EFFECTS OF HARMONICS IN UNIVERSITY OF NOVI SAD SUPPLY NETWORK – A CASE STUDY OF FACULTY OF TECHNICAL SCIENCES

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INTRODUCTION

Nowadays, power quality issue becomes more and more important due to a number of devices, called sensitive devices, which require power supply with good characteristics. On the other hand, an increasing number of non-linear loads such as fluorescent tubes, AC and DC drive, air conditioners, computers, etc. contribute to degradation of power supply quality.

Information technology (IT) equipment, i.e. PC's, printers, faxes, monitors, etc., are widely used today. Those devices are non-linear single phase loads and their non-linearity is caused by the bridge rectifier at the input of the switching power supply. If huge number of such loads is located at one place, as for example personal computers in a computer centre, it is necessary to distribute them per phases evenly in order to have loads close to balance. However, regardless of the fact that the loads are balanced, neutral conductor current may appear. Such effect can be more expressed if PC's are distributed unevenly [1].

The main goal of this paper is to show effects of PC's and other IT devices on electrical installation of the Faculty of Technical Sciences (FTN) as a case study. The number of such devices is steadily increasing and their effects are becoming significant as they are connected to the same grid. The focus will be on neutral current, which could increase up to 73%, as it will be shown latter in the paper. Such a high current value will overload power feeders, overload transformers, produce voltage distortion and common mode noise. These effects are significant and need to be analysed.

POWER SYSTEM HARMONICS

Ideally, voltage and current waveform should be perfectly sinusoidal. However, due to increased usage of electronic and other non-linear loads, this waveform becomes distorted quite often. This deviation from a perfect sine wave is represented by harmonics. Harmonics are sinusoidal components with frequencies which are multiple of the fundamental one. Thus, a pure voltage or current sine wave has no distortion and no harmonics and a non-sinusoidal wave has distortion and harmonics.

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In order to quantify the distortion, individual harmonic distortion (HD) and total harmonic distortion (THD) are used as indices. They are defined as:

$$HDI_n = (I_n / I_1) \cdot 100(\%) \tag{1}$$

$$HDU_n = (U_n / U_1) \cdot 100(\%) \tag{2}$$

$$THDI_n = \sqrt{\sum_{n=2}^{\infty} \frac{I_n^2}{I_1^2}} \cdot 100 \ (\%) \tag{3}$$

$$THDU_n = \sqrt{\sum_{n=2}^{\infty} \frac{U_n^2}{U_1^2}} \cdot 100 \ (\%) \tag{4}$$

Effects of current harmonics may be source of problem because they can cause increased losses in the customer and utility power system components. Transformers are especially sensitive to this problem and may need to be derated to as mush as 50% capacity when feeding load with extremely distorted current waveforms (THDI above 100%). When the current THD is below 15%, the derating of transformer would be so small that can be neglected. On the other hand, when the current THD exceed 15% the transformer capability should be evaluated using IEEE recommendations [4].

In addition, current harmonics can distort the voltage waveform, due to voltage drop on the grid impedance caused by non-linear current. Single-phase, non-linear loads like PC's generate odd harmonics. The harmful single phase harmonic are the 3rd and odd multiple of the 3rd (9th, 15th, etc.), called "triplens". These triplens harmonics are in phase and they will add rather than cancel on the neutral conductor of a 3-phase 4-wire system. This can overload the neutral if it is not sized to handle this type of load [2].

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 [6].

COMPUTER LOAD AND NEUTRAL CONDUCTOR CURRENT ANALYSIS

Analyses of the phase current

Fig. 1 and Fig. 2 show current waveform and current harmonic spectrum of a PC taken at power grid at the Computer laboratory of the Faculty of Technical Sciences. The waveform consists of two peaks, which are result of capacitor smoothing in the switching power supply of the device. It is far away from the sinusoidal, i.e. THDI = 131%. The dominant harmonic is the third one, but the 5th, 7th and 9th are also not negligible.

