Mechanics Transport Communications

Academic journal http://www.mtc-aj.com

ISSN 1312-3823 (print)
ISSN 2367-6620 (online)
volume 21, issue 3/2, 2023
article № 2446

MODELING THE INFLUENCE OF PERSONAL COMPUTERS ON THE QUALITY OF ELECTRICITY AND ELECTROMAGNETIC COMPATIBILITY AT THE POINT OF SUPPLY

Branislav Gavrilovic[1], Zoran Bundalo[2], Vladimir Aleksandrovich Baboshin[3]
gavrilovicbranislav5@gmail.com, cheminot2@gmail.com, boboberst@mail.ru

[1,2]Professors of Academy of Tehnical and Art Applied Studies Belgrade, Department: Railway College, Zdravka Celara 14, Belgrade
SERBIA
[3] Associate Professor of Military institute (Railway troops and military communications), Department of Reconstruction of Automation, Telemechanics and Communication Devices on Railways, Sankt. Peterburg
RUSSIA

Key words: *personal computer, quality of electrical energy, electromagnetic compatibility*

Abstract: *The paper presents the results related to the influence of personal computers on the quality of electrical energy and electromagnetic compatibility at the point of connection to the electrical grid by implementing a simulation model in Matlab/Simulink. The paper presents the results of simulations related not only to the computer unit but also to the computer system with a number of external units such as monitors, printers, scanners, UPS devices, etc. Due to the small load power of individual computers, In order to meet the set standards related to the quality of electricity and electromagnetic compatibility at the point of connection of personal computers, the paper also presents the results of the simulation of the operation of personal computers with the application of passive filters used by real ATX (Advanced Technology eXtended) power supply units of personal computers.*

INTRODUCTION

The presence of higher harmonics of voltage and current is one of the most important parameters of voltage quality because higher harmonics are permanently present in the network and can be very difficult to eliminate. Their growing level, as well as the negative consequences for the power supply system and connected consumers, have made the study of this issue very current and extremely important.

The issue of voltage quality is dealt with by a number of valid international technical standards, such as EN 50160, then the group of standards IEC 61000, standard IEEE 519 and others [1-7].

IEC 61000-2-1 addresses equipment of Electric Power System, industrial consumers and other non-linear consumers as sources of higher harmonics. From this standard, it is important to note that in the category of household appliances, the main sources of distortion are appliances that are powered by a rectifier consisting of a capacitor for smoothing the voltage: (PCs, TV sets,...).

IEC 61000-2-2 prescribes compatibility levels for low-frequency conduction disturbances and signaling in low-voltage distribution networks (networks below 1 kV). Table 1 gives the permissible limits of voltage harmonics that arise due to the use of household appliances or appliances with similar characteristics.

Table 1. Limit values of voltage harmonics IEC 61000-2-2

A row of accordions h	3.	5.	7.	9.	11.	13.	15.<h<39.	2	4.<h<40.
V_h (%)	0,85	0,65	0,60	0,40	0,40	0,30	0,25	0,30	0,20

IEC standards from the IEC 61000-3-x group (electromagnetic compatibility) prescribe limit values for distortions arising from devices connected to the network (low-voltage, medium-voltage and high-voltage networks), i.e. limit the influence of non-linear consumers on voltage quality and harmonic voltage distortions. Subgroups of this standard are divided by devices whose input current is ≤ 16 A and by devices whose input current is > 16 A, and which are connected to LV, MV and HV networks.

The IEC 61000-3-2 standard defines the limit values of current harmonics that may be emitted by devices with input current ≤ 16 A per phase. This standard divides devices into four categories, and the division is made according to the power of the device, according to the harmonic spectrum of the device, as well as according to the duration of operation and simultaneous use of these devices.

Category A includes the following devices: three-phase devices with an evenly distributed load per phase, household devices (except devices of category D), power tools (except portable tools), dimmers for incandescent lamps, audio devices and all other devices not listed in categories B, C and D. Category B includes portable electric tools and non-professional welding devices, while category C includes electric lighting. Category D includes the following devices: personal computers and monitors, TV receivers (the power of devices from this category is from 75 W to 600 W). Tables 2 and 3 show the permissible levels of higher harmonics for low-power consumers according to IEC 61000.

Table 2. Permissible levels of higher odd harmonics for low power consumers IEC 61000-3-2

Odd harmonics				
Harmonic, n	Category A (A)	Category B (A)	Category C (% of the fundamental harmonic)	Category D (mA/W)
3.	2,30	3,45	30 x cos(φ)	3,4
5.	1,14	1,71	10	1,9
7.	0,77	1,155	7	1,0
9.	0,40	0,60	5	0,5
11.	0,33	0,495	3	0,35
13.	0,21	0,315	3	3,85/13
15. ≤ n ≤ 39.	0,15 x 15/n	0,225 x 15/n	3	3,85/n

Table 3. Permissible levels of higher double harmonics for low-power consumers IEC 61000-3-2

Double harmonics				
Harmonic, Harmonic, n	Category A (A)	Category B (A)	Category C (% of the fundamental harmonic)	Category D (mA/W)
2.	1,08	1,62	2	-
4.	0,43	0,645	-	-
6.	0,30	0,45	-	-
8. ≤ n ≤ 40.	0,23x8/n	0,345 x 8/n	-	-

Norm EN 50160 (European Norm) is the basic standard for the quality of electricity in the European Union, formed by the European Committee for Standardization in Electrical Engineering CENELEC. The standard defines important voltage quality parameters at the point of delivery of electricity to consumers in LV and MV distribution networks, under normal operating conditions.

The EN 50160 norm for the level of permissible harmonic distortions provides a table with voltage values of higher harmonics that must not be exceeded at any time (table 4), namely 95% of the time of ten-minute observations of the mean effective voltage values of each individual higher harmonic under normal operating conditions during one week. The value of the THDU total harmonic distortion factor for (n = 2...40) should be ≤ 8%.

Table 4. Permissible voltage values of higher harmonics at the EN 50160 supply point

Odd harmonics				Even harmonics	
Odd harmonics that are not divisible by 3		Odd harmonics divisible by 3			
Harmonic h	U_h in % U_n	Harmonic h	U_h in % U_n	Harmonic h	U_h in % U_n
5.	6,0	3.	5,0	2.	2,0
7.	5,0	9.	1,5	4.	1,0
11.	3,5	15.	0,5	6. – 24.	0,5
13.	3,0	21.	0,5		
17.	2,0				
19.	1,5				
23.	1,5				
25.	1,5				

When talking about the quality of electricity in a certain hub of the distribution network, it is very important to take into account the connected consumers at that hub, for the reason that the quality of electrical energy is closely related to the characteristics of consumers. It follows from this that it is not enough to just monitor the quality of energy in a certain hub, but in addition to the voltage and current, the norms related to electromagnetic compatibility EMC (Electromagnetic compatibility) of the connected devices must also be met. The standards related to EMC define the interference norms that consumer devices can

generate in the network, as well as the interference norms that these same devices can withstand without damage or eventual loss of functions, i.e. device compatibility [1-7].

Non-linear low-power consumers, such as personal computers with appropriate printers and scanners, cause more harmonics in the waveform of supply voltages and currents. Due to the above reasons, this paper presents the results achieved by the realization of simulation models of the connection of personal computers to the electrical network.

MATLAB/SIMULINK MODEL OF A PERSONAL COMPUTER POWER SUPPLY UNIT

A personal computer consists of an LCD (Liquid Crystal Display) or TFT (Thin Film Transistor) monitor and a case with computer components.

The most influential component in terms of generating higher voltage and current harmonics is the power supply unit. It provides stable DC voltages necessary for the smooth functioning of the components and the operation of the computer. The conversion of the 230 V mains AC voltage into the required DC voltages is realized by means of electronic converters, which are characteristic sources of current higher harmonics of odd order.

