.8%, 7.3%, 5.3% and 1.5%, respectively (see Fig. 6) and the values of *THDI* and HDI_3 are even greater than IEEE standard limits. At the same time 95% probability values of *THDV*, HDV_3, HDV_5, HDV_7 and HDV_9 are small: 2.7%, 0.6%, 2.5%, 1% and 0%, respectively. Therefore, in spite of very high presence of harmonics in the current, supply voltage of TS "Dimitrija Tucovica 3" is among the voltages which have the lowest harmonic pollution (see Table I).

Total and individual harmonic distortions of current and voltage in TS that supplies both commercial and residential load, TS "Niska banka" are given. All these values are below considered limits.

At the end of Table I, the results of measurement in transformer station supplying industrial load are presented. This TS supplies the workshop in mechanical factory "Masinska industrija Nis" and 95% probability values of total and individual harmonic distortions of currents and voltages are much below IEEE and EN 50160 limits.

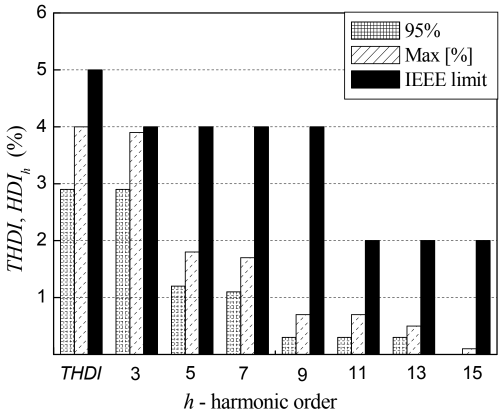

Fig.4. *THDI* and harmonic spectrum of TS "Selo Gabrovac" total current

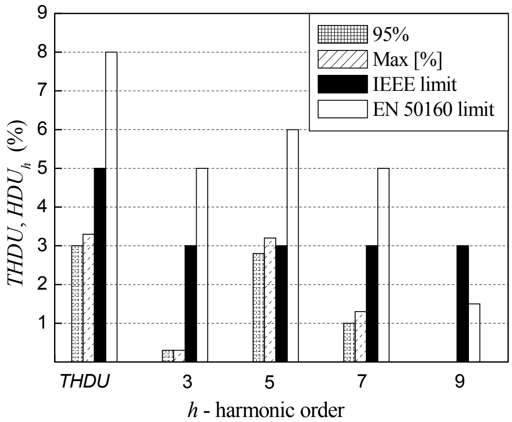

Fig.5. *THDV* and harmonic spectrum of TS "Selo Gabrovac" supply voltage

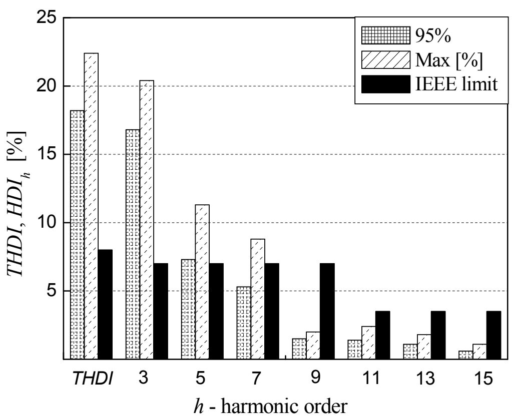

Fig.6. *THDI* and harmonic spectrum of TS "Dimitrija Tucovica 3" total current

At the end, due to the space limitation, brief comparative analysis of the results from this paper and some of results concerning the presence of harmonics at 0,4kV voltage level in another region of Republic of Serbia is made. Memoir [1] comprehends the results of harmonic analysis that relates to different load classes. In two examined TS that supply residential load 95% probability value of *THDI* is above IEEE standard limit as obtained for TS "Dom studenata", too. It confirms that load devices of this load class can cause the problems regarding the presence of higher harmonics. Commercial load investigated in [1] has *THDI* even greater than 16%, but less than the value obtained for TS "Dimitrija Tucovica 3" in this paper. On 0,4kV level of industrial loads *THDI* is greater than 25% that is much above the limits. This is opposite to the result obtained for TS in "Masinska industrija Nis" that supplies mostly linear load devices. Nonlinear load devices of industrial load cause voltage harmonics to be above standard limits [1], but in all TS in Nis these are much below IEEE and EN 50160 limits.

III. Conclusion

The paper presents the results of the research of harmonics in great number of transformer stations TS 10/0.4kV in the area of Nis. Investigated transformer stations are grouped according to the load class and the season and total and individual harmonic distortions of currents and voltages are averaged and mutually compared. In all TS harmonic distortion of currents are below the limits according to IEEE Standard 519 and distortion of voltages are much below IEEE Standard 519 and EN 50160 limits. Harmonic distortions of voltages in considered low voltage network do not significantly depend on harmonic distortion of load currents that approve the network in strong enough to keep the voltage to be with little distortion.

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