

# Problems in Electric Systems Caused by Harmonics and Solution Proposals

Kemal Metin, Huseyin Ceylan, Ertugrul Demirkesen, Kadir Canatan, and Mikail Hizli

**Abstract** — Together with globalization, factories, companies and even countries can survive by competing with their rivals. Nowadays, technological superiority is one of the most important factors determining competitive power. This situation causes the result of rapid change and development of technology. Due to improvement in technology, humanity dependence on electricity is increasing day by day. Many new devices get in our lives, and both the continuity and quality of electricity comes across as an important issue. Different researches are carried out to make the energy more qualified and efficient. In terms of the stability of the used electrical devices, it is important to keep the harmonic amount in electrical energy under a certain value. Besides this, these unwanted harmonics cause additional energy losses in the energy system and negatively affect energy efficiency, which is an economically important problem. In this exercise, the problems in electrical systems, the damages in electrical devices caused by harmonics have been researched and various solution suggestions have been developed for this problem.

**Index Terms** — Harmonic, Harmonic Distortion, Quality of Energy.

## I. INTRODUCTION

Due to the steady improvement in technology, electrical devices used at homes and industrial areas have started to contain more electronic parts. Although these devices are sensitive to energy quality, they are sources that degrade energy quality. In the middle of 1900s with the invention of the transistor, there was a revolutionary bounce in electronics. By that time, power electronics have also been affected by these developments and electronic devices have become a part of our lives in every field. Humanity has met the terms of energy quality and harmonic with the introduction of electronic devices into our lives. Before the improvement in electronics, electrical devices used in enterprises generally had linear weighted loads such as engines, lighting and heating devices. The effect of these devices on the fundamental frequency was negligible. In linear loads, the increase or decrease of current is directly proportional to the voltage. Due to the improvement in power electronics, semiconductor devices (LED, diode, transistor, etc.) have been used in many industrial areas to

increase efficiency and reduce energy consumption. The disproportionality of current and voltage of these devices causes distortion in the network sinus wave. These loads are called nonlinear loads. With the increase in the use of devices with nonlinear loads, unexplainable problems have started to appear in enterprises. Investigations and researches have shown that harmonics are the reason of these problems. The required form of the fundamental energy frequency is shown in Fig. 1. In this article, harmonics in energy systems, harmful effects of harmonics and solution methods that can eliminate these harmful effects will be discussed.

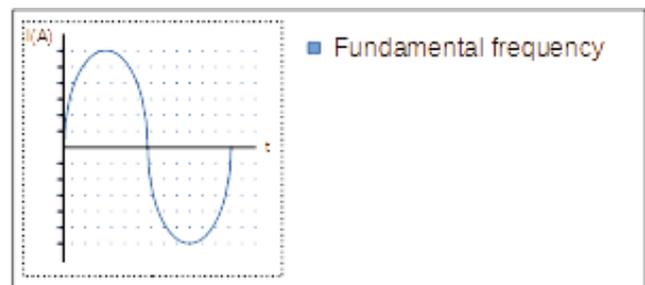


Fig. 1. The required sinus wave of fundamental frequency

## II. WHAT IS HARMONIC?

Harmonic is sinusoidal waveform, formed as singular multiples of fundamental frequency cycle in power lines, as semiconductor circuit elements used in power electronics are not linearly loaded. Briefly, all sinusoidal forms in the electrical system except the fundamental frequency are called harmonics. Fundamental frequency component and third, fifth and seventh harmonics are shown in the full period in Fig. 2. For example, in a 50 (Hz) network, for the third harmonic, we find the frequency as  $3 \cdot 50 = 150$  (Hz). Some sources that generate harmonics and generated harmonics are given in Table 1 [1].