Voltage waveform (Fig.3) is characteristically deformed on the top, due to the voltage drop on the grid impedance. Fig.4 shows voltage harmonic distortion. It is evident that in the case of one PC operation, voltage harmonic distortion is under value which is set by IEEE 519 Standard ($THDU_{LIM}$ = 5%). In case of large number of PCs connected at the same grid, the current will have higher value and therefore cause higher distortion and endanger proper work of the other consumers connected on the same feeder.

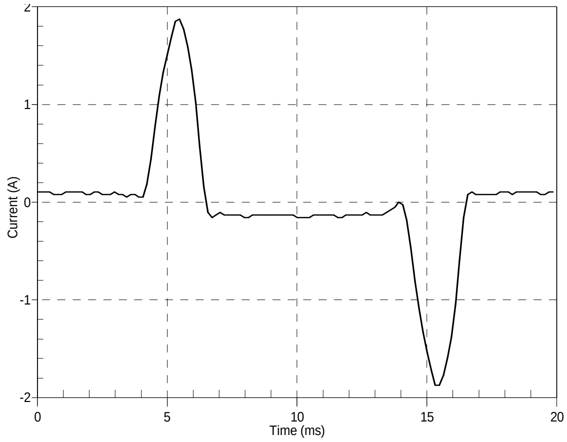

Fig. 1. Phase current waveform

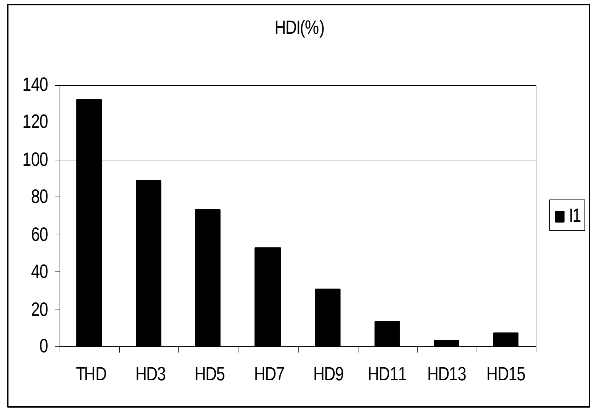

Fig. 2. Current harmonic spectrum

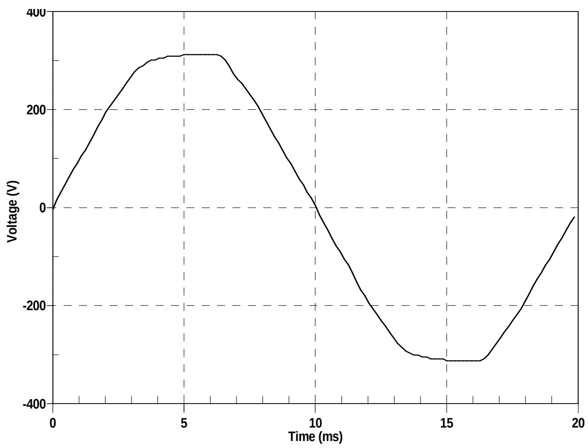

Fig. 3. Voltage waveform

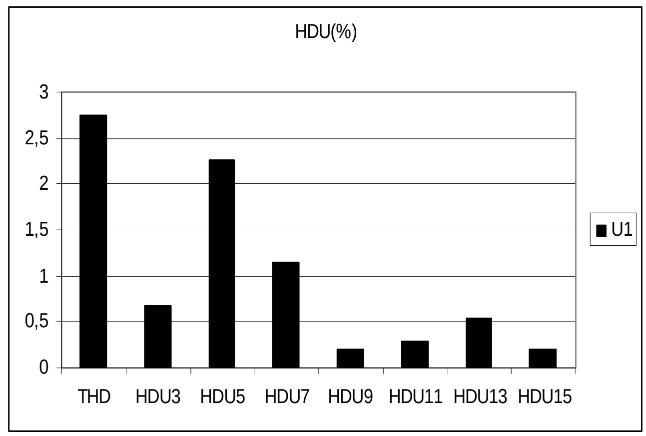

Fig. 4. Voltage harmonic spectrum

Analyses of the neutral conductor current

On the three-phase wye power system, neutral current is obtained as a sum of line to neutral currents. In three-phase symmetrical system with sinusoidal current waveform, neutral current will be zero and therefore there will be no neutral conductor current (Fig.5). However, in the three-phase power system supplying single phase-loads, an unbalance can occur and therefore a neutral current may appear. For typical building power systems, such a current resulting from a small unbalance can not cause the problems.

