Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 8, S. 746-757, 11, 2024
© Telif hakkı IJANSER'e aittir
Araştırma Makalesi

IJANSER
https://as-proceeding.com/index.php/ijanser
ISSN:2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 8, pp. 746-757, 11, 2024
Copyright © 2024 IJANSER
Research Article

Mobile Application Design: Monitoring of Power Quality in Smart Buildings

Gokhan Tuncay[*1], Cihat Cagdas Uydur [1], Nedret Noyan Ozyakali [1] and Seckin Mandaci [1]

[1]*Technical Sciences Vocational School, Trakya University, Turkey*

[*]*gokhantuncay@trakya.edu.tr*

(Received: 11 December 2024, Accepted: 29 December 2024)

(5th International Conference on Scientific and Academic Research ICSAR 2024, December 23-24, 2024)

ATIF/REFERENCE: Tuncay, G., Uydur, C.C., Ozyakali, N.N. & Mandaci, S. (2024). Mobile Application Design: Monitoring of Power Quality in Smart Buildings. *International Journal of Advanced Natural Sciences and Engineering Researches*, 8(11), 746-757.

Abstract – Considering the ideal conditions during the operation of the electrical grid, the electrical energy supplied to all consumers is expected to be problem-free in terms of power quality. In this context, the effective value of the voltage and the frequency should be constant, the waveform should be sinusoidal, and it should not contain harmonic components. Achieving these conditions is not possible due to the complex nature of the loads in the network. In line with the developing technology, the increasing prevalence of renewable energy plants, smart building applications and electrical transportation systems will cause the power quality to deteriorate further with the effect of harmonic components in the network. The use of non-linear loads and the widespread use of electronic equipment will lead to an increase in undesirable situations such as losses in power systems, voltage drops, resonance events, erroneous measurements and wrong decisions taken in control systems. For this reason, it is necessary to investigate the effects of smart building systems on power quality and to evaluate the equipment in terms of power quality reliability. In this study, the negative effects of automatic control systems and electronic circuit-based loads in smart building systems on power quality and their behavior in the system was investigated. The positive and negative interaction were examined by revealing the relationship with the existing harmonic components. A mobile application was developed in order to remotely monitor all power quality parameters. Thus, it was aimed to reduce the failures experienced by low voltage system users and to contribute to the product design of equipment manufacturers.

Keywords – Harmonic Orders, Smart Building Systems, Remote Monitoring, Power Quality, Mobile Application

I. Introduction

Harmonic distortion is often not considered in domestic installations and associated wiring systems as its potential is considered negligibly small. Various standards exist to limit harmonic manifestations in the low voltage (LV) network, but these can be violated as a result of electronic equipment developments used in smart home systems that cause higher levels of harmonic distortion than permitted. While these devices may not individually be considered serious in terms of system-level harmonic distortion symptoms, electrical equipment failures and insulation failures suggest that this issue should be examined more closely.

A 10% increase in THD in a circuit will result in a 10% increase in cable temperature. Recently, attempts have been made to introduce harmonic derating factors in BS 7671 to inform the design of electrical equipment, but this approach currently prioritizes large power devices [1]. Although a wide variety of definitions have been made in the literature to characterize smart buildings, currently the whole concept and its characteristics are not clearly and uniquely defined. Analyzing the equipment used in smart building systems as a source of harmonics and evaluating the entire system is very important for developers who manufacture and design equipment in this field.

With increasing energy demand and environmental concerns, different approaches are used by researchers to use active power and energy more efficiently. In terms of energy efficiency, the importance of the results obtained is quite clear. On the other hand, as a result of the proliferation of smart building systems, the consumers in the power systems turn into a non-linear load profile and harmonic distortion will always be a valid concern. This issue has received even more attention in recent years with the proliferation of electronic devices with nonlinear elements, i.e. the increasing number of power electronic devices connected to power systems [2-4]. This leads to power quality problems due to harmonic oscillations in the power grid [5-10]. Moreover, distributed generation has become a real alternative to improve grid efficiency and reliability. Therefore, power quality is one of the main concerns of both power plant owners and grid system operators [11].

