**EFFECTS OF COMPUTER CENTER OPERATION ON HARMONICS IN DISTRIBUTION NETWORK**

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## INTRODUCTION

Historically observed, harmonics concept in electrical engineering was founded relatively early, about a hundred years ago in Steimetz's publications. Initially current harmonics were produced by the mercury arc rectifiers used to convert AC to DC current for railway electrification and for DC variable speed drives in industry. More recently the range of types and the number of units of equipment causing harmonics have risen sharply, and will continue rise in future following industry development.

In an ideal clean power system, the current and voltage waveforms are pure sinusoids. In practice, non-sinusoidal currents result when the current flowing in the load is not linearly related to the applied voltage. In a circuit containing only linear circuit elements (resistors, capacitors, inductors), the current which flows is proportional to the applied voltage (at a particular frequency). In such situation, if sinusoidal voltage is applied, a sinusoidal current will flow. In contrast to linear loads, non-linear loads draw non-sinusoidal currents even if fed with sinusoidal voltage.

Single phase non-linear loads include: switched mode power supplies (SMPS), electronic fluorescent lighting ballasts and small uninterruptible power supplies (UPS) units. Typical and very common SMSP is the input stage for personal computer (PC) based on the single phase, diode-bridge (full-wave rectifier) and reservoir capacitor (Fig. 1.).

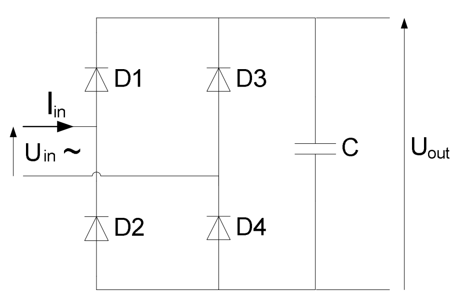


Fig. 1. Full-wave rectifier and reservoir capacitor

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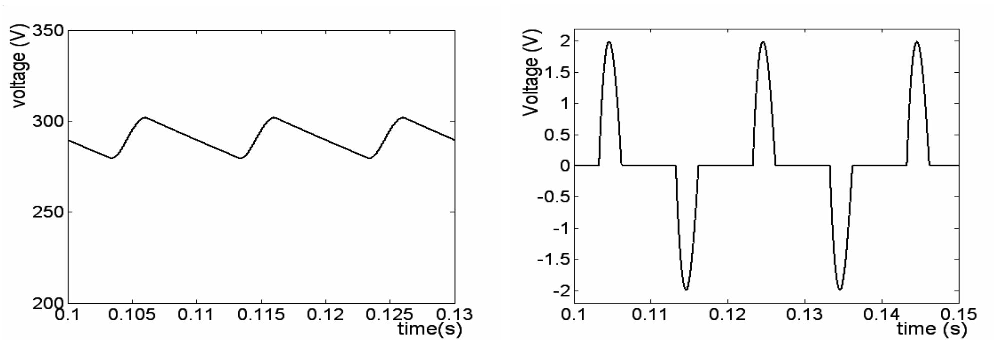
In this case, current flows only when the supply voltage exceeds that stored on the reservoir capacitor (Fig. 2.a), i.e. close to the peak of the voltage sine wave, as shown on the Fig. 2.b.  That is the reason why the personal computer is designated as non – linear load.




a) Output voltage ($U_{out}$)    b) Input current ($I_{in}$)

Fig. 2. Output voltage and input current of the full-wave rectifier

It is obvious from Fig. 2.b that full-wave rectifier input current is not sinusoidal. If there are many computers connected to the same line, input current distortion will be even greater. Therefore, it would be very interesting to analyze impact of the great computer concentration such as Computer Centre at Faculty of the Technical Sciences on the part of Novi Sad distribution network supplying University Campus, where the Faculty of Technical Sciences is located. Distorted currents produced by computers and other non-linear loads result in distorted voltages and currents that can adversely impact the system performance in different ways. Each item of non-linear equipment produces some disturbance that aggregates in some way with that from other equipment. That results disturbances on the network which could affect the proper operation of other equipment on the network. In this paper it will be considered how increasing the number of computers in Computer Centre affects propagation of the voltage harmonic distortion at few characteristic points in electric power grid in the University Campus and neighbouring residential areas.