Still, there are some conditions when even ideally balanced single phase loads can result in significant neutral current [3]. Non-linear loads such as personal computers evenly distributed per phase, have phase currents, which are not sinusoidal. The vector current of the three balanced non-sinusoidal currents does not necessarily have to be zero. Also, if three balanced square-wave currents are considered, like in DC motor drives, significant neutral current can occur. Cause of these currents is not unbalance, but waveform of the signals (Fig.6).

Computers are generally non-linear loads with triplen harmonics (Figs.1 and 2). Using the Fourier transformation, the phase currents in symmetric and balanced network can be written. The neutral conductor current is obtained as a summation of the three phase currents. This can be represented by the following equations:

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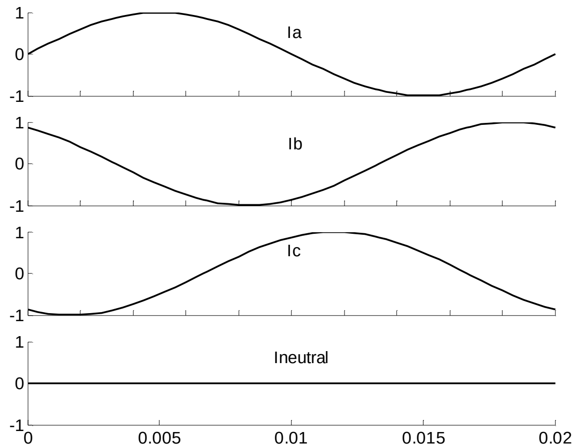

Fig.5 Balanced linear three phase loads

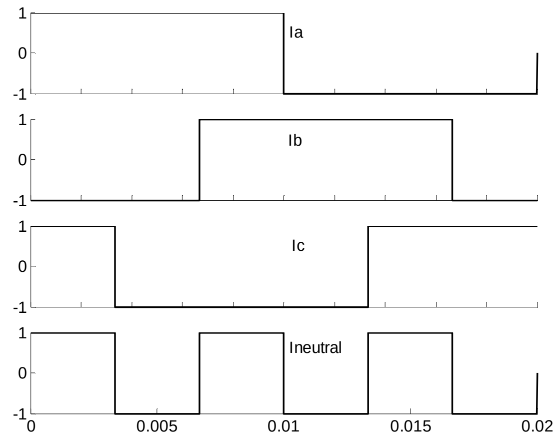

Fig.6 Balanced non-sinusoidal three phase loads

$$I_u = I_1 \cdot \sin(\omega t + \varphi_1) + I_3 \cdot \sin(\omega t + \varphi_3) + I_5 \cdot \sin(\omega t + \varphi_5) + \ldots \tag{5}$$

$$I_v = I_1 \cdot \sin(\omega t - \frac{2\pi}{3} + \varphi_1) + I_3 \cdot \sin(3 \cdot (\omega t - \frac{2\pi}{3}) + \varphi_3) + I_5 \cdot \sin(5 \cdot (\omega t - \frac{2\pi}{3} + \varphi_5) + \ldots \tag{6}$$

$$I_w = I_1 \cdot \sin(\omega t - \frac{4\pi}{3} + \varphi_1) + I_3 \cdot \sin(3 \cdot (\omega t - \frac{4\pi}{3}) + \varphi_3) + I_5 \cdot \sin(5 \cdot (\omega t - \frac{4\pi}{3} + \varphi_5) + \ldots \tag{7}$$