An essential characteristic of a computer power supply unit is its switching character, which defines the waveform of the computer's load current. It significantly deviates from the ideal sinusoidal form, with a very pronounced distortion, i.e. the presence of higher harmonics.

Rectifiers, as the most commonly used power electronic converters, are one of the main sources of higher harmonics. The switching mode results in constant changes in the configuration of the active part of the rectifier. This results in the rectifier grid current waveform being composed of segments and non-sinusoidal in shape. The flow of a non-sinusoidal current causes a voltage drop across the network impedance, which leads to a distortion of the basic sinusoidal voltage. At the same time, on the consumer's side, the voltage waveform consists of parts of a sinusoid, i.e. in addition to the direct component, there are also alternating components - higher harmonics.

Single-phase rectifiers are used in the power supply part of electronic devices and they are required to generate stable direct current voltages, to be as simple as possible and of high reliability. For these reasons, they are usually diode rectifiers with a filter capacitor on the DC side or, more recently, DC switching power supplies, which also have a capacitor at the output.

This rectifier distorts the mains current and partially the voltage. Distortion is a consequence of the charging of the capacitor in periods when the mains voltage is higher than the DC voltage, that is, the voltage on the capacitor.

From the point of view of power quality issues, the computer's power supply unit is undoubtedly the most important component of the computer. In addition to providing stable DC voltages: ±12 V, ± 5 V and + 3.3 V, for the smooth functioning of computer components, its switching character affects that the waveform of the generated current of the computer deviates significantly from the sinusoidal current.

Figure 1 shows a typical electrical diagram of a power supply unit that is installed in a standard PC computer [10, 11, 12].. The same power supply unit modeled in Matlab/Simulink is given in Figure 2 .

Oscillograms of input current and input voltage waveforms are read on the oscilloscope marked on the modeled circuit "Scope" (Figure 2). This temporal shape of the current, which is of an impulse character, explicitly indicates the significant presence of higher harmonics in the harmonic spectrum of the current and the low value of the power factor (Figure 3).

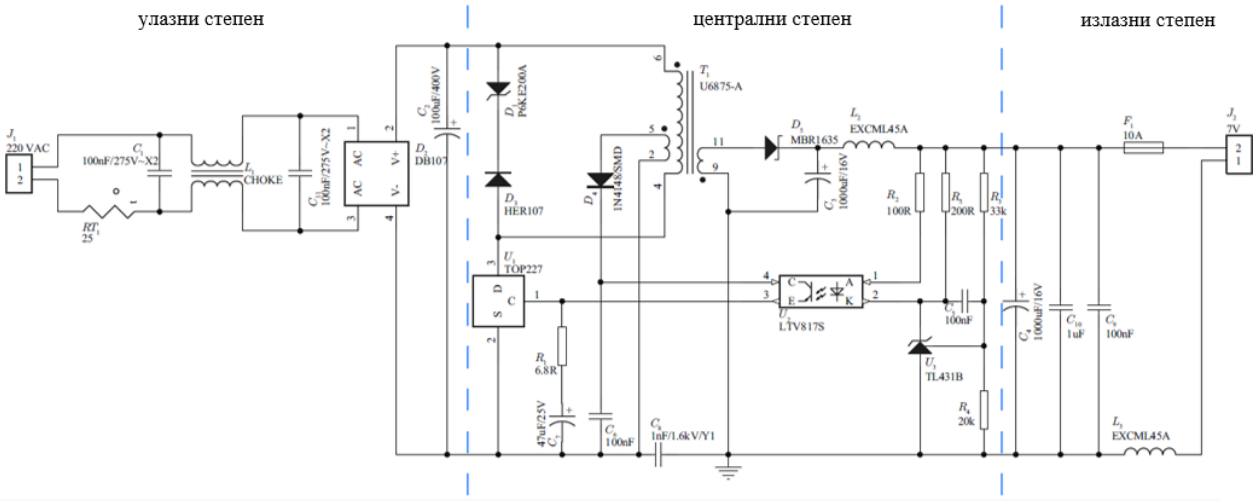

Figure 1. A real switching power supply of a personal computer

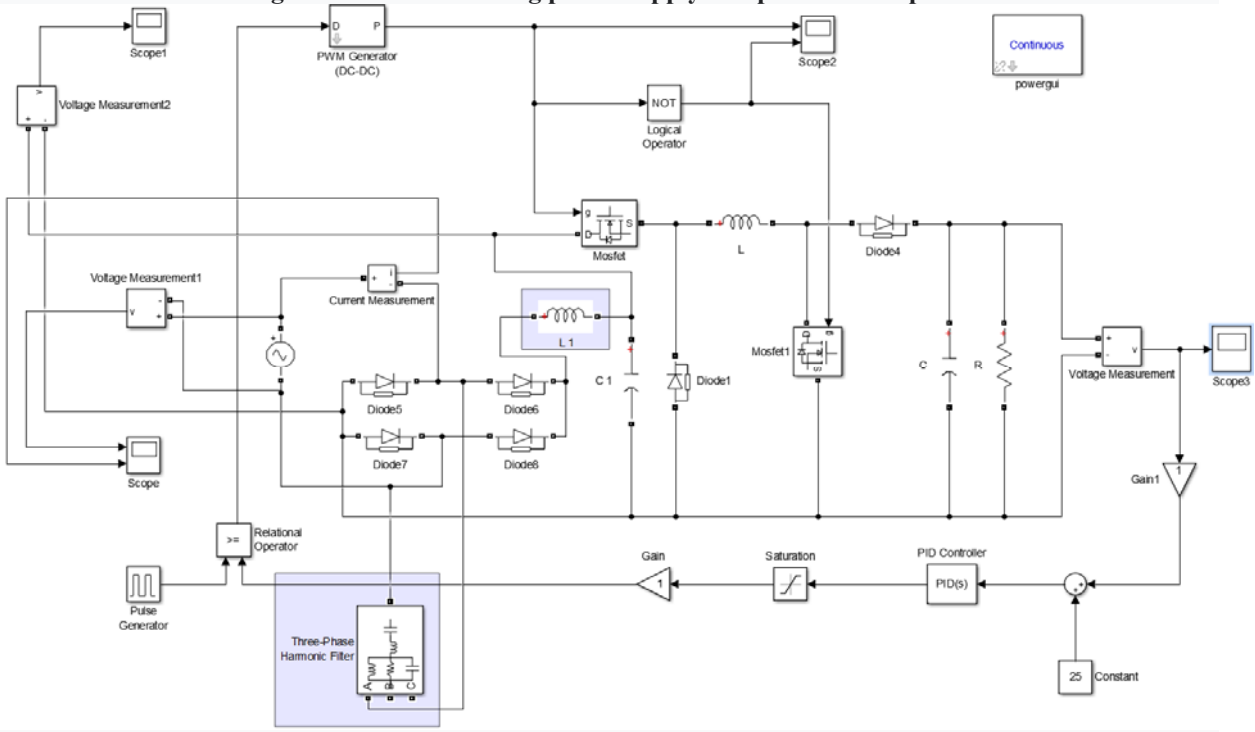

Figure 2. Matlab/Simulink model of a switching power supply of a personal computer

