MEĐUNARODNO REGIONALNO SAVETOVANJE O ELEKTRODISTRIBUTIVNIM MREŽAMA

REGIONAL CONFERENCE AND EXHIBITION ON ELECTRICITY DISTRIBUTION

Crna Gora, Herceg Novi, 5 - 8. oktobar 2004. / ***Montenegro, Herceg Novi, October 5 - 8, 2004***
* *

INFLUENCE OF PERSONAL COMPUTERS ON THE POWER QUALITY, A CASE STUDY

B. Dumnić - Faculty of Technical Sciences, Novi Sad, Serbia and Montenegro
V. Katić - Faculty of Technical Sciences, Novi Sad, Serbia and Montenegro
D.Dujić - Faculty of Technical Sciences, Novi Sad, Serbia and Montenegro

SUMMARY

This paper presents power quality in a case when a large number of nonlinear loads, Personal Computers (PC), are present. The PC is at one hand a sensitive device that requires a stable and high supply quality, but on the other hand it is also a source of harmonics. That way it has reflexive influence on power quality and represents a menace even for its own proper operation. First part of the study is theoretical introduction about power quality and harmonics distortion. After that a brief description of load characteristics and supply unit of the PC is given.

Next, measurement results and their analysis are presented. Measurements are done in the Computer Center of Faculty of Technical Sciences, Novi Sad. Power harmonics has been measured at the 400 V grid (PCC) connected directly to University transformer station TS ZKI 20/0.4 kV. Results of measurement were analyzed and compared with IEEE - 519 limits. In order to get the right interpretation of measuring results, they are presented also in time domain and statistically.

Further, operation of single PC is modeled using Matlab - Simulink software. Results of simulation were compared with the measurement. Very good agreement has been achieved. The developed model has been used for prediction of the “worst” case i.e. the highest possible harmonic level. It is shown that a single PC is significant source of harmonics. If a large number of PCs is connected to the grid, like in the Computer Center, than they present a serious threat to power quality. The results of measurement prove this conclusion.

B.Dumnic, dumnic@uns.ns.ac.yu Tel. +381(0)21 350122 ext. 205

INFLUENCE OF PERSONAL COMPUTERS ON THE POWER QUALITY, A CASE STUDY

B. Dumnić - Faculty of Technical Sciences, Novi Sad, Serbia and Montenegro
V. Katić - Faculty of Technical Sciences, Novi Sad, Serbia and Montenegro
D. Dujić - Faculty of Technical Sciences, Novi Sad, Serbia and Montenegro

1. INTRODUCTION

Term "Power quality" generally means technical quality of electrical energy. Two aspects are observed [1]:

1. quality of power delivery and
2. quality of delivered electrical energy (voltage quality).

The first case is actually question of reliability and it will not be considered in this paper. In the second case, quality is observed like voltage quality at the point of common coupling (PCC). The main parameters are frequency, amplitude (r.m.s. value), waveform etc. In the past, most of the electronic equipment has been able to operate with relatively wide variations of these parameters. However, in the meantime number of nonlinear devices (power electronics converters, arc furnaces, etc.), which inject harmonics currents in the AC system, have rapidly increased. Also, developments in the digital electronics and in the process control put into network large number of so called sensitive loads, which require almost ideal sinusoidal supply voltages for their proper operation.

Ideally, the voltage supplied to the customer equipment and the resulting load currents should be perfect sine waves. But in practice, due to non-linear loads and other imperfections, these waveforms are often distorted. The deviation from perfect sinusoids is usually expressed in terms of harmonic distortion of the voltage and current waveforms for electric power system in steady state, or in terms of voltage sags, swells, impulses, oscillations etc. for system in transient states. In this paper only harmonics will be treated.

