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Araştırma Makalesi

Experimental Analysis of Energy Quality at Campus Network-Case Study: Bolu Abant Izzet Baysal University (Engineering Building)

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ABSTRACT

In this study energy quality of university campus network have been analyzed experimentally. The experimental tests and measurements have been implemented at Engineering Building of the Bolu Abant Izzet Baysal University (Turkey). Energy quality analysis has been performed by making current, voltage, frequency, power factor, harmonics, neutral-earth voltage measurements at the main distribution board of the Engineering Building. Besides, active power filter has been connected and its effects examined. The reasons for the energy quality problems on the electric power distribution system of the campus building have been revealed and required solutions have been offered.

Keywords: *Energy Quality, Active Power Filter, Harmonics, Campus Network, Load Unbalance*

Kampüs Şebekesinde Enerji Kalitesinin Deneysel Olarak Analizi-Örnek Çalışma: Bolu Abant İzzet Baysal Üniversitesi (Mühendislik Binası)

ÖZET

Bu çalışmada üniversite kampüsü şebekesinin enerji kalitesi deneysel olarak analiz edilmiştir. Deneysel testler ve ölçümler Bolu Abant İzzet Baysal Üniversitesi Mühendislik binasında gerçekleştirilmiştir. Mühendislik binasının ana dağıtım panosunda akım, gerilim, frekans, güç faktörü, harmonikler, nötr-toprak gerilim ölçümleri yapılarak enerji kalitesi analizi yapılmıştır. Ayrıca, aktif güç filtresi bağlanmış ve etkileri incelenmiştir. Kampüs elektrik dağıtım sistemindeki binaların enerji kalitesi sorunlarının nedenleri ortaya konulmuş ve gerekli çözümler sunulmuştur.

Anahtar Kelimeler: *Enerji Kalitesi, Aktif Güç Filtresi, Harmonikler, Kampüs Şebekesi, Yük Dengesizliği*

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I. INTRODUCTION

Energy quality in electrical energy systems is gaining importance day by day. In order to qualify the electrical energy as quality, the network frequency and voltage amplitude must be within tolerances, the phase voltages must be balanced, the waveform must be sinusoidal, and the energy must be uninterrupted. The limit values of these parameters were determined by the EN 50160 standards.

In recent years, energy quality problems have emerged due to the increasing number of electronic-based devices in electrical energy distribution systems. Today, harmonics are the most important energy quality problem. Harmonic filters are used to reduce the effect of their harmonics, which cause serious damage to energy system elements. Energy quality problems have negative effects on the energy distribution system and consumers [1]. Energy quality problems cause energy losses in energy systems, decreased device life, noisy operation of devices, incorrect measurement of sensitive devices, damage of compensation systems, overload of transformers, decrease in insulation life, failures in relay protection and automation processes [2]-[7]. The electrical energy distribution system of university campuses and the quality of energy on campuses is an important issue. In this context, various studies have been published on improving campus electrical energy infrastructure [8], harmonic analysis of campus energy distribution system [9]-[10], improving energy efficiency and reducing energy consumption on campuses [11].

To reduce the neutral-earth voltage at the plant; power source must be located as close as possible to the building, the neutral cross-section must be at least as much as the phase cross-sections, and phase-loads in the plant must be balanced. If there is not enough planning at the plant stage or unexpected conditions occur during use, the use of active power filter can be recommended as a suitable solution [12].

In this study, energy quality of the BAIBU Main Campus Engineering Building was analyzed by experimental measurements. Within the scope of the analysis, the causes and solutions of high neutral-earth voltage were investigated. In addition, the effect of active power filter usage on load distribution, harmonic and voltage drop was investigated. In order to perform energy quality analysis, measurements were made at the Engineering Building. The data obtained from energy quality measurements were evaluated within the framework of EN 50160 standard and suggestions were made for the solution of existing problems in the electric power system and for new infrastructures.