## HARMONIC DISTORTION, LIMITS AND STANDARDS

Harmonics effect on equipment can be negative, i.e. they may induce overheating in wiring, motors and transformers winding resulting in premature breakdown in insulating material and in a considerable reduction in the useful life, Acha, Madrigal (3). Equally important, they interfere with highly sensitive processes in industry, governed by programmable microprocessors, such as variable speed drives used in assembly lines, robots and numerically controlled machines.

In order to prevent harmful behaviour, IEEE and different national institutions proposed harmonic distortion limits, which should be respected by any consumer connected to electrical network. Generally, as it is well known, voltage and current harmonic distortion are specified with two main parameters: harmonic distortion (HD) and total harmonic distortion (THD):

$$\mathrm{HDI_h} = \frac{I_h}{I_1}, \ \mathrm{THDI} = \sqrt{\frac{\sum_{h=2}^{\infty} I_h^2}{I_1^2}}, \ \mathrm{HDU_h} = \frac{U_h}{U_1}, \ \mathrm{THDU} = \sqrt{\frac{\sum_{h=2}^{\infty} U_h^2}{U_1^2}} \qquad (1)$$

Considering above definitions, IEEE appointed standard IEEE 519-1992 for current and voltage harmonic limits (Tables 1.a and 1.b).

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TABLE 1.a - Harmonic Current Limits (in %) from IEEE Standard 519 - 1992

| $I_{sc} / I_{load}$ | Harmonic order | | | | | THD |
|---|---|---|---|---|---|---|
| | <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 |

$I_{sc}/I_{load}$ is the short-circuit current calculated at the point of common coupling (PCC) to the nominal fundamental frequency load current.

TABLE 1.b - Voltage Distortion limits (in %) from IEEE Standard 519 - 1992

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

**DISTRIBUTION NETWORK AND LOAD DESCRIPTION**

Here will be briefly described a part of Novi Sad distribution network which supplies the Computer Centre at the Faculty of Technical Sciences, as well as the University campus. The starting point of this network is medium to low voltage level distribution substation “Liman”, which consists of four transformer units 35/10 kV. Two of these transformers, connected to the bus LM1 (Fig. 3.), are used for supplying the University campus and neighboring consumers. From Fig. 3. it can be seen that there are two main 10 kV feeders starting from buses LM2 and LM22, respectively. Each feeder is connected to its own transformer and supplies a number of low voltage substations 10/0.4 kV.

That implies that considered distribution network is divided in two main branches regarding harmonics. Namely, the bus LM1 is the point where high amount of apparent power from transmission network is connected. That means that harmonic distortion present in one branch couldn’t affect harmonic distortion in another one. The branch which starts from the bus LM2 is called “left branch’’, and the another branch is called ‘’right branch’’. Computer centre of the Faculty of Technical Sciences (FTN) is located at the right branch (bus RC on the Fig. 3.) and connected to the bus RO via its own cable. Bus RO is the concentration grid of all the electric circuits of the main building of the Faculty of Technical Sciences.

University campus is predominantly supplied by the left branch what implies that FTN Computer Centre couldn’t affect harmonic distortion in that Campus branch. So, effects of the FTN Computer Centre harmonic injection should be expected only through the same, right branch, where it is coupled to the distribution network. It should be noted that some buildings of the Faculty of Technical Sciences are connected to the left branch also, while the others, including the Computer Centre are connected to the right branch.

Computer Centre itself presently consist of 120 personal computers located in four labs and two other rooms. Nominal power of all PC-s is 18kW (rated power of a single PC is 150 W). Except PC-s, on the concetration grid only laboratory lighting and several printers are connected. According to the results presented in the paper of Dumnic, Katic, Dujic (1), that number of computers caused voltage THD above the IEEE limit (Table 1. b). From this point of view, it would be very interesting to investigate effects of increase of the number of PC-s on propagation of voltage harmonics toward the grid, as well as into described distribution network. Other faculties of University of Novi Sad have their own computer centers (or labs) also, but the greatest one is located at FTN. The influence of the other centers and consumers generally will be modeled using characteristic harmonic distortion table (Table 2.) for so called “office type consumers”, presented in Dragovic (2). Parameters of the distribution network, transformers and cables (Fig. 3.) are obtained from “Elektrovojvodina”, regional Power Supply Company.