Numerous studies have concentrated on evaluating the distortion observed in voltage and current waveforms caused by various devices, including generators, transformers, static compensators, fluorescent and LED (light-emitting diode) lamps, LCD (liquid crystal display) televisions, household appliances (such as washing machines, dishwashers, and refrigerators), as well as other contemporary electronic systems [12–15]. Harmonic distortion commonly originates from two primary sources: saturable electromagnetic devices and power electronic components. In the case of saturable devices, harmonics arise due to core saturation, as observed in transformers, electrical machines, and fluorescent lamps with magnetic ballasts [16,17]. Conversely, power electronic devices, such as voltage source converters, switching power supplies, power electronic converters, and fluorescent lamps with electronic ballasts, contribute to harmonics in different ways [18–20]. These distortions, which degrade power quality in electrical systems, can disrupt the normal operation of electrical equipment and lead to unpredictable behavior under exposure to multiple frequency components [21–24]. Consequently, various monitoring techniques have been developed to identify and quantify harmonic sources and their impacts within the system [25–29].

To address these issues, standards and guidelines have been introduced to regulate harmonic distortion in electrical systems. For instance, IEEE Std 519™ 2014 recommends maintaining total harmonic voltage distortion (THDv) below 8% in low-voltage networks ($V \leq 1.0$ kV). This threshold is applied at the point of common coupling and does not extend to individual pieces of equipment [12]. Similarly, IEC Std 61000-3-2 establishes limits for harmonic currents introduced into public power supply networks. This standard specifies the permissible harmonic components of the input current generated by devices under defined conditions, covering electrical and electronic equipment with rated input currents up to 16 A per phase, designed for public low-voltage distribution systems. Notably, systems with nominal voltages below but not equal to 220 V (phase-to-neutral) remain unaddressed within this framework [30].

Smart buildings require a network and communication center and sensors to connect and manage the systems. Mobile applications are the user interface that provides access to the entire system [31]. Smart home applications, often referred to as smart home automation applications, are applications used to remotely control and manage non-computer connected devices in the home, usually from a smartphone or tablet [32]. Smart home applications can be single-purpose, such as controlling smart bulbs to automate and manage a home's lighting system, or they can be used to manage heating and air conditioning, entertainment systems, doors and windows, window coverings, security systems, and all non-computer electrical appliances. In addition, smart building systems equipped with appropriate sensors can monitor the environment and send alerts through the app in case of a problem.

In this study, in order to contribute to the studies in the literature, harmonic measurements covering the entire system for smart building systems will be made and the negative effects of the results obtained on the network are examined. In this context, the relationship and interaction with harmonic distortions in the grid are investigated. Experimental setups representing smart building systems are composed of building automation systems, electronic load systems, automation systems, microprocessors. By using independent experimental sets, both the results obtained from individual measurements were evaluated and the measurements were repeated by creating a smart building system in which all systems work together. A mobile application was developed for remote monitoring of the measurements and it was aimed to monitor power quality parameters with a single application independent of the measurement instrument manufacturers. Widespread use is targeted with the mobile application covering all manufacturers.

II. MATERIALS AND METHOD

Within the scope of this study, within the facilities of Trakya University, Edirne Technical Sciences Vocational School, harmonic measurements were made on smart building automation systems, covering each system component and the entire system. In this section, detailed information about the equipment and methods are shared.

In the simplest terms, harmonics can be defined as the deviation of current and voltage waveforms from sinusoidal form. Figure 1 shows the function graph [f(t)] of a waveform containing harmonics [1,2].