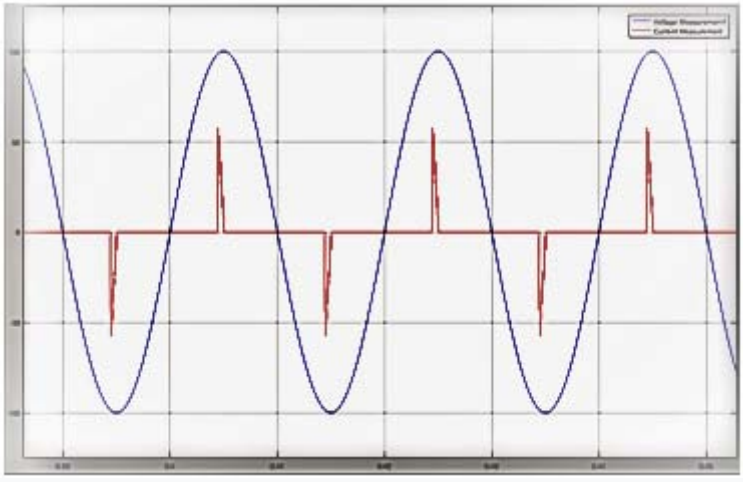

Figure 3. Oscillogram of the waveform of the input voltage and current of the PC rectifier without elimination of higher harmonics

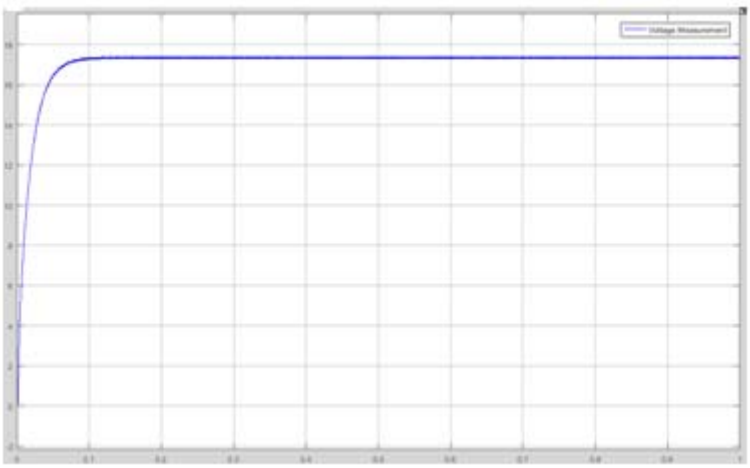

Figure 4. Oscillogram of the output voltage waveform of the PC rectifier

The oscillogram of the output DC voltage (Figure 4) is read on the oscilloscope marked on the modeled circuit "Scope 3".

Figure 5 shows the harmonic analysis of the input voltage signal. The input voltage has not undergone major changes, it is almost sinusoidal, as indicated by its THDU= 0.03%.

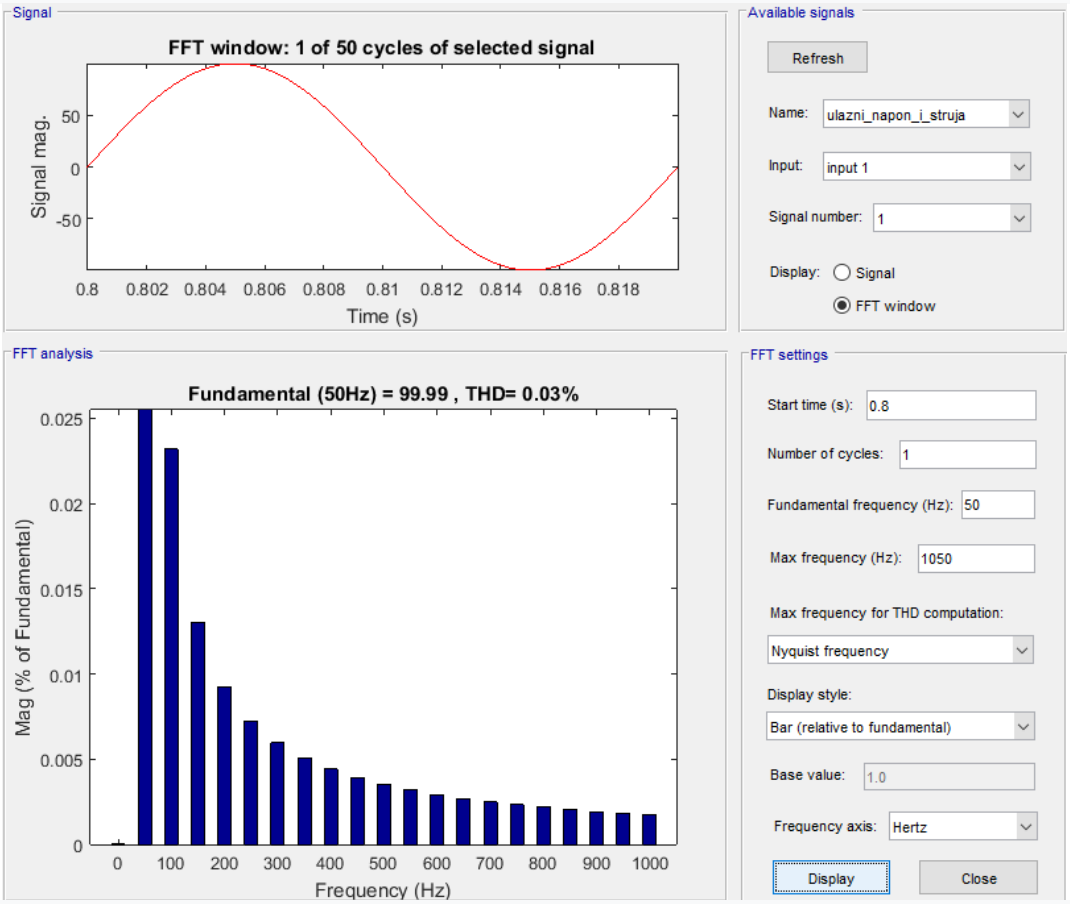

Figure 5. Harmonic analysis of PC rectifier input voltage

In further harmonic analyzes (Figure 6), a high degree of distortion of the computer current, as well as its impulse character, can be observed. The third harmonic is dominant in the spectrum, and the other odd harmonics, the 5th, 7th, 9th, etc., are also expressed. The contribution of even harmonics is negligible.

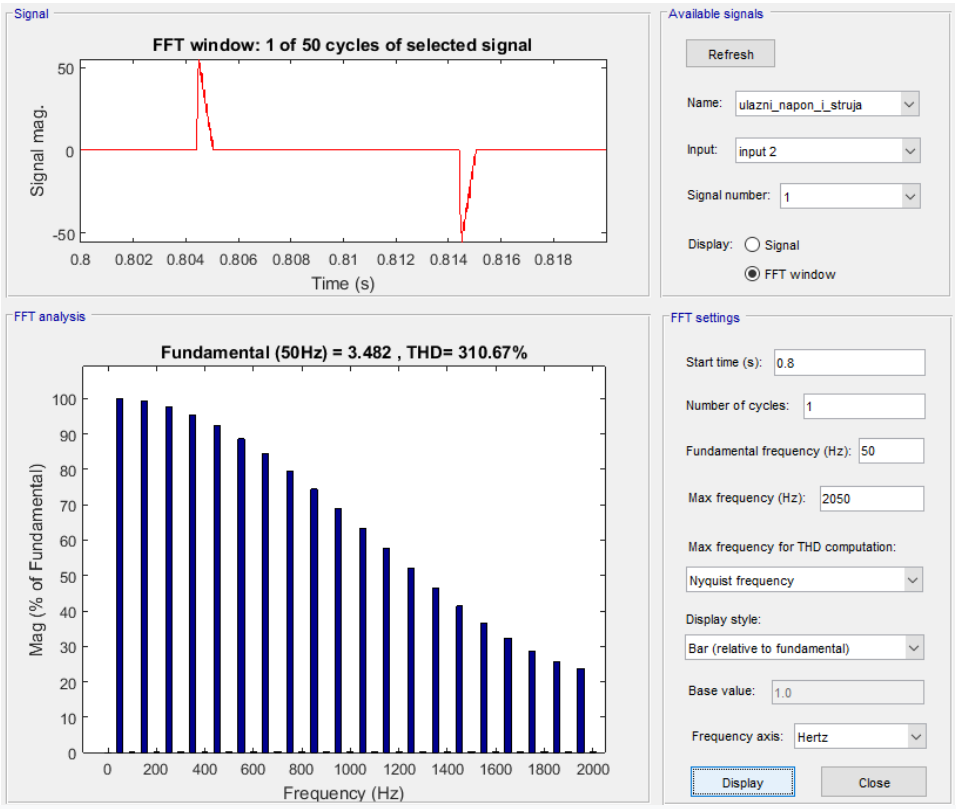

Figure 6. Harmonic analysis of PC rectifier input current without elimination of higher harmonics

In addition, the output voltage of the rectifier has an extremely low value of THD= 0.19% (Figure 7).