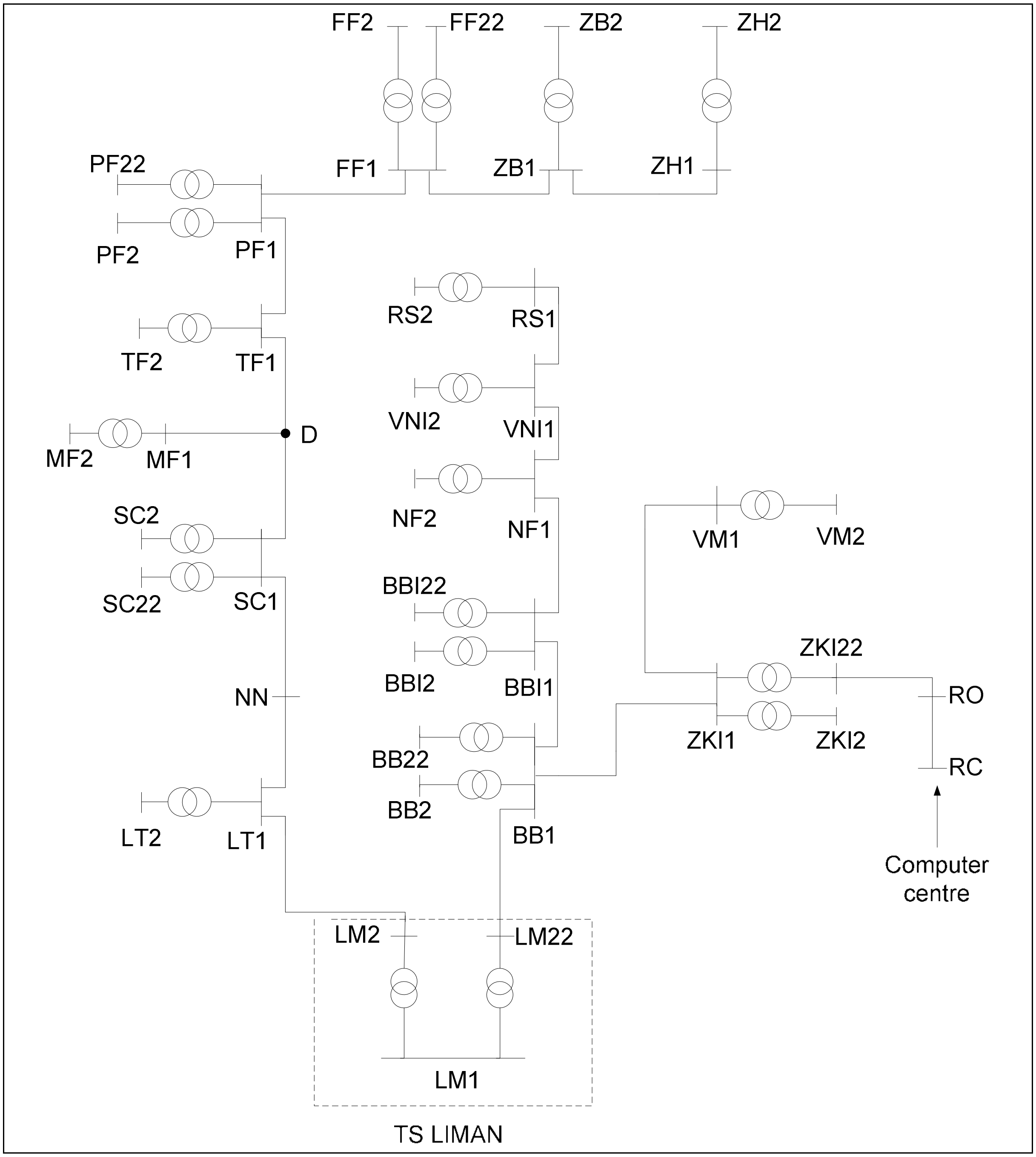


Fig. 3. Distribution network supplying the University Campus and neighboring consumers

TABLE 2 - Current harmonic spectra for “office type consumers”

| Harmonic order | $HDI_h$ [%] | Phase angle[°] |
|---|---|---|
| 1 | 100 | 148.1 |
| 5 | 4.72 | 142 |
| 7 | 4.0 | -85 |
| 11 | 0.8 | 162 |

## SIMULATION RESULTS

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It is assumed that considered distribution network is supplied from the ideal voltage source coupled at the bus LM1. This supposition is realistic one, because voltage harmonic distortion at medium voltage level (35 kV) is insignificant comparing it with harmonic distortion at low level voltage in regular situation. At the other hand, when the ideal source is employed, influence of the Computer Centre could be much easier noticed. In order to research dispersion of high order voltage harmonics caused by FTN Computer Centre, simulation model is utilized. To simulate the Computer Centre operation, a model of full-wave rectifier and reservoir capacitor (Fig. 1) is developed. Current harmonic spectrum for the single PC is obtained in Matlab (Simulink) (Fig. 4.) and it is used as input data for the harmonic simulation program SuperHarm.