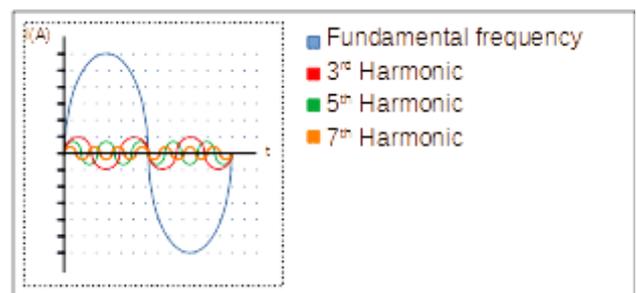


Fig. 2. Fundamental frequency and harmonics

Published on January 26, 2021.  
Kemal Metin, Kirikkale University, Turkey.  
(e-mail: kml-mtn@hotmail.com)  
Huseyin Ceylan, Kirikkale University, Turkey.  
(e-mail: husceylan@hotmail.com)  
Ertugrul Demirkesen, Kirikkale University, Turkey.  
(e-mail: yakamoz\_kaptan\_1999@hotmail.com).  
Kadir Canatan, Kirikkale University, Turkey.  
(e-mail: ka-canatan@hotmail.com).  
Mikail Hizli, Kirikkale University, Turkey.  
(e-mail: mikail.hzl@hotmail.com).

TABLE I: SOME HARMONIC GENERATING SOURCES AND GENERATION REASONS [2]

Harmonic Generators	Harmonic Generation Reason
Uninterruptible power supplies	Not being fully sinus during the conversion of the energy stored as DC into the energy AC
Speed control devices (Frequency converters)	Six-pulse speed control devices make the most degradation
Rectifiers and battery chargers	Nonlinear operating characteristic of semiconductor elements
Computers	Nonlinear operating characteristic of semiconductor elements
Transformers	Nonlinear magnetization characteristic of transformer core
Engines	Magnetic interaction between stator and rotor slots
Synchronous generators	Magnetic relationship between stator and rotor grooves and saturation of main circuit
Arc furnaces	Harmonics occur as a result of active resistance variability
Welding machines	Load over variability during welding and spot welding and transformer saturation
Induction hotplates	High frequency and Eddy currents cause harmonics generation
Nonlinear power electronics elements	Nonlinear operating characteristic of semiconductor elements
Gas discharge lighting elements	Nonlinearity of electrical characteristics

### III. PROBLEMS CAUSED BY HARMONICS AND THEIR HARMFUL EFFECTS ON ENERGY QUALITY

Since there is a 120 degrees phase difference in three-phase alternating current systems, the currents in the frequency of the 3rd harmonic 150 (Hz) are in the same phase, namely, they do not balance each other as there is no phase difference. They are added on top of each other and provide three times more current. Therefore, 3rd harmonic causes current draw through the neutral line. As the result current draw through neutral line, can cause heating in power lines, additional heat and losses in transformers.

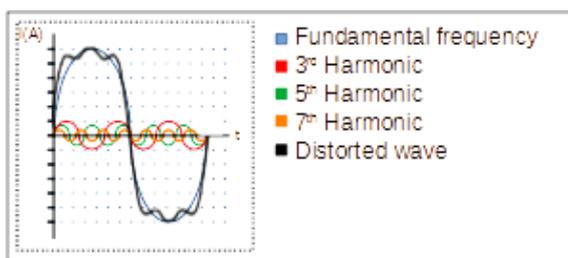


Fig. 3. Effects of harmonics on fundamental frequency

In enterprises harmonics appear as current harmonics. One of the main reasons of the problem occurrence in electrical devices is current harmonics. The generation of harmonics in the system does not always cause problems. The system can continue to work properly with a certain amount of harmonics. The presence of harmonics in the voltage affects all electrical devices. Harmonic currents affect only devices with harmonic sources. Capacitor bank system components cause further increase of harmonics [3].

### IV. EFFECTS OF HARMONICS ON DEVICES

Most of the harmonic-sourced devices are those, which are mostly affected by it. This situation creates a vicious circle in electrical systems.