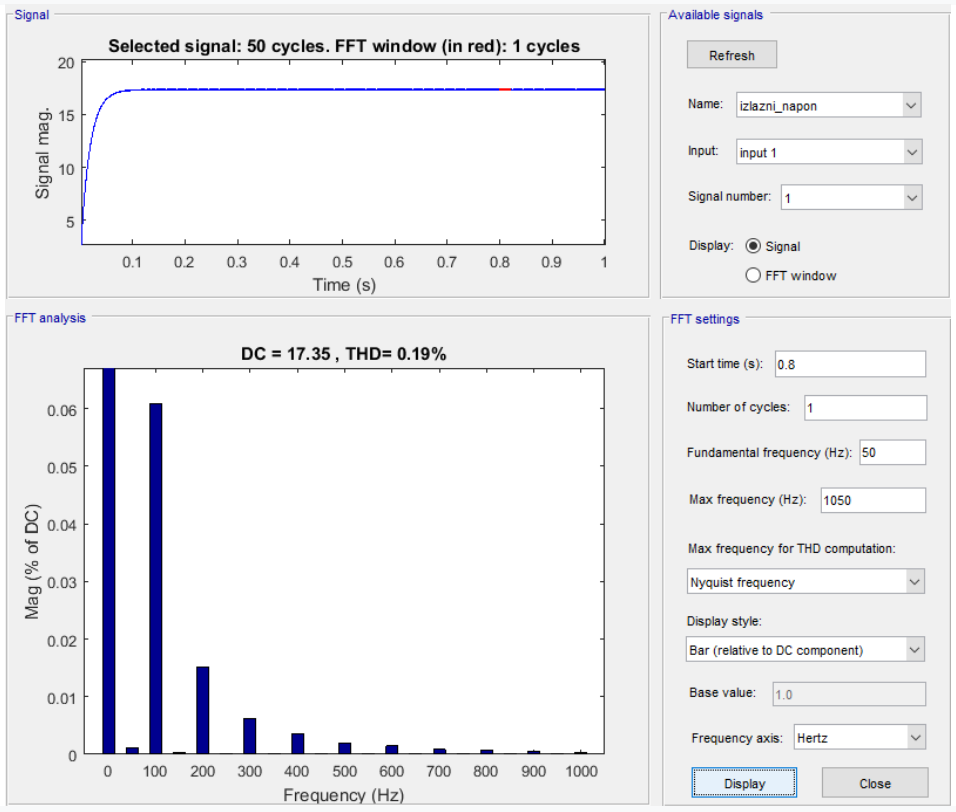

Figure 7. Harmonic distortions of the output voltage of the PC rectifier

The conducted simulations indicate that, in addition to the significant distortion of the computer current, there is also an impulse character of the active power of the computer. The structure of the harmonic spectrum of the computer current and the THDI value are given in Table 5.

Table 5. THDI value and harmonic spectrum of PC current in "stand-by" operating mode

Harmonic	THDI	3	5	7	9	11	13	15	17	19	21
(%)	109,9	85,3	60,3	30,0	10,23	7,9	12,5	10,3	8,3	3,5	3,5

Table 6 shows the values of current, power, power factor and total harmonic distortion factor of the computer current for different operating modes of the personal computer.

Table 6. Electrical parameters and THDI values for different PC operating modes

Mode	I (A)	P (W)	Q (Var)	D (Vad)	λ	THDI (%)
Stand-by	0,75	103,90	-0,96	127,53	0,63	109,9
Copying	0,78	110,60	-0,12	130,96	0,64	106,21
Printing (laser)	2,46	451,70	-3,54	271,15	0,85	37,76
Matlab/Simulink	0,81	110,50	-2,11	133,53	0,64	104,10
Measurements [10,11]	0,80	115,80	-0,21	133,75	0,65	102,73

From Table 6, it can be concluded that the THDI value of the computer also depends on the operating mode of the computer. For the program operating modes of the computer, THDI values are around 105%, and the highest value is 109.9% in "stand by" mode. When the external printing unit is turned on, the THDI value decreases, up to 37.76% in the case of a laser printer. It is also concluded that changes in the operating mode, with the printing mode turned off, do not significantly affect the structure of the harmonic spectrum of the computer current.

Regardless of the significant distortions of the computer load current, with high THDI values and a high participation of higher harmonics (odd) in the current spectrum, due to the low power of the computer load, their individual impact on the quality of the mains voltage is negligible. However, during the simultaneous operation of a large group of computers, their influence on the quality of the voltage at the common connection point can be significant. That influence depends on a number of factors related to the computers themselves, which form a group non-linear load, and also on the characteristics of the power supply system itself. Figure 8 shows a model of a personal computer where the modeling is performed with current generators where each current generator injects the current amplitude of individual harmonics with a certain phase angle.

After the completed simulation, the time diagram of the current was obtained as in Figure 9. The value of THDI and the value of harmonic distortion HDI for odd harmonics are shown in Figures 10. For the sake of simplicity, the consideration goes to the 13th harmonic. It is considered that the other higher harmonics do not change the THD to a significant extent.