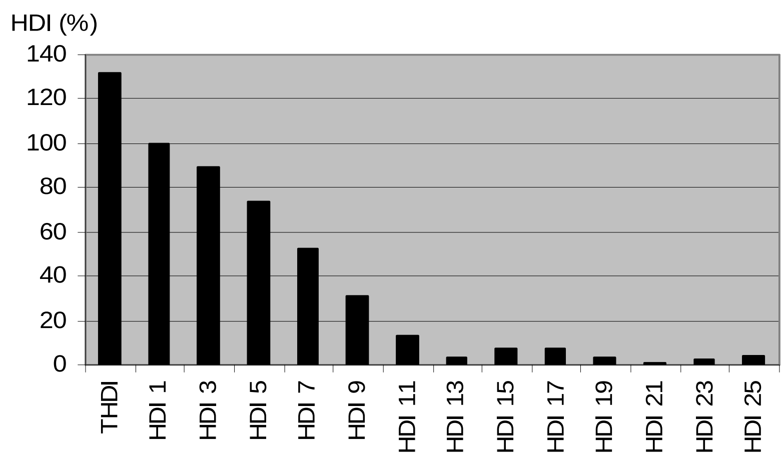


Fig. 4. Current harmonic distortion of the single PC

Simulation results for 120, 240 and 800 PC-s will be presented. FTN. Computer centre has temporary 120 PC-s with total nominal power of 18kW. Number of PC-s is steadily increasing every year, so it could be expected that the number of 120 computers will be doubled in the near future. The amount of 800 PC-s is theoretical situation, but not so far from reality. Namely if such circumstance is considered, where each student has his own handbook PC, supposed situation of 800 computers becomes reality. To illustrate voltage harmonic propagation, characteristic busses RC, RO, ZKI22, BB1 and VM1 are chosen. Buses BB1 and VM1are points where the residential areas are connected to the distribution network, while buses RC and RO are transfer cases of the Computer Centre and the Faculty of technical sciences respectively. On the Fig. 5 voltage harmonic distortion for bus RC for different number of coupled PC-s (120, 240 and 800) is shown.

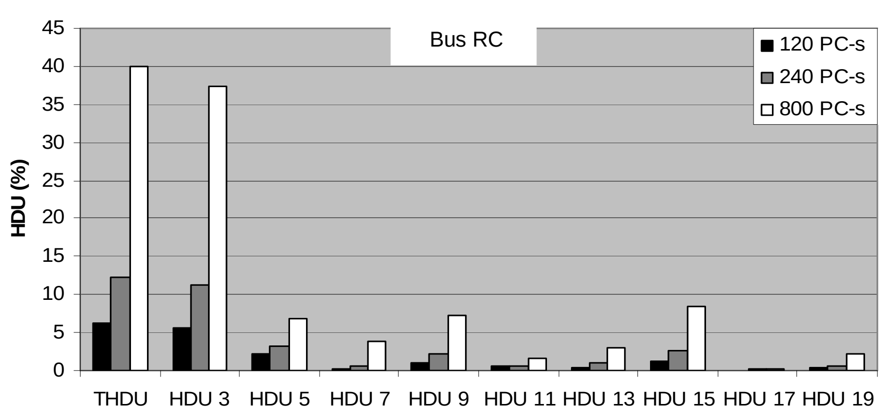


Fig. 5. Voltage harmonic distortion at the bus RC

From Fig. 5. it can be noticed that THDU is above limit of the IEEE Standard 519 - 1992 (Table 1. b) even for the smallest amount of coupled PC-s. In the case where 800 PC-s are connected, THDU is very high –

about 40%. Of course, it was supposed the worst condition where all computers had been consuming rated power. Notice the high amount of the third harmonic which practically determines such a high THD.
On the Fig. 6. voltage harmonic distortion at the bus RO is shown.