A non-linear load draws a non-sinusoidal current (rich in harmonics) when a sinusoidal voltage is applied. The distorted load current then causes distortion of the bus voltages. The harmonic distortion is described as a continuous or steady state variation of the fundamental frequency waveform. Typical symptoms of harmonic problems include spurious fuse blowing, unexplained breaker trips, overheating of transformers and motors, erroneous operation of measurement instrumentation, drives, relays, computers, etc. [1,2].

B.Dumnic, dumnic@uns.ns.ac.yu Tel. +381(0)21 350122 ext. 205

2. HARMONIC DISTORTION

Harmonics distortion can be described by two main parameters, the total harmonic distortion and the individual harmonic distortion. The total harmonic distortion is the ratio of the total harmonic content (not including fundamental component) to the fundamental component:

$$\mathrm{THDI}=\sqrt{\frac{\sum_{h=2}^{\infty} I_h^2}{I_1^2}}, \qquad \mathrm{THDU}=\sqrt{\frac{\sum_{h=2}^{\infty} U_h^2}{U_1^2}}.$$

The individual harmonic distortion is the ratio of individual harmonic component to the fundamental one:

$$\mathrm{HDI_h}=\frac{I_h}{I_1}, \qquad \mathrm{HDU_h}=\frac{U_h}{U_1} \qquad h=2,3,\ldots\mathrm{n}.$$

Two criteria are now used to evaluate the harmonic distortion [3]. The first is a limitation in the harmonic current that a user can transmit into the utility system. Table 1, from IEEE Standard 519, lists the harmonic current limits based on the size of a user with respect to the size of the power system to which it is connected. The ratio I_{sc}/I_{load} is the short-circuit current available at the point of common coupling (PCC) to the nominal fundamental frequency load current. As the size of the user load decreases compared to the size of the system, the percentage of harmonic current the user is allowed to inject into the utility system becomes larger. This protects other users of the same feeders as well as the utility, which is required to furnish a certain quality of power to its customers.

Table 1- Harmonic Current Limits (in %) from IEEE Standard 519 [3]

I_{sc}/I_{load}	Harmonic order					THDI
	<11	11-16	17-22	23-34	>35	
<20	4.0	2.0	1.5	0.6	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

The second limitation recommends the maximum allowable harmonic voltage distortion that is acceptable from the utility system to a user. The cooperation among users, utilities and equipment designers is needed to ensure an adequate power quality to all users and proper equipment operations. This table is a simplified version of the one in the present draft of IEEE 519. The recommended values of Table 2 are low enough to ensure that the properly designed equipment will operate correctly, provided the sensitive load itself generates no additional harmonics. This latter point is not realistic and, therefore, represents a potential problem area for a customer [3].

Table 2 - Maximum Voltage Distortion from IEEE Standard 519 [3]

Maximum distortion (%)	System voltage [kV]		
	2.3 - 6.9	69-138	>138
Individual harmonic	3.0	1.5	1.0
Total harmonic	5.0	2.5	1.5

The IEEE Standard 519 - 1992 that provides recommended practices, requirements and limits for harmonic current and voltage distortion levels, is used in this paper to evaluate power quality in system with large number of personal computers.

B.Dumnic, dumnic@uns.ns.ac.yu Tel. +381(0)21 350122 ext. 205

3. LOAD CHARACTERISTICS

One of the sensitive devices and also sources of harmonics that has influence on power quality is a personal computer (PC). Today, PC is wide used in all aspects of human work. Their application changes structure of electrical consumer significantly increasing number of small nonlinear or harmonic generating loads. Wave forms of load current for PC is not ideal sinusoid and has forms like on the Fig. 1. Because of distorted current wave form, PC has effects on voltage distortion, too. Deviation of load current makes power factor lower. Main characteristics of PC loads are: load current (wave forms and value), active power, reactive power and power factor [4,5].