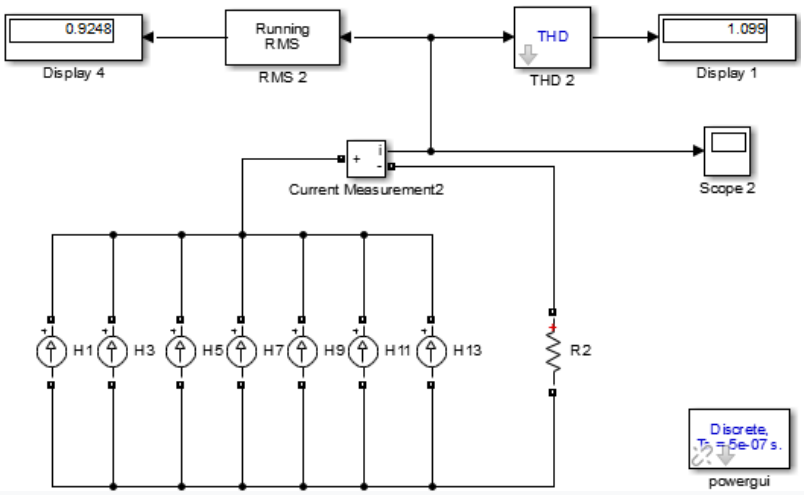

Figure 8. Modeling of a personal computer with current generators

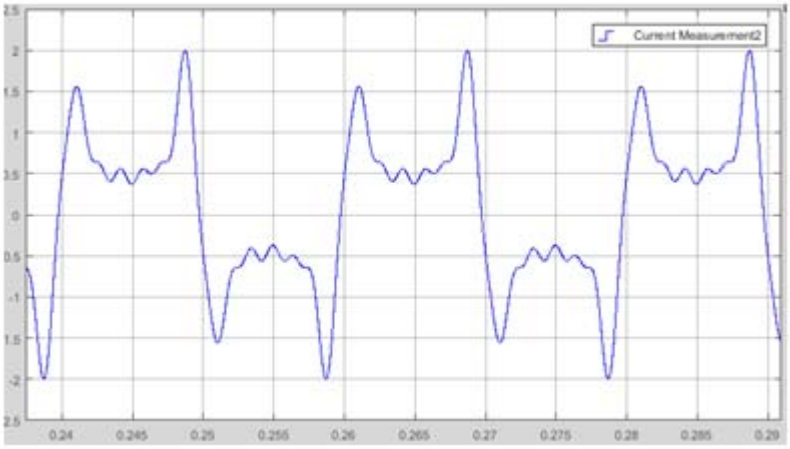

Figure 9. Timing diagram of the input current of a personal computer

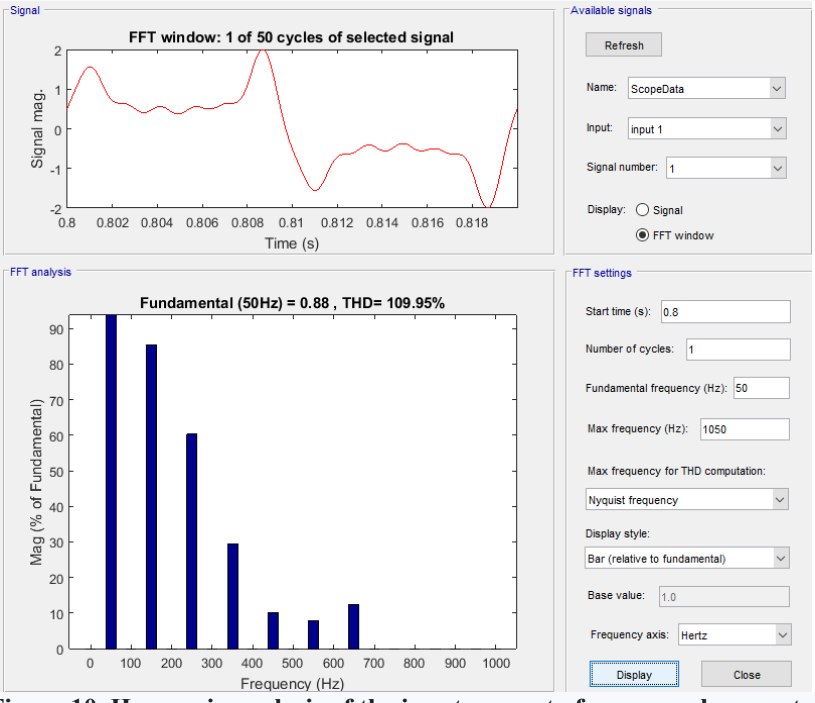

Figure 10. Harmonic analysis of the input current of a personal computer

The previous considerations apply directly to the computing unit. In practice, the computer is used in a system with a number of external units: monitors, printers, scanners, UPS devices, etc. Recently, instead of classic CRT (Cathode Ray Tube) monitors, modern LCD or TFT monitors are increasingly being used, and also the most modern types of computers consist only of a monitor, which includes a housing with a power supply unit and other electronics necessary for operation. computer. Due to a number of advantages, modern monitors have practically put classic monitors out of use. Figure 11 shows the time diagram of the input current of the LCD monitor, and Figure 12 shows the harmonic analysis of the input current of the monitor and THDI = 19.24%.

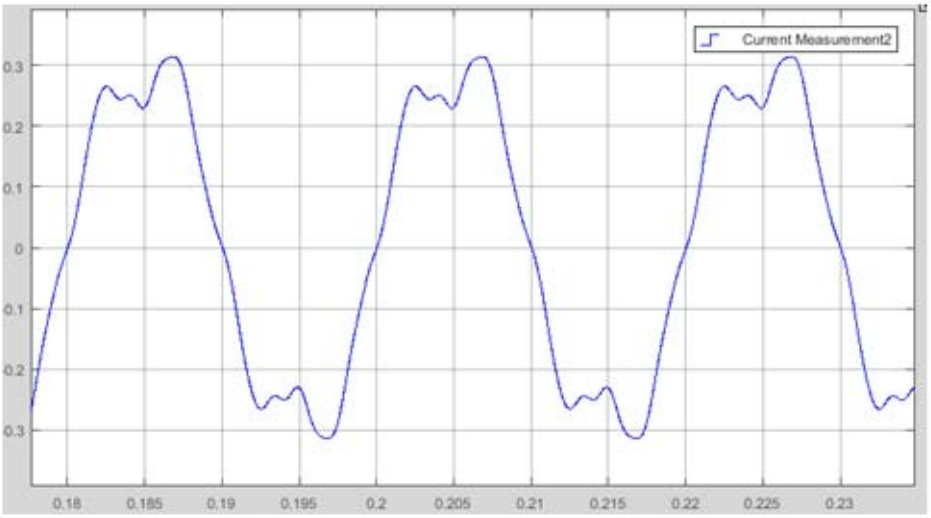

Figure 11. Time diagram of the input current of the LCD monitor

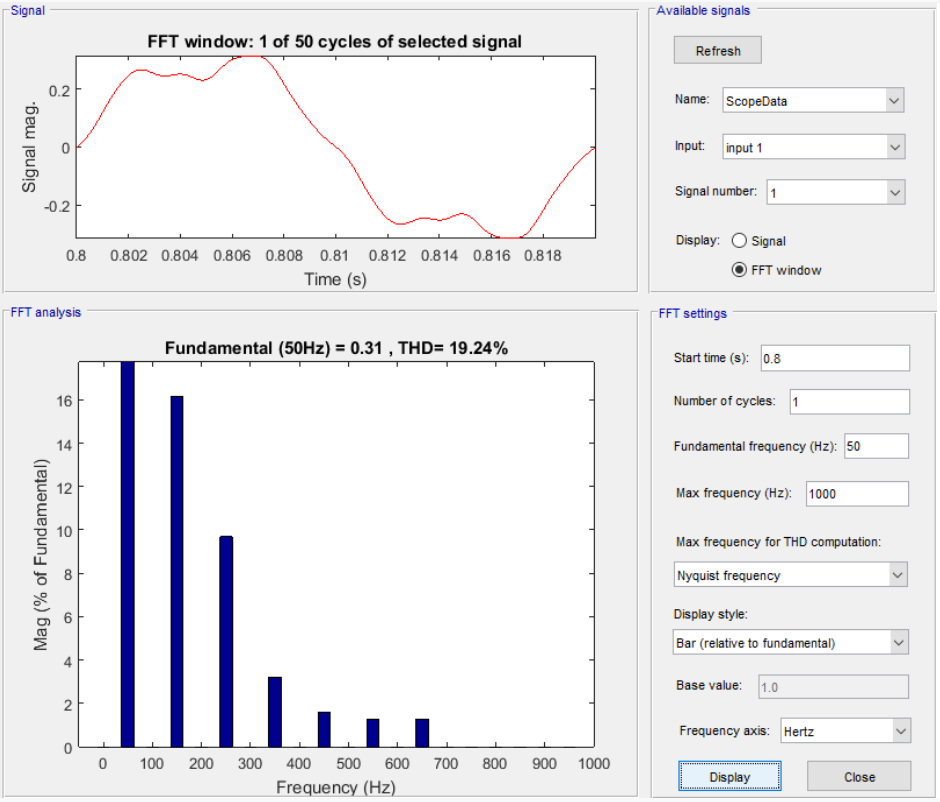

Figure 12. Harmonic analysis of the input current of the LCD monitor

Figure 13 shows the time diagram of the input current of the CRT monitor, and Figure 14 shows the harmonic analysis of THD of this current.