TABLE II: EFFECTS OF HARMONICS ON SOME ELECTRICAL DEVICES [3]

Devices	Effects of Harmonics
Transformers	<ul style="list-style-type: none"> <li>• Overload</li> <li>• Overheating</li> <li>• Increase in eddy currents and more heating</li> </ul>
Engines	<ul style="list-style-type: none"> <li>• Efficiency loss</li> <li>• Overheating</li> <li>• Vibration and noise</li> </ul>
Control Devices	<ul style="list-style-type: none"> <li>• More switching than required occurs due to harmonics</li> </ul>
Measurement Tools	<ul style="list-style-type: none"> <li>• Inaccurate reading on average measuring devices</li> </ul>
Circuit Breakers	<ul style="list-style-type: none"> <li>• Over currents caused by harmonics and noise caused by harmonic sources cause unnecessary tripping in circuit breakers as a result of heating and incorrect measurement</li> </ul>
Cables	<ul style="list-style-type: none"> <li>• Active power carrying capacity decreases as a result of overloading</li> </ul>
Insulation Materials (Insulation in transformer and motor windings, Capacitor insulation)	<ul style="list-style-type: none"> <li>• In case of voltage resonance, it causes punctures in insulating materials</li> </ul>
Communication Tools	<ul style="list-style-type: none"> <li>• Causes noise and abnormal operations</li> </ul>
Computers and Microprocessors	<ul style="list-style-type: none"> <li>• Computers are the mostly affected devices by harmonics</li> </ul>
Mechanical Electricity Meters	<ul style="list-style-type: none"> <li>• Causes incorrect measure of meters</li> </ul>
Capacitors	<ul style="list-style-type: none"> <li>• Causes explosion or melting in connection cables</li> <li>• <b>Note:</b> Capacitors do not generate harmonics, but they multiply existing harmonics.</li> </ul>

#### A. Effects on Transformers

In transformers operated with apparent power, harmonic currents will increase the running apparent power value (kVA) of the transformer even more and cause the transformer to be overloaded. Thereby, increasing effective current will lead to an increase in conductor losses. Eddy currents also cause serious losses in transformers as well as heating. Eddy current losses, which are approximately 10% in transformers under normal conditions, create more losses and heat with the effect of high frequency harmonics [4].

#### B. Effects on Engines

Engines are severely affected from the damages caused by harmonics. Harmonic voltages in the stator windings transform into harmonic current in the rotor, as a result harmonic currents of large frequencies are generated in the rotor. Harmonics cause nonstandard heating, vibration and noise in engines. Because of this, the efficiency of the engines decreases, and it shorten their life. Harmonic components reduce the efficiency of engines between 5% and 10%.

#### C. Effects on Control Devices

Voltage zero crossing causes over-switching in switching systems. This happens, because while voltage zero crossing occurs twice in one period of 50 Hz frequency, in third harmonic it occurs 6 times, and in 5th harmonic it occurs 10

times. As the result, control devices cannot realize the desired control.

#### D. Effects on Measurement Tools

While there is no deviation in the measurement of effective value measurement tools (RMS), the measurements will be inaccurate between 32% and 40%, as average value measuring tools are based on zero voltage point. It is presumable that, mechanical electrical meters measurements in harmonic circuits are faulty up to %20 [2].

#### E. Effect on Neutral Conductor

Current combination in neutral three phase power system, where loads are equally distributed, is zero. That's why, in order to obtain saving, neutral conductor approximately equal to the half of phase conductor is used in power systems. However, this balancing is not valid for harmonic currents. Although the load of the phases is equally distributed, the combination of harmonics on the neutral conductor is equal to the sum of the harmonic percentages per phase. Since the cross section of the neutral conductor of the harmonic currents in neutral is lower than the phase conductor, heating occurs in the neutral conductor. This heating is very dangerous. In case of the neutral conductor burning, if the circuit breakers do not open the circuit in time, our single-phase devices connected to the electrical system will be connected between two phases in sequence and will be damaged.

#### F. Effect on Cables

Harmonics cause unnecessary overload on cables, causing the breaker and thermal switches in electrical panels open circuit. They cause heating in the cables under normal load and damage to the cable insulation. With the increase in harmonic frequency, the so-called skin effect occurs, where the current concentrates on the outer surface of the conductor. Effective resistance increases in the skin effect, this causes extra heat in the cables.