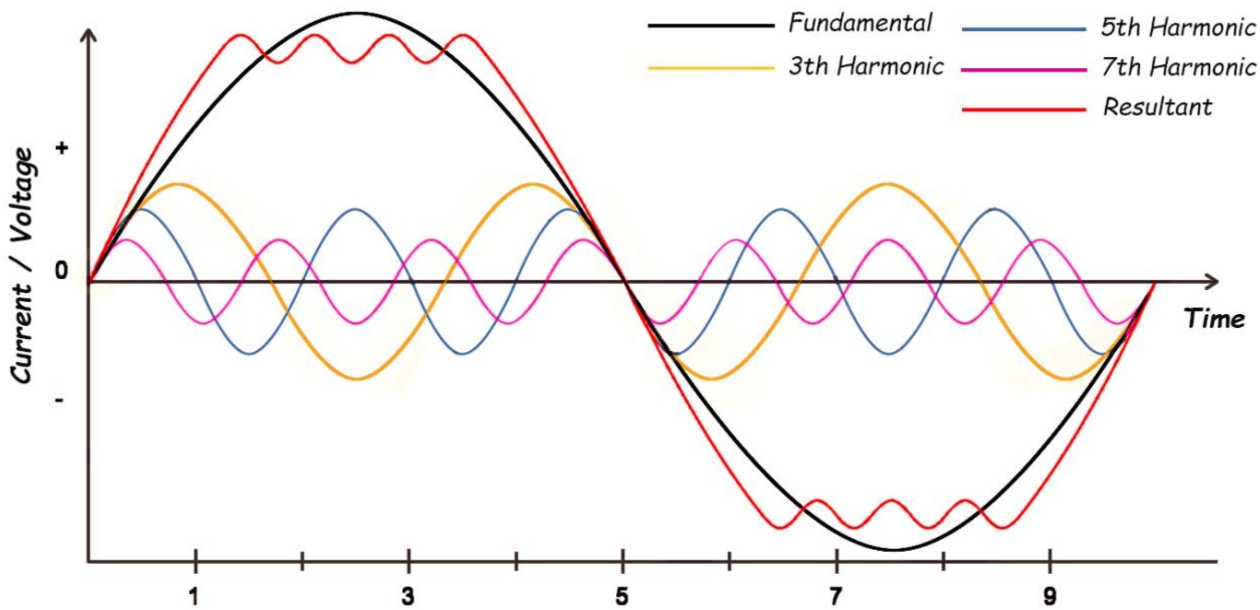


Fig. 1 Sinusoidal wave form include harmonic orders

The concept of harmonics is defined in the Regulation on Quality of Service for Electricity Distribution and Retail Sales as “Each of the sinusoidal components occurring at frequencies that are integer multiples of the frequency of the main component in an alternating current or voltage that has been distorted due to non-linear loads or generators whose voltage waveform is not ideal” [1,2]. THB formulation is shared in Equation 1.

This expression, which is referred to as THD (Total Harmonic Distortion) in foreign sources, is defined in the Service Quality Regulation on Electricity Distribution and Retail Sale and Electricity Network Regulation as “The square root of the sum of the squares of the sum of the squares of the effective values of the effective values of the voltage harmonic components is the ratio of the effective value of the main component and is the expression of the waveform distortion as a percentage.”. However, in the formulation specified in the service quality regulation, harmonic components up to 40th order are taken into account, while in the network regulation, harmonic components up to 50th order are taken into account.

$$THB_V = \frac{\sqrt{\sum_{h=2}^{40} (U_h)^2}}{U_1} x100 \quad (1)$$

TTB is defined in the same sentence in the Service Quality Regulation and the Network Regulation. This definition is as follows; “It is the expression of the waveform distortion which is the ratio of the square root of the sum of the squares of the effective values of the current harmonic components to the maximum load current (IL). The TTB formulation is shared in Equation 2.

It is defined as TDD (Total Demand Distortion) in IEEE Std 591-2014. The IL value is defined as the largest of the 15 or 30 minute averages of the principal component effective value of the load current drawn from the grid connection point during the 12-month measurement period. In this definition, there is no information about in which cases the 15-minute averages and in which cases the largest of the 30-minute averages will be taken [12].

$$TTB = \frac{\sqrt{\sum_{h=2}^{40} (I_h)^2}}{I_L} x100 \quad (2)$$

Harmonic measurements on smart building systems equipment were performed in two steps. In the first step, automation systems are analyzed with harmonic measurements within the framework of TS EN 61000 and IEEE 519 standards. Measurements were recorded using a power analyzer. In the second step, harmonic measurements were made using the Lutron DW 6095 power analyzer in our laboratory on the smart building automation system created by integrating all components. In addition, measurements were repeated by creating various variations by integrating the load simulations and electronic cards in the electronic system into the system at different times and numbers. In this context, the evaluation of smart building automation systems in terms of harmonic source was evaluated in detail to cover different situations.