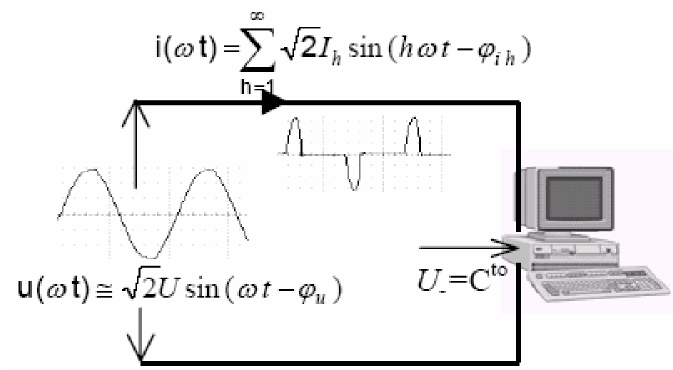

Fig. 1. PC – Nonlinear load

Supply unit determines characteristics of PC loads. It is for PC "source" of DC voltage for their operation. Power unit is usually single phase diode rectifier with capacitive filter on the DC side. Further conversion is done by switch mode DC/DC converters with HF transformer and output rectifier with LC filter for all generated DC voltages. This switching power supply has high efficiency and small dimensions and provides PC with stable DC voltage of levels: ±12 V, ± 5V and 3.3 V. Fig. 2 presents the scheme and characteristic voltage waveform of power supplies unit.

Current, which power supplies unit consumes from grid, which is also a load current, is highly distorted and has impulse wave-shape. The impulses are result of charging filter capacitor C1 in the every half period of rectified mains voltage. At the same time high switching frequency impulses (20 kHz or more), which are characteristic for this DC/DC converter, additionally "pollutes" the grid. The problem is that frequency spectrum is especially rich in low order harmonics, like the 3rd, 5th, etc., which are hard to mitigate.

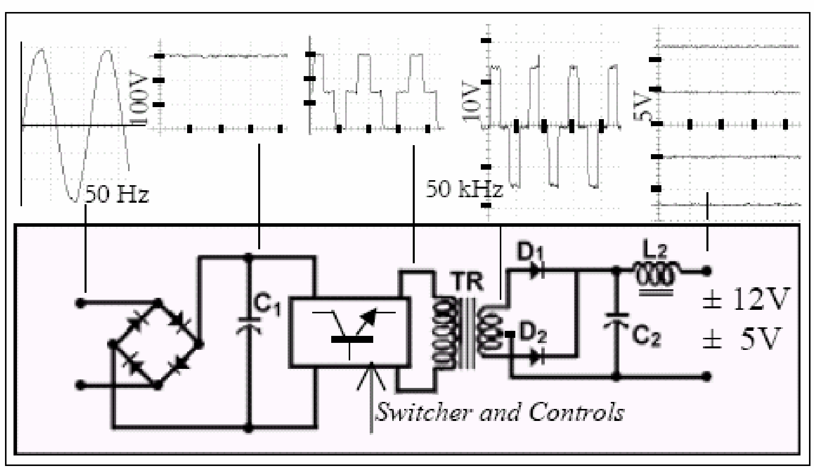

Fig. 2. Power supplies unit

B.Dumnic, dumnic@uns.ns.ac.yu Tel. +381(0)21 350122 ext. 205

4. MEASUREMENT SITE

Harmonics measurements for this study were done in the building of the Faculty of Technical Sciences at the 0.4 kV grid supplying Computer Center. The center has around 120 PC-s, which are placed in 7 laboratories. Nominal power of all PC-s is 18 kW. Except PC-s, at the grid only light for laboratories and one printer are connected. Maximum allowable values of THDI and HDI, according to IEEE Standard 519, are presented in Table 1 (case where I_{sc}/I_{load} = 100 – 1000). Allowed value of THDU and for HDU are presented in Table 2.

5. MEASUREMENT RESULTS

Results of measurement were analyzed and compared with IEEE - 519 limits. In order to get the right interpretation of measuring results they are presented in time domain and statistically. Current as well as voltage harmonics have been measured during one day. A great number of data was recorded.