#### G. Effects on Circuit Breakers

Due to faulty measurement leakage in leakage current protection systems current circuit breakers cause power cut in electrical systems because of harmonic components due to faulty measurement, leakage current circuit breakers open in the electrical system and cause the electricity to be cut. Receptors connected to the electrical system suffer from frequent power cuts.

#### H. Effects on Capacitors

Heating in overloaded capacitors causes destruction and aging in capacitors. As capacitors are linear loads, they do not generate harmonics, but they increase the amplitude of harmonics in the network. Capacitors, parallel connected to the network in inductive characteristics, cause harmonic resonance. In this case, an increase in impedance is seen at the resonance frequency. Thus, the increase occurs in harmonics amplitude in the system. Harmonic currents with high amplitude are transmitted to the network side [5].

#### I. Insulator Puncture

Due to voltage increase by distorted needlepoint-shaped wave, which happens by adding harmonics to fundamental frequency form, can cause puncture and burst in engine, transformer and capacitor components.

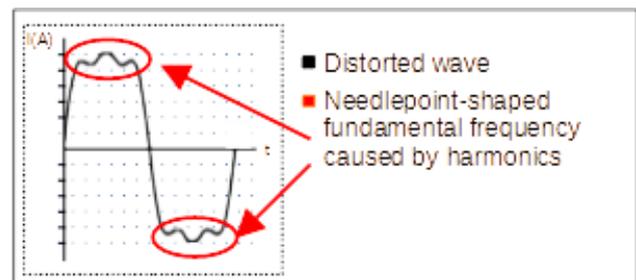


Fig. 4. Needlepoint-shaped voltage frequency caused by harmonics.

#### J. Effects on Lighting Elements

Harmonics cause audible noise in the ballasts of gas discharge lamps (fluorescent, sodium and mercury vapor), iron losses and warming in ballasts. In filament lamps, voltage increase caused by harmonics shortens lamp life because of overheat. For example, with a 5% increase in voltage, the lamp life decreases by up to 50% [4].

### V. SOLUTION METHODS TO REDUCE HARMFUL EFFECTS OF HARMONICS

The distortion in the fundamental frequency signal caused by harmonics is the biggest factor that reduces the energy quality. It has become a necessity to keep the energy quality at a certain level in order to protect the devices connected to the electricity grid, to ensure the continuity of the correct operation of the devices and to prevent energy losses. There are various kinds and types of filter applications for the systems in order to prevent harmonics. Filtering types are given in the table below.

TABLE III: HARMONIC FILTER TYPES AND MAIN CHARACTERISTICS [6]

	Filter Type	Filter Characteristics
1.	Passive Filter	<ul style="list-style-type: none"> <li>• Tuned to one or two frequencies</li> </ul>
1.1.	Series Filters	<ul style="list-style-type: none"> <li>• Needs a new filter during harmonic value changings</li> </ul>
1.2.	Shunt Filters	<ul style="list-style-type: none"> <li>• Resonance may occur</li> <li>• Efficiency decreases with the change of the fundamental frequency</li> <li>• Problems occur in current increases</li> <li>• It is difficult to control harmonic sequence</li> </ul>
a)	Single-tuned filters	
b)	Double-tuned filters	
c)	Damped filters	
2.	Active Filters	<ul style="list-style-type: none"> <li>• Adjustable to multiple frequencies</li> </ul>
2.1	Series Filters	<ul style="list-style-type: none"> <li>• Does not cause problems in current increases</li> </ul>
2.2	Shunt Filters	<ul style="list-style-type: none"> <li>• Harmonic sequence can be controlled</li> </ul>

As we see in Table III, passive filtering applications can be preferred in small scale industries. In large scale industries (factory, hotel, etc.), active filter applications that will be activated and deactivated according to the number of harmonics and the current state of the load should be preferred.