$$I_n = 0 + 3 \cdot I_3 \cdot \sin(3\omega t + \varphi_3) + 0 + \ldots \tag{8}$$

From equations (5) to (8) it can be noticed that the first order harmonics (i=6k+1), where i is the order harmonic and k is the natural number, are forming a direct system in the phase currents, the third order harmonics (i=6k+3) are forming homopolar system and the fifth order harmonics (i=6k+5) an inverse system [1]. The neutral conductor current consists of the third order harmonic only, because the other harmonics are canceled out, as explained earlier (Fig. 7). These spectrums are obtained as a result of computer simulation. On the left one, a great presence of all the high order harmonics can be noticed. Neutral current is obtained under consideration that one PC is connected per phase. When neutral conductor current is calculated using (7), the right spectrum of Fig. 7 is obtained. It is obvious, that neutral conductor current consists only of the homopolar components of the phase currents. In case of symmetric and balanced network that correspond to the third order harmonics.

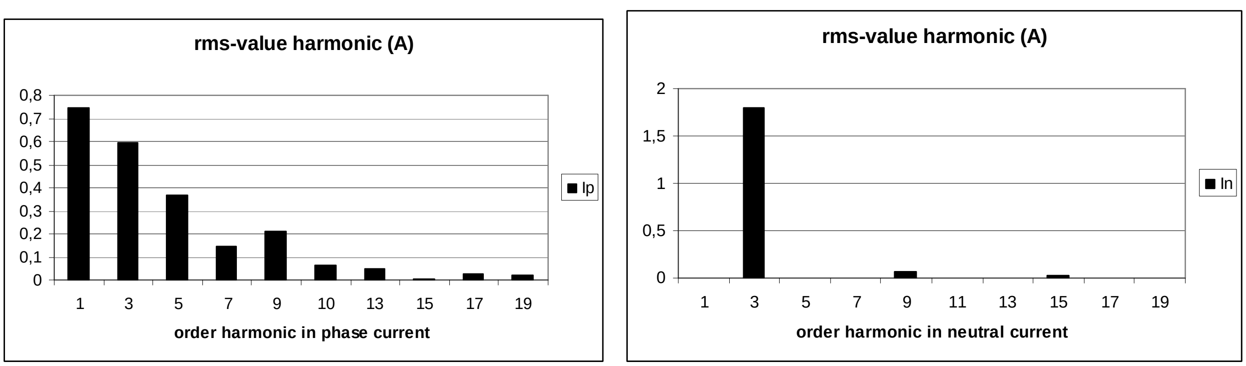

Fig.7 Phase and neutral current harmonic spectra

From the point of design of neutral current it is important to know the r.m.s.-ratio of the neutral conductor current and phase current. It could be easily done for symmetric and balanced network. The r.m.s.-ratio

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increases with increasing the third order harmonic and decreases with increasing the first and the fifth order harmonics in the phase current:

$$\frac{I_n}{I_{phase}} = \frac{\sqrt{\sum(3\cdot I_{6k+3})^2}}{\sqrt{\sum(I_{6k+1})^2 + \sum(I_{6k+3})^2 + \sum(I_{6k+5})^2}} \tag{9}$$

where I_n stands for r.m.s.-value of the neural conductor current, I_{phase} for r.m.s. value of the phase current and I_{6k+1}, I_{6k+3}, I_{6k+5} for the first, the third and the fifth order harmonic of the phase current, respectively. The maximum r.m.s.-ratio of the neutral conductor current and phase current is obtained when the phase current consists of the third harmonic only and its value is $\sqrt{3}$ [1].

At the end of this part, effects of different load conditions on neutral conductor current are discussed using measurement. Measurement was preformed in the laboratory, which has five PC's connected at the same grid. Table 1 summarizes r.m.s. value of the neutral conductor current for a different load conditions concerning a constant power. The neutral conductor current increases with increase load unbalance. The lowest value of the neutral conductor current have been obtained for a balanced load, while the highest for all PC's connected on the one phase. Such difference can be great and should be taken into account when the electrical installations are designed. It is obvious that influence of the third harmonic is dominated. As the system is closer to the balanced load condition, the part of the third harmonic is greater. In Fig. 8 the harmonic content of the neutral conductor current is shown for different load conditions, considering a constant three phase power. It is important to notice that the third harmonic has almost the same value irrespective the load conditions. The first harmonic is quite dependable of load conditions and its value is the greatest when all the PC's are connected on the same phase.