II. SYSTEM DESCRIPTION

BAIBU Engineering Building receives energy from the substation 450 m away with 3x (3x120 / 70) NYY cable (Figure 1). In the substation, there is a 1200 kVA transformer, 1200 kVA generator, 400 kVA compensation board. 10 buildings used for different purposes in this region receive energy from this substation. The Engineering Building has classrooms, laboratories, and office rooms. Fluorescent luminaires with electronic ballasts are used for the interior lighting of the building. There are many computers and sensitive electronic laboratory devices with different technical characteristics that may cause harmonics and load unbalances.

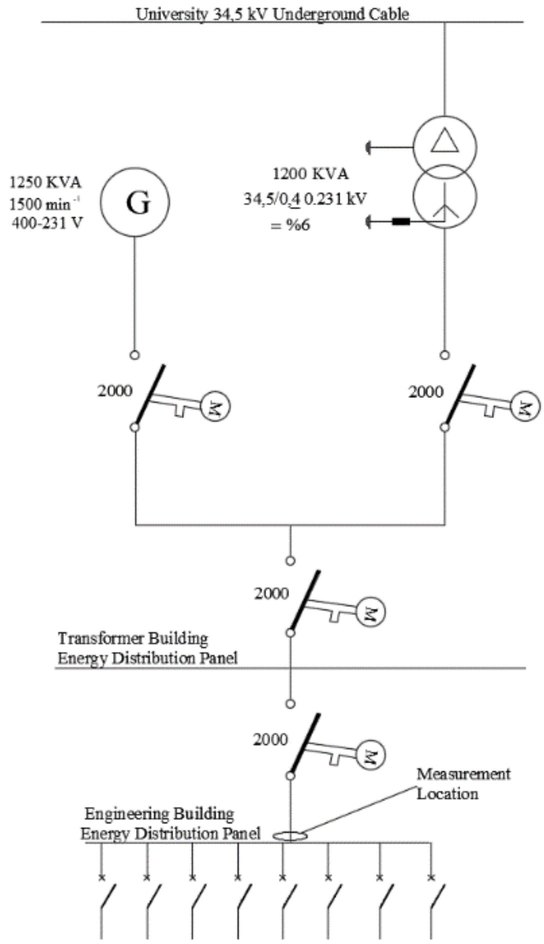

Fig. 1. *Engineering Building Single-Line Diagram*

III. <u>ENERGY QUALITY MEASUREMENTS</u>

The engineering building has many nonlinear loads, such as electronically controlled devices, computers, uninterruptible power supplies, fluorescent lamps and electronic ballasts. High neutral currents are generated due to nonlinear loads and unbalanced load distributions between three-phases. The earth-neutral voltage value increases due to the neutral currents. This can adversely affect the operation of sensitive devices. The studies and measurements related to the detection and solution of this problem are given below. In order to solve the neutral-earth voltage problem, an active power filter is connected to the energy main distribution panel of the engineering building to fit the load profile of the building. In order to clearly identify the energy quality problem in the system, the active power filter was disabled for the first three days of the one-week measurement period and the last four days were activated. Thus, it is aimed to determine the energy quality problem in a measurement period and to see the effect of the active power filter. Phase loads, phase voltage amplitudes, power factor, voltage imbalance, current and voltage harmonics were measured in energy quality measurements.

Engineering Building's energy quality measurement test set-up is shown in Figure 2. Power quality and energy analyzer were used for energy quality measurements.

Fig. 2. Engineering Building Energy Quality Measurement Set-Up

A. ANALYZING PHASE LOADS AND NEUTRAL CURRENT GRAPHICS

In Figure 3, the load currents of the three-phase and neutral current graphs are given for one-week measurement period. As shown in the figure, there are load imbalances in the phase currents when the active power filter is deactivated. It is seen that the neutral current increases up to 40 amperes due to unbalanced loading of the phases, the phases are loaded evenly after the active harmonic filter is activated and the neutral current decreases up to 8 amperes. In Figure 4, three-phase and neutral current waveforms are shown when the active power filter is inactive. In Figure 5, three-phase and neutral current waveforms are given when the active power filter is active. The waveforms of the phase currents are close to ideal and the neutral current decreases with the connection of the active power filter.