Fig. 3 shows a typical phase current waveform per cycle. A considerable distortion from perfect sinusoid is obvious. This is a source of voltage distortion.

Fig. 4 shows recorded THDI time variation compared with IEEE - 519 limits. It can be seen that it is much above the limit.

Fig. 5 presents THDU compared with IEEE - 519 limits. In spite of the huge current harmonic distortion, the THDU is below, but very close to the limit.

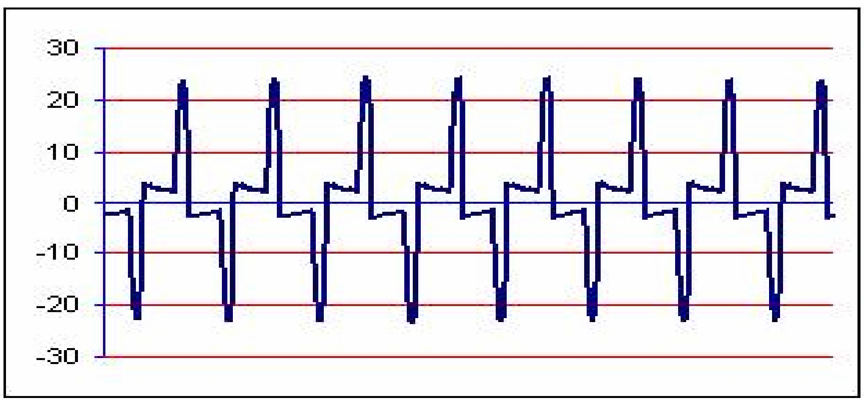

Fig. 3. Phase current waveform.