TABLE 1 – NEUTRAL CONDUCTOR CURRENT FOR DIFFERENT LOAD CONDITIONS

number of PC's per phase	neutral conductor current	third harmonic
phase U: 1 phase V: 3 phase W: 1	2,241	2,048
phase U: 2 phase V: 2 phase W: 1	2,174	1,98
phase U: 0 phase V: 5 phase W: 0	3,381	1,916

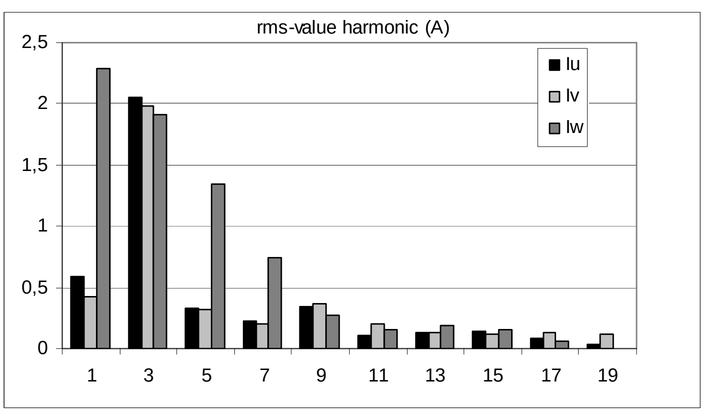

Fig.8 Influence of load unbalance on the neutral current.

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MEASUREMENT RESULTS – CASE FTN

Measurement of the current and voltage waveform, as well as high order harmonic were done on transformer bus (PCC) on which all PC's are connected. This transformer is using only for supplying PC's. Phase currents, phase voltages and neutral conductor current were measured and measurement results are shown in pictures below.

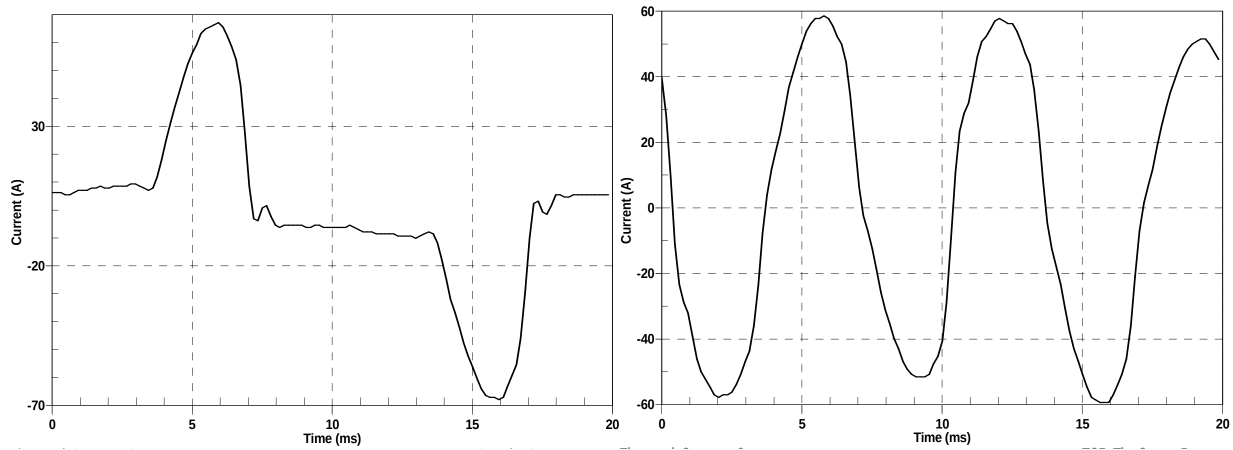

Fig.9 Phase current and neutral conductor current waveform

It can be seen that increased number of personal computers influence the current waveform. Current pulses are broadened in case of higher number of PC's as illustrated in Fig. 9. Neutral conductor current consists of six pulses, which are obtained by addition of three phase currents. The load is approximately disposes per phase and because of that pulses have nearly the same values. After applying Fourier transformation the currents spectra are obtained. That is pointed out in Fig. 10.