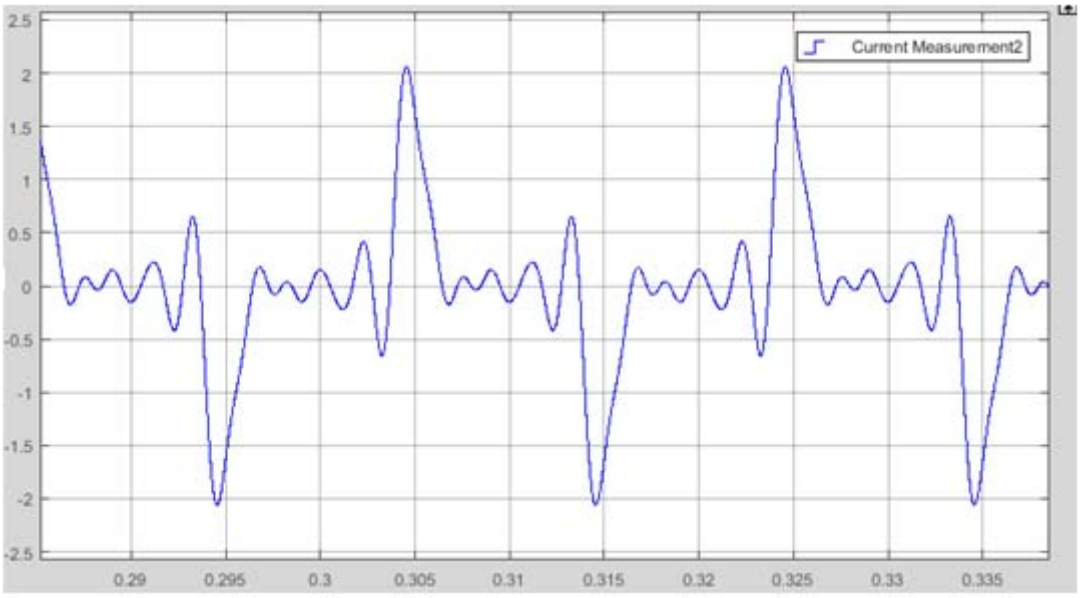

Figure 13. Time diagram of the input current of the CRT monitor

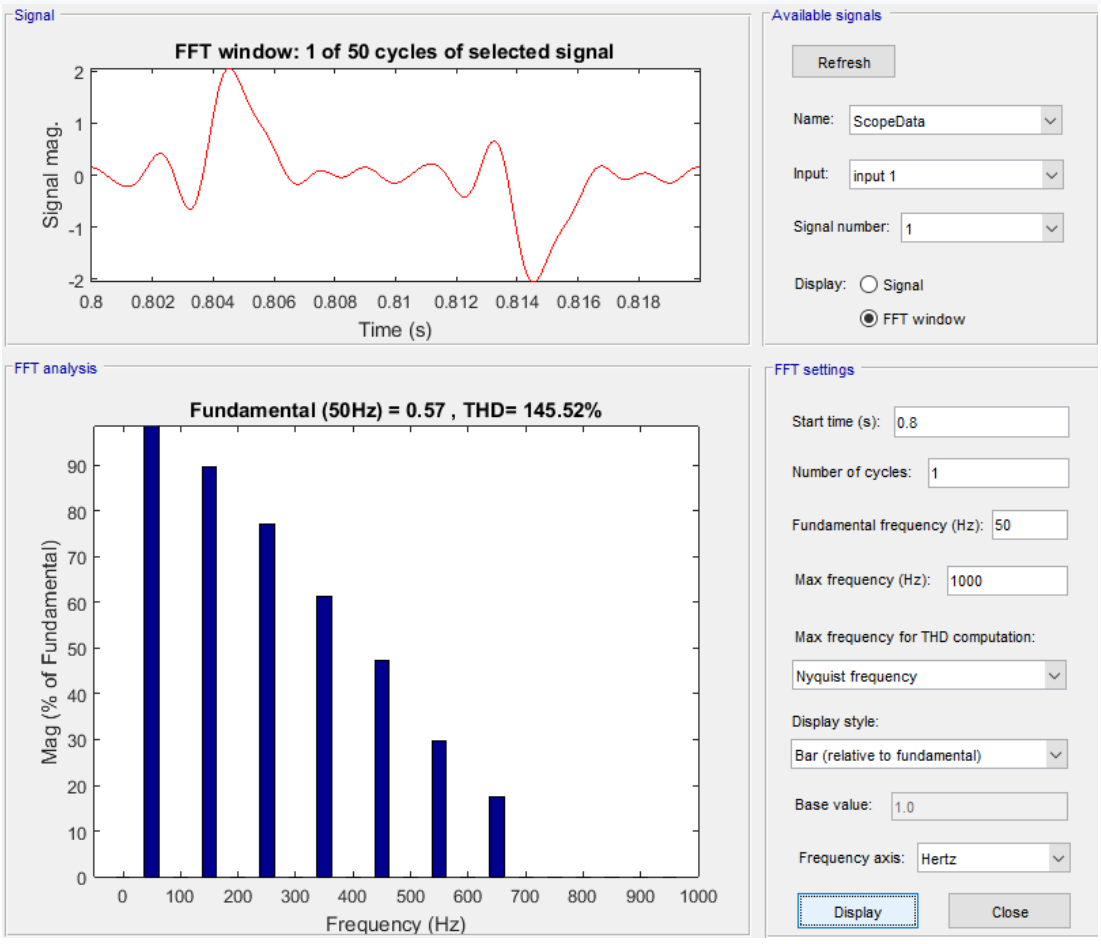

Figure 14. Harmonic analysis of THD input current of CRT monitor

PRINTERS AND SCANNERS

During the operation of personal computers, other additional devices are usually included, such as: printer, scanner, speakers, uninterruptible power supply devices, UPS, etc. Therefore, often when analyzing the impact of computers on the quality of electricity, the impact of PCs is considered together with certain, that is, all these additional components.

However, when it comes to e.g. administrative and business facilities where the use of printers is practically daily, with significant time of use during the working day. For such conditions, a separate analysis of the influence of these devices on harmonic voltage distortion at the point of their connection is important. Due to its speed, way of working and economy, laser printers are most often used in business facilities.

LASER PRINTER AS A SOURCE OF HIGHER HARMONICS

The results of the analysis of the characteristics of current and voltage harmonic distortions during the operation of the laser printer were taken from the literature, where the "HP Laser Jet 1200" type of printer was considered. The value of THDI and the structure of the current harmonic spectrum are given in Table 7 [10,11,12].

.

Table 7. THDI value and structure of harmonic spectrum of laser printer

Harmonic	THDI	3	5	7	9	11	13	15	17	19	21
(%)	7,23	4,45	4,13	2,96	1,61	1,16	0,99	0,54	0,40	0,25	0,15

Based on the data presented, it can be concluded that the level of current distortion in laser printers is low. Odd harmonics appear in the current spectrum with a low percentage, which also causes a low value for THDI. Of course, then the waveform of the current is quite close to an ideal sinusoidal signal.

It should be noted that the power of the laser printer varies during the printing process, as well as that the time forms of the current, the harmonic spectrum and the THDI value are different in the idle mode compared to the printing mode, where e.g. the THDI value is more pronounced in the idle process than in the printing process.

SCANNER AS A SOURCE OF HIGHER HARMONICS

To see the influence of the scanner on the harmonic distortions of the mains voltage, the results from the literature are presented here, where the "HP Scan Jet 4850" type of scanner is considered. The value of THDI and the structure of the current harmonic spectrum are given in table 8 [10,11,12].

Table 8. THDI value and structure of the harmonic spectrum of the scanner

Harmonic	THDI	3	5	7	9	11	13	15	17	19
(%)	124,65	90,0	70,0	45,0	20,0	6,0	7,0	10,0	7,0	4,0

Based on the previous table, it can be concluded that odd harmonics have a dominant influence in the structure of the harmonic spectrum of the scanner, with the third, fifth, seventh and ninth harmonics being very pronounced. The shape of the scanner's load current is significantly distorted compared to the ideal sinusoidal signal with a very pronounced current distortion.