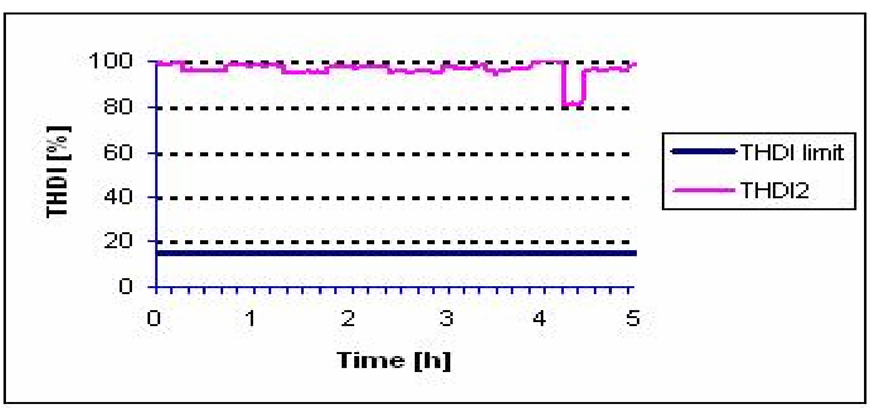

Fig. 4 Current total harmonic distortion

B.Dumnic, dumnic@uns.ns.ac.yu Tel. +381(0)21 350122 ext. 205

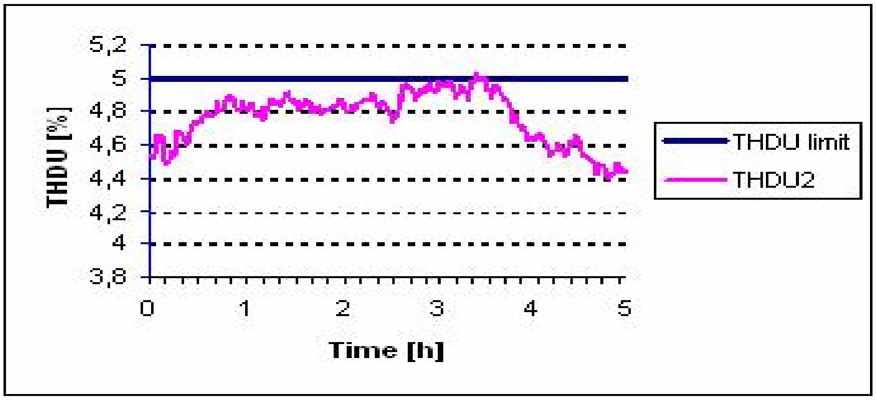

Fig. 5. Voltage total harmonic distortion

With regard to the numerous data that have been recorded for the period of measuring, there is a need for statistical data processing. During harmonic analysis it is important to know if the level of harmonic distortion exceeds the limit, the mean value, etc. For that reason the statistical interpretation does not take care of curves of distribution, but pays attention on cumulative probability. Besides the maximum level of the harmonic distortion, it is essential to know 95% level of the harmonic distortion, also. Such approach respects harmonic dynamics, but neglects short transients. Fig. 6 shows the statistical interpretation of the THDI compared with IEEE - 519 limits for all three phases. The level of the harmonic distortion (95% THDI) is much above IEEE - 519 limits. All current, I_1, I_2, I_3 have similar minimum, maximum, 95%, 5% and mean value.

In Fig. 7, 95% HDIn values are compared with IEEE - 519 limits. All current also have similar value of individual harmonics distortion. The 3^{rd} harmonics has the largest value. The reason of this appearance is existing single-phase non-linear loads that generate odd harmonics. Single-phase diode rectifier, that is the subject of discussion, generates odd harmonics (3^{rd}, 5^{th}, 7^{th}, 11^{th}, 13^{th}…) and the most significant are the 3^{rd}, and the 5^{th} and the 7^{th}.

In Figs. 8 and 9, voltage harmonic distortions (THDU and HDU) are illustrated. Even though there is high level of current harmonic distortions, voltage harmonic distortion (THDU) is below the limit. All voltage harmonics with the exception of the 5^{th} are under the limit. The 5^{th} harmonic is over the IEEE – 519 limits, and it is the result of the current 5^{th} harmonic. Even though the rest of current harmonics are significantly above the tolerable boundary, they do not involve large voltage harmonic distortions.

The 3^{rd} current harmonic which has the largest value compared with other harmonics is especially interesting. However, the 3^{rd} voltage harmonic is not over the limit. A possible explanation could be the difference in the phase position of 3^{rd} harmonics. On the place of measurement there are a huge number of customers. Because of that, 3^{rd} harmonics have different phase position and depending on their amount, this can cause certain cancellation of these harmonics.