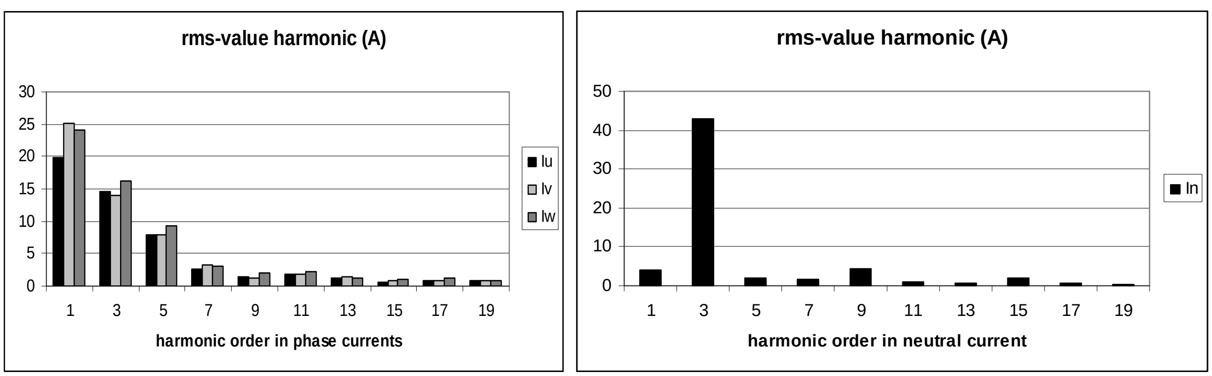

Fig. 10 Phase and neutral harmonic current spectra

As it is explained earlier phase current spectra is reach in harmonics. Neutral harmonic current consists of triplens only and that is consequence of matched phase angle of third harmonic and other triplens. R.M.S. value of neutral conductor current is, in this case 43,48 [A] and that is 1,4 times higher value than the r.m.s. value of the phase current. That should be taken into account during designing electrical installations. Individual harmonic distortion has a value, which is higher than limited value provided by IEEE 519 – 1992. That can cause overheating in wiring and transformer resulting in premature breakdown in insulating material and reduction in the useful life of equipment.

The voltage drop in the neutral conductor current caused by all triple harmonic became harmonic voltage distortions of the supply. For the case of installation of Faculty of Technical Sciences, measured voltage harmonic spectra are shown in Fig. 11. It is evident that the voltage harmonic distortion level is close to the IEEE limit. This may require further increase in neutral cross section if condition in the load is changed [3].

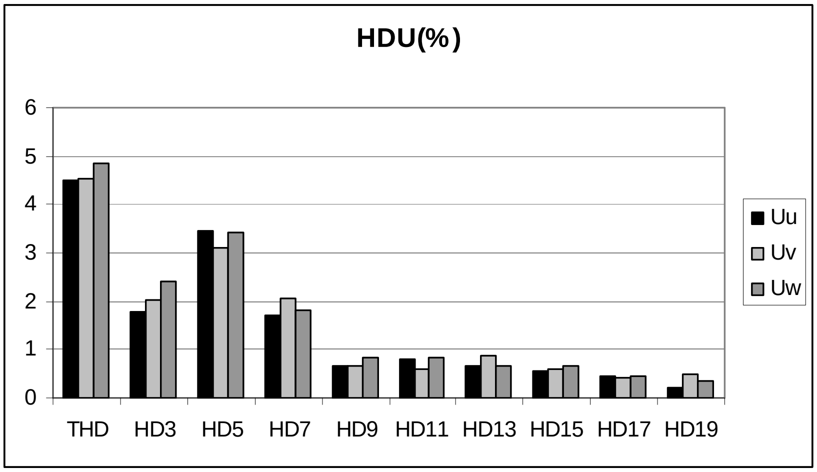

Fig. 11 Voltage harmonic spectra

SIMULATION RESULTS

The simulation has been carried using Matblab – Simulink software. The model of a computer contains single-phase diode rectifier with corresponding resistance and capacitance filter representing a single PC. Then several PC's are connected together and neutral conductor current is calculated.