All power quality parameters obtained from the experimental setups are saved in a database. With the help of Kotlin programming language, a mobile application was developed for mobile devices using Android operating systems to remotely monitor these parameters. The application was created to serve as an interface on power quality parameters, to provide an overview of the system, to monitor components, to filter values according to desired time intervals, to monitor threshold values, to change component status by sending commands to microcontrollers, to warn of possible malfunctions, and to provide reports.

III. Measurement Results

The frequency of alternating voltage in our country is 50 Hz and it is a sine wave alternating voltage. In the measurement of harmonics formed in sine waves, harmonics can be measured by measuring current and voltage with the help of an oscilloscope. But because of the difficulty of this measurement, an energy analyzer was used. When making harmonic measurements, it is necessary to measure a large number of current and voltage values at short intervals at the same point.

The energy analyzer measures and records three phases simultaneously current, voltage and power values and these records are graphically recorded and a visual document is created. Energy analyzer devices generally have the ability to connect directly to the network up to 1000 V. Current measurements are made with the help of current clamp, i.e. current transformer. In this way, current and voltage values of all phases are measured. The measurement of power quality parameters of smart building automation systems was carried out with the Lutron DW-6093 power analyzer shown in Figure 2.

Fig. 2. Lutron DW-6093 power analyser

First of all, as a result of our researches, Lutron DW-6093 Power Analyzer was preferred by searching for an energy analyzer that complies with local and international standards such as TS EN 61000, IEEE 1459, EN 50160, IEEE 519 in order to have harmonic measurements with appropriate standards. The device is manufactured in accordance with IEC/EN 61000-4-15, IEC/EN 61000-4-30, IEC/EN 61000-4-7, IEEE 1459, IEEE 1448, IEEE 519, EN 50160 standards. During the measurement processes, default situations were analyzed by choosing time zones where all lighting and motor relays are active. In addition, resistive load models such as kettle, coffee maker, electric stove and air conditioners were chosen to represent the loads operated by the smart socket module.