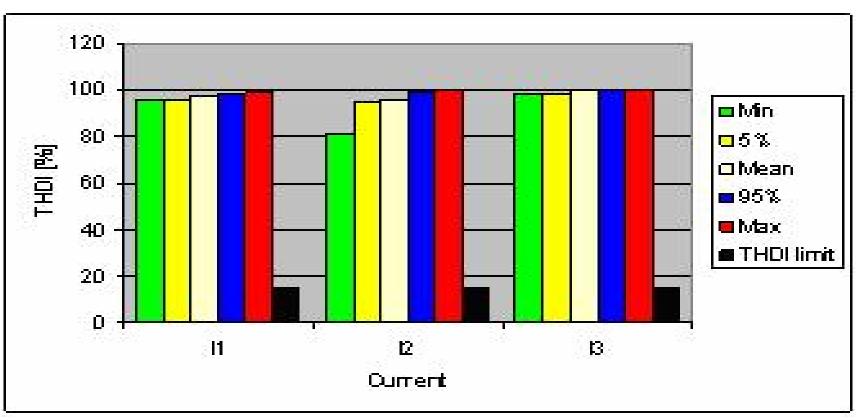

Fig. 6. Current total harmonic distortions

B.Dumnic, dumnic@uns.ns.ac.yu Tel. +381(0)21 350122 ext. 205

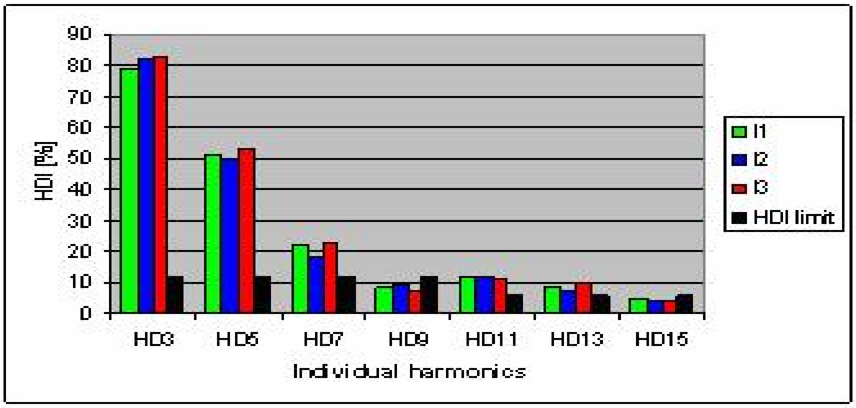

Fig. 7. Current individual harmonic distortions

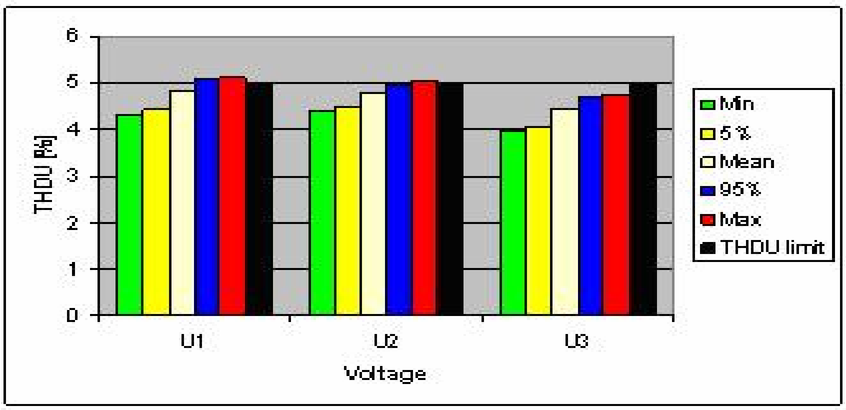

Fig. 8. Voltage total harmonic distortions

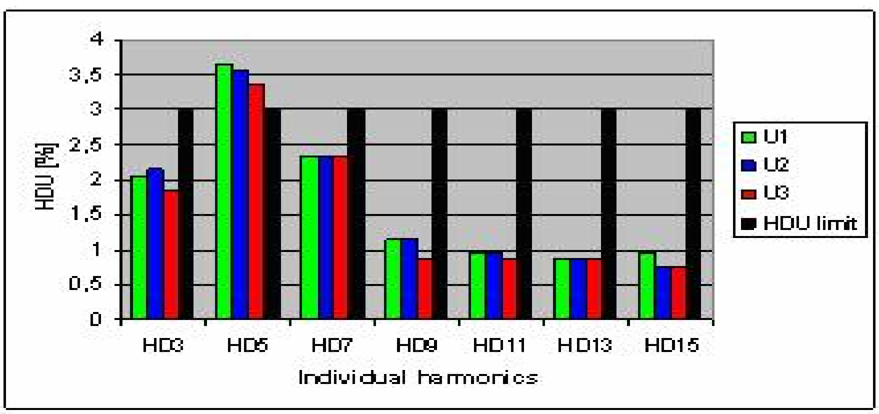

Fig. 9. Voltage individual harmonic distortions

6. COMPUTER SIMULATION

This part presents results of computer simulation. Simulation of operation of determined number of PC-s has been modeled using Matlab – Simulink software. The model has been developed using available data. This computer simulation gives results in real time. Model is consisting of single – phase diode rectifier with corresponding induction, capacity filter and resistance on the DC side. The first simulation has been performed in order to check if the simulation results match measured ones. Results of such simulation, compared with measured ones, are illustrated in Fig. 10.

