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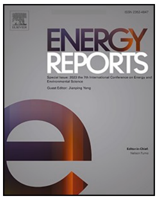

Research paper

Investigation of harmonics analysis power system due to non-linear loads on the electrical energy quality results

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ABSTRACT

With the increase in the demand for electrical energy, more reliable and better quality energy is needed. This concept has taken its place in the field of electrical engineering with the title of "power quality". Today, power electronics elements, transformers, arc furnaces, converters, etc. used in industry, harmonic emitting elements have caused deterioration of power quality and as a result, it has led us to ways to get rid of harmonics. In order to provide quality electrical energy, some criteria such as continuity of energy, stability of voltage and frequency, proximity of power factor to 1, balance of phase voltages and harmonic amounts in voltage should be taken into consideration. In this study, the energy quality of different units in Giresun University Güre Campus was investigated with CA 8333 energy analyzer. The results obtained were transferred to the computer environment with the help of graphics. In order to analyze the harmonics and inter harmonics in the power system and to see the effect on the system, series active power filter is modulated and simulated against different nonlinear loads in MATLAB/Simulink program. The results are shown with the FFT (Fast Fourier Transform) analysis program to see the elimination of harmonics in the system and their response to filtering. The results of harmonics in the power system with nonlinear loads before and after filtering are analyzed and examined. As a result of the analysis, suggestions are made regarding the measures that can be taken.

1. Introduction

The increasing use of nonlinear loads in power systems has led to an increased interest in the field of power system harmonics. Nonlinear loads are fed by a sinusoidal source. On the other hand, the currents drawn contain harmonics, which can lead to overheating and insulation breakdown. Harmonic resonance can cause extremely large problems in the system. In order to detect these problems, modeling and analysis of power systems are of great importance (Kaushal and Basak, 2020). These requirements for safer and higher quality electrical energy must be taken into account in the generation, transmission and distribution of electrical energy. In order for an electric power system to operate in a reliable and desirable manner, there are a number of factors that must be taken into account during the design and operation phases of the system. Harmonics generated by elements with nonlinear characteristics are one of these factors (Apriansyah et al., 2019). Harmonics are an important factor in the quality of the energy produced. Harmonics can be defined as the deviation of the current and voltage waveforms from the sine waveform (Rüstemli et al., 2013). Rüstemli et al. in their study (Rüstemli et al., 2015) said that the most important and useful method to reduce or eliminate harmonics is to use harmonic filters. In this study, the parameters of power losses (voltage waveforms, harmonics) were determined using ZERA MT 310 signal analyzer. The causes of these unwanted losses in power were investigated (Rüstemli and Cengiz, 2015). In another study, a detailed examination of various parameters such as (harmonics, instantaneous electrical values, current and voltage waveforms) measured with the help of Zera MT310's power analyzer in two different factories in Van city was carried out on different dates. With these measurements, they identified some power deficiencies and designed a single-tuned passive filter with the help of Matlab/Simulink software as a solution. In another study by Rüstemli and Cengiz (2016), information about the structure and application of passive filter system is given. In Efenin's first study (Efe, 2016), harmonics, which have the largest share in the degradation of power quality in electrical power systems and industrial environments, are analyzed. In the second study (Efe and Kocaman, 2018), harmonics are defined, information about the system is given, how and why they occur, their effects on electrical energy, power systems and which methods are used in filtering are

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examined. In another study (Wang, 2017), an analysis study was carried out using data measured from an installed horizontal axis wind turbine. They focused on harmonic distortions in renewable energies. (Tabak and Yalçın, 2004) explained the importance of quality for electrical energy systems. In relation to this, energy quality is defined. By making recommendations for the quality of energy, the effects that play a deteriorating role on quality are explained. Güven and Yörükeren (2019) examined the quality of electrical energy consumed in the central campus of Yalova University. Within the scope of the study, a power quality analyzer was connected to the power distribution centers at various points of the central campus, and parameters such as voltage, current, power and frequency of the system and power quality events occurring in the system were measured with the power quality analyzer, and then transferred to digital media and analyzed. In line with the data obtained as a result of harmonic measurements, the causes of power quality problems were investigated and solutions were proposed (Kesler and Sunan, 2010). The design of a new low-cost Digital Signal Processor (DSP) application development board, which is widely used in industrial applications, automotive industry and laboratory prototype development, is presented and how to perform harmonic analysis in power systems using the Fast Hartley Transform (FHT) method is investigated. Dağ et al. (2011) developed an approach to harmonic source localization by firstly exemplifying the 2-prong impedance-based fault localization method. Şahin (2003) gave information about harmonic sources, the effects of harmonics in power systems and harmonic filtering. In another study, the effects of harmonics on underground power cables were determined and suggestions were made to reduce the harmonic effects (Şahin, 2006). Aydemir (2006) investigated the reduction of selected harmonics in a single-phase half-bridge inverter. Eroğlu (2009) gave basic information about harmonics related to energy quality problems and discussed why and how they occur, analysis methods, their effects on electrical energy systems, standards and filtering methods. Afterwards, measurements made in an electricity distribution network are analyzed and the effects of harmonics on this distribution network are interpreted. Erişti (Erişti and Tümen, 2012) analyzed harmonic distortions in power quality by using k-means algorithm, one of the clustering techniques of data mining. (Küçükilhan, 2017) observed the synchronization process between the photovoltaic system and the grid and the harmonic effect caused by the inverter in the photovoltaic system. (Keçecioğlu et al., 2015) measured the point where a SPP is connected to the grid by MV through a grid analyzer and analyzed the obtained data in terms of harmonic distortion and flicker. Germeç and Erdem (2014) developed a multifunctional system structure that includes fundamental frequency determination and estimation of amplitude and phase angles of harmonic and arharmonic components for time-varying signals in electrical power systems. Akçay and Arifoğlu (2019) investigated the design of series active power filter for unbalanced loads. Ruviaro et al. (2018) aimed to analyze the harmonic distortions caused by lighting devices in power systems and the economic analysis of various types of lighting devices individually and together in a renewable energy system. Ellis (1996) analyzed the effects of short circuits, on-off events and large load changes on the network voltage and the waveform disturbances in the network current and voltage of power electronic circuits, which have been increasing in number and use in recent years, with the help of computer and explained their effects on other consumers in the network. In his study, Shankar and Kumar (2017) investigated how the harmonics generated by a 3-phase AC frequency converter vary according to the frequency converter structure and filtering type. In his study, Alawasa (2017) provides basic information about harmonics, why and how harmonics are generated, analysis methods, their effects on electrical energy systems, standards and filtering methods. Then, he analyzed the measurements made in an electricity distribution network and interpreted the effects of harmonics on the existing distribution network and compared active filter and passive filter solutions with simulation studies. Simulation studies were performed using Simplorer 6.0 program for passive filter and parallel active power filter at different power values. Chenyi (2018) tried to detect disturbances in current and voltage waveforms in power systems with the help of discrete wavelet transform. They designed and analyzed the current and voltage waveform disturbances such as harmonics, notch effect, noise, instantaneous events using Matlab/Simulink.In the study by Uddin et al. (2021), various methods such as Fourier transform, Discrete Hartley transform, multiple signal classification, slope-dropout based adaptive filters were investigated, their mathematical backgrounds were examined and classified according to their principles. By combining the presented methods, a harmonic estimation application was created in MATLAB program. Ogunjuyigbe (2017) investigated the factors affecting the electrical power quality, classified the power quality impairments, introduced the formulations used to define and size the power quality, and explained the adverse effects of power quality on the system.

In this study, harmonics were examined for nonlinear loads in a power system of the substations located in Giresun University Güre Campus. The harmonic effect in the power system was modulated and simulated with the MATLAB/Simulink program. The purpose of this study is to analyze the harmonic result on the power system with different types of load and examine what can be done. As a matter of fact, only harmonic sourced loads such as power electronic devices, converters and high power induction motors have been analyzed and their effects on the distortion of the ideal waveform of the current and voltage in the power have been examined.

2. Materials and methods

In this section, a harmonic filter is implemented in a modeled system and the responses given by the system are analyzed. MATLAB/Simulink program is used in the simulation and series active power filter is used as one of the filter types. Giresun University Güre Campus is taken as a model. In this campus, harmonic analysis of six different electricity subscriptions according to their electricity consumption behavior has been investigated. There are a total of 6 substations on a single main line in the Güre Campus area. The total transformer installed power of the 6 transformers in the Güre campus subscriptions is 5430 kVA and the total generator installed power is 4825 kVA. Çamlık substation has an 800 kVA transformer and a 700 kVA diesel generator. The electrical energy needs of Çamlık Lodgings, Vocational School of Health Sciences and the Department of Health, Culture and Sports are met from this substation. The Engineering substation has an 800 kVA transformer and a 550 kVA diesel generator. From this substation, the electrical energy needs of the Faculty of Engineering, Faculty of Science and Literature Additional Service Building and Giresun University Central Research Laboratory Application and Research Center are met. There is a 1000 kVA transformer and a 450 kVA diesel generator in the Faculty of Education substation. From this substation, the electrical energy needs of the Faculty of Education, State Conservatory and Central Library Building are met. There is a 1600 kVA transformer and a 2250 kVA diesel generator in the Faculty of Arts and Sciences substation. From this substation, the electrical energy needs of the Faculty of Arts and Sciences, Faculty of Economics and Administrative Sciences, School of Foreign Languages, Faculty of Islamic Sciences, Institute of Science, Institute of Social Sciences, Institute of Health Sciences and Department of Student Affairs are met. The Rectorate building substation has a 600 kVA transformer and a 415 kVA diesel generator. From this substation, the electrical energy needs of the Department of Personnel, the Department of Construction and Technical Affairs, the Department of Administrative and Financial Affairs, the General Secretariat and the Rectorate Office are met. The Faculty of Sports Sciences substation has a 630 kVA transformer and a 460 kVA diesel generator. The electrical energy needs of the Faculty of Sports Sciences, Scientific Research Projects Coordination, School of Civil Aviation and Faculty of Maritime Studies are met from this substation. If we compare the loading rates of Güre Campus substations, it is seen that the Faculty of Science and Letters has the highest rate of 45 %, the lowest rate is 20 % in Çamlık and the average rate is 35 %. The satellite image of the measured transformers of 6 different faculty buildings in Giresun University Güre Campus is shown in Fig. 1. As a result of the analysis, graphs were examined, harmonics were identified and eliminated and the results were analyzed.

2.1. CA 8333 energy analyzer

The energy analyzer is used to determine the quality of the electricity network by measuring the voltage and current levels of the devices. CA 8333 energy analyzer was used for the measurements to be made at Giresun University Güre Campus and is shown in Fig. 2.

2.2. MATLAB/Simulink

It supports system-level design, simulation, automatic code generation and continuous testing and verification of embedded systems. Simulink provides a graphical editor, customizable libraries, and solutions for modeling and simulation of dynamic systems. In summary, Simulink enables simulation using block diagrams without writing code. Some of the areas where Simulink is used are image processing applications, control systems (PID control), digital signal processing, electrical circuit solution, state-space models and transfer functions (Chenyi, 2018; Dhoriyani and Kundu, 2020; Uddin et al., 2021). MATLAB/Simulink is a block diagram environment within the MATLAB program that helps simulation in many engineering applications. The main reason why this environment is preferred is that it provides a great convenience in design and can be done by drag and drop method without the need to write code. In addition, it provides many visual possibilities and conveniences for modeling, simulating and analyzing different systems. Since Simulink works integrated with MATLAB, the data in the program section can be transferred directly to Simulink, and the results obtained in the Simulink environment can be transferred directly to MATLAB. Although it provides ease of design without the need for code writing, it can work compatible with C/C+ + coding applications. In this system design, MATLAB/Simulink program was preferred in order to achieve the most practical and clearest results without the need for any code software.

2.3. Mathematical calculations of harmonics

A periodic wave signal defined as a function and not in ideal sine wave form can be written. The famous scientist Fourier summed the fundamental frequency and harmonic elements and wrote them in the same function as in the equations given below:

$$y = f(x) = C_0 + C_1\sin(x+\varphi_1) + C_2\sin(2x+\varphi_2) + \ldots + C_n\sin(nx+\varphi_n) \quad (9)$$

If the current in the time domain is written based on this equation;

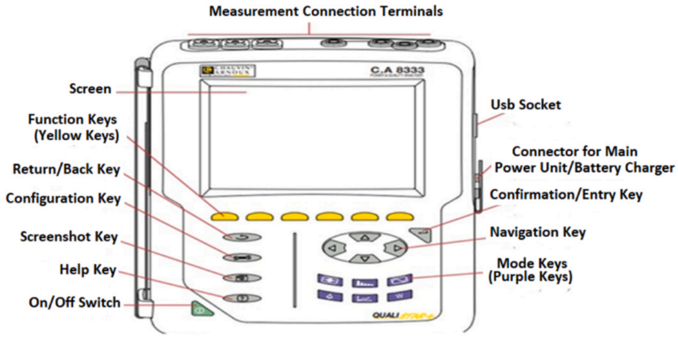


Fig. 2. CA 8333 energy analyzer.

$$i(t) = I_0 + I_{m1}\sin(wt+\varphi_1) + I_{m2}\sin(2wt+\varphi_2) + \ldots + I_{mn}\sin(nwt+\varphi_n) \quad (10)$$

is obtained. In this equation, $\omega = 2\pi f$ and f is the frequency. In addition, n is the highest harmonic degree, I_0 is the current element, h is the harmonic degree (n = 1,2,., n) and I_{mn} and φ_n are the highest value and phase angle of the n^{th} harmonic current element.

2.3.1. Single setting shunt filter modeling

When designing the filter; effects such as harmonic current curves, total harmonic distortion value, reactive power of the system, the effect of other harmonic sources should be taken into consideration. Single tuned shunt filter was preferred due to the harmonics being effective in the system, its usefulness in terms of other filters and its low cost. In the single tuned shunt filter design, calculations were made with the help of the equations given below. To find the impedance value;

$$Z = R + j\left(\omega L - \frac{1}{\omega C}\right) \quad (1)$$

At the frequency at which the filter is tuned, the imaginary part of the impedance becomes equal to zero and resonance occurs. Thus, the impedance at resonance is equal to the resistance value R. The resonant frequency value f_r at which the filter is tuned is found by calculating the inductance value L and the capacitance value C with the following equation.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (2)$$

Considering the harmonic components, the inductive reactance and capacitive reactance values, which are the elements of the filter at the resonance at the nth harmonic, are calculated with the help of the equations given below.

$$X_{Ln} = nwL \quad (3)$$

Fig. 1. Giresun University Güre Campus taken as a model.

$$X_{Cn} = \frac{1}{n\omega C} \tag{4}$$

In case of resonance; the calculation is made with the help of the equation given below.

$$X_{Ln} = X_{Cn} \tag{5}$$

The following equations are used to calculate the resistance value, coil value and capacitor value that make up the filter: Capacitor capacity equation:

$$Q_c = \omega.C.V^2 \tag{6}$$

The number of shunt filter arms is denoted by "k" and the following equation is used to calculate the capacity of each filter.

$$C_r = C/k \tag{7}$$

The quality factor Q is the ratio of the reactance values $(X_{Ln} ve X_{Cn})$ to the resistance at resonance and is calculated by the following equation

$$Q = \frac{\sqrt{L/C}}{R} = \frac{X_{Lr}}{R} = \frac{X_{Cr}}{R} \tag{8}$$

This resistance (R) value consists of the resistance in the inductance, so it has a small value. It consists of a random value generally selected. The smaller the quality factor is chosen, the sharper the filter will be. If we are asked to find the inductance and capacitance values given a quality factor Q, calculations are made with the help of the equations given below.

$$L_r = \frac{X_{Lr}}{2\pi f_r} = \frac{R.Q}{2\pi f_r} \tag{9}$$

$$C_r = \frac{1}{2\pi f_r.X_{Cr}} = \frac{1}{2\pi f_r.R.Q} \tag{10}$$

Resonance may occur after the filter interacts with the source impedance. This frequency is smaller than the filter frequency. L_s is the source self-inductance value and L is the filter inductance, calculated by the following equation.

$$f_r = \frac{1}{2\pi}.\sqrt{\frac{1}{(L_s + L).C}} \tag{11}$$

Firstly, the active power (P) values measured by the analyser at Güre Campus are found.

$$S = \frac{P}{\cos\varphi} \tag{12}$$

In this equation, the apparent power (S) is calculated by substituting the active power and cosφ values measured separately for each unit in Güre Campus.

To find the measured reactive power (Q) of each unit separately;

$$Q = \sqrt{S^2 - P^2} \tag{13}$$

Since the reactive powers of each system are known and the capacitor powers of each unit can be easily calculated from here, the following formulas are calculated with the measurement results obtained and written in MATLAB simulation (Ogunjuyigbe, 2017).