MEASURES FOR POWER FACTOR CORRECTION AND REDUCTION OF HIGHER CURRENT HARMONICS

In order to meet the standards mentioned in the introductory part of this paper, PFC (Power Factor Correction) converters were created, with the task of reducing higher current harmonics, that is, increasing the power factor of switching consumers. There are two basic types of PFC circuits – passive and active. The passive PFC technique used here shapes the input current using a passive filter consisting of chokes and capacitors. With passive filters, it is, in principle, difficult to achieve a power factor close to unity.

Using filters, harmonics cannot be completely eliminated, but can only be reduced to an acceptable level, which is defined by European and state energy standards, which was discussed earlier.

In the modeled power supply unit, passive electrical filters are used, which are normally used in real ATX (Advanced Technology eXtended) PC power supply units. Passive filters represent a mature technology that is used to reduce the harmonic components of the current and compensate the reactive power in alternating current networks, but also to eliminate the harmonic components of the voltage, to regulate the voltage at the connection point and to suppress voltage flicker and improve the voltage balance in three-phase systems.

As a subtype of passive electrical filters, two types of these filters are used in the computer power supply unit, namely:

- parallel passive filter and
- low-pass (broadband) filter

Parallel filters (Figure 15) are connected at the load connection point in parallel with it, thus providing a low impedance through which as much of the current harmonics should pass. Conducting harmonics through passive elements (chokes and capacitors) prevents current harmonics from reaching the power supply, while reducing losses at the same time. This configuration is used to filter certain harmonic frequencies for which the filter is designed (5th, 7th, 11th,… harmonic).

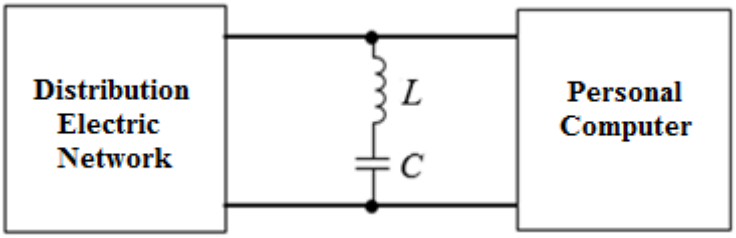

Figure 15. Parallel passive filter

A low-pass (broadband) filter (Figure 16) is used to eliminate all harmonic components that have a frequency above the resonant frequency. The resonant frequency is usually around the 5th harmonic, so the filter is tuned to cancel the 5th and all harmonics above.

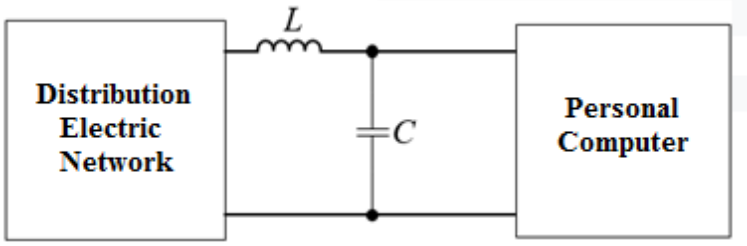

Figure 16. Low-pass (broadband) filter

Capacitance and inductance values in these filters are taken from actual values used in real power supply units in PC platforms. After using these filters and reducing-eliminating the higher harmonics, the time diagrams of the input current and the input voltage look like in Figure 17 and 18.

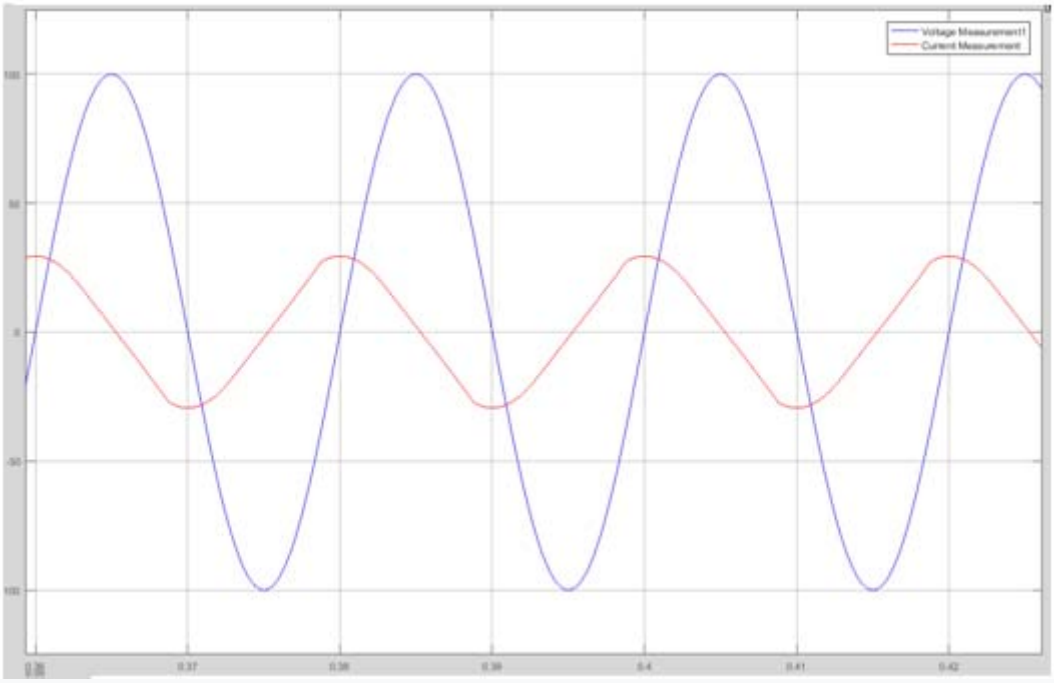

Figure 17. Oscillogram of the waveform of the input voltage and current of the PC rectifier with the elimination of higher harmonics

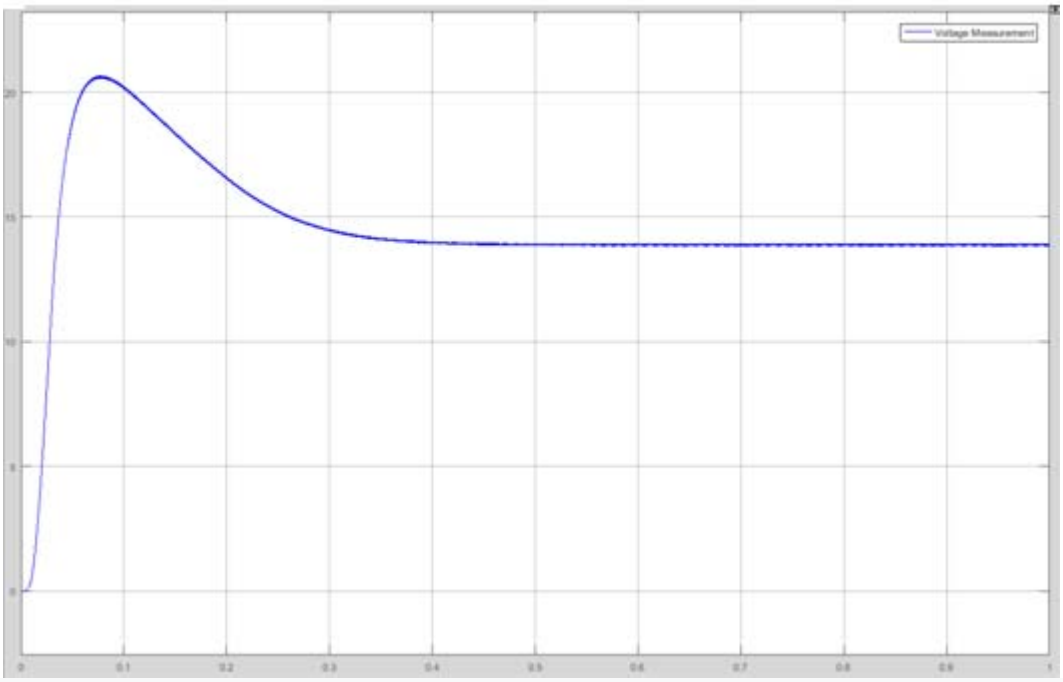

Figure 18. Oscillogram of the output voltage waveform of the PC rectifier with elimination of higher harmonics

After using these filters to reduce and eliminate higher harmonics, the input current takes on an almost sinusoidal character, and this is supported by the value of THDI=5.56%, which is in accordance with all the mentioned standards for the quality of electricity (Figure 19).