PRETRAŽIVANJE / SEARCH
ŠTAMPANJE / PRINT
IZLAZ / EXIT

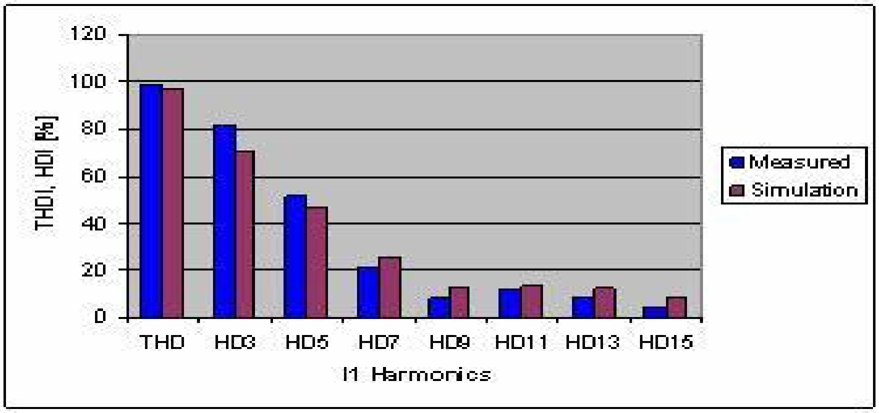

Fig 10. Comparison between THDI - measured and simulated.

As one can see, there is a good agreement between measured data and data obtained by computer simulation. The model is applied also to investigate the effects current harmonics to voltage distortion. Following expression has been used:

$$U_n = (R_e + j \cdot n \cdot X_e) \cdot I_n \,, \;\; n = 5, 7, 11, 13, ...$$

where R_e and X_e are equivalent resistance and reactance, I_n is current of *n* order harmonic and *n* is the order of harmonic. Results are presented in Fig. 11.

The developed model has been used for prediction of the “worst” case i.e. the highest possible harmonic level [6]. It is the case when all PC-s are turned on. The results of such simulation show that the voltage harmonic distortion is much above IEEE - 519 limits. This is presented at Fig. 12.

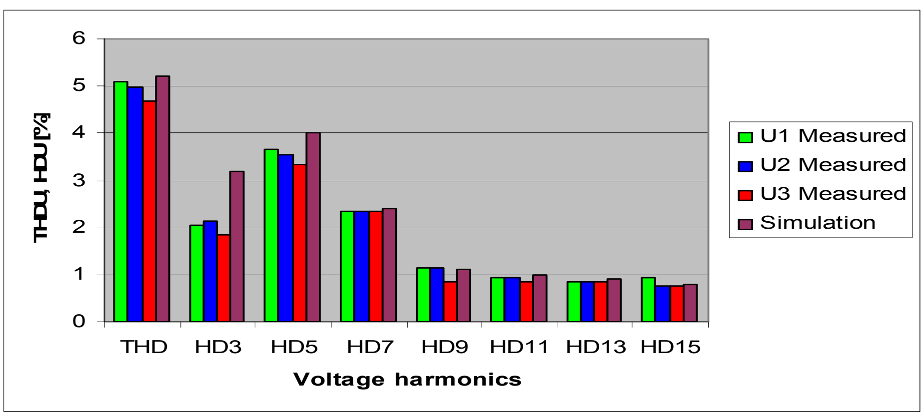

Fig. 11. Comparison between THDU - measured and simulated.