In the equation given below, C_t capacitor powers are calculated by substituting the reactive powers (Q), frequency (f) values and input bus voltage (V_{bara})values (Alawasa, 2017).

$$C_t = \frac{Q}{2\pi f.(V_{bara})^2} \tag{14}$$

Since the filter design will be made for the first three harmonics, the capacitor capacities in each arm are calculated by dividing the capacitor capacities of each unit separately by three as shown in the equation given below.

$$C = \frac{C_t}{3} \tag{15}$$

In order to calculate the coil resistance values as a result of the values measured by the analyser, firstly the reactance value(X_{rn}) at the resonance moment is calculated with the help of the equation given below.

$$X_{rn} = \frac{1}{n.\omega.C} = \frac{1}{n.2\pi f.C} \tag{16}$$

Based on the following equation, the resistance value R_n at the nth harmonic is equal to the ratio of the reactance value X_{rn} at resonance to the quality factor Q_f.

$$R_n = \frac{X_{rn}}{Q_f} \tag{17}$$

According to the equation given below, the inductance value L_n at the nth harmonic is equal to the ratio of the reactance value X_{rn} at the resonance instant to the number of n harmonics and the angular frequency ω.

$$L_n = \frac{X_{rn}}{n.\omega} = \frac{X_{rn}}{n.2\pi f} \tag{18}$$

2.3.2. Series active power filter modeling

The source voltages generated by the series active power filter are described in the equations below. The source voltages are used in the formation of the trigger signals required for the series active power filter to function. Based on the instantaneous power theory, the source voltages calculated at the α-β level are then converted into the voltages of the 3-phase system using the inverse Clarke transformation.

Instantaneous power is represented by the Eq. (19).

$$Pa(t) = VI\cos\varphi(1 - \cos 2\omega t) - VI\sin\varphi \sin 2\omega t \tag{19}$$

The average active power value is shown by the Eq. (20).

$$P(t) = VI\cos\varphi \tag{20}$$

The effective value of the current in phase A is found by the Eq. (21).

$$I = (I_1^2 + I_2^2 + I_3^2 + I_4^2 + \ldots)1/2 \tag{21}$$

The calculation of the apparent powers of the three phases in the system is shown by the Eq. (22).

$$S = 3VI \tag{22}$$

The equations used to find the reactive power and harmonic power of nonlinear loads are given below:

$$Q = 3VI\sin\varphi \tag{23}$$

$$D = 3V(I_2^2 + I_2^2 + I_3^2 + \ldots)1/2 \tag{24}$$

After the equations given above,

$$S_2 = P_2 + Q_2 + D_2 \tag{25}$$

The apparent power in the equation is calculated in this way. The following equation is used to find the total power factor in the system:

$$S_2\cos\varphi = \frac{P}{S_1} \tag{26}$$

Instantaneous power values are found with the Clarke transformation used in the calculation of the parameters. The purpose of this method is to convert the current and voltage values of three phases into a two-phase system by mathematical operations. The formulae of the transformation are presented below (Shankar V. K. A. and Kumar N. S., 2017):

$$\begin{bmatrix} V_a \\ V_B \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{27}$$

$$\begin{bmatrix} I_a \\ I_B \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_{sa} \\ I_{sb} \\ I_{sc} \end{bmatrix} \tag{28}$$

It is found with the instantaneous active power equation of the system.

$$P_3 = Va \times Ia + V\beta \times I\beta \tag{29}$$

Instantaneous reactive power of the system is found with the equation:

$$Q_3 = V\beta \times Ia - Va \times I\beta \tag{30}$$

$$\begin{bmatrix} P_3 \\ Q_3 \end{bmatrix} = \begin{bmatrix} I_a & I_\beta \\ -I_\beta & I_a \end{bmatrix} \begin{bmatrix} V_a \\ V_\beta \end{bmatrix} \tag{31}$$

The instantaneous power of the system is found by calculating the instantaneous voltage and instantaneous current values in the equation. The instantaneous voltage values of the system are found with the equation.

$$\begin{bmatrix} V_a \\ V_\beta \end{bmatrix} = \begin{bmatrix} I_a & I_\beta \\ -I_\beta & I_a \end{bmatrix}^{-1} \begin{bmatrix} P_3 \\ Q_3 \end{bmatrix} \tag{32}$$

There is the instantaneous voltage of the system and the source voltage.

$$\begin{bmatrix} V_{ca*} \\ V_{cb*} \\ V_{cc*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{ca*} \\ V_{c\beta*} \end{bmatrix} \tag{33}$$

The voltages found in the inequality are converted to three-phase V_{ca}, V_{cb}, V_{cc} source voltages at the α-β level. These equations are used to convert the voltage values from the a-β plane to three-phase V_{ca}, V_{cb}, V_{cc} source voltages by mathematical operation. With the source voltages, it generates the trigger signals required for the use of the series active power filter.

In order to find the source voltages of the three-phase series active power filter and the generation of the trigger signal, the selection of the power is shown by using block diagrams with P-Q theory. Conjugately, P-Q theory is used and the compensation voltages, the current drawn from the network and how the power elements are found are expressed with the help of block diagrams.

Fig. 3 shows the block diagram of the control structure of the three-phase series active power filter.

3. Result and discussion

3.1. Giresun university Güre campus electricity energy quality

If we summarize energy quality briefly, it can be defined as prioritizing the standard of living and service quality in homes, and the standard of living in industrial enterprises can be defined as minimizing energy consumption per unit or product quantity without causing a decrease in the quality and quantity of production. Energy quality stands out as one of the strategic objectives of our country and the world and one of the indispensable components of energy policies to ensure energy supply security in our country, to minimize the rate of foreign dependency in energy, to protect it by taking measures against environmental pollution and to further increase its effectiveness in the fight against the factors causing climate change. In order to contribute to the studies carried out in terms of energy quality in our country, the energy quality elements of the electrical energy consumed in Giresun University Güre Campus were examined. In this section, where the energy quality in Giresun University Güre Campus is discussed, analyzes were made in accordance with the electrical energy consumption behavior of electricity subscriptions in the Güre Campus area.

3.2. Purpose of measurements in energy quality in electrical systems

The most basic types of disturbances that occur in electrical systems

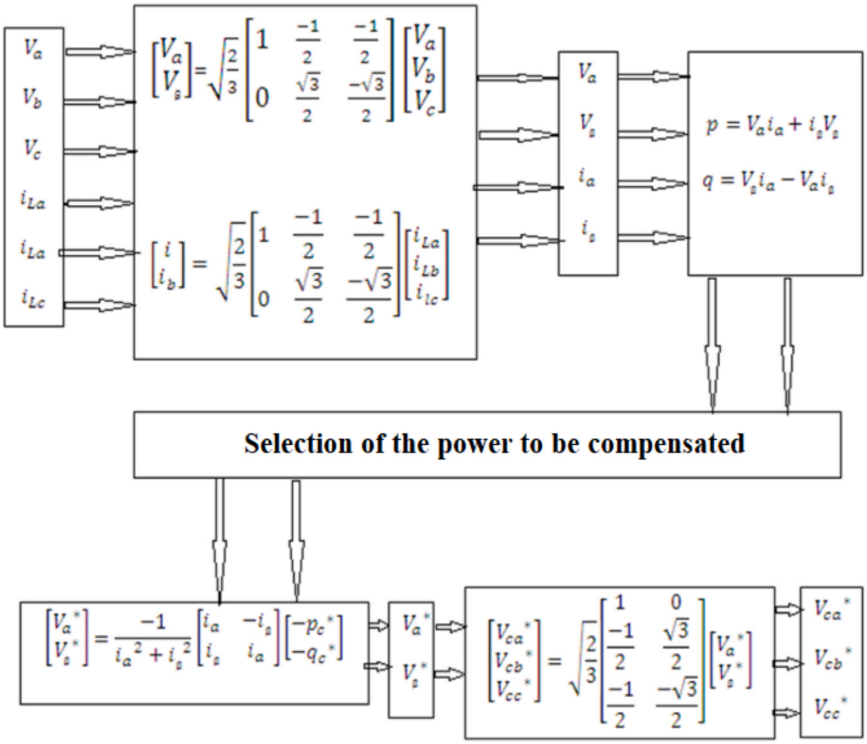


Fig. 3. Three-phase series active power filter control block diagram.

can undoubtedly cause significant damage, economic losses and life-threatening problems in electronic circuits operating at low voltages and electrical machines operating at high voltages. In order to eliminate these problems, it is necessary to improve the quality by utilizing network data. The purpose of measuring energy quality in electrical systems; In order to start measuring energy quality at any point, the software or hardware systems installed to measure energy quality at any point should be examined and reported and the solution proposals should be interpreted and used to provide quality energy to the consumer.

3.3. *Energy analysis of electricity subscriptions in Güre campus*

In this section, an optimal tenergy analysis is performed according to the electrical energy consumption behavior of six different electricity subscriptions in Giresun University Güre Campus. The electrical energy needs of the Faculty of Engineering, Faculty of Arts and Sciences Additional Service Building and Giresun University Central Research Laboratory Application and Research Center are met. The Rectorate building substation has a 600 kVA transformer and a 415 kVA diesel generator. From this substation, the electrical energy needs of the Department of Personnel, the Department of Construction and Technical Affairs, the Department of Administrative and Financial Affairs, the General Secretariat and the Rectorate Office are met. There is a 1600 kVA transformer and a 2250 kVA diesel generator in the Faculty of Arts and Sciences substation. From this substation, the electrical energy needs of the Faculty of Arts and Sciences, Faculty of Economics and Administrative Sciences, School of Foreign Languages, Faculty of Islamic Sciences, Institute of Science, Institute of Social Sciences, Institute of Health Sciences and Student Affairs Department are met. The Çamlık substation has an 800 kVA transformer and a 700 kVA diesel generator. From this substation, the electrical energy needs of Çamlık Lodgings, Vocational School of Health Sciences and the Department of Health, Culture and Sports are met. On 10/01/2022, measurements were made for one day with the Energy Analyzer Device at the Faculty of Sports Sciences, Faculty of Engineering, Rectorate Building, Faculty of Science and Letters, Faculty of Economics and Administrative Sciences and Çamlık Transformer. With this study, time-dependent power, voltage, current harmonic, voltage harmonic and current graphs of the electricity consumed in the panel were obtained.

Table 1 When we examine the One-day total power parameters curve measured at the transformer of the Faculty of Sports Sciences building in Fig. 4, when we look at the usage times when power consumption increases, very low power consumption is observed when the learning intensity increases, and power consumption is observed when there is little or no learning intensity. Likewise, in Appendix B-Fig. 1, we can see the one-day power consumption graphs and daily power consumption data of the Faculty of Engineering, Rectorate building, Çamlık transformer building, Faculty of Arts and Sciences, Faculty of Education and Faculty of Sports Sciences, respectively, in Appendix A-Table 2. In this data, we can see that the power consumption gives the same result as in the Faculty of Sports Sciences building.

When we examine the one-day daily Voltage Parameters of Each Phase of Three Phase Systems graph of the Faculty of Sports Sciences building in Fig. 5; the minimum value of the voltage, the average value of the voltage and the maximum value of the voltage are given in Appendix A - Table 3. When we look at the maximum and minimum values of the voltages, there is no sudden voltage increase and sudden voltage decrease. Likewise, in Appendix B-Fig. 2, we can see that the one-day power measurement graphs and daily measurement data of the Faculty of Engineering, Rectorate building, Çamlık transformer building, Faculty of Arts and Sciences, Faculty of Education and Faculty of Sports Sciences are given in Appendix B-Table 3. In this data, we can see that the daily voltage curve gives the same voltage curve graph as in the Faculty of Sports Sciences building. A daily current harmonic graph of the Faculty of Sports Sciences building can be seen in Fig. 6.

Table 1

Single tuned shunt filter calculations of the transformers measured at Güre campus.

Units measured	C	R	L
Engineering Faculty	0.0011 F	0.022 Ohm	3.60×10^{-4} H
Education Faculty	0.0017 F	0.023 Ohm	2.36×10^{-4} H
Arts and Sciences and Economics Faculty	0.0066 F	0.0059 Ohm	60.098×10^{-4} H
Çamlık	0.0016 F	0.024 Ohm	2.48×10^{-4} H
Rectorate	0.0013 F	0.028 Ohm	2.94×10^{-4} H
Sport Sciences Faculty	0.0019 F	0.020 Ohm	2.08×10^{-4} H

When we examine the one-day current harmonic graph of the Faculty of Sports Sciences in Fig. 6; the minimum value of the voltage, the average value of the voltage and the maximum value of the voltage are given in Appendix A-Table 4. In the international standard (IEC 519–1992), harmonic distortion values are given as [Total Harmonic Distortion (THD)]$_I < 5$ % for current. Normally $[\mathrm{THD}]_I < 15$–20 % in the network. As seen in Fig. 6, the harmonic distortions are above the 5 % limit throughout the day and the average value is 11.40 % respectively. Harmonic pollution creates adverse conditions on capacitors, transformers, alternating current motors, electrical control devices (breakers, fuses, relays) and electrical cables. They cause overheating and faulty operation and frequent malfunctions that may occur in these elements. $[\mathrm{THD}]_I < 15$–20 % exceeds the limit. Current harmonics must be brought within acceptable limits. In the same way, in Appendix B-Fig. 3, we can see a daily voltage harmonics graph of the Faculty of Education, Faculty of Engineering, Rectorate building, Çamlık transformer building, Faculty of Arts and Sciences transformer center. In these data, we can see that the daily voltage harmonics give the same voltage harmonics graph as in the Faculty of Sports Sciences building. A daily voltage harmonics graph of the Faculty of Sports Sciences building is given in Fig. 7.

When the one-day voltage harmonic graph in Fig. 7 is analyzed; the minimum value of the voltage, the average value of the voltage and the maximum value of the voltage are given in Appendix A-Table 5. When the total harmonic distortion $[\mathrm{THD}]_V > 3$ observed on the voltage, contamination is observed. When the above graphs are analyzed, no contamination is observed in the voltage harmonic curve. Likewise, in Appendix B-Fig. 4, we can see that one-day power consumption graphs of the Faculty of Engineering, Rectorate building, Çamlık transformer building, Faculty of Arts and Sciences, Faculty of Education and Faculty of Sports Sciences are given respectively. In this data, we can see that the power consumption gives the same result as in the Faculty of Sports Sciences building. The one-day current curve graph of the Faculty of Sports Sciences building is given in Fig. 8.

When we examine the one-day current curve graph in Fig. 8 according to the usage times, it is observed that the current increases when the learning intensity is the highest, and the current is very low when the learning intensity is low or non-existent. The currents of the phases are close to each other. The minimum, average and maximum values of the current in the current curve can be seen in Appendix A-Table 5. Likewise, in Appendix B-Fig. 5, we can see the one-day current curve graphs of the Faculty of Engineering, Rectorate building, Çamlık transformer building, Faculty of Arts and Sciences, Faculty of Education and Faculty of Sports Sciences, respectively. In these data, the power consumption has the same current values as in the Faculty of Sports Sciences building.

When we look at the measurement results, all variables of the single-tuned shunt filter and series active power filter are obtained and the results obtained are written in Table 1.

As seen in Table 1, the filter design will be made by entering the inductance, resistance and capacitor data of the single tuned shunt filter into the MATLAB / simulation program. The variables given in Table 2 will be entered into the MATLAB/simulation program and the system will be modeled and simulated with series active power filter. Each parameter of the system is given in Table 2. A series active power filter

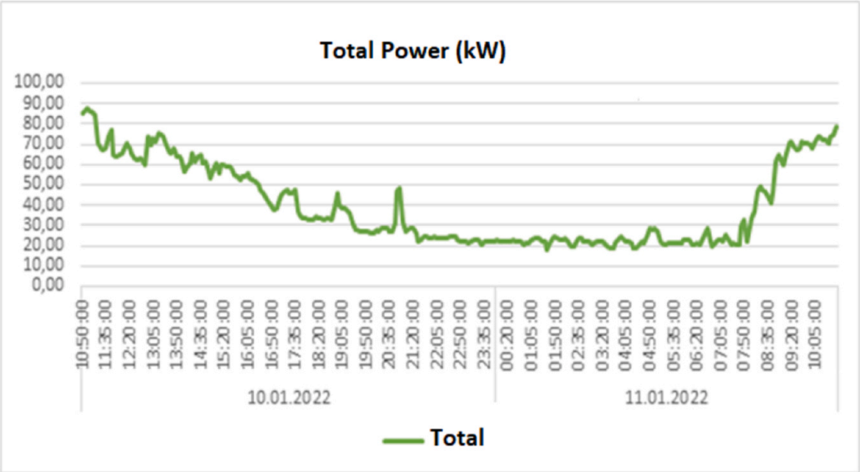


Fig. 4. One-day total Power Parameters curve measured at the transformer of the Faculty of Sports Sciences building.

Table 2
Variables of the series active power filter.

Series active power filter parameters	Source voltages (Va, Vb, Vc)	Source impedance (Rk, Ck)	Load power (Py, Qy)
Camlik Transformer	400 V	1 Ω, 78,61 μF	57 kW; 24,795 kVAr
Engineering Faculty Transformer	400 V	1 Ω, 86,03 μF	28,83 kW; 9.1813 kVAr
Education Faculty Transformer	400 V	1 Ω, 111,14 μF	52,38 kW; 17,95 kVAr
Arts, Sciences, Economics and Administrative Sciences Faculty Transformer	400 V	1 Ω, 221,66 μF	203.14 kW; 15,71 kVAr
Rectorate Transformer	400 V	1 Ω, 53,42 μF	31,21 kW; 6812 kVAr
Sports Sciences Faculty Transformer	400 V	1 Ω, 19,01 μF	39 kW; 5,85 kVAr

supplied with 240 V voltage, which has the power to resist all harmonics in the system without n$^{\text{th}}$ harmonic monitoring, is used.

3.4. Simulation of harmonic elimination with MATLAB simulink

The data obtained as a result of the measurements made at the Güre campus, the calculations required for the design of the single-tuned shunt filter and series active power filter were taken into consideration and the system was set up on the program for MATLAB/Simulink modeling. This situation is shown in Figs. 9–12.

The MATLAB/Simulink modeling process and harmonic sources of the Güre Campus, where harmonic analysis was performed, are given in block form. Considering the transformers and load values, the harmonic results are added to the system to show the current source and FFT analysis. Afterwards, the calculated values were entered into the passive

Table 3
Test result values of harmonics for Total Harmonic Distortion Current with single tuned shunt filter and series active power filter activated when the filter is not activated.

Measured Transformers	THD_I without filter	THD_I with Single Adjustable Shunt Filter	THD_I with Series Active Power Filter
Camlik Transformer	%32.50	%23.51	%5.65
Engineering Faculty Transformer	%42.37	%33.79	%3.51
Education Faculty Transformer	%11.42	%8.65	%5.23
Arts, Sciences, Economics and Administrative Sciences Faculty Transformer	%27.26	%17.55	%5.49
Rectorate Transformer	%35.08	%27.53	%3.27
Sports Sciences Faculty Transformer	%35.77	%31.07	%3.17

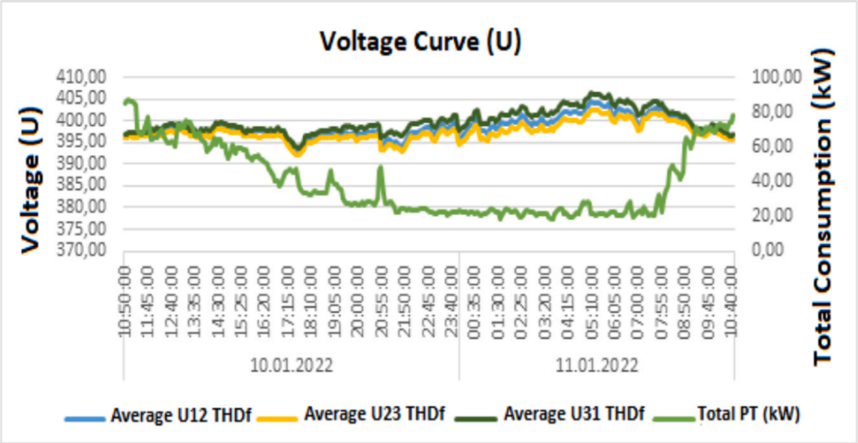


Fig. 5. One-day voltage parameters graph of each phase of three phase systems of the faculty of sports sciences, substation-380 V.

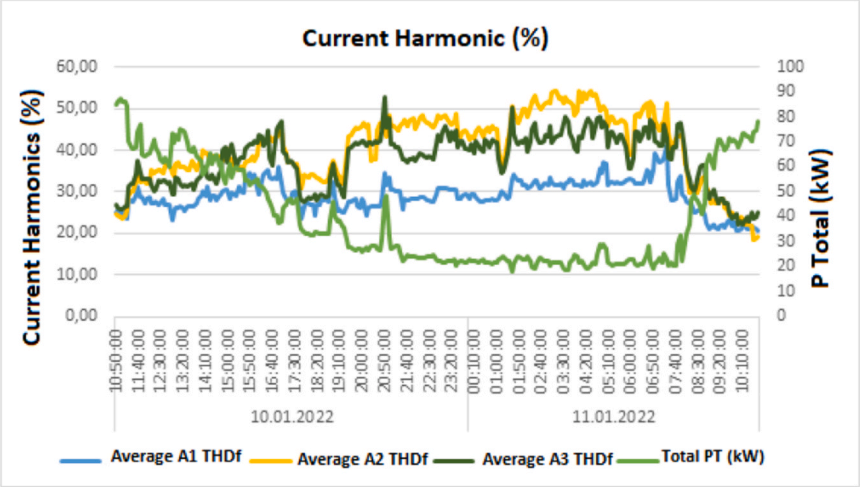


Fig. 6. One-day current parameters graph of each phase of three phase system of the faculty of sports sciences substation.

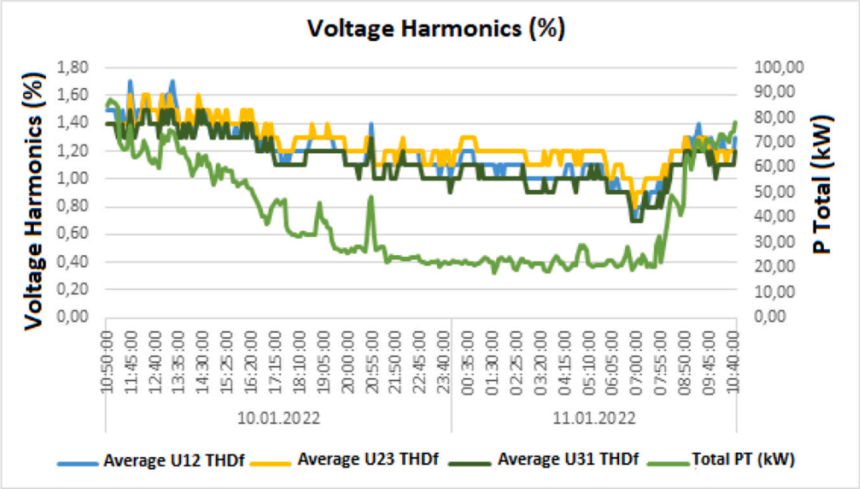


Fig. 7. One-day voltage harmonic parameters graph of each phase of three phase system of the faculty of sports sciences building substation.

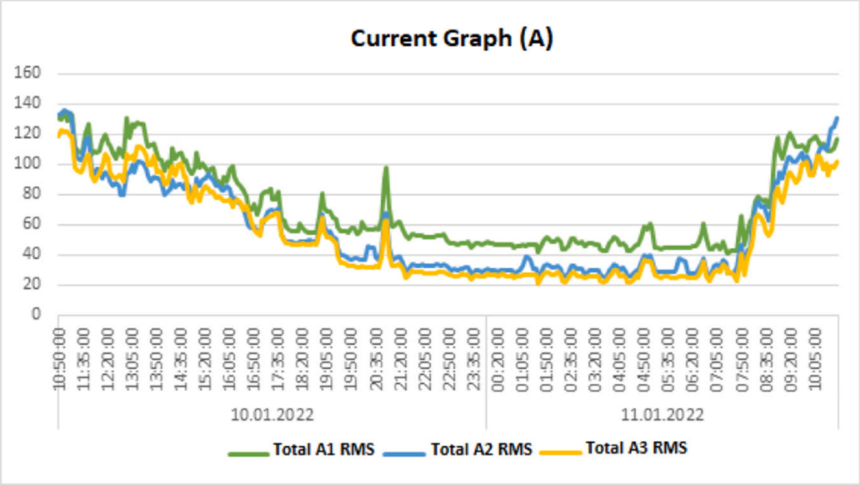


Fig. 8. One-day current harmonic parameters graph of each phase of three phase system of the faculty of sports sciences building.

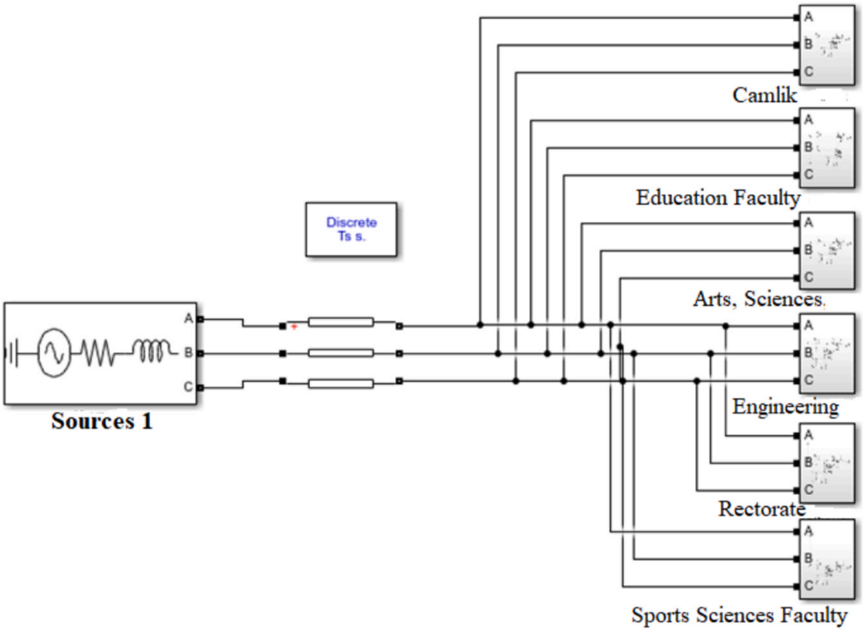


Fig. 9. MATLAB/Simulink modeling of Güre campus serial active power filter and single tuned shunt filter design.

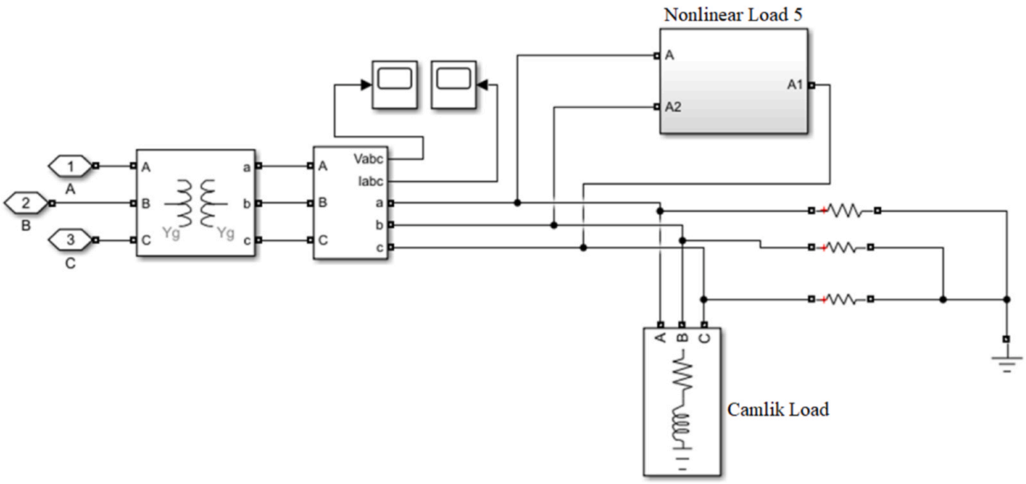


Fig. 10. Modeling of all units of Güre campus for MATLAB/Simulink unfiltered simulation.

harmonic filter and active harmonic filter design, which will eliminate the disturbing effects of harmonics, and made ready for simulation. For the simulation of the system, the harmonic state of the transformer of the Faculty of Sports Sciences with and without filter is shown in Fig. 13.

If we give information for the inductively loaded system of the analysis diagram and amplitude spectrum of the Matlab/Simulink outputs of the simulation of the transformer of the Faculty of Sports Sciences in Fig. 13, it is seen that the harmonics (3, 5, 7, 9 and 11) of the transformer of the Faculty of Sports Sciences in the system exceed the limit determined according to the international (IEC 519–1992) standard. The fundamental frequency value for the system is 50 Hz. After analyzing the loaded parts in the unfiltered condition for harmonics, the results are presented in a table. In the same way, it is seen that the harmonics (3, 5, 7, 9 and 11) of the Rectorate building transformer in Fig. 5, the Faculty of Engineering transformer in Fig. 4, the Faculty of Science, Letters and Economics and Administrative Sciences transformer in Fig. 3, the Faculty of Education transformer in Fig. 2 and the Çamlık transformer in Fig. 1 exceed the limit determined according to the international (IEC 519–1992) standard. It is seen that the 5, 7 and 11 harmonics of the transformer of the Faculty of Science and Letters and Faculty of Economics and Administrative Sciences, and the 5, 7 and 11 harmonics of the transformer of the Faculty of Education exceed the limit determined according to the international (IEC 519–1992) standard. The fundamental frequency value for the system for all faculties is 50 Hz. After analyzing the loaded parts in the unfiltered condition for harmonics, the results are presented in the form of a table.

If we give information for the inductively loaded system from the analysis diagram and amplitude spectrum based on the Matlab/Simulink outputs of the single-tuned shunt filtered state of the Faculty of Sports Sciences transformer in Fig. 14, it is seen that the 3, 5, 7, 9 and 11th harmonics of the Faculty of Sports Sciences transformer are partially eliminated according to the Matlab/Simulink outputs. In the same way, it is seen that the 3rd, 5th, 7th, 9th and 11th harmonics of the Rectorate building transformer in Fig. 5 in Appendix-D, the Faculty of Engineering transformer in Fig. 4, the Faculty of Science and Economics and Administrative Sciences transformer in Fig. 3, the Faculty of Education transformer in Fig. 2, and the Çamlık transformer in Fig. 1 are partially eliminated. It is seen that the 3rd and 9th harmonics of the Faculty of

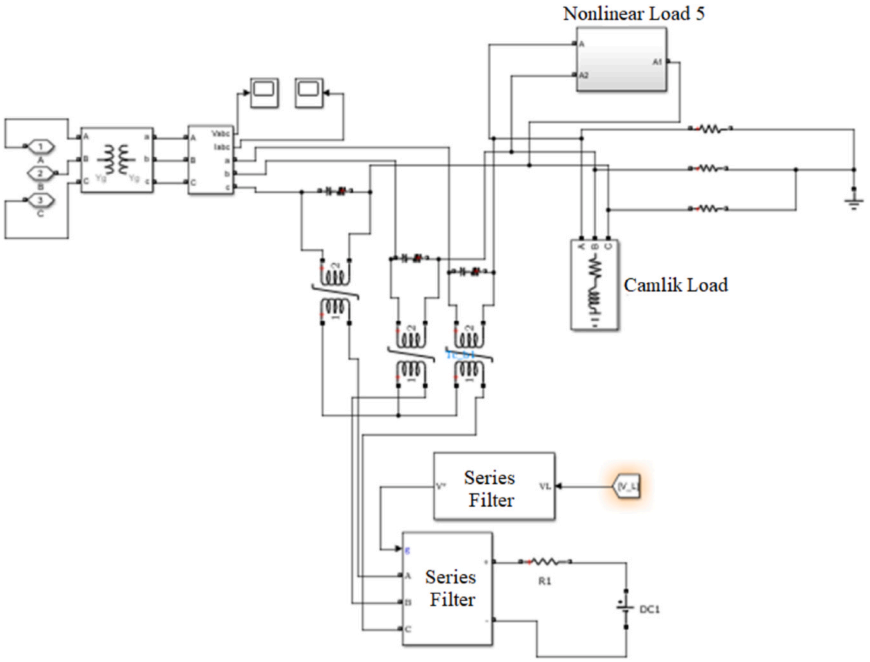


Fig. 11. MATLAB/Simulink modeling of Güre campus schematic with Series active power filter for simulation of all units design.

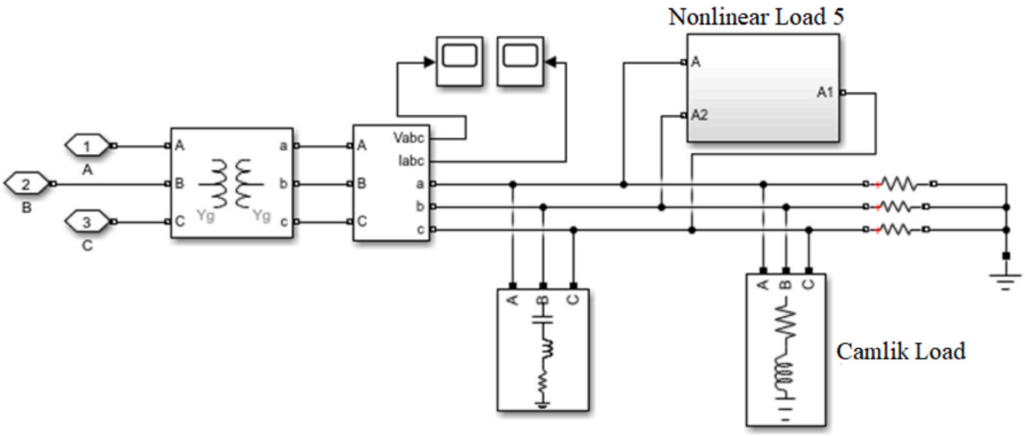
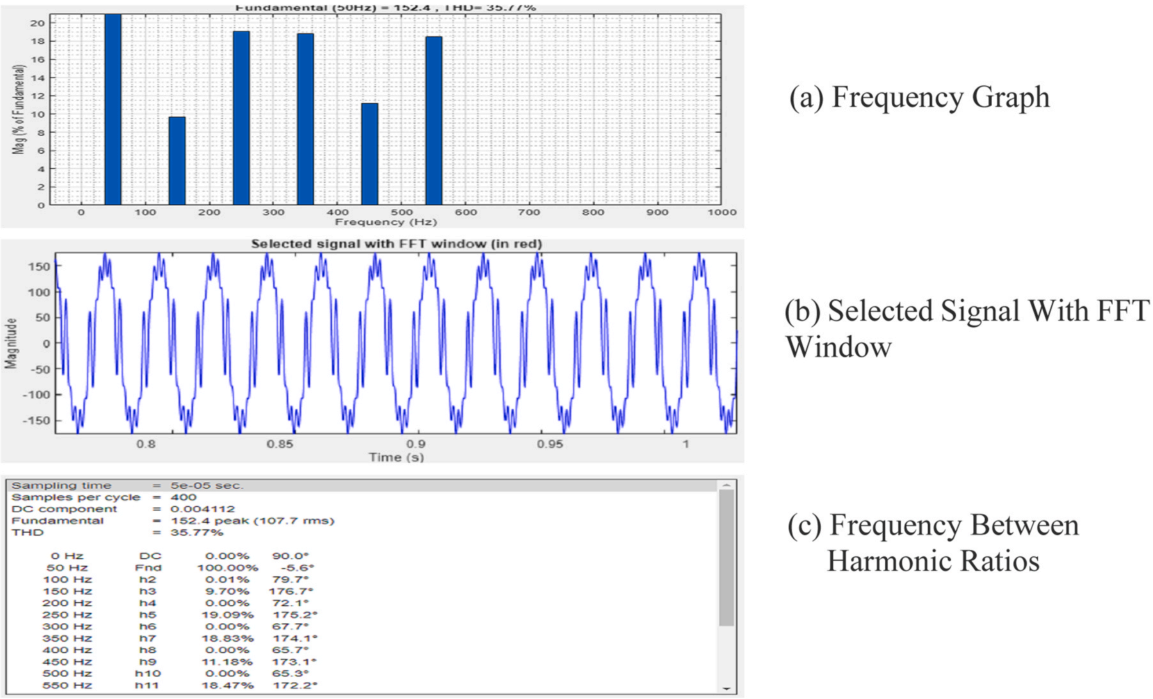


Fig. 12. MATLAB/Simulink modeling of Güre campus schematic for simulation of a single-tuned shunt filter with all units design.

Science and Letters, Faculty of Economics and Administrative Sciences transformer have reached the international (IEC 519–1992) standard, and the 5th, 7th and 11th harmonics have been partially eliminated, but not to the limit determined according to the international (IEC 519–1992) standard. It is seen that the 3rd, 5th, 7th, 9th harmonics of the transformer of the Faculty of Education come to the international (IEC 519–1992) standard and the 11th harmonic is almost at the international (IEC 519–1992) standard. For all faculties, the basic frequency value for the system is 50 Hz. After the analysis of the loaded parts in the case of single tuned shunt filter for harmonics, the results are presented in the form of a table.

When we look at the FFT analysis given in Fig. 15, it is seen that the result values of harmonics 3, 5, 7, 9 and 11 of the single tuned shunt filtered state of the Faculty of Sports Sciences transformer exceed the international (IEC 519–1992) standard. Again, when we examine the graphs given in Annex-D, it is seen that the result values for the harmonics of the Rectorate transformer with single tuned shunt filter exceed the international (IEC 519–1992) standard. It is seen that the result values of the 3, 5, 7, 9 and 11 harmonics of the Faculty of Engineering and the 5, 7 and 11 harmonics of the transformer of the Faculty of Science, Literature and Economics and Administrative Sciences exceed the international (IEC 519–1992) standard. Except for the result values of the 11th harmonic of the Faculty of Education transformer, it is understood that the other harmonics meet the international (IEC 519–1992) standard.

If we give information for the inductively loaded system from the analysis diagram and amplitude spectrum based on the Matlab/Simulink outputs of the case with series active power filter of the Faculty of Sports Sciences transformer in Fig. 15, it is seen that the 3, 5, 7, 9 and 11harmonics of the Faculty of Sports Sciences transformer are reduced to the limit values determined according to the (IEC 519–1992) standard, respectively, based on the Matlab/Simulink outputs of the case without filter and the case with a single tuned shunt filter. In the same way, it is seen that the same harmonics of the Rectorate transformer, the Faculty of Engineering transformer, the Faculty of Science and Letters and Faculty of Economics and Administrative Sciences transformer, the Faculty of Education transformer in Fig. 2, and the Çamlık transformer in Fig. 1, which are given in Appendix-E, have decreased to the limit values determined according to the (IEC 519–1992) standard. The fundamental frequency value for the system is 50 Hz. After the analysis



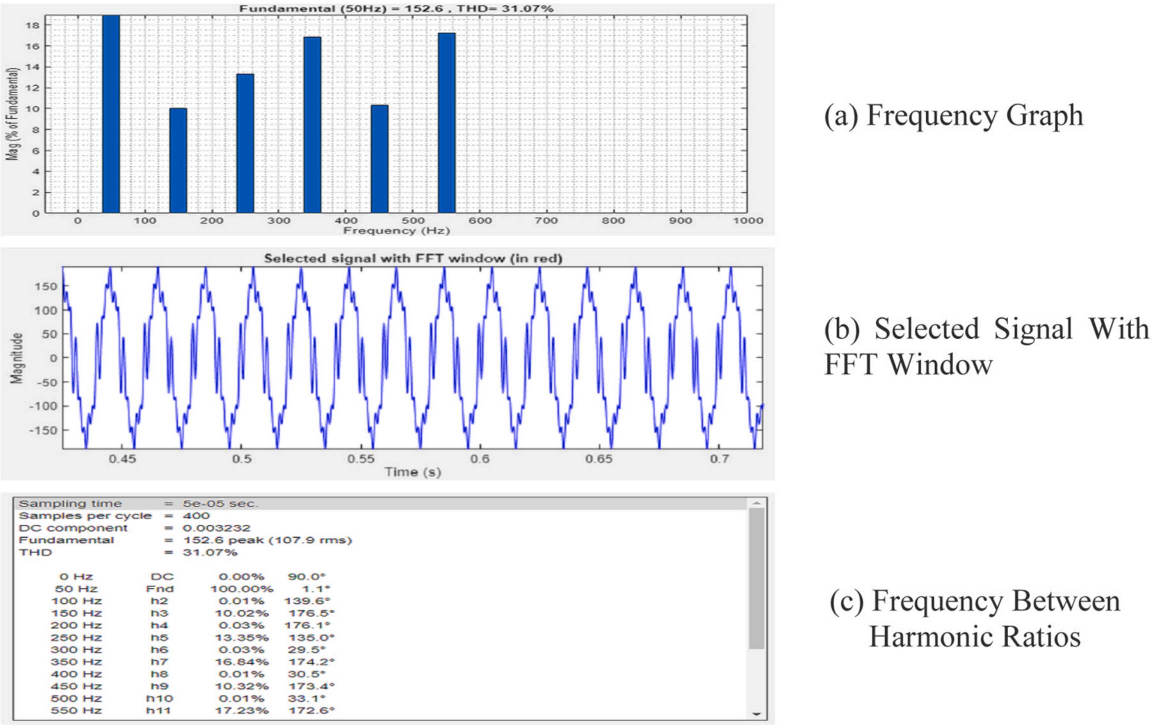
(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

```
Sampling time      =  5e-05 sec.
Samples per cycle  =  400
DC component       =  0.004112
Fundamental        =  152.4 peak (107.7 rms)
THD                =  35.77%

     0 Hz      DC       0.00%    90.0°
    50 Hz      Fnd    100.00%    -5.6°
   100 Hz      h2       0.01%    79.7°
   150 Hz      h3       9.70%   176.7°
   200 Hz      h4       0.00%    72.1°
   250 Hz      h5      19.09%   175.2°
   300 Hz      h6       0.00%    67.7°
   350 Hz      h7      18.83%   174.1°
   400 Hz      h8       0.00%    65.7°
   450 Hz      h9      11.18%   173.1°
   500 Hz      h10      0.00%    65.3°
   550 Hz      h11     18.47%   172.2°
```

Fig. 13. Matlab/Simulink outputs of the simulation of the Faculty of Sports Sciences transformer without filter.



(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

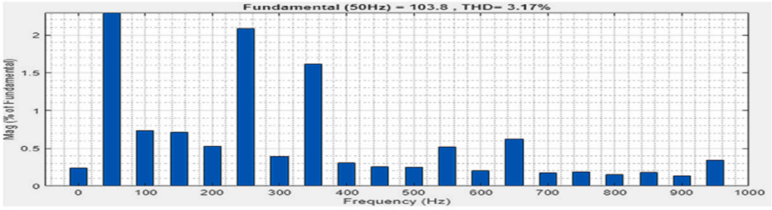
```
Sampling time      =  5e-05 sec.
Samples per cycle  =  400
DC component       =  0.003232
Fundamental        =  152.6 peak (107.9 rms)
THD                =  31.07%

     0 Hz      DC       0.00%    90.0°
    50 Hz      Fnd    100.00%     1.1°
   100 Hz      h2       0.01%   139.6°
   150 Hz      h3      10.02%   176.5°
   200 Hz      h4       0.03%   176.1°
   250 Hz      h5      13.35%   135.0°
   300 Hz      h6       0.03%    29.5°
   350 Hz      h7      16.84%   174.2°
   400 Hz      h8       0.01%    30.5°
   450 Hz      h9      10.32%   173.4°
   500 Hz      h10      0.01%    33.1°
   550 Hz      h11     17.23%   172.6°
```

Fig. 14. Matlab/Simulink outputs of the Sports Sciences transformer with single tuned shunt filter.

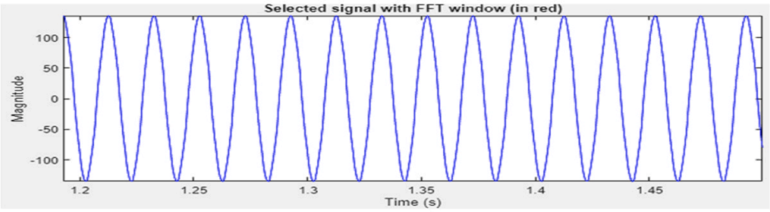
of the loaded parts in the case of series active power filter for harmonics, the results are presented in the form of a table.

In the FFT analysis shown in Fig. 12, it is understood that the result values come to the international (IEC 519–1992) standard for the harmonics of the series active power filtered condition of the transformer of the Faculty of Sports Sciences and that the system eliminates harmonics. When we examine the graphs given in Appendix-E, we see that the harmonics of Çamlık transformer, Faculty of Education transformer, Faculty of Science, Literature and Economics and Administrative Sciences transformer, Faculty of Engineering transformer and Rectorate transformer with series active power filter give the same result in FFT analysis.

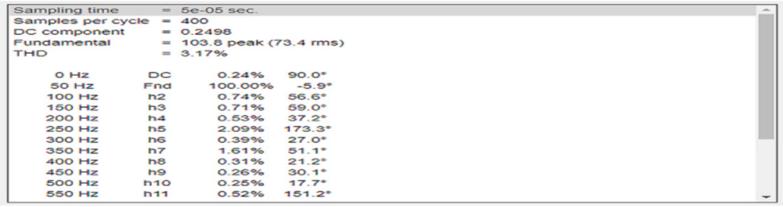
Looking at the simulation results, first of all, the effects of current harmonics are seen when the filter is not activated and based on the information provided by the results, the flickering in the ideal sine waves indicates the presence of harmonics in the system. After the single



(a) Frequency Graph



(b) Selected Signal With FFT Window



```
Sampling time      =  5e-05 sec.
Samples per cycle  =  400
DC component       =  0.2498
Fundamental        =  103.8 peak (73.4 rms)
THD                =  3.17%

   0 Hz      DC       0.24%    90.0°
  50 Hz      Fnd    100.00%    -5.9°
 100 Hz      h2       0.74%    56.6°
 150 Hz      h3       0.71%    59.0°
 200 Hz      h4       0.53%    37.2°
 250 Hz      h5       2.09%   173.3°
 300 Hz      h6       0.39%    27.0°
 350 Hz      h7       1.61%    51.1°
 400 Hz      h8       0.31%    21.2°
 450 Hz      h9       0.26%    30.1°
 500 Hz      h10      0.25%    17.7°
 550 Hz      h11      0.52%   151.2°
```

(c) Frequency Between Harmonic Ratios

Fig. 15. Matlab/Simulink outputs of the Faculty of Sports Sciences transformer with series active power filter.

tuned shunt filter is activated, the current harmonics are reduced and after the series active power filter is activated, they are almost at the level of international standards. Table 3 shows the test result values for Total Harmonic Distortion Current when the single tuned shunt filter is activated and when the series active power filter is activated.

4. Discussion

In the results obtained, there were harmonic current collection and cancellation effects between individual loads operating on the same grid caused by phase angle variation as well as a system impedance and corresponding voltage distortions. This is in line with harmonic studies on the impact of electrical equipment on the power grid (Committee and Power, 2014; Gong et al., 2021). Current harmonic pollution in the distribution system. Another value of this study is that it provides a framework for comparing harmonic pollution in the distribution system. The harmonic impact of various devices in a consistent manner. The next effort is to increase the number of devices. Thus, a useful database can be created (Yazdani-Asrami et al; Santha Kumar et al., 2021). Appliances commonly used in commercial and residential installations can be significant sources of harmonic currents. This is especially true when considering the simple approach to estimate the level of harmonic current injection into the power grid. The composite approach also contributes to the harmonic generating characteristics of electrical equipment (Michalec et al., 2021). In this study, a one-day measurement was made with the help of an energy analyzer in the transformers belonging to the units located in Giresun University Güre Campus. Measurements were made by recording harmonic analysis, voltage values, current values and power values. When the energy network of Giresun University is examined in general terms, it is seen that there are many power electronics circuits that will cause harmonic generation. The effects of the ballasts of fluorescent lamps in the Güre Campus electrical facilities should be minimized. LED luminaires or electronic ballasts are recommended for lighting. As a result of the simulation application, a series active power filter is proposed to bring harmonics to the IEEE standard. By integrating the design into the system, the energy quality and harmonic problem will be eliminated to a great extent. The disturbing harmonic effects on laboratories, electronic devices in classrooms, computers and many devices exposed to harmonics can be minimized. All these arrangements to be made in the examinations made on the Güre campus will minimize the negativities in both material and moral terms, and positive results will be achieved in terms of energy quality. As it is known, energy quality is an important variable in terms of the continuity and stability of the system. Thus, when we reduce energy quality problems with the help of filters, we will go a long way in terms of using the corporate economy efficiently and using resources efficiently. There are typical mitigation techniques used in industry today to reduce harmonic loading in a system (Yazdani-Asrami, M. et al., 2011). These include active filtering, series and shunt passive filtering, multiple pulse rectifiers and isolation transformers (Senthil Kumar et al., 2019; Lumbreras et al., 2020; Park et al., 2021). Power electronics problems and their mitigation techniques play a crucial role in future electrical engineering.

5. Conclusion

For electrical energy systems to operate smoothly, the system must have a certain quality condition. Harmonic currents in the electricity network cause a voltage drop in the impedance of the electricity network. This situation leads to distortion of the waveform of the voltage, increase in losses and malfunctioning of the devices used in the electricity network. As a result of the measurements made at the Güre campus, the analysis results of the existing units have been examined and the THDI of Çamlık transformer is 32.50%, where the harmonic voltage values comply with the IEEE standard and the harmonic current values do not comply with the IEEE standard, The THDI of the Faculty of Engineering transformer was 42.37 %, the THDI of the Faculty of Education transformer was 11.42 %, the THDI of the Faculty of Arts, Sciences, Economics and Administrative Sciences transformer was 27.26 %, the THDI of the Rectorate transformer was 35.08 %, and the THDI of the Faculty of Sports Sciences transformer was 35.77 %. As a result of these results, it is also shown in the form of harmonic graphs and FFT analysis of each unit. Considering the disturbing effects of harmonics, considering that the infrastructures of the units in the Güre campus produce harmonic sources; passive harmonic filter and active harmonic filter design were made with the help of simulation. A single tuned shunt filter was used as a passive harmonic filter and was included in the system due to its design, cost and ease of connection. After the existing energy system in Güre campus was modeled through MATLAB program and harmonic sources were added to the system; As a result of the measurements made by including a single-tuned shunt filter in the simulation of the units, among the units where the harmonic current values do not comply with the IEEE standard, the THDI of Çamlık transformer is 23.51 %, the THDI of Engineering Faculty transformer is 33.79 %, the THDI of Education Faculty transformer is 8 %, 65 %, the THDI of the transformer of the Faculty of Arts, Sciences, Economics and Administrative Sciences was 17.55 %, the THDI of the rectorate transformer was 27.53 %, the THDI of the transformer of the Faculty of Sports Sciences was 31.07 %, and the harmonics were eliminated to a certain extent but did not reach the IEEE standard. As a result of these results, it is also shown in the form of harmonic graphs and FFT analysis of each unit. Series active power filter was used as active harmonic filter and it was included in the system due to its design and cost. After the existing energy system in Güre campus was modeled through MATLAB program and harmonic sources were added to the system; As a result of the measurements made by including a series active power filter in the simulation of the units, the harmonic current values came to the IEEE standard in almost all units, the THDI of Çamlık transformer was 5.65 %, the THDI of the Engineering Faculty transformer was 3.51 %, the THDI of the education faculty transformer was 5 %, 23 %, the THDI of the transformer of the Faculty of Arts, Sciences, Economics and Administrative Sciences is 5.49 %, the THDI of the Rectorate transformer is 3.27%, and the THDI of the transformer of the Faculty of Sports Sciences is 3.17 %, which eliminates harmonics and almost reaches the IEEE standard. In this study, harmonics are analyzed for different types of nonlinear loads in the power system and measures that can be taken are presented. Here, the system is modeled and simulated in MATLAB/ Simulink program to see the harmonic distortions before and after using the filter for inductive and capacitive load cases.

Ethical approval and permission to participate

This article does not require ethical approval or permission to participate.

Financing

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Release permission

The authors performed this work themselve. There was no need for a release from elsewhere.

Declarations

All manuscripts should include the following sections under the heading 'Declarations':

CRediT authorship contribution statement

Sabir Rustemli: Software, Writing – review & editing, Investigation of Electrical Energy Quality and Investigation part of harmonics analysis power system due to non-linear loads. **Mehmet Ali Satici**: Software, Writing – review & editing Investigation of Electrical Energy Quality and Investigation part of harmonics analysis power system due to non-linear loads. **Gökhan Şahin:** Software, Writing – review & editing, Investigation Investigation of Electrical Energy Quality and Investigation part of harmonics analysis power system due to non-linear loads. **Wilfried van Sark:** Software, Writing – review & editing, Investigation Investigation of Electrical Energy Quality and Investigation part of harmonics analysis power system due to non-linear loads.

Declaration of Competing Interest

No conflict of interest.

Data availability

No data was used for the research described in the article.

Appendix A

Table1

Average power consumed in the faculties on 10/01/2022 between 08:00–18:00 and 20:00–08:00 by analyzing the faculty subscriptions.

	Sport Sciences Faculty	Education Faculty	Education **Faculty**	Rectorate Building	Çamlık Transformer	Arts and Sciences Faculty and Economics and Administrative Sciences Faculty
Average power consumed during the measurement	39,72 kW	52,38 kW	28,88 kW	31,21 kW	57,40 kW	203,14 kW
Power consumed between 08:00–18:00 on 10/01/2022	60,47 kW	71,24 kW	41,59 kW	46,36 kW	65,08 kW	238,24 kW
Power consumed between 20:00–08:00	23,48 kW	35,55 kW	18,78 kW	21,04 kW	49,42 kW	137,77 kW

Table 2

Minimum, average and maximum voltage values when the voltage curve graph is analyzed.

	Sport Sciences Faculty	Education Faculty	Education **Faculty**	Rectorate Building	Çamlık Transformer	Arts and Sciences Faculty and Economics and Administrative Sciences Faculty
Minimum value of U1 (RMS) (V) voltage	393,10 V	391,80 V	392,10 V	392,00 V	391,80 V	395,18 V
Minimum value of U2 (RMS) (V) voltage	392,10 V	392,60 V	392,90 V	393,40 V	391,10 V	394,13 V
Minimum value of U3 (RMS) (V) voltage	393,80 V	393,30 V	393,90 V	392,90 V	392,70 V	393,60 V
Average value of U1 (RMS) (V) voltage	398,51 V	397,45 V	397,30 V	397,13 V	399,54 V	399,53 V
Average value of U2 (RMS) (V) voltage	402,60 V	398,44 V	398,19 V	399,17 V	398,99 V	399,36 V
Average value of U3 (RMS) (V) voltage	399,76 V	399,60 V	399,85 V	398,07 V	401,16 V	399,67 V

(*continued on next page*)

Table 2 (*continued*)

Maximum value of U1 (RMS) (V) voltage	404,40 V	402,70 V	402,30 V	402,30 V	408,30 V	403,30 V
Maximum value of U2 (RMS) (V) voltage	402,60 V	404,30 V	403,80 V	405,70 V	407,40 V	402,70 V
Maximum value of U3 (RMS) (V) voltage	406,30 V	406,00 V	406,10 V	404,00 V	410,80 V	405,60 V

Table 3
Minimum, average and maximum voltage values when the graph of one-day current harmonics consumed when the subscriptions of the faculties are analyzed.

	Sport Sciences Faculty	Education Faculty	Education Faculty	Rectorate Building	Çamlık Transformer	Arts and Sciences Faculty and Economics and Administrative Sciences Faculty
A1 Minimum value of THDI	%20,50	%5,00,	%18,30	%21,60	%19,14	%22,56
A2 Minimum value of THDI	%18,50	%6,70,	%13,50	%17,89	%17,88	%19,07
A3 Minimum value of THDI	%22,10	%7,90	%27,20	%22,16	%21,02	%23,18
A1 Average value of THDI	% 29,05	% 8,43,	%38,81	%27,11	% 27,36	%26,16
A2 Average value of THDI	% 40,57	% 10,43,	%28,40	%41,03	%38,47	%28,78
A3 Average value of THDI	%37,67	% 15,33	%60,79	%37,10	%33,13	%28,65
A1 Maximum value of THDI	%41,00	%15,90,	%66,10	%43,06	%40,61	%41,12
A2 Maximum value of THDI	%54,20	%23,30,	%48,40	%55,10	%52,14	%55,03
A3 Maximum value of THDI	%52,60	%33,00	%93,70	%51,39	%49,75	%53,36

Table 4
Minimum, average and maximum voltage values when the graph of one-day voltage harmonics consumed in faculties is analyzed.

	Sport Sciences Faculty	Education Faculty	Education Faculty	Rectorate Building	Çamlık Transformer	Arts and Sciences Faculty and Economics and Administrative Sciences Faculty
U1 Minimum value of THDV	%0,70	%0,90	%1,00	%0,70	%0,70	%0,71
U2 Minimum value of THDV	%0,80	%0,80	%0,80	%0,80	%0,80	%0,82
U3 Minimum value of THDV	%0,70	%0,80	%1,00	%0,70	%0,70	%0,69
U1 Average value of THDV	%1,19	%1,28	%1,46	%1,19	%1,19	%1,24
U2 Average value of THDV	% 1,25	%1,24	%1,11	%1,25	%1,25	%1,31
U3 Average value of THDV	%1,12	%1,13	%1,38	%1,12	% 1,12	%1,10
U1 Maximum value of THDV	%1,70	%1,50	%1,70	%1,70	%1,70	%1,71
U2 Maximum value of THDV	%1,60	%1,40	%1,30	%1,60	%1,60	%1,62
U3 Maximum value of THDV	%1,50	%1,40	%1,70	%1,50	%1,50	%1,49

Table 5
Minimum, average and maximum voltage values when the current graph of a day consumed in faculties is analyzed.

	Sport Sciences Faculty	Education Faculty	Engineering Faculty	Rectorate Building	Çamlık Transformer	Arts and Sciences Faculty and Economics and Administrative Sciences Faculty
A1 (RMS) (I) akımının minimum değeri	40.40	47.80 A	33 A	19.90	73.30	43.30%0,71
A2 (RMS) (I) akımının minimum değeri	24.30	51.30 A	27.20 A	17.70	65.70	26.16
A3 (RMS) (I) akımının minimum değeri	21.00	51.50 A	23.50 A	26.90	67.40	23.11
A1 (RMS) (I) akımının ortalama değeri	72.14	77.45 A	57.51 A	44.77	92.44	75.56
A2 (RMS) (I) akımının ortalama değeri	57.35	81.32 A	47.48 A	40.63	92.97	53.44
A3 (RMS) (I) akımının ortalama değeri	53.66	80.98 A	35.68 A	55.36	86.17	56.71
A1 (RMS) (I) akımının maksimum değeri	135.70	139.10 A	97.90	107.20	120.40	139.72

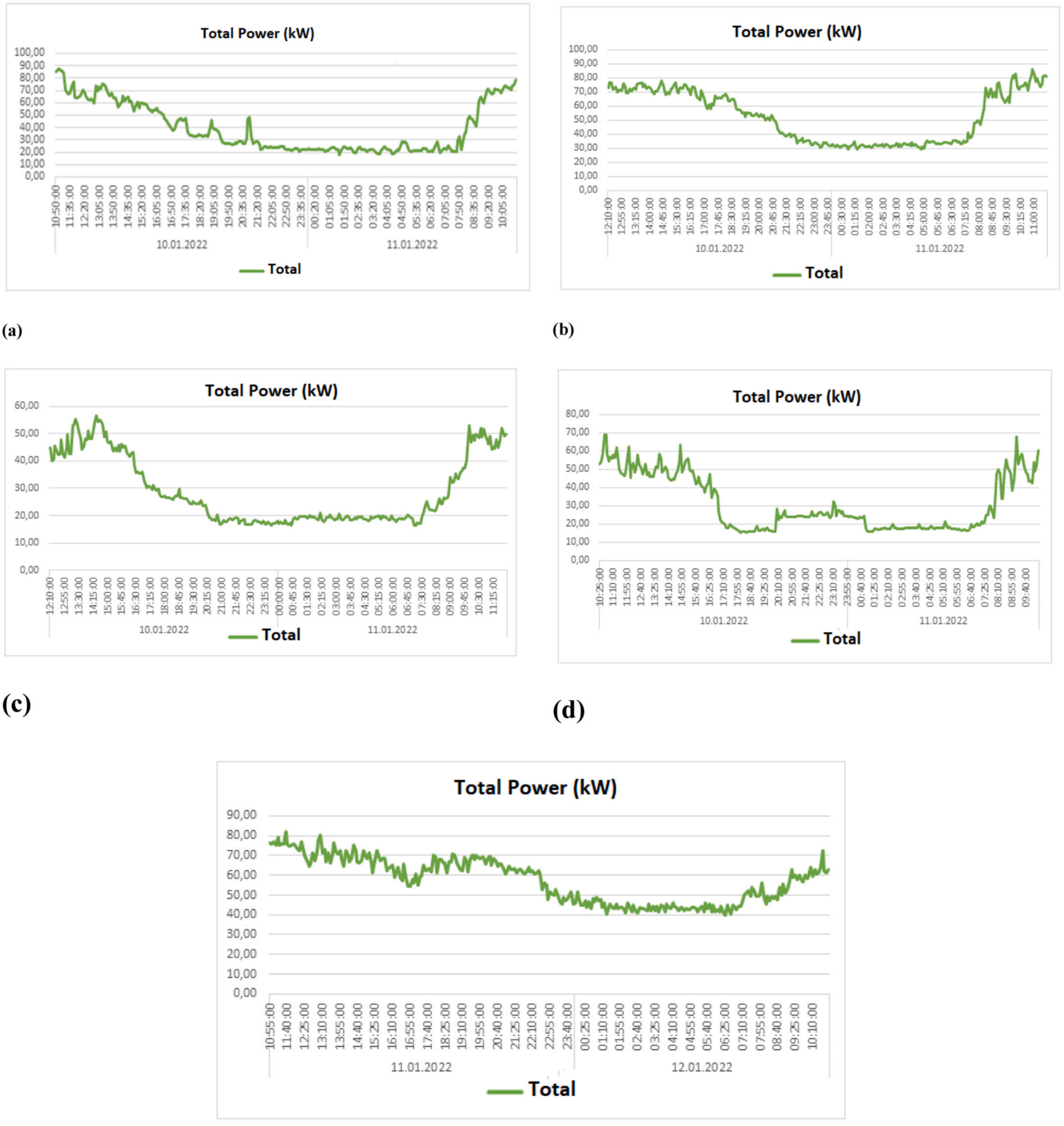
(*continued on next page*)

Table 5 (*continued*)

A2 (RMS) (I) akımının maksimum değeri	135.70	134.50 A	96.50	92.70	146.10	138.13
A3 (RMS) (I) akımının maksimum değeri	123.10	126.80 A	70.40	123.70	121.20	132.16

Appendix B

On 10/01/2022, measurements were made for one day with the Energy Analyzer Device at the Faculty of Sports Sciences, Faculty of Engineering, Rectorate Building, Faculty of Science and Letters, Faculty of Economics and Administrative Sciences and Çamlık Transformer. With this study, time-dependent power, voltage, current harmonic, voltage harmonic and current graphs of the electricity consumed in the panel were obtained.



(a)

(b)

(c)

(d)

(e)

Fig. 16. One-day total power parameters curve for (a) Faculty of Sports Sciences building, (b) Faculty of Education building, (c) Faculty of Engineering building, (d) Rectorate building, (e) Çamlık transformer building.

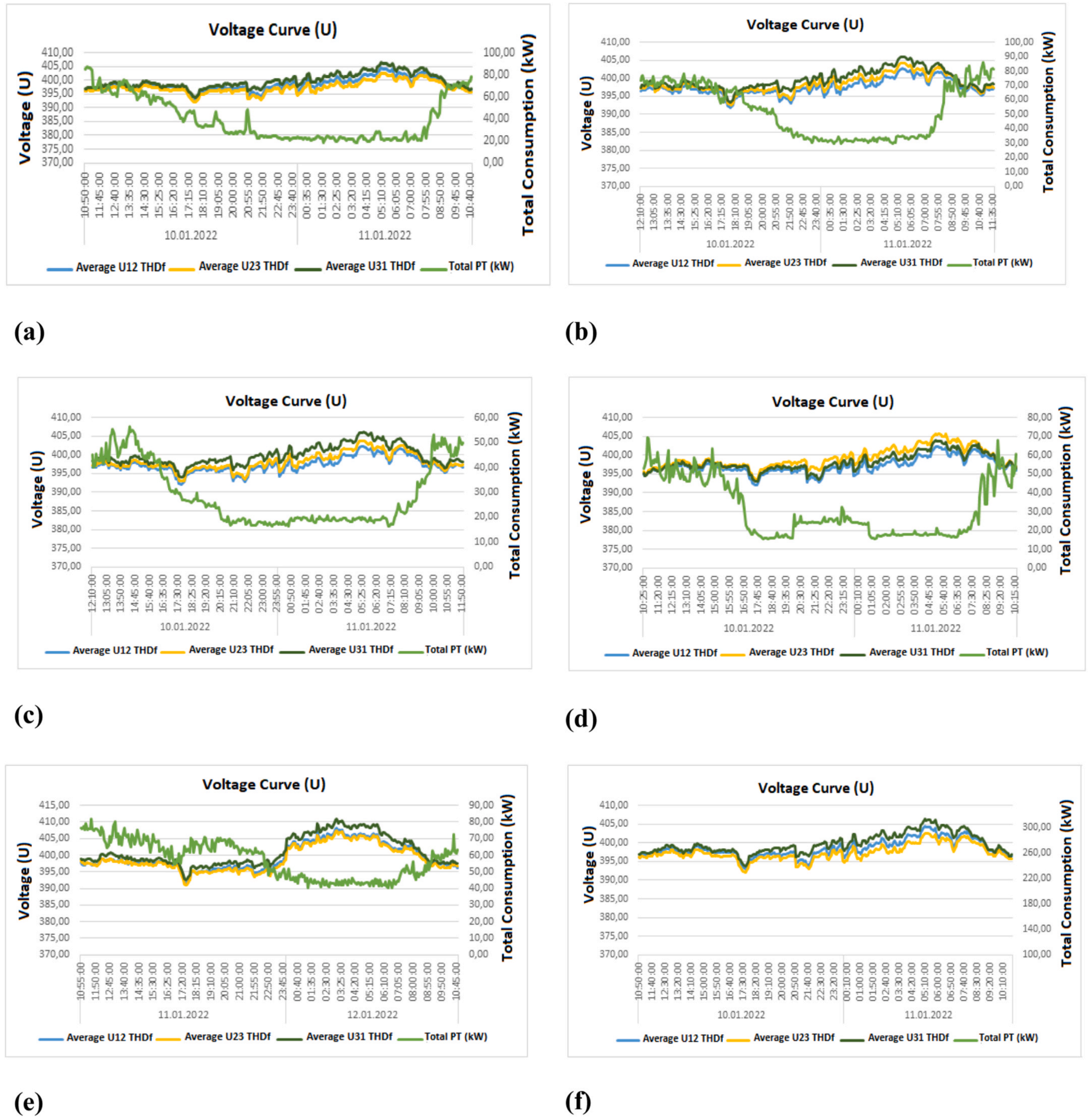


Fig. 17. One-day Voltage Parameters curve of Each Phase of Three Phase System of (a) Faculty of Sports Sciences, (b) Faculty of Education, (c) Faculty of Engineering, (d) Rectorate building, (e) Çamlık transformer building and (f) Faculty of Arts and Sciences substation-380 V.

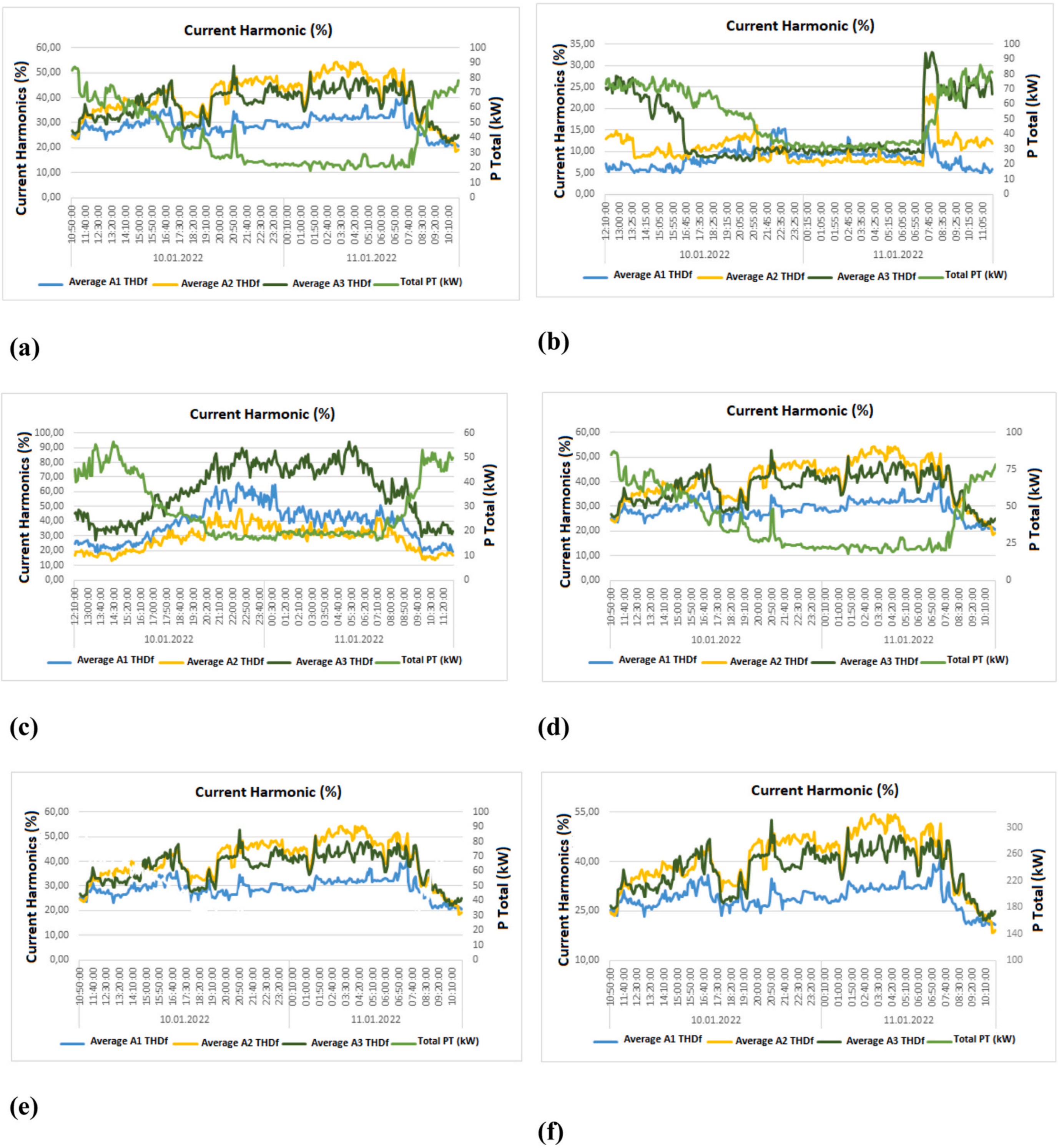
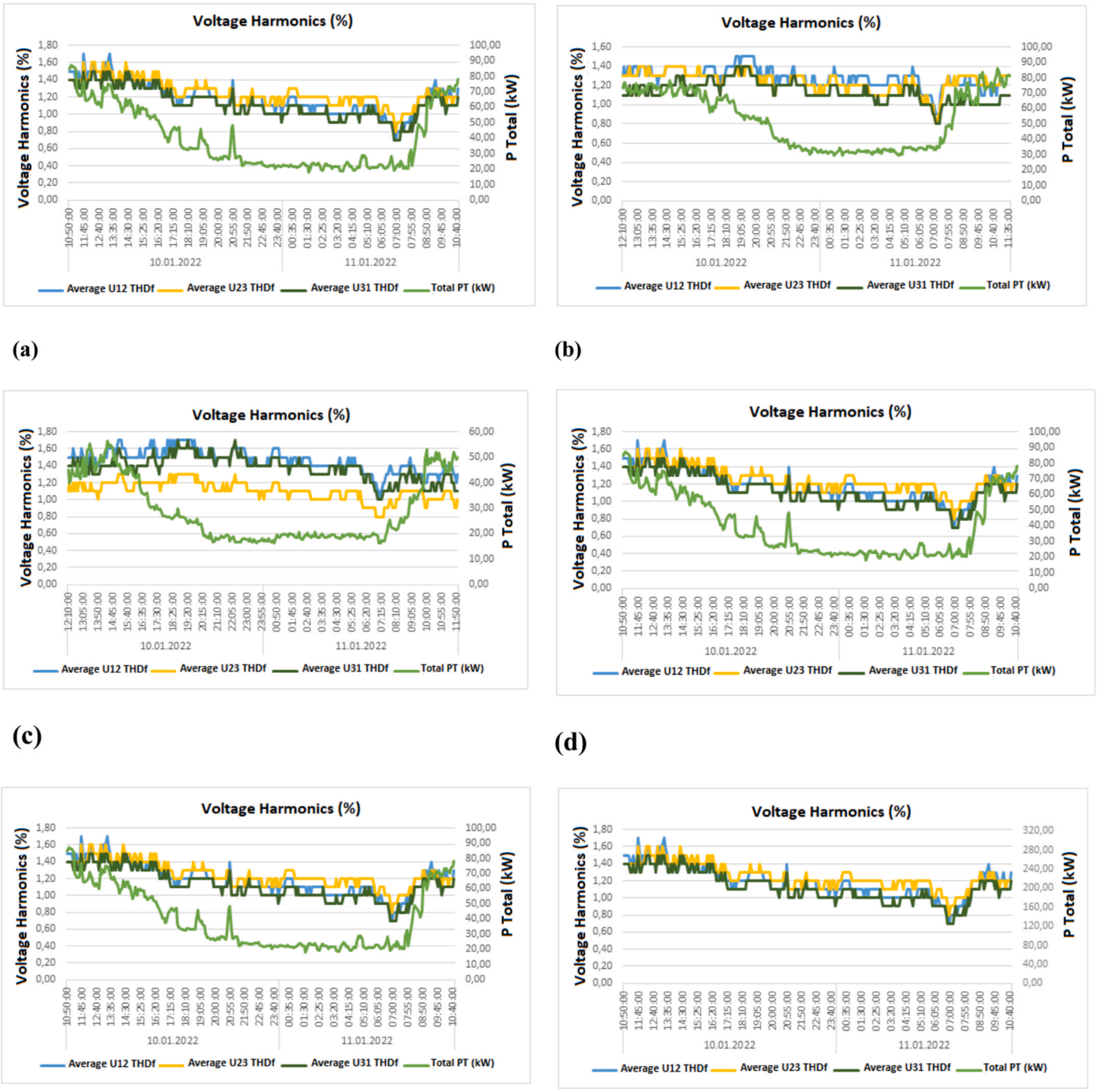


Fig. 18. One-day Current Parameters graph of Each Phase of Three Phase System of (a) Faculty of Sports Sciences, (b) Faculty of Education, (c) Faculty of Engineering, (d) Rectorate building, (e) Çamlık substation and (f) Faculty of Arts and Sciences substation.



(a)

(b)

(c)

(d)

(e)

(f)

Fig. 19. One-day Voltage Harmonic Parameters graph of Each Phase of Three Phase System of (a) Faculty of Sports Sciences building, (b) Faculty of Education building, (c) Faculty of Engineering building, (d) Rectorate building, (e) Çamlık substation building, (f) Faculty of Arts and Sciences substation.

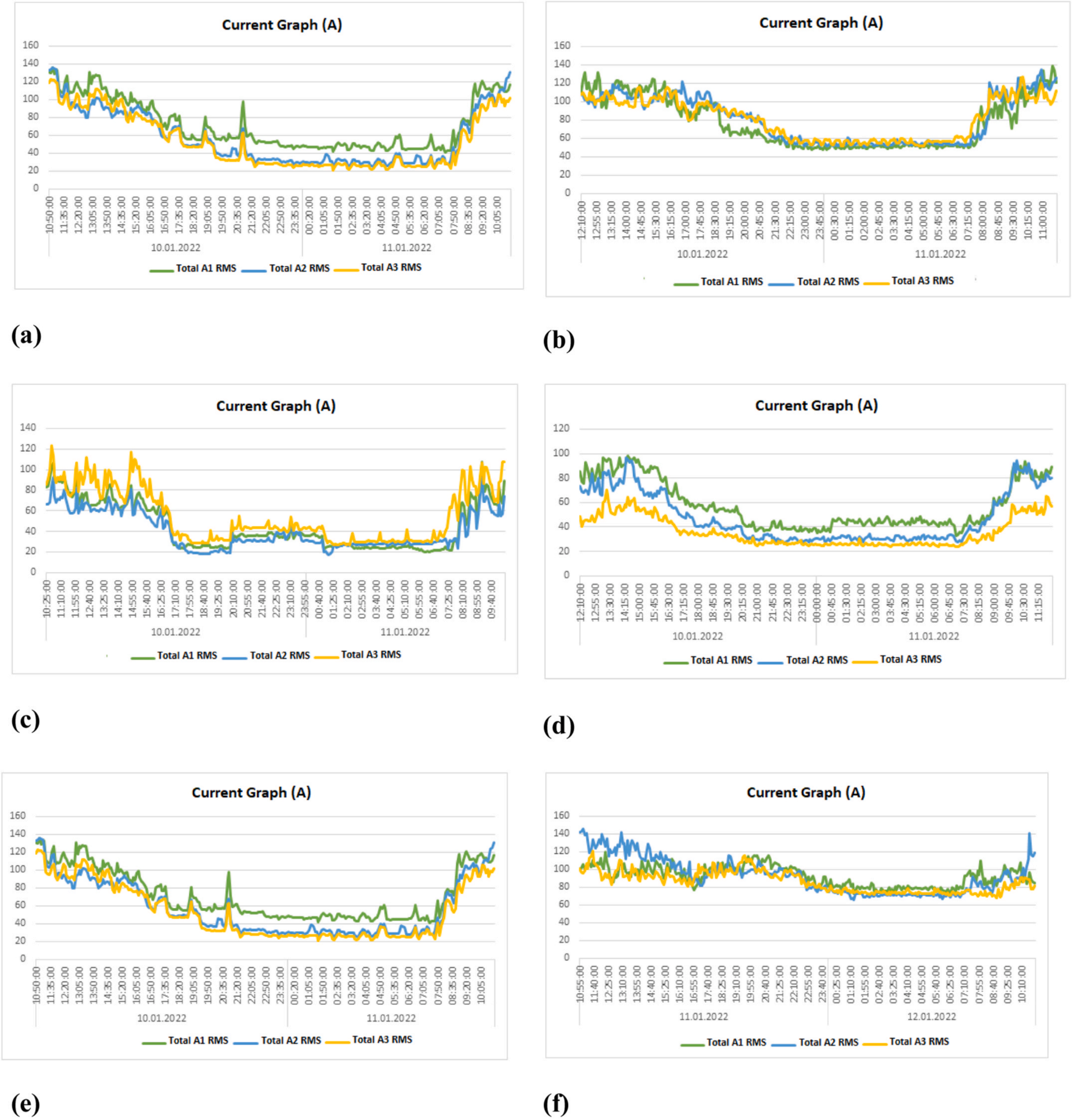


Fig. 20. A daily Current Harmonic Parameters graph of Each Phase of Three Phase System of (a) Faculty of Sports Sciences building (b) Faculty of Education building (c) Rectorate building (d) Faculty of Engineering building (e) Faculty of Arts and Sciences building and (f) Çamlık transformer building.

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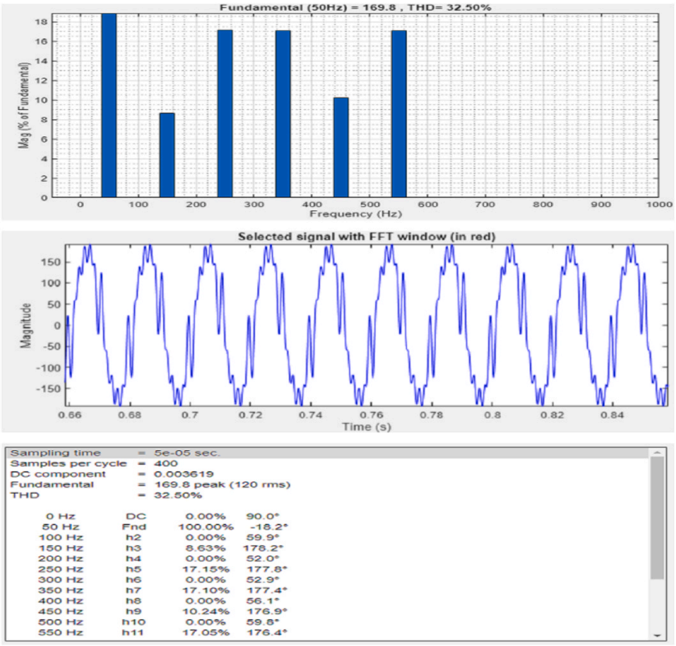
Appendix C

For the simulation of the system, the harmonic state of each unit without filter and the harmonic state with filter are shown in Fig. 1-Fig. 5.



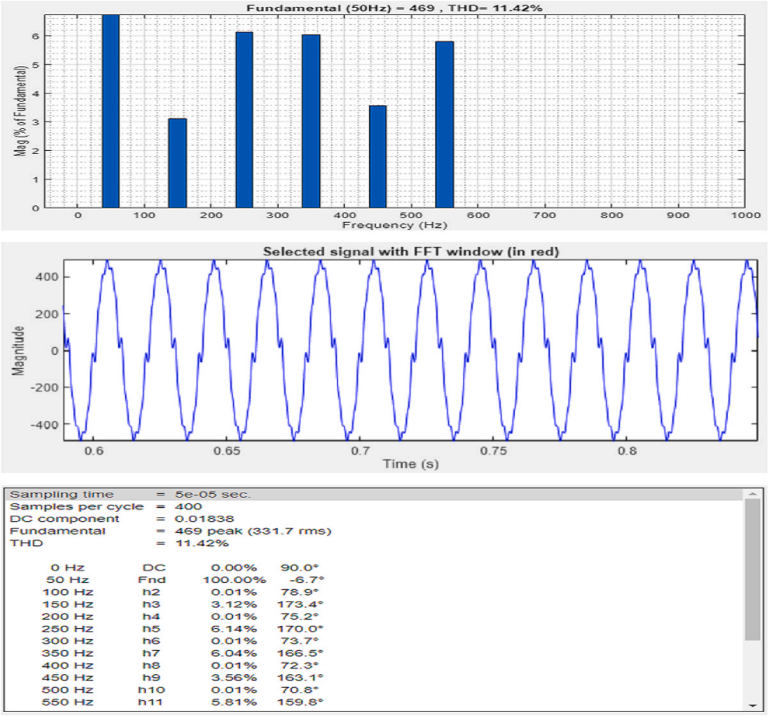
```
Sampling time        =  5e-05 sec.
Samples per cycle    =  400
DC component         =  0.003619
Fundamental          =  169.8 peak (120 rms)
THD                  =  32.50%

      0 Hz        DC       0.00%     90.0°
     50 Hz        Fnd    100.00%    -18.2°
    100 Hz        h2       0.00%     59.9°
    150 Hz        h3       8.63%    178.2°
    200 Hz        h4       0.00%     52.0°
    250 Hz        h5      17.15%    177.8°
    300 Hz        h6       0.00%     52.9°
    350 Hz        h7      17.10%    177.4°
    400 Hz        h8       0.00%     56.1°
    450 Hz        h9      10.24%    176.9°
    500 Hz        h10      0.00%     59.8°
    550 Hz        h11     17.05%    176.4°
```

(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

Fig. 21. Matlab/Simulink outputs for the simulation of Çamlık transformer without filter.



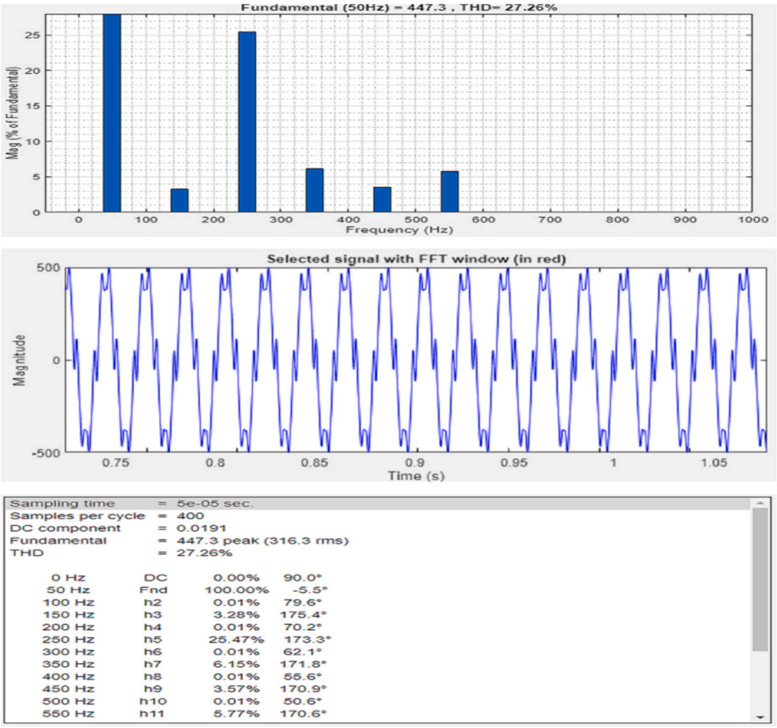
```
Sampling time        =  5e-05 sec.
Samples per cycle    =  400
DC component         =  0.01838
Fundamental          =  469 peak (331.7 rms)
THD                  =  11.42%

      0 Hz        DC       0.00%     90.0°
     50 Hz        Fnd    100.00%     -6.7°
    100 Hz        h2       0.01%     78.9°
    150 Hz        h3       3.12%    173.4°
    200 Hz        h4       0.01%     75.2°
    250 Hz        h5       6.14%    170.0°
    300 Hz        h6       0.01%     73.7°
    350 Hz        h7       6.04%    166.5°
    400 Hz        h8       0.01%     72.3°
    450 Hz        h9       3.56%    163.1°
    500 Hz        h10      0.01%     70.8°
    550 Hz        h11      5.81%    159.8°
```

(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

Fig. 22. Matlab/Simulink outputs of the simulation of the Faculty of Education transformer without filter.



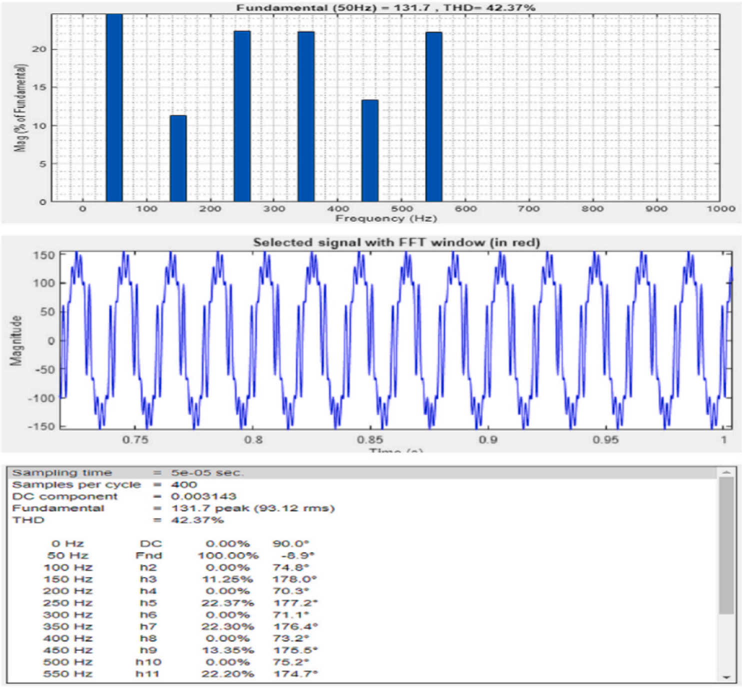
(a) Frequency Graph

(b) Selected Signal With FFT Window

```
Sampling time       =  5e-05 sec.
Samples per cycle   =  400
DC component        =  0.0191
Fundamental         =  447.3 peak (316.3 rms)
THD                 =  27.26%

      0 Hz          DC        0.00%     90.0°
     50 Hz          Fnd     100.00%     -5.5°
    100 Hz          h2        0.01%     79.6°
    150 Hz          h3        3.28%    175.4°
    200 Hz          h4        0.01%     70.2°
    250 Hz          h5       25.47%    173.3°
    300 Hz          h6        0.01%     62.1°
    350 Hz          h7        6.15%    171.8°
    400 Hz          h8        0.01%     55.6°
    450 Hz          h9        3.57%    170.9°
    500 Hz          h10       0.01%     50.6°
    550 Hz          h11       5.77%    170.6°
```

(c) Frequency Between Harmonic Ratios

Fig. 23. Matlab/Simulink outputs for the simulation of the transformer of the Faculty of Arts and Sciences and Faculty of Economics and Administrative Sciences without filter.



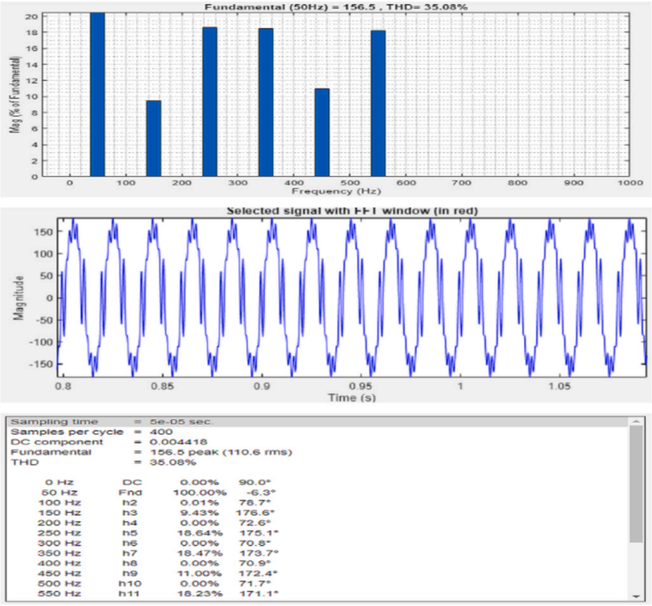
(a) Frequency Graph

(b) Selected Signal With FFT Window

```
Sampling time       =  5e-05 sec.
Samples per cycle   =  400
DC component        =  0.003143
Fundamental         =  131.7 peak (93.12 rms)
THD                 =  42.37%

      0 Hz          DC        0.00%     90.0°
     50 Hz          Fnd     100.00%     -8.9°
    100 Hz          h2        0.00%     74.8°
    150 Hz          h3       11.25%    178.0°
    200 Hz          h4        0.00%     70.3°
    250 Hz          h5       22.37%    177.2°
    300 Hz          h6        0.00%     71.1°
    350 Hz          h7       22.30%    176.4°
    400 Hz          h8        0.00%     73.2°
    450 Hz          h9       13.35%    175.5°
    500 Hz          h10       0.00%     75.2°
    550 Hz          h11      22.20%    174.7°
```

(c) Frequency Between Harmonic Ratios

Fig. 24. Matlab/Simulink outputs of the simulation of the Faculty of Engineering transformer without filter.



(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

```
Sampling time         =  5e-05 sec.
Samples per cycle     =  400
DC component          =  0.004418
Fundamental           =  156.5 peak (110.6 rms)
THD                   =  35.08%

      0 Hz          DC        0.00%    90.0°
     50 Hz          Fnd     100.00%    -6.3°
    100 Hz          h2        0.01%    78.7°
    150 Hz          h3        9.43%   176.6°
    200 Hz          h4        0.00%    72.6°
    250 Hz          h5       18.64%   175.1°
    300 Hz          h6        0.00%    70.8°
    350 Hz          h7       18.47%   173.7°
    400 Hz          h8        0.00%    70.9°
    450 Hz          h9       11.00%   172.4°
    500 Hz          h10       0.00%    71.7°
    550 Hz          h11      18.23%   171.1°
```

Fig. 25. Matlab/Simulink outputs for the simulation of the Rectorate transformer without filter.

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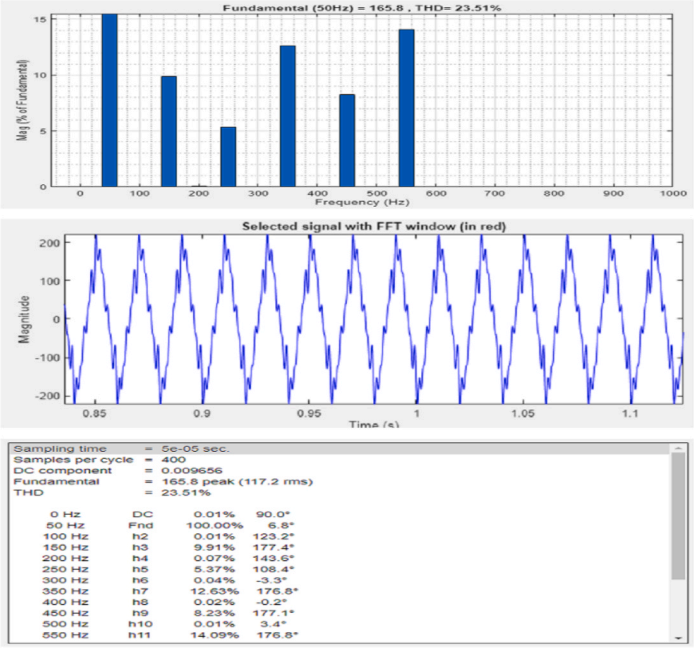
Appendix D

After the analysis of the loaded sections in the unfiltered case for harmonics, the results are presented in the form of tables. Matlab/Simulink outputs for the case with single tuned shunt filter are shown in Fig. 1-Fig. 5.



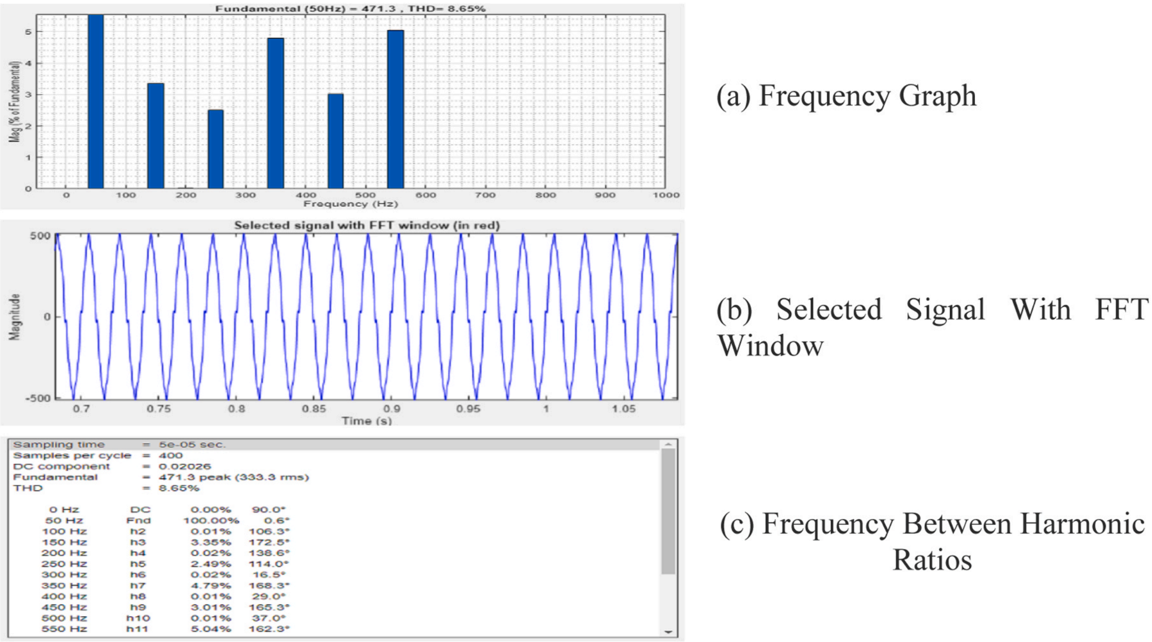
(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

```
Sampling time         =  5e-05 sec.
Samples per cycle     =  400
DC component          =  0.009656
Fundamental           =  165.8 peak (117.2 rms)
THD                   =  23.51%

      0 Hz          DC        0.01%    90.0°
     50 Hz          Fnd     100.00%     6.8°
    100 Hz          h2        0.01%   123.2°
    150 Hz          h3        9.91%   177.4°
    200 Hz          h4        0.07%   143.6°
    250 Hz          h5        5.37%   108.4°
    300 Hz          h6        0.04%    -3.3°
    350 Hz          h7       12.63%   176.8°
    400 Hz          h8        0.02%    -0.2°
    450 Hz          h9        8.23%   177.1°
    500 Hz          h10       0.01%     3.4°
    550 Hz          h11      14.09%   176.8°
```

Fig. 26. Matlab/Simulink outputs of Çamlık transformer with single tuned shunt filter.



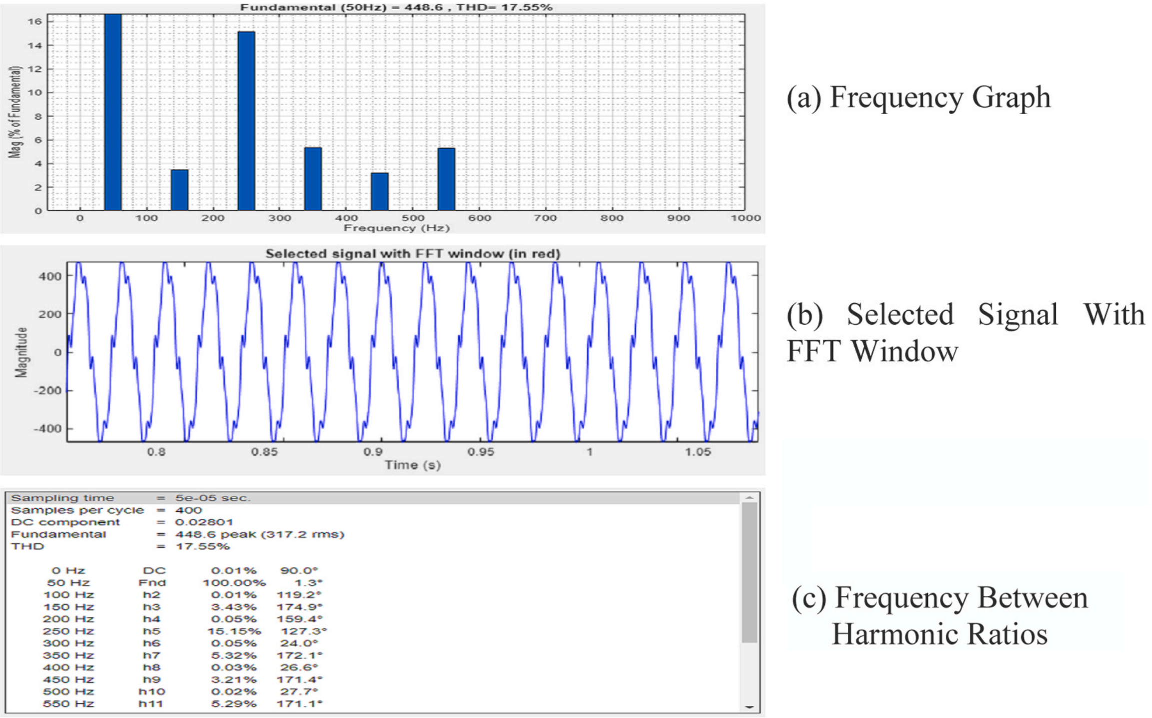
(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

```
Sampling time       =  5e-05 sec.
Samples per cycle   =  400
DC component        =  0.02026
Fundamental         =  471.3 peak (333.3 rms)
THD                 =  8.65%

      0 Hz        DC       0.00%    90.0°
     50 Hz       Fnd     100.00%     0.6°
    100 Hz        h2       0.01%   106.3°
    150 Hz        h3       3.35%   172.5°
    200 Hz        h4       0.02%   138.6°
    250 Hz        h5       2.49%   114.0°
    300 Hz        h6       0.02%    16.5°
    350 Hz        h7       4.79%   168.3°
    400 Hz        h8       0.01%    29.0°
    450 Hz        h9       3.01%   165.3°
    500 Hz       h10       0.01%    37.0°
    550 Hz       h11       5.04%   162.3°
```

Fig. 27. Matlab/Simulink outputs of the Faculty of Education transformer with single tuned shunt filter.



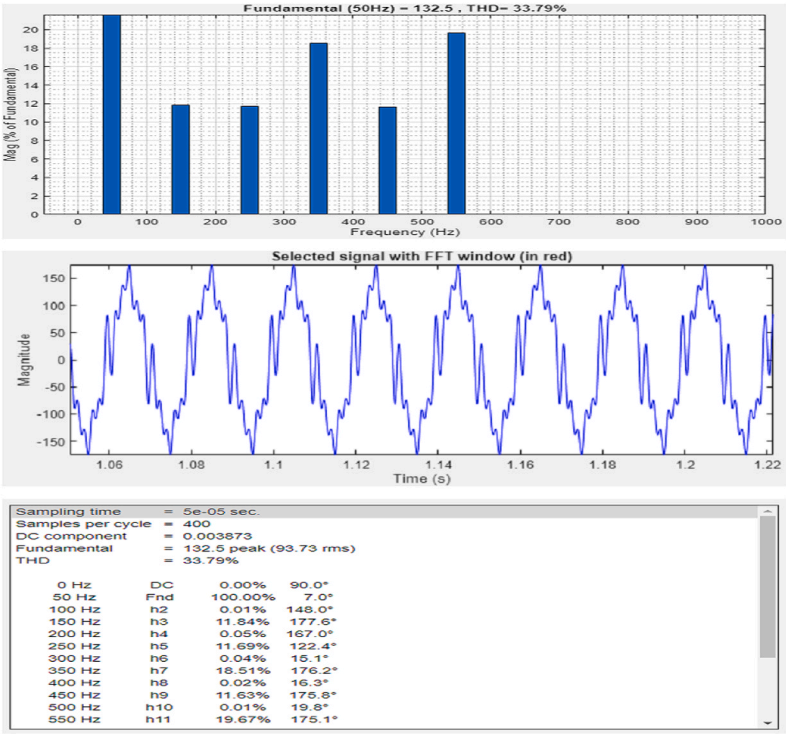
(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

```
Sampling time       =  5e-05 sec.
Samples per cycle   =  400
DC component        =  0.02801
Fundamental         =  448.6 peak (317.2 rms)
THD                 =  17.55%

      0 Hz        DC       0.01%    90.0°
     50 Hz       Fnd     100.00%     1.3°
    100 Hz        h2       0.01%   119.2°
    150 Hz        h3       3.43%   174.9°
    200 Hz        h4       0.05%   159.4°
    250 Hz        h5      15.15%   127.3°
    300 Hz        h6       0.05%    24.0°
    350 Hz        h7       5.32%   172.1°
    400 Hz        h8       0.03%    26.6°
    450 Hz        h9       3.21%   171.4°
    500 Hz       h10       0.02%    27.7°
    550 Hz       h11       5.29%   171.1°
```

Fig. 28. Matlab/Simulink outputs of the Faculty of Arts and Sciences and Faculty of Economics and Administrative Sciences transformer with single tuned shunt filter.



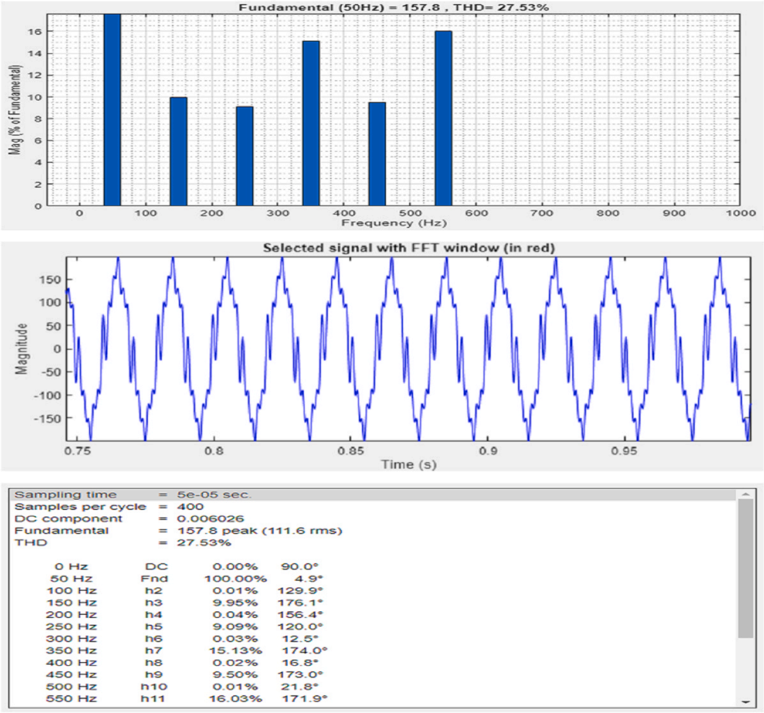
```
Sampling time        =  5e-05 sec.
Samples per cycle    =  400
DC component         =  0.003873
Fundamental          =  132.5 peak (93.73 rms)
THD                  =  33.79%

      0 Hz       DC      0.00%    90.0°
     50 Hz      Fnd    100.00%     7.0°
    100 Hz       h2      0.01%   148.0°
    150 Hz       h3     11.84%   177.6°
    200 Hz       h4      0.05%   167.0°
    250 Hz       h5     11.69%   122.4°
    300 Hz       h6      0.04%    15.1°
    350 Hz       h7     18.51%   176.2°
    400 Hz       h8      0.02%    16.3°
    450 Hz       h9     11.63%   175.8°
    500 Hz      h10      0.01%    19.8°
    550 Hz      h11     19.67%   175.1°
```

(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

Fig. 29. Matlab/Simulink outputs of the Faculty of Engineering transformer with single tuned shunt filter.



```
Sampling time        =  5e-05 sec.
Samples per cycle    =  400
DC component         =  0.006026
Fundamental          =  157.8 peak (111.6 rms)
THD                  =  27.53%

      0 Hz       DC      0.00%    90.0°
     50 Hz      Fnd    100.00%     4.9°
    100 Hz       h2      0.01%   129.9°
    150 Hz       h3      9.95%   176.1°
    200 Hz       h4      0.04%   156.4°
    250 Hz       h5      9.09%   120.0°
    300 Hz       h6      0.03%    12.5°
    350 Hz       h7     15.13%   174.0°
    400 Hz       h8      0.02%    16.8°
    450 Hz       h9      9.50%   173.0°
    500 Hz      h10      0.01%    21.8°
    550 Hz      h11     16.03%   171.9°
```

(a) Frequency Graph

(b) Selected Signal With FFT Window

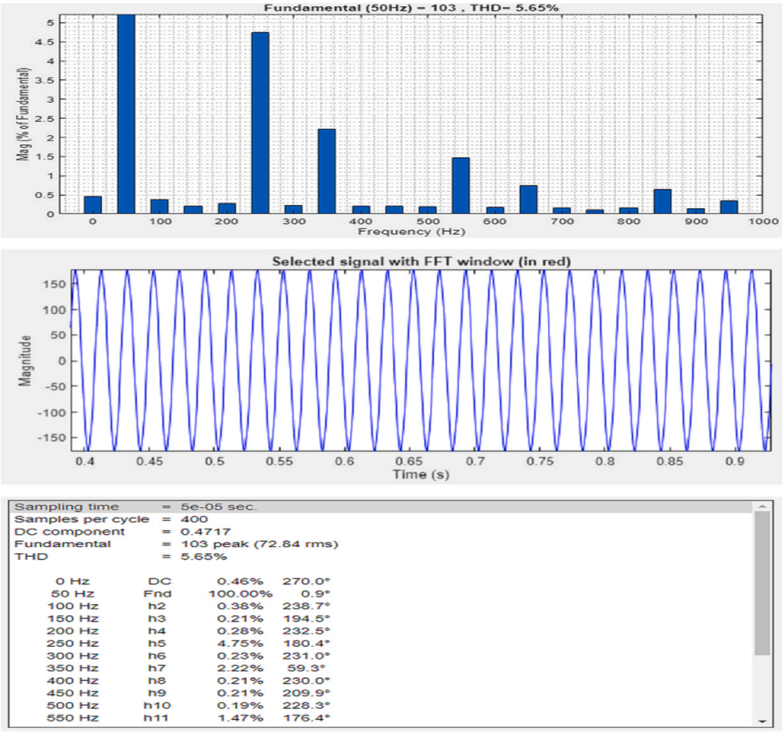
(c) Frequency Between Harmonic Ratios

Fig. 30. Matlab/Simulink outputs of the Rectorate transformer with single tuned shunt filter.

.

Appendix E

After the analysis of the loaded parts in the unfiltered case for harmonics, the results are presented in the form of tables. Matlab/Simulink outputs for the case with series active power filter are shown in Fig. 1-Fig. 5.



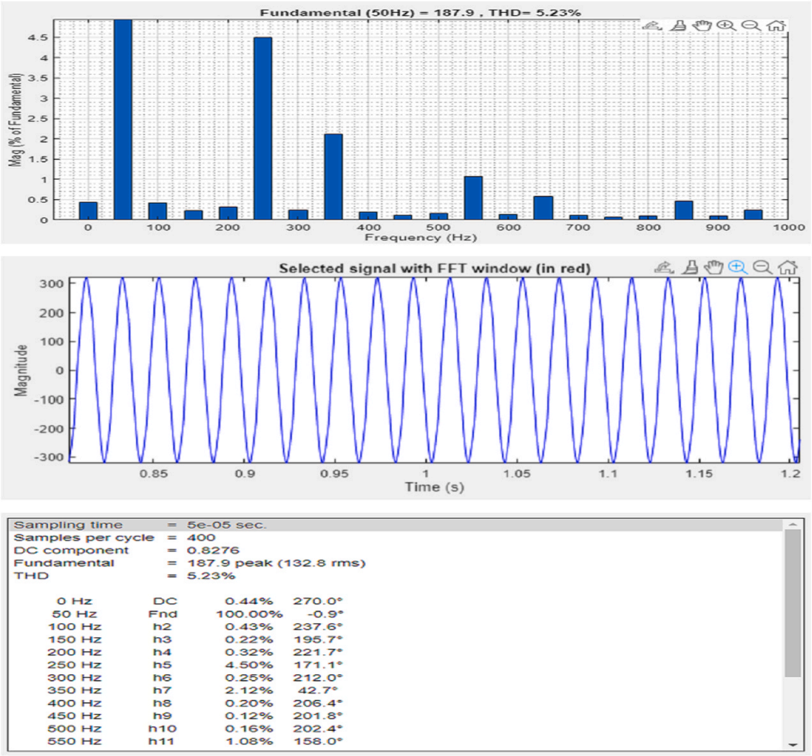
(a) Frequency Graph

(b) Selected Signal With FFT Window

(c) Frequency Between Harmonic Ratios

```
Sampling time       =  5e-05 sec.
Samples per cycle   =  400
DC component        =  0.4717
Fundamental         =  103 peak (72.84 rms)
THD                 =  5.65%

     0 Hz       DC      0.46%    270.0°
    50 Hz      Fnd    100.00%      0.9°
   100 Hz       h2      0.38%    238.7°
   150 Hz       h3      0.21%    194.5°
   200 Hz       h4      0.28%    232.5°
   250 Hz       h5      4.75%    180.4°
   300 Hz       h6      0.23%    231.0°
   350 Hz       h7      2.22%     59.3°
   400 Hz       h8      0.21%    230.0°
   450 Hz       h9      0.21%    209.9°
   500 Hz      h10      0.19%    228.3°
   550 Hz      h11      1.47%    176.4°
```

Fig. 31. Matlab/Simulink outputs of Çamlık transformer with series active power filter.



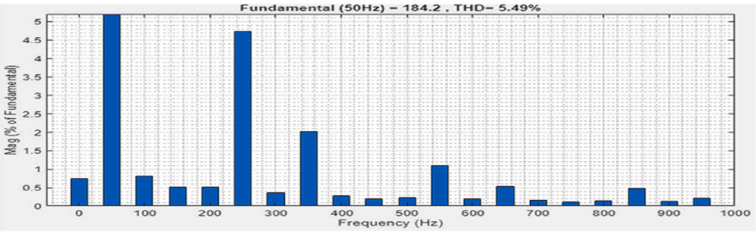
(a) Frequency Graph

(b) Selected Signal With FFT Window

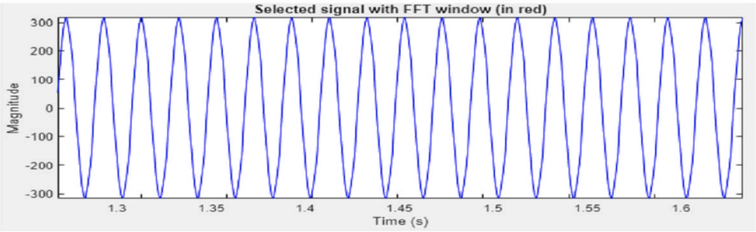
(c) Frequency Between Harmonic Ratios

```
Sampling time       =  5e-05 sec.
Samples per cycle   =  400
DC component        =  0.8276
Fundamental         =  187.9 peak (132.8 rms)
THD                 =  5.23%

     0 Hz       DC      0.44%    270.0°
    50 Hz      Fnd    100.00%     -0.9°
   100 Hz       h2      0.43%    237.6°
   150 Hz       h3      0.22%    195.7°
   200 Hz       h4      0.32%    221.7°
   250 Hz       h5      4.50%    171.1°
   300 Hz       h6      0.25%    212.0°
   350 Hz       h7      2.12%     42.7°
   400 Hz       h8      0.20%    206.4°
   450 Hz       h9      0.12%    201.8°
   500 Hz      h10      0.16%    202.4°
   550 Hz      h11      1.08%    158.0°
```

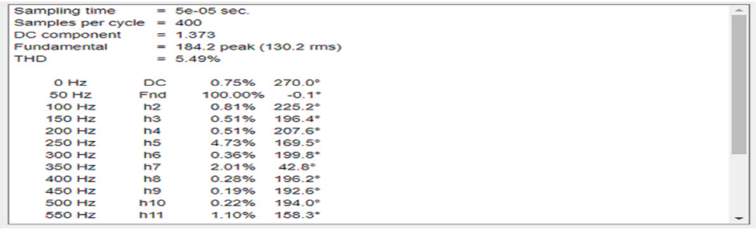
Fig. 32. Matlab/Simulink outputs of the Faculty of Education transformer with series active power filter.



(a) Frequency Graph



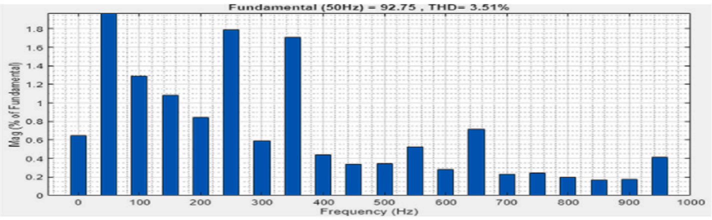
(b) Selected Signal With FFT Window



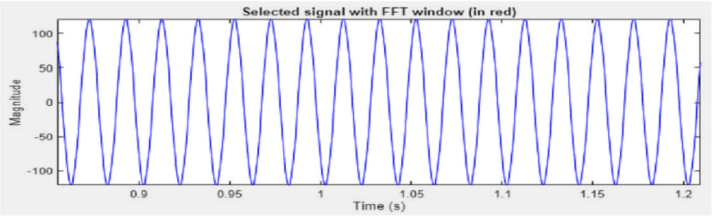
```
Sampling time        =  5e-05 sec.
Samples per cycle    =  400
DC component         =  1.373
Fundamental          =  184.2 peak (130.2 rms)
THD                  =  5.49%

      0 Hz         DC        0.75%    270.0°
     50 Hz         Fnd     100.00%     -0.1°
    100 Hz         h2        0.81%    225.2°
    150 Hz         h3        0.51%    196.4°
    200 Hz         h4        0.51%    207.6°
    250 Hz         h5        4.73%    169.5°
    300 Hz         h6        0.36%    199.8°
    350 Hz         h7        2.01%     42.8°
    400 Hz         h8        0.28%    196.2°
    450 Hz         h9        0.19%    192.6°
    500 Hz         h10       0.22%    194.0°
    550 Hz         h11       1.10%    158.3°
```

(c) Frequency Between Harmonic Ratios

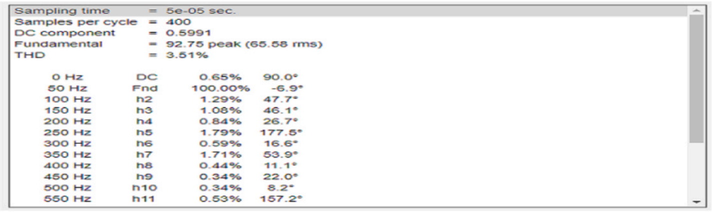
Fig. 33. Matlab/Simulink outputs of the transformer of Faculty of Arts and Sciences and Faculty of Economics and Administrative Sciences with series active power filter.



(a) Frequency Graph



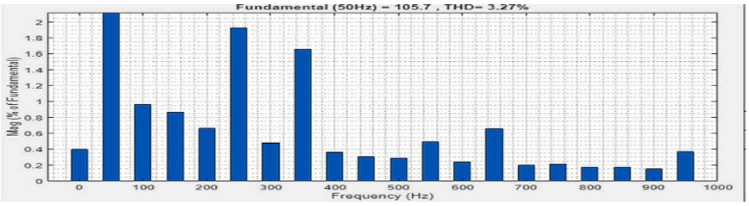
(b) Selected Signal With FFT Window



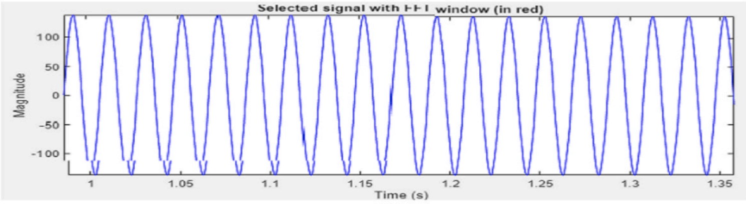
```
Sampling time        =  5e-05 sec.
Samples per cycle    =  400
DC component         =  0.5991
Fundamental          =  92.75 peak (65.58 rms)
THD                  =  3.51%

      0 Hz         DC        0.65%     90.0°
     50 Hz         Fnd     100.00%     -6.9°
    100 Hz         h2        1.29%     47.7°
    150 Hz         h3        1.08%     46.1°
    200 Hz         h4        0.84%     26.7°
    250 Hz         h5        1.79%    177.5°
    300 Hz         h6        0.59%     16.6°
    350 Hz         h7        1.71%     53.9°
    400 Hz         h8        0.44%     11.1°
    450 Hz         h9        0.34%     22.0°
    500 Hz         h10       0.34%      8.2°
    550 Hz         h11       0.53%    157.2°
```

(c) Frequency Between Harmonic Ratios

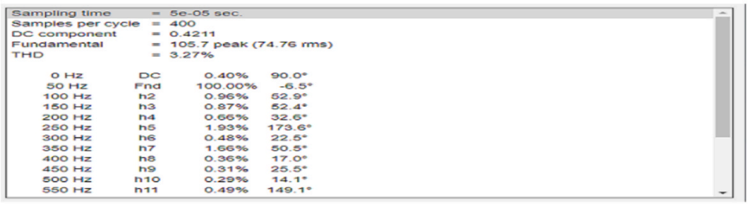
Fig. 34. Matlab/Simulink outputs of the Faculty of Engineering transformer with series active power filter.



(a) Frequency Graph



(b) Selected Signal With FFT Window



```
Sampling time        = 5e-05 sec.
Samples per cycle    = 400
DC component         = 0.4211
Fundamental          = 105.7 peak (74.76 rms)
THD                  = 3.27%

     0 Hz      DC      0.40%    90.0°
    50 Hz      Fnd   100.00%    -6.5°
   100 Hz      h2      0.96%    52.9°
   150 Hz      h3      0.87%    52.4°
   200 Hz      h4      0.66%    32.6°
   250 Hz      h5      1.93%   173.6°
   300 Hz      h6      0.48%    22.5°
   350 Hz      h7      1.66%    50.5°
   400 Hz      h8      0.36%    17.0°
   450 Hz      h9      0.31%    25.5°
   500 Hz      h10     0.29%    14.1°
   550 Hz      h11     0.49%   149.1°
```

(c) Frequency Between Harmonic Ratios

Fig. 35. Matlab/Simulink outputs of the Rectorate transformer with series active power filter.

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