#### A. Passive Filters

Passive filters are generally designed with capacitor bank systems. Passive harmonic filter systems generally consist of capacitors, harmonic filters and resistors. Its cost is cheaper than active filter. New harmonic filters are needed for different frequency generators added to the circuit, as it filters a limited number of frequencies. Calculation faults in design can cause serious resonance problems in the enterprise. As you can see in Fig. 5, serial filters must be

added to the system at the design stage. Series filters are generally used with the same switching as motor drivers and high-power AC-DC converters. Parallel filters can be easily added to the system later. Parallel passive filters prevent harmonics to flow over the load [7].

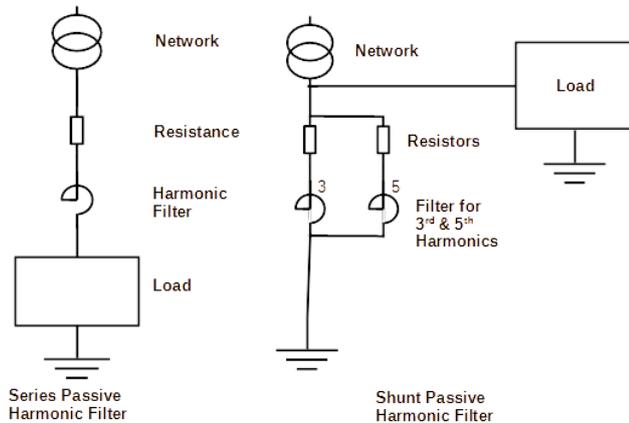


Fig. 5. Connection scheme of passive harmonic filters.

Passive filters are generally used in small and medium scale industries. They provide protection of the system and energy quality with newly added devices and capacitor bank systems, added by power increase.

### B. Active Filters

Active filters are more advanced systems than passive filters. Power quality protection is provided by analyzing real-time reactive power and harmonic with reactive power analyzer, which is the part of capacitor bank system. In fact, active harmonic filter can be called as harmonic generator. Active harmonic filter systems work according to the principle of eliminating current harmonics with resonance effect by measuring harmonics in the grid in real time and generating harmonics at the same frequency against current harmonics. They prevent voltage harmonics by suppressing them. Active harmonic filter systems work according to the principle of eliminating current harmonics with resonance effect by measuring harmonics in the grid in real time and generating harmonics at the same frequency against current harmonics. Active harmonic filter systems are indispensable for power quality and durability of the devices in large industrial enterprises [7].