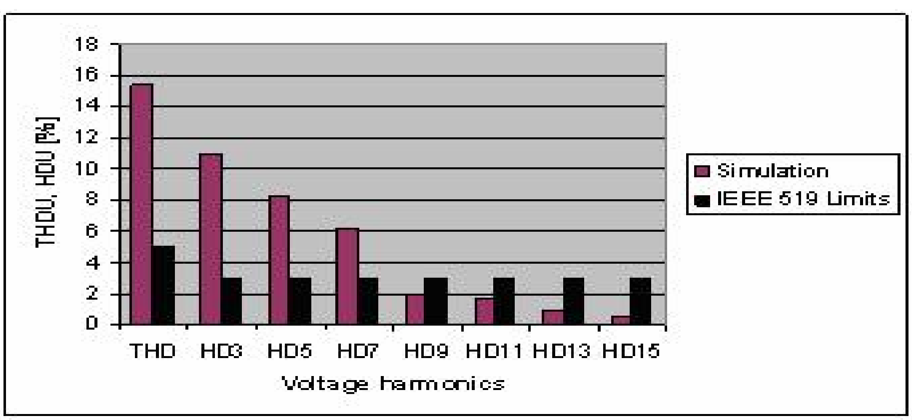

Fig. 12. Simulation of the “worst“ case

B.Dumnic, dumnic@uns.ns.ac.yu Tel. +381(0)21 350122 ext. 205

7. CONCLUSION

This paper presented results of research of electric power quality when a large number of small nonlinear loads, i.e. personal computers (PC) are present. Effects of PCs on the power quality is very interesting matter and requires a lot of research, especially as number of PC-s in constantly increasing in all aspects of human work and living. The research comprised of harmonic measurement and computer simulation.

The measurement was made at Computer Centre 0.4 kV grid. After processing of data, it has been shown that the levels of the current harmonic distortions (THDI and HDI) are much above IEEE - 519 limits. However, the voltage distortion (THDU) and all voltage harmonics (HDU) with the exception of the 5^{th} were under the limit. The current harmonics did not involve large voltage harmonic distortions, proving that connecting grid (PCC) has been well designed (large short circuit power).

Operation of a determined PC is modeled using Matlab - Simulink software. Results of simulation were compared with measured ones and achieved good agreement. The developed model has been used for prediction of the "worst" case i.e. the highest possible harmonic level. Results of such simulation have showed that the voltage harmonics are much above IEEE - 519 limits.

However, it should be noted that this "worst" case situation (all PC-s are turned on) is rarely present in practice of operation of Computer Center. Also, in simulation does not cover cancellation of any harmonics because of the phase angle. So, the probability that the distortion will arise to the presented level is not so high. But, the level of harmonic distortions might become higher than tolerable level, defined by IEEE - 519.

LIST OF REFERENCES

1. Katić V, 2002, *"Electric power quality - harmonics"*, Edition: Technical Sciences – Monographs, No.6, University of Novi Sad – Faculty of Technical Sciences, Novi Sad (in Serbian).
2. Schlabbach J, Blume D, Stephanblome T, 2001, *"Voltage quality in electric power systems"*, IEE Power and Energy Series 36, The Institution of Electrical Engineers, London
3. IEEE Standard 519, 1992, *"Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems"*, IEEE Press, New York.
4. Radović J, Mujović S, 2003, "Characteristics of computer load from the aspect of influence on power quality", 12^{th} International Symposium on Power Electronics- Ee2003, Novi Sad, (CD ROM), (in Serbian).
5. Burker J, Griffith D, Ward D, 1990, "*Power Quality – Two Different Perspectives*", IEEE Transactions on Power Delivery, Vol. 5, No. 3, pp.1501-1513.
6. Katić V, 2003, *"Harmonics calculation based on measurement results"*, XLVII Conference ETRAN, Herceg Novi, CD-ROM & Book, Vol.1, pp.409-412, (in Serbian).

B.Dumnic, dumnic@uns.ns.ac.yu Tel. +381(0)21 350122 ext. 205