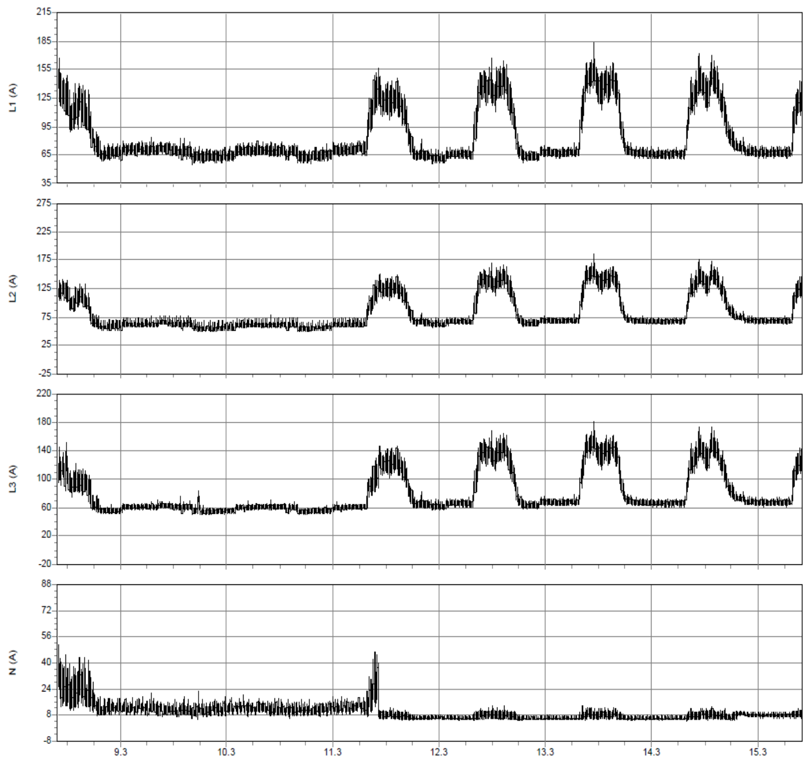

Fig. 3. *Load Current of Phases and Neutral Current Changes*

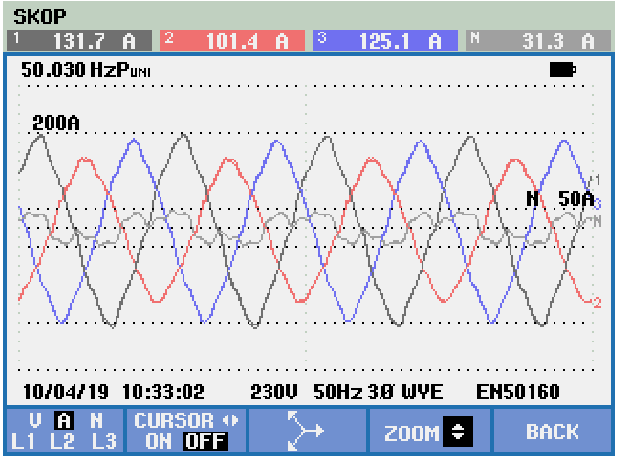

__Fig. 4.__ Three-Phase and Neutral Currents while Active Power Filter Disconnected

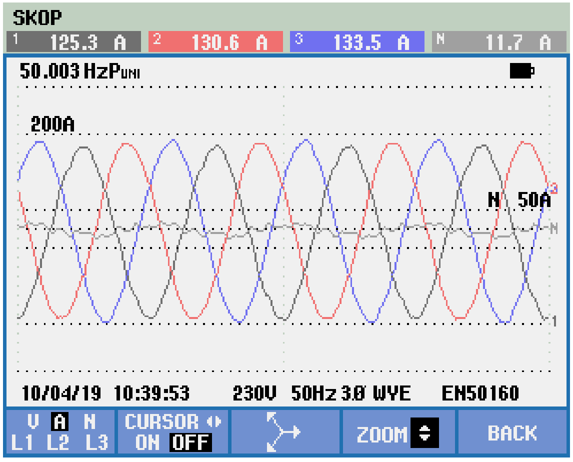

__Fig. 5.__ Three-Phase and Neutral Currents while Active Power Filter Connected

B. ANALYZING VOLTAGE VALUES OF ENGINEERING BUILDING

Voltage amplitudes of three phases were also measured in energy quality measurements. In Figure 6, the voltage change graphics for a week are given. In these measurements active power filter is not connected.