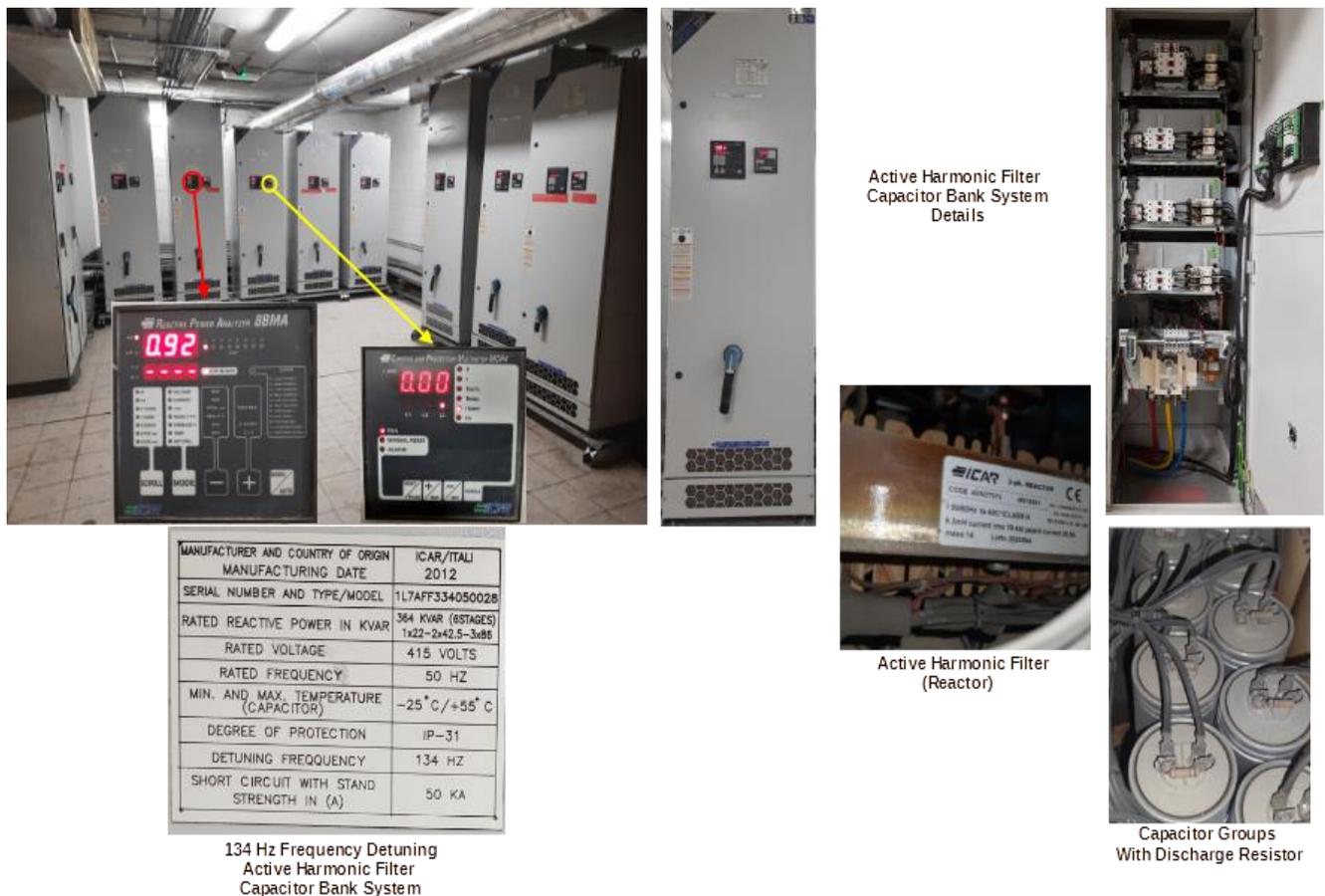


Fig. 6. Active harmonic filter capacitor bank system of a modern enterprise.

Although the costs of active filter harmonic systems are high, they redeem the initial investment cost in a short time by ensuring the durability of the devices and installation in the system. Another advantage of active filter harmonic system is that through accurate measurements of electricity meters, they prevent additional electricity bill and fine.

### C. Isolation Transformers

Isolation transformers are used to ensure the proper operation of sensitive measurement and switching devices protection of them. As the name suggests, the secondary winding supply the device while isolating from the main grid. Since it provides isolated supply from the main grid, harmonics and noises in the main network do not affect our device. Another advantage of isolation transformer is that

the secondary side does not work with zero volt reference, so it prevents electric shocks.

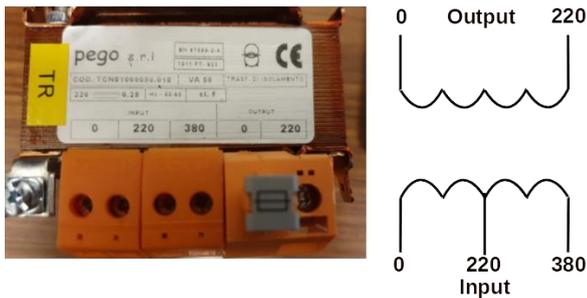


Fig. 7. Isolation Transformer and its symbol.

## VI. CONCLUSION, DISCUSSION AND PROPOSALS

In order to benefit from the advantages of today's high technology, power quality and power efficiency are the most important issues in small, medium and large scale industrial enterprises to keep production continuity and cost reduction. Harmonics are one of the many factors, perhaps the most important one, that determine energy quality. Below you can see the conclusions of this article, where we analyzed the harmonic causes and prevention measures:

✓ Voltage increases up to critical levels in harmonic systems. This critical voltage increase is a danger for all our devices connected to the electrical system [8].

✓ Although it is not possible to eliminate harmonics completely, it must be reduced up to the stated limits in order to avoid fine.