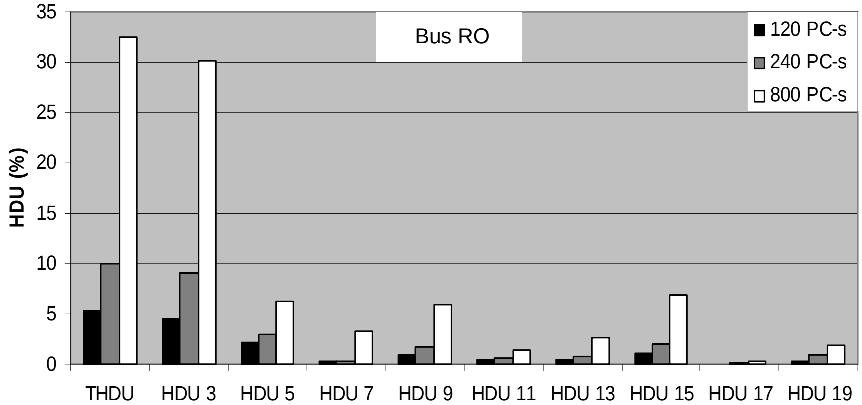


Fig. 6. Voltage harmonic distortion at the bus RO

The harmonic configuration presented on the Fig. 6. is very similar to the configuration on the Fig. 5. The third harmonic and other triplens have predominantly influence on THDU. However, THDU is markedly lower at the bus RO comparing it with the bus RC. This is because the bus RO is transfer case of the Faculty of Technical Sciences where are coupled many other consumers with supposed total apparent power of 200 kVA.
Fig. 7. shows voltage harmonic distortion at the bus ZKI22.

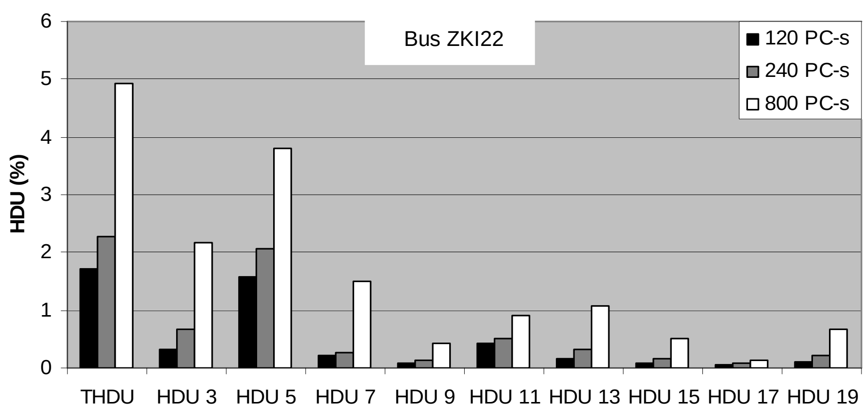


Fig. 7. Voltage harmonic distortion on the bus ZKI22

The bus ZKI22 is the transformer secondary (Fig. 3.), where many other consumers with total apparent power of 250 kVA are also connected. It can be seen that even for the extreme case of 800 coupled PC-s, the THDU wouldn't exceed IEEE Standard 519 limit of 5%. Contribution of the triplens is significantly decreased here. However, it can be noticed when 240 PC-s are connected, THDU is higher than 2%. That implies that none larger source of high order harmonics should be connected to the bus ZKI22. Otherwise, it could lead to the voltage harmonic distortion which is above 5%, for instance in case where 800 PC-s from the other faculty are coupled.

Fig. 8. presents voltage harmonic distortion at the bus BB1, where a large residential area is connected. The situation is substantially different in this case. The contribution of triplens to harmonic distortion is insignificant, because transformers from Fig. 3. are predominantly connected in delta which is "short circuit'' for triplens. Following absence of triplens, as well as high amount of apparent power on BB1, THDU is much lower comparing it with THDU at buses ZKI22, RO and RC.