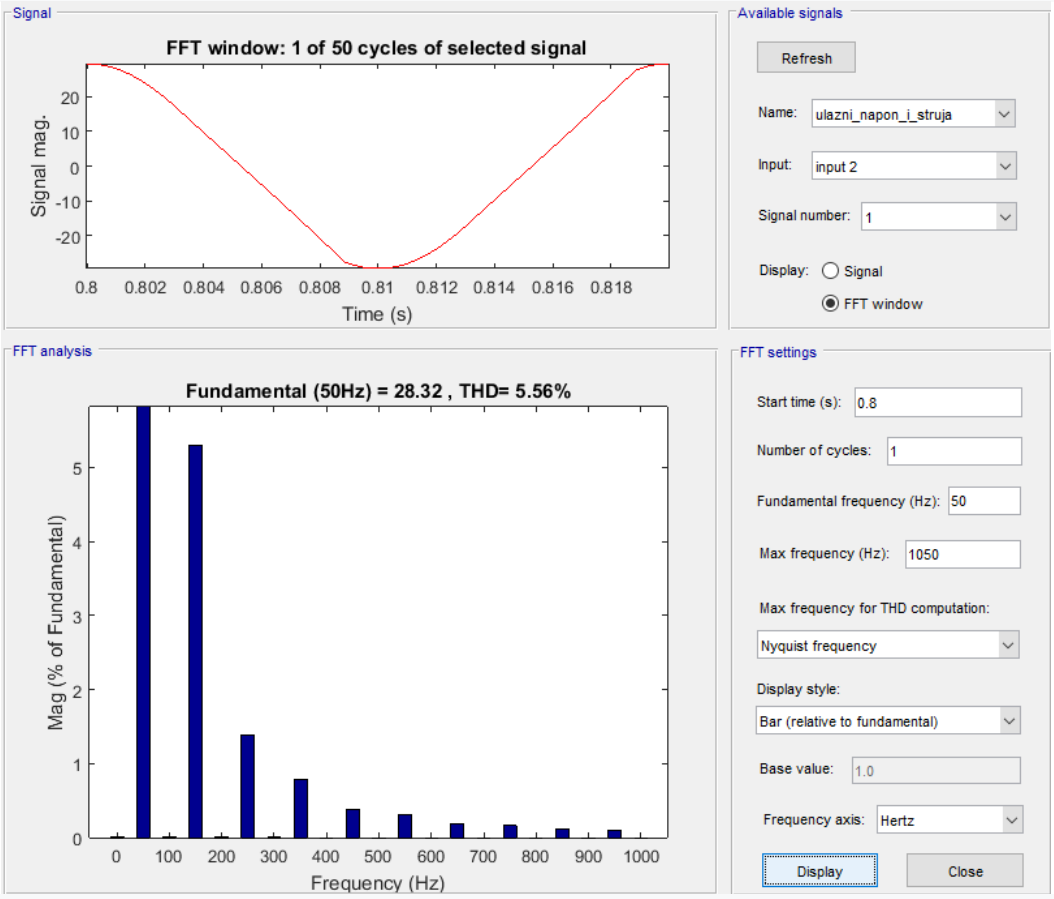

Figure 19. Waveform and harmonic analysis of the input current after elimination of higher harmonics

CONCLUSION

Nonlinear low-power consumers, such as personal computers with corresponding printers and scanners, cause odd higher harmonics in the waveform of supply voltages and currents. Odd harmonics have a dominant influence, with the third, fifth, seventh and ninth harmonics being very pronounced. The total distortions of the computer's THDI current also depend on the computer's operating mode. and range up to 109.9%. in "stand by" mode When external printing units are turned on, the THDI value decreases, up to 37.76% in the case of a laser printer, and when using a scanner, the THDI value increases up to 124.65%.

Regardless of the significant distortions of the computer load current, with high THDI values and a high participation of odd higher harmonics in the current spectrum, due to the small power of the computer load, their individual impact on the quality of the mains voltage is negligible. However, during the simultaneous operation of a large group of computers, their influence on the quality of the voltage at the common connection point can be significant. That influence depends on a number of factors related to the computers themselves, which form a group non-linear load, and also on the characteristics of the power supply system itself.

The results of modeling the power supply unit with passive electrical filters, which are often used in real ATX (Advanced Technology eXtended) power supply units of personal computers, indicate values of the total distortion of the input current of THDI=5.56%. This obtained value of the total distortion of the input current in the power supply unit of the personal computer is in accordance with all standards for the quality of electricity.

REFERENCES:

[1] Electromagnetic compatibility (EMC), Part 2-1, *Environment - Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems*, IEC Standard 61000-2-1, International Electrotechnical Commission, 1990.

[2] Electromagnetic compatibility (EMC), Part 2-2, *Environment – Compatibility levels for low – frequency conducted disturbances and signalling in public low – voltage power supply systems,* IEC Standard 61000-2-2, International Electrotechnical Commission, 2002.

[3] Electromagnetic compatibility (EMC), Part 2-4, *Environment – Compatibility levels in industrial plants for low-frequency conducted disturbances*, IEC Standard 61000-2-4, International Electrotechnical Commission, 2002.

[4] Electromagnetic compatibility (EMC), Part 3-2, *Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*", IEC Standard 61000-3-2, International Electrotechnical Commission, 2005.

[5] Electromagnetic compatibility (EMC), Part 3-4*, Limits – Limitation of emission of harmonic currents in low-voltage power supply systems, for equipment with rated current greater than 16 A*, IEC Standard 61000-3-4, International Electrotechnical Commission, 1998.

[6] Electromagnetic compatibility (EMC), Part 4-30, *Testing and measurement techniques - Power quality measurement methods*, IEC Standard 61000-4-30, International Electrotechnical Commission, 2010.

[7] EN 50160, *Voltage characteristics of electricity supplied by public electricity networks*, Cenelec, 2010.

[8] Acarkan Bora, Kilic Osman, *Electrical Harmonics Modeling of Office Equipments Using MATLAB and SIMULINK*, Bilimde Modern Yontemler Sempozyum – BMYS – 2005, Koceeli, Turkey, November 2005., pp. 596-604.

[9] Acarkan Bora, Kilic Osman, *Harmonics Modeling and Harmonic Activity Analysis of Equipments with Switch Mode Power Supply using MATLAB and SIMULINK*, IEEE International Electric Machines & Drives Conference – IEMDC'07, Antalya, Turkey, Vol. 1, 3-5 May 2007., pp. 508-513.

[10] Saša Mujović and others, *Modeling of non-linear consumers of small power with a special reference to computer modeling,* II Consultation of CG KO CIGRE, Miločer, Montenegro, May, 2011., Report C4-4, pp.16-19.

[11] Saša Mujović and others, *The influence of grouping of non-linear low-power consumers on the reduction of the harmonic spectrum of the generated current,* ETF Journal of Electrical Engineering, Vol. 19, No. 1, October, 2011.

[12] Ilija Derikučka, *Analysis of the influence of the structure of consumption on distribution networks* - , master's thesis, Podgorica, February 2017.