The simulation results compared with the measured ones are presented in Fig.12. They almost perfectly match the measured one. Slightly mismatch is noticed in first, the fifth and the third harmonic but that is consequence of non-ideal measuring conditions.

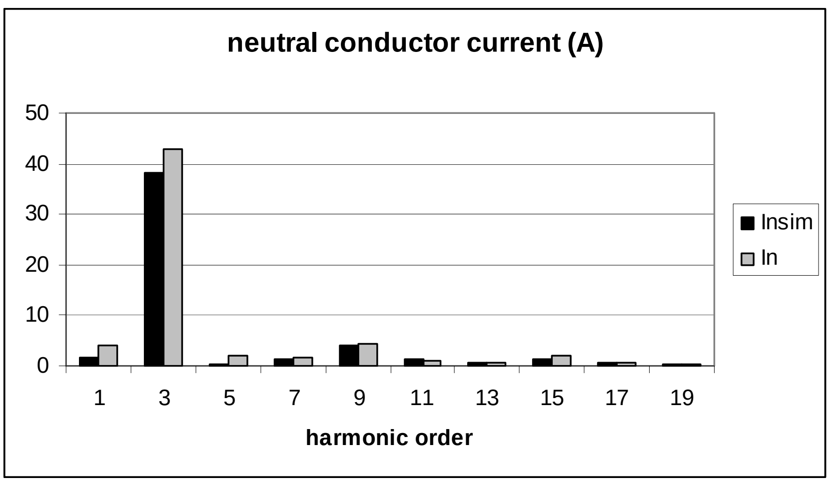

Fig. 12 Comparison between measurement and simulation.

Simulation model has been used to find number of PC's connected to the grid that cause 8% THD, which is the value required by IEC 61000 standard. The result of simulation (Fig. 13) shows that 8% voltage harmonic distortion would be achieved if 160 PC's are connected. Taking into account present situation and steadily increasing number of PC's it could be expected that in nearer future THDU will reach limited value provided by IEC 61000 standards.

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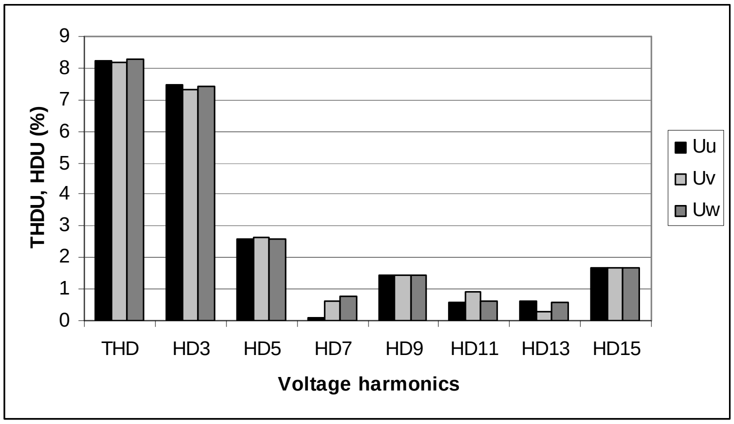

Fig. 13 Voltage harmonic spectra in case of 160 PC's

CONCLUSION

In this paper effects of PC's and other IT devices on electrical installation of the Faculty of Technical Sciences (FTN) have been shown. The number of such devices is steadily increasing and their effects are becoming significant as they are connected to the same coupling point. The stress was on neutral current, which could increase up to 73%. Such a high current value can overload power feeders, overload transformers, and produce voltage distortion and common mode noise.
Simulation and measurement results were presented in this paper. The simulation results almost perfectly match the measured one. Slightly mismatch is noticed in the first, the fifth and the third harmonic but that is consequence of non-ideal measuring conditions. It was shown that the THDU and THDI are very close to IEEE limit. It could be noticed that progress in voltage distortion follows increasing number of PC's. According to the simulation results the critical situation emerges when 160 PC's is coupled to the grid. In that case THD exceed value set by IEC standard.

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