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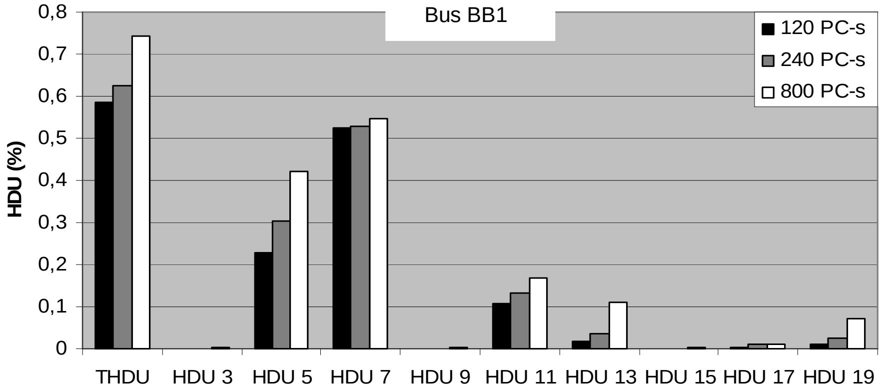


Fig. 8. Voltage harmonic distortion on the bus BB1

Fig. 9. shows voltage harmonic distortion at the bus VM2. The bus VM2 is transformer secondary to which another residential area is coupled. Qualitatively, the situation here is similar to those on Fig. 8.

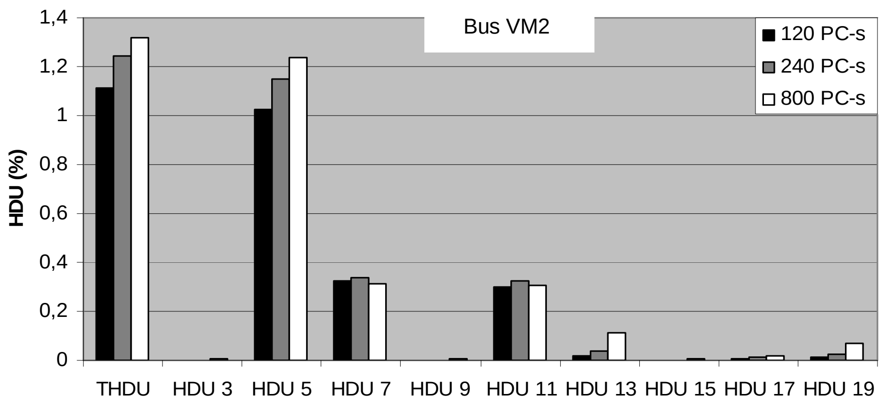


Fig. 9. Voltage harmonic distortion on the bus VM2

If two last figures (Fig. 8. and Fig. 9) are compared, it can be noticed that THDU at the bus VM2 is higher than THDU at the bus BB1. This is because BB1 is on the high voltage level, while VM2 is on the low voltage level. Besides, consumers which inject harmonics are directly coupled to VM2 in contrast to BB1.

## CONCLUSIONS

This paper has presented power quality at characteristic points of the distribution network when the Computer Centre as a great concentration of non – linear loads (PC-s) is coupled to that network. It was considered how increasing the number of computers in Computer Centre affects propagation of the voltage harmonic distortion. From high order harmonics aspect, considered distribution network is decoupled in two main branches regarding the medium voltage substation ''Liman'' which prevent harmonic injection from one branch to another. So, we analyzed only the ''right branch'' because it contains Computer Centre. The most critical situation is considered where all available computers (real number of 120, or hypothetic numbers of 240 and 800) consume the rated power. Generally, from simulation results it can be noticed that progress of the voltage harmonic distortion follows increasing the number of PC-s. As it was expected, the rise of voltage THD is the highest at the point RC where the Computer Centre is coupled and also at neighboring points RO and ZKI22. Regarding simulation results, appropriate filter should be employed in the near future at the bus RC. Situation at the bus ZKI22 is not so critical, but voltage harmonic distortion is high enough that any greater non-linear load shouldn't be coupled on that bus. That could be a problem, because many Faculties beside the Faculty of Technical Sciences are presently supplied via ZKI22 and many of them have significant and increasing number of

PC-s. Influence of the Computer Centre from the voltage harmonic distortion view can be noticed even at neighboring residential area, but that influence according simulation results shouldn't be a problem in the near future.

In this paper we used current harmonic spectrum from Fig. 4. to make model of the Computer Centre and Table 2. to model all other non – linear consumers. This model could be improved if directly measured data replace table data. However, this could contribute to model be more realistic, but it wouldn't change qualitatively and even quantitatively picture of the Computer Centre influence on harmonic distortion through the considered distribution network.

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