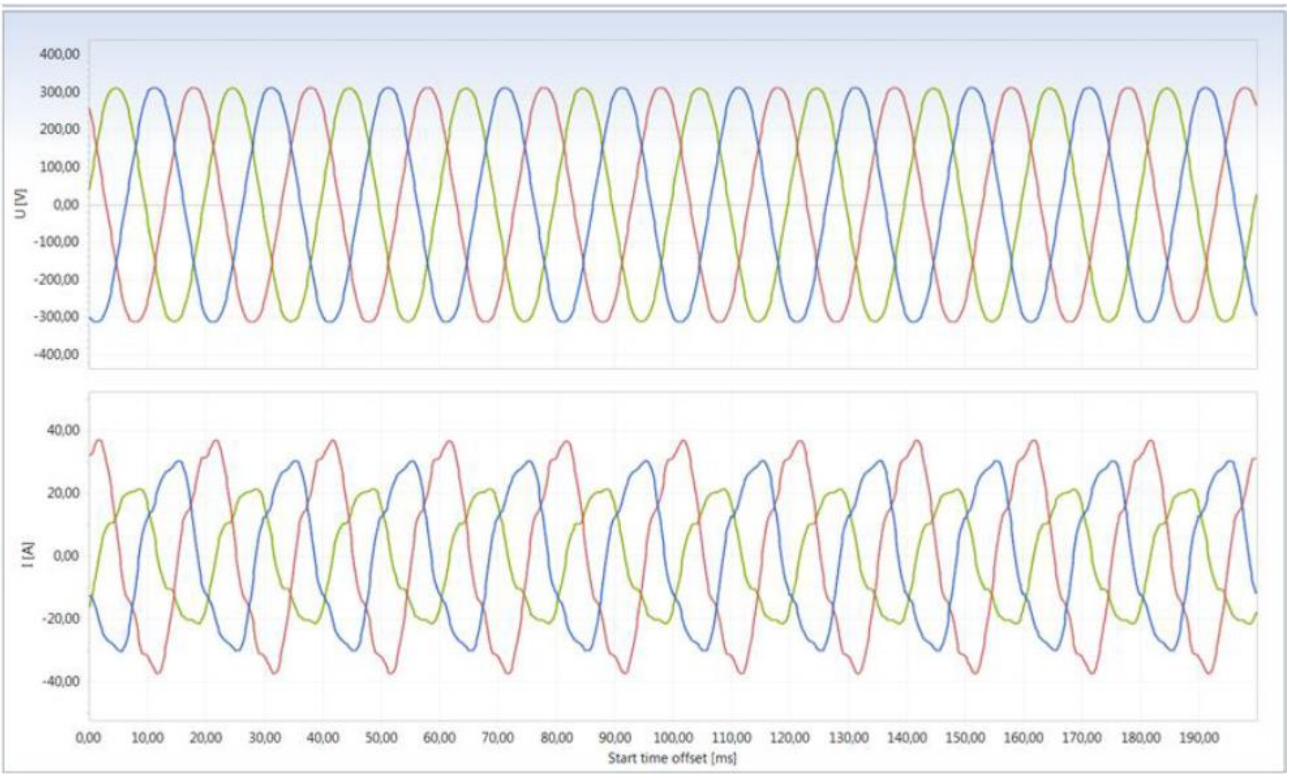


Fig. 3. Voltage and current graphics from power analyser

In order to prevent the system from being affected by the transient situation during operation, the measurement was started after the luminaires were commissioned. Figure 3 shows the current voltage graphs. As seen in the measurement results, the frequency varies between 50.008 and 50.01 Hz. Since this change is very small, it can be considered constant. In Figure 4, Total Harmonic Distortion (THD) is the most important indicator of the system. The THD value for Phase 1 is 11.66%, THD value for Phase 2 is 10.82% and THD value for Phase 3 is 12.36%. In cases where the determinants of the parameters used in the analysis of the measurement results were not in line with the relevant standards and the content of the publications in the literature, fire detection and security systems were included in the scenarios and the measurements were repeated. This means that all systems belonging to smart building automation components are activated. Total Harmonic Distortion (THD) is the most important indicator of the system. The THD value for Phase 1 is 13.52%, for Phase 2 it is 12.65% and for Phase 3 it is 11.89%.

A commonly used measurement of the deviation of a periodic wave from an ideal sine wave is called total harmonic distortion (THD) or distortion factor. As a result of THD calculation in a system, it is possible to say the following for THD values if a rough generalization is made, although it varies from facility to facility.

- If $THD_V < 2.5\%$ and $THD_I < 10\%$, there is no energy pollution due to harmonics in the facility.
- If $THD_V \approx 2.5$ -3% and $THD_I \geq 10\%$, it is technically appropriate to apply harmonic filtration in the facility. However, it may not be suitable for economic conditions.
- If $THD_V \geq 3\%$, there is a risk of parallel resonance and the application of a harmonic filtration system suitable for the plant conditions is the most appropriate solution both technically and economically.