✓ According to energy market regulatory authority administration, retaining harmonics in a stated value is under the responsibility of enterprise.

✓ For accurate value in harmonic systems we need true value measurement tools (RMS), as average value devices give faulty results.

✓ Harmonic filtering and suppression systems should be calculated and implemented by professional experts during the project and design stage.

✓ Information and trainings about the system problems caused by harmonics and their effects on electrical devices should be given to technicians in enterprises.

✓ Periodic maintenance of existing harmonic filtering systems must be carried out.

✓ In systems with renewed production technology, the effects of selected products on energy quality should be also checked as well as their price and performance.

## ACKNOWLEDGMENT

I would like to express my deep sense of gratitude to our department head – Assoc. Prof. Huseyin Ceylan for his valuable guidance and support. His instructions have served as a major contributor towards the completion of this article.

## REFERENCES

- [1] Dandan, T. (2003) *Guc sistemlerinde harmonik harmoniklerin etkisi SAU Fen Bilimleri Enstitusu Dergisi* 7(1), 129-131.
- [2] Apay, F.T. (2008) 'Guc kalitesi parametrelerinin olculmesi ve degerlendirilmesi' *Yildiz Teknik Universitesi Fen Bilimleri Enstitusu Yuksek Lisans Tezi* 2008.
- [3] Sahin, M., Oguz, Y., Tugcu, H.Z. (2014) *Guc sistemlerinde enerji kalitesini etkileyen harmoniklerin incelenmesi EUFBED - Fen Bilimleri Enstitusu Dergisi*, 7(2), 199-218.
- [4] Kocatepe, C., Uzunoglu, M., Yumurtaci, R., Karakas, A., Arkan, O. (2003) *Elektrik tesislerinde harmonikler*.
- [5] Kakilli, A., Tuncalp, K., Sucu, M., (2008) *Harmoniklerin reaktif guc kompanzasyon sistemlerine etkilerinin incelenmesi ve simulasyonu Firat Univ. Fen ve Muh. Bil. Dergisi* 20(1), 109-115.
- [6] Sucu, M. (2003) 'Elektrik enerji sistemlerinde olusan harmoniklerin filtrenmesinin bilgisayar destekli modellenmesi ve simulasyonu' *Marmara Universitesi Fen Bilimleri Enstitusu* 2003.
- [7] Efe, S.B. (2016) *Endustriyel tesisler icin aktif ve pasif harmonik filtre uygulaması BEU Fen Bilimleri Dergisi* 5(1), 65-76.
- [8] Alasahin, Y., Ercan, I., Ozturk, A., Tosun, S., (2016) *Guc sistemlerinde harmoniklerin kritik degerlere etkisi İleri Teknoloji Dergisi* 5(1), 190-202.



**Kemal Metin** was born in Ankara, Turkey, in 1977. He has completed his high school education as electrical technician in Ankara. From 2019 he studies Control and Automation Technology Program in Kirikkale University. He is working in different international hotels as head of Engineering department for more than 10 years.



**Huseyin Ceylan** was born in Kirikkale, Turkey, in 1971. He has completed his bachelor's degree in Electrical and Electronics Engineering from Gaziantep University. He has received his Master's degree in Electrical and Electronics Engineering from Kirikkale University. He has received his PhD in Occupational Safety from Gazi University. His research interests include, occupational safety, vocational and technical education.



**Ertugrul Demirkesen** was born in Istanbul, Turkey, in 1999. He completed his high school education by graduating from the Department of Information Technologies and Web Programming at Orfi Cetinkaya Vocational and Technical Anadolu High School. Currently he studies Control and Automation Technology Program in Kirikkale University.



**Kadir Canatan** was born in Mersin, Turkey, in 1979. He completed his high school education as electrical technician in Tarsus Atlem high school. Currently he studies Control and Automation Technology Program in Kirikkale University.



**Mikail Hizli** was born in Corum, Turkey, in 1990. In 2015 he graduated from Public Administration Department of Anadolu University. Currently he studies Control and Automation Technology Program in Kirikkale University.