When the active power filter is disabled, voltage amplitude values due to unbalanced loading of phases are 221V, 226V, 226V respectively (Figure 7), after the active power filter is activated, the voltage amplitudes of the phases are balanced as 224V, 225V, 225V respectively (Figure 8) and the voltage waveforms of the phases close to the ideal. Unbalance of three voltages should be compliance with %95 limit according to the EN 50160 standard.

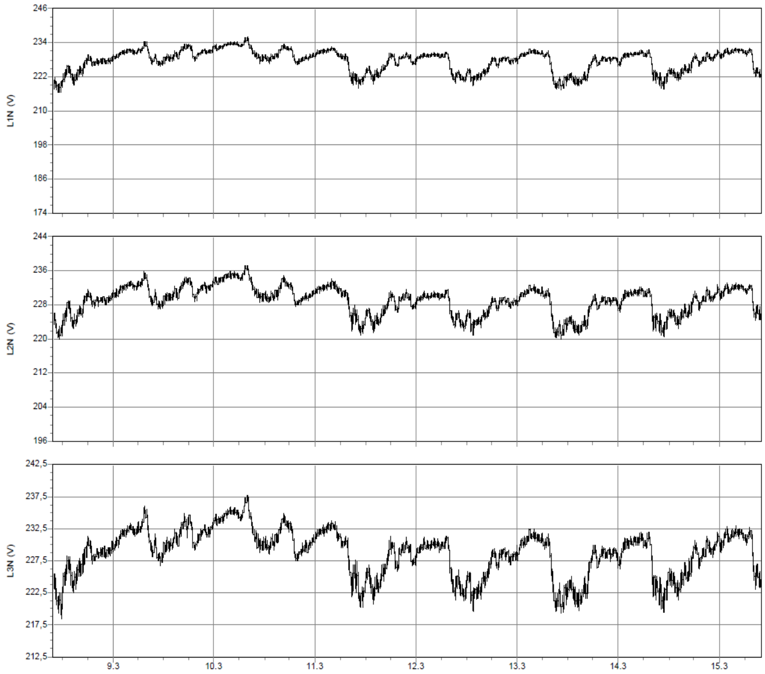

Fig. 6. Graph of Variation in Voltage Amplitudes

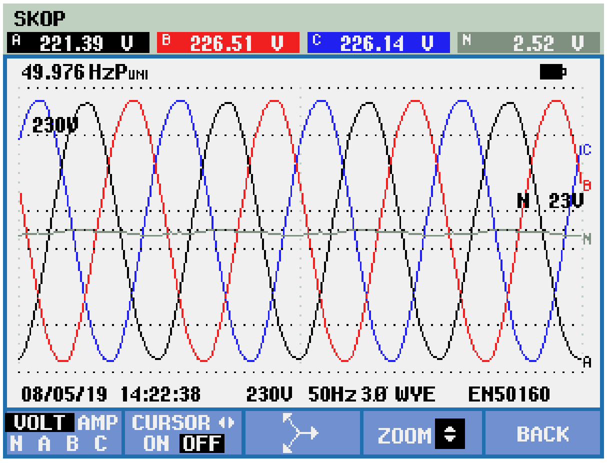

Fig. 7. Voltage Waveforms while Active Power Filter Disconnected

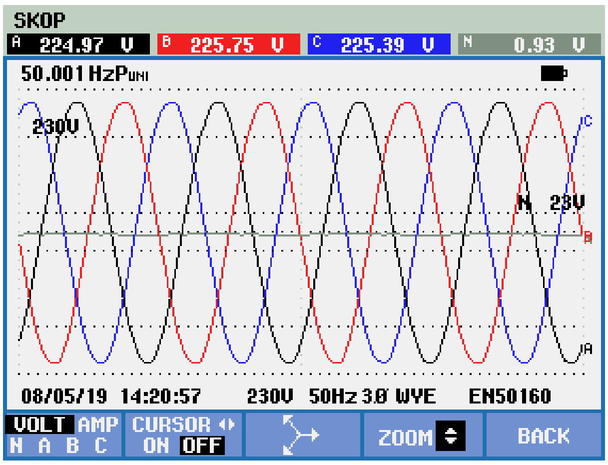

Fig. 8. Voltage Waveforms while Active Power Filter Connected

C. ANALYZING NEUTRAL CURRENT AND NEUTRAL-EARTH VOLTAGE VARIATIONS OF ENGINEERING BUILDING

A one-week measurement was made to examine the neutral current and neutral-earth voltage changes at the Engineering Building. Active power filter has not been connected in the first three days of the one-week measurement period in which energy quality measurement has been made, and active power filter has been connected in the last four days. The neutral current and neutral-earth voltage change graphs are shown in Figure 9. During a one-week measurement period, the neutral current increases up to 40 amps when the active power filter is disabled according to the load state of the phases, while the active power filter is activated and drops to an average level of 8 amps. While the active power filter is disconnected, the neutral-earth voltage is measured as 2,82 volts, while the active power filter is connected, it is measured as 1 volt.

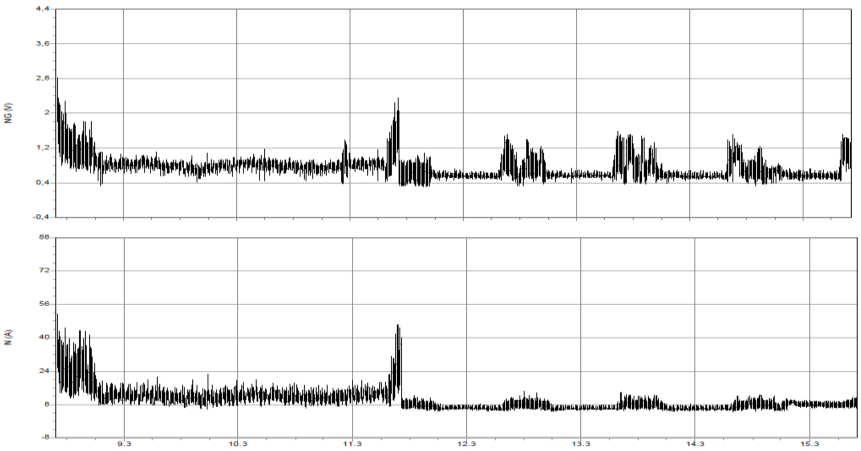

Fig. 9. *Neutral-Earth Voltage and Neutral Current Change Graph*

D. HARMONICS ANALYZING OF ENGINEERING BUILDING

Harmonics measurements of phase voltages were made within the scope of energy quality measurements. The THDv variations of the phase voltages were within acceptable limits when the active power filter was active and inactive and did not exceed 5% according to EN 50160 Standard (Figure 10). The value of THDv higher during the interval around 9.3 to 11.4 because of these measurements were implemented while active power filter was not connected and there were more load imbalances.

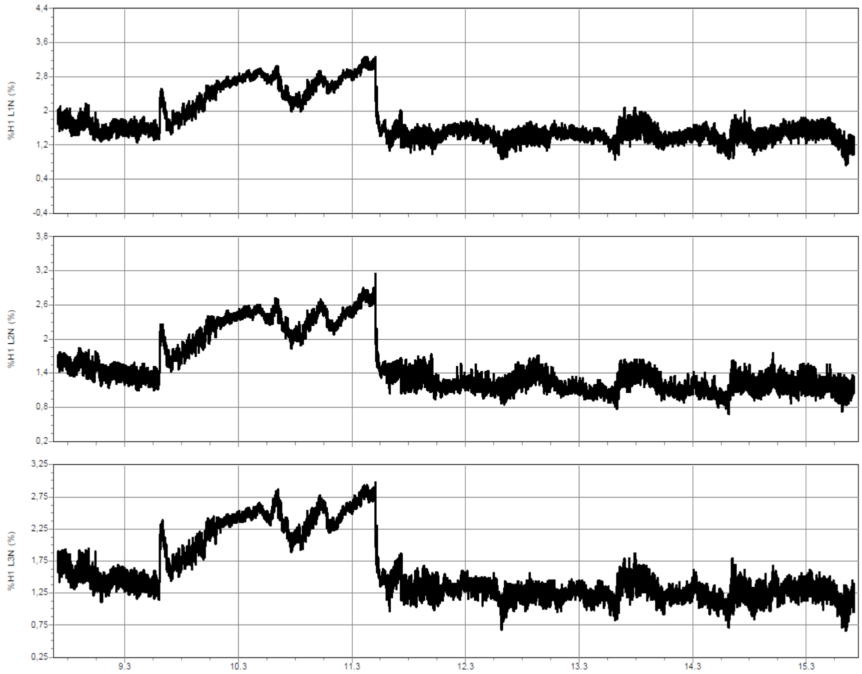

Fig. 10. *THDv Change Graph of Phase Voltages*

The third voltage harmonics variations of the phase voltages were found to be within acceptable limits and did not exceed 5% according to EN 50160 standard when the active power filter was off and on (Figure 11).

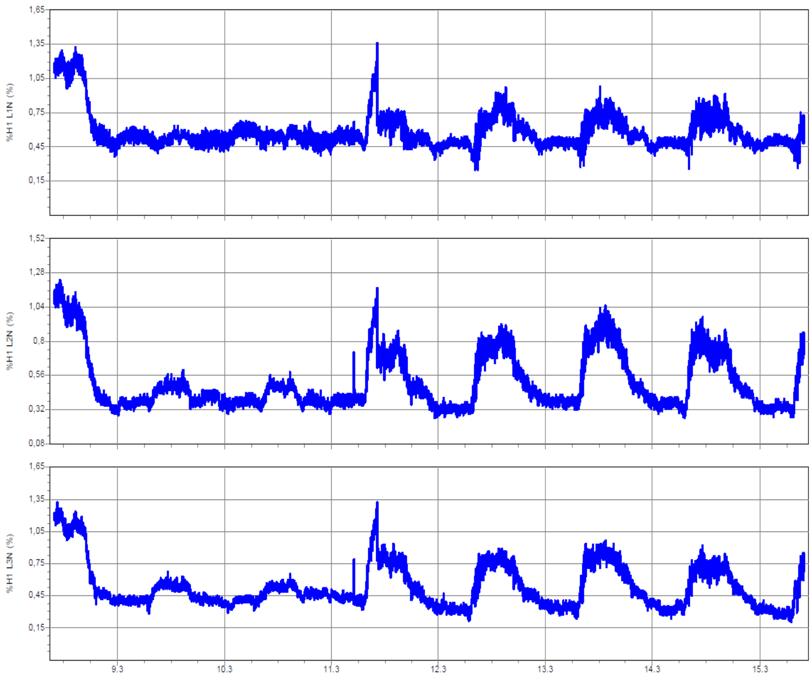

Fig. 11. *Third Voltage Harmonics Change Graph of Phase Voltages*

5., 7., 9, and 11. voltage harmonics values were not shown graphically as they were very low. All voltage harmonic values measured in the Engineering Building are shown in Table 1.

***Table 1**. Voltage Harmonics Values of Engineering Building*

Engineering Building Voltage Harmonics										
	Maximum			Minimum			Average			EN 50160 Value
%	L1	L2	L3	L1	L2	L3	L1	L2	L3	%
THDv	3,26	3,15	2,98	0,74	0,7	0,67	1,78	1,544	1,604	5
2. Harmonic	0,46	0,42	0,47	0,01	0,01	0,01	0,028	0,037	0,037	2
3. Harmonic	1,36	1,23	1,32	0,25	0,26	0,21	0,587	0,514	0,532	5
4. Harmonic	0,37	0,41	0,33	0,01	0,02	0,01	0,032	0,053	0,021	1
5. Harmonic	3,15	2,89	2,85	0,04	0,04	0,12	1,341	1,162	1,224	6
6. Harmonic	0,29	0,36	0,36	0,01	0,01	0,01	0,042	0,051	0,032	0,5
7. Harmonic	1,31	0,95	0,87	0,04	0,01	0,01	0,52	0,345	0,348	5
8. Harmonic	0,14	0,24	0,13	0,01	0,01	0,01	0,024	0,022	0,028	0,5
9. Harmonic	0,98	0,65	0,66	0,04	0,02	0,02	0,419	0,336	0,332	1,5
10. Harmonic	0,1	0,13	0,09	0,01	0,01	0,01	0,024	0,042	0,028	0,5
11. Harmonic	0,83	0,72	0,77	0,02	0,02	0,02	0,348	0,334	0,392	3,5

The harmonic analysis was also performed for phase currents. Figure 12 shows a graph of the change in phase currents during a one-week measurement. THDi values for L1 phase are 3% to 20.22% while active filter disabled, 2.03% to 11% while active filter connected, 4% to 22% while active filter disabled, 1.71% to 12.5% while active filter connected, It is seen that for the L3 phase, varies between 3% and 20.98% while active filer disabled, 1.79% and 11% while active filer connected. When the active filter is not active, the THDi values of the phase currents exceed the limit values set by the EN 50160 standard from time to time. After the active power filter is activated, it is observed that the THDi values of the phase currents are within the limit values set by EN 50160 standard.

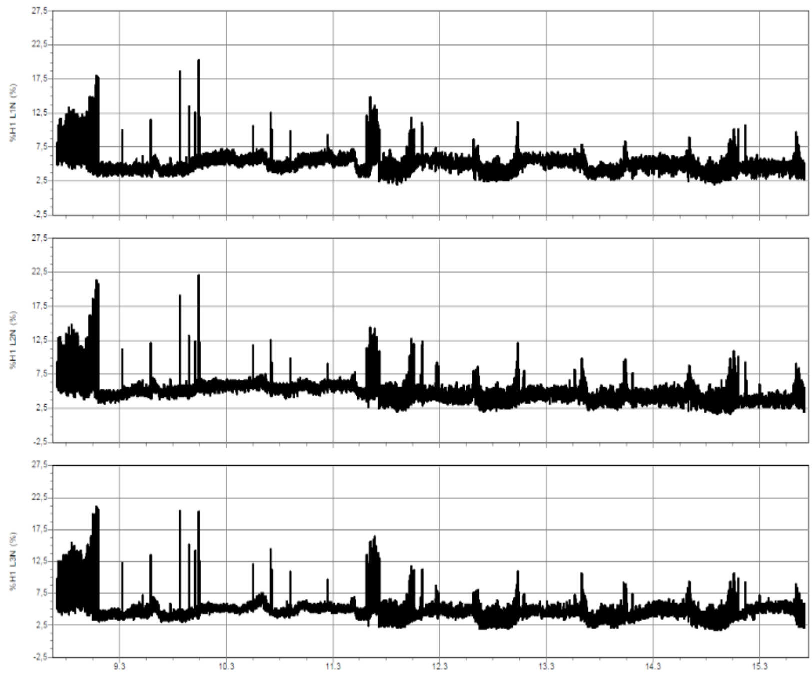

***Fig. 12.** THDi Change Graph of Phase Currents*

It is seen that the phase currents are within acceptable limits since the third current harmonic changes do not exceed 5% according to EN 50160 Standard when active power filter is disabled and active (Figure 13).

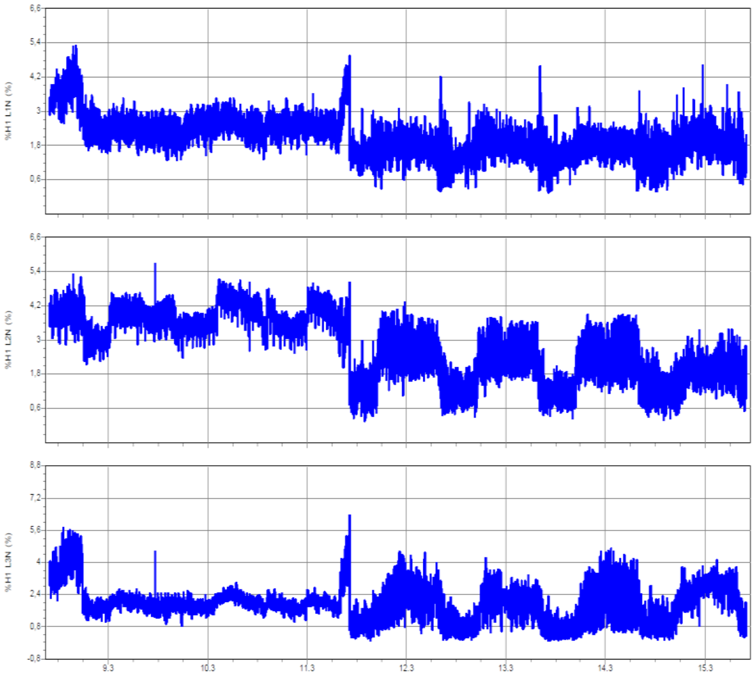

Fig. 13. *Third Current Harmonics Change Graph of Phase Currents*

As the 5., 7., 9, and 11. current harmonics values are very low in Engineering Building energy quality measurements, their graphics are not shown. All current harmonics values measured are shown in Table 2.

Table 2. *Current Harmonics Values of the Engineering Building*

Engineering Building Current Harmonics										
	Maximum			Minimum			Average			EN 50160 Value
%	L1	L2	L3	L1	L2	L3	L1	L2	L3	%
THDI	20,22	22	20,98	2,03	1,71	1,79	4,866	4,675	4,548	12
2. Harmonic	2,11	2,72	2,26	0,16	0,07	0,26	0,594	0,346	1,245	2,5
3. Harmonic	5,3	5,64	6,3	0,18	0,17	0,14	2,094	2,809	1,886	10
4. Harmonic	1,36	1,62	1,06	0,06	0,11	0,05	0,517	0,378	0,321	2,5
5. Harmonic	15,72	16,2	15,67	0,13	0,1	0,13	2,71	1,766	1,8	10
6. Harmonic	0,95	1,01	1,11	0,04	0,06	0,04	0,124	0,325	0,149	2,5
7. Harmonic	10,44	13,6	11,83	0,11	0,11	0,1	1,419	1,238	1,253	10
8. Harmonic	0,56	0,85	0,68	0,03	0,04	0,04	0,115	0,193	0,22	2,5
9. Harmonic	3,26	2,11	2,15	0,16	0,06	0,06	1,579	0,866	0,894	10
10. Harmonic	0,43	0,75	0,51	0,03	0,03	0,03	0,12	0,279	0,129	2,5
11. Harmonic	5,52	6,18	6,98	0,06	0,07	0,08	1,191	1,144	1,482	4,5

IV. CONCLUSION

Energy quality measurements have been made at the main distribution panel of the BAIBU main campus Engineering Building. It is observed that voltage amplitude, voltage unbalances, current and voltage harmonics are within the limit values according to EN 50160 standard. In energy quality measurements, it is seen that the phase currents are unbalanced and consequently high current flows through the neutral line. The neutral-earth voltage increases due to the remote transformer center where the Engineering Building receives energy and the low neutral cross-section. It has been found that after the active power filter is connected, the phases are loaded evenly, and the neutral current is reduced. It has been shown that the neutral-earth voltage decreases as a result of the decrease of the neutral current. In order to avoid energy quality problems in the building; It is important to select the power source point as close as possible, to select the neutral cross-section at least as much as the phase cross-sections, and to distribute the loads in the plant in a balanced manner. Active power filter solution has been found suitable for eliminating current load imbalances, reducing harmonics and keeping neutral-earth voltage within the limit values.

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