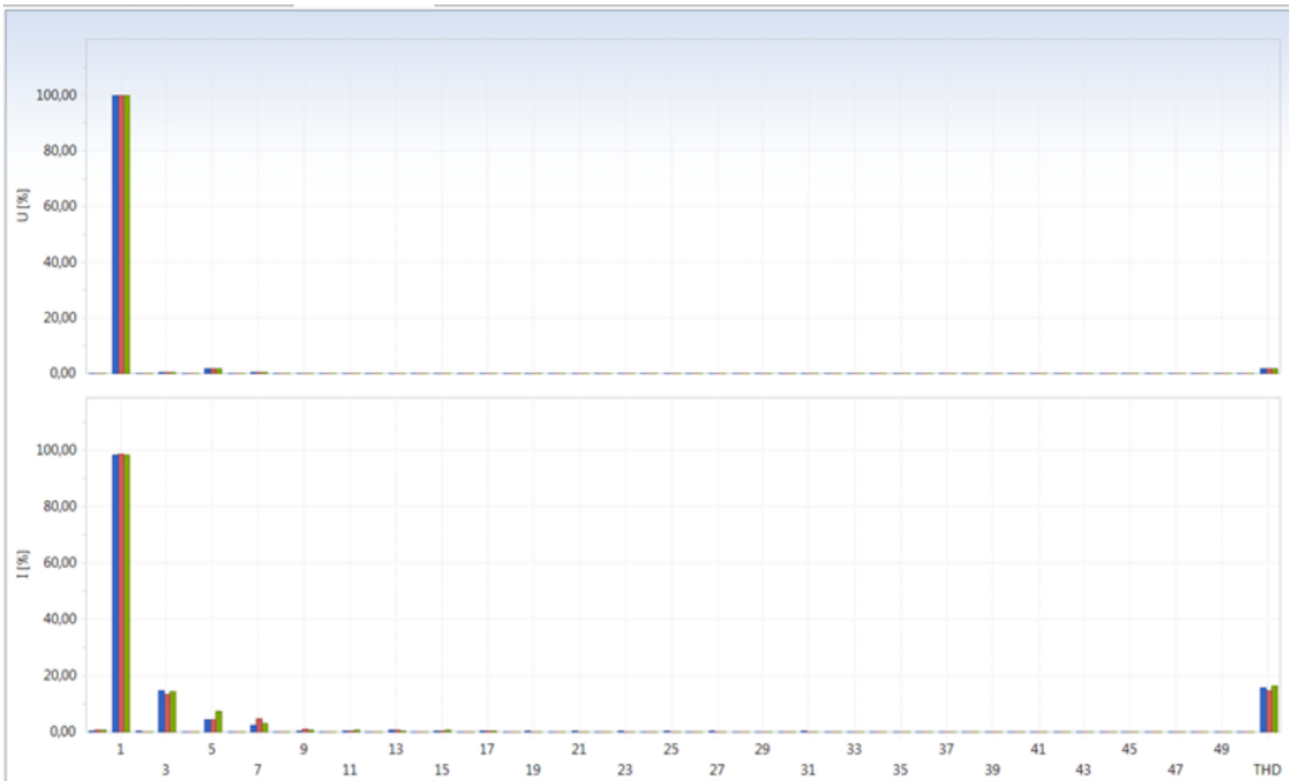


Fig. 4. THB% and values of phase currents harmonic orders

IEC 61000-2-2 contains voltage harmonic limitations for residential low voltage networks. Detailed information is shared in Table 1.

Table 1. IEC 61000–2-2 limitations

n	%Vn	n	%Vn	n	%Vn
5	6	2	2	3	5
7	5	4	1	9	1,5
11	3,5	6	0,5	15	0,3
13	3	8	0,5	≥21	0,2
17	2	10	0,5	*Not: k=0,2+12,5/n	
19	1,5	≥12	0,2		
23	1,5				
25	1,5				
≥ 29	k*				

When the measurement results obtained from the experimental studies were evaluated within the scope of the limits specified in the IEC 61000-2-2 standard, it was observed that the limit values were not exceeded.

IV. MOBILE APPLICATION

At the center of the smart building automation systems application set, which can be seen in Figure 5, is the Fibaro Home Center controller.

Fig. 5. Smart building automation systems application kit

The Home Center controller can communicate bi-directionally with all modules connected to it thanks to the Z-Wave wireless communication protocol. The Home Center also includes an Application Programming Interface (API) where each module has a Uniform Resource Locator (URL) that can be interacted with. This interface is a distributed system known as Representational State Transfer (REST), which includes various functions, protocols and technologies that clients use to access server data. Due to these technical features of the controller, Node.js and Express.js technologies were used for the backend operations of the mobile application developed, and MySQL management system was preferred for database operations.

Node.js is an open source, cross-platform environment that allows the JavaScript programming language to be run on the server side. Ideal for developing fast and scalable network applications, this system enables the creation of high-performance and low-latency applications thanks to its asynchronous input/output operations and event-driven architecture. Express.js is a minimal and flexible web application framework built on Node.js. It provides a simple and powerful interface that allows for easy processing of Hyper-Text Transfer Protocol (HTTP) requests and responses, and is an ideal tool for creating RESTful application programming interfaces to systems that provide REST principles. MySQL is an open source relational database management system widely used all over the world. It enables data processing and management operations to be performed with the help of Structured Query Language (SQL).

On the Android side, single activity and multiple fragment structure is preferred. Fragment/Child View Controller operation for each screen of the application is as follows.

Login Screen (LoginFragment/ChildViewController): It contains username and password entry fields. When the login button is pressed, the backend initiates the authentication process. When the user successfully logs in, the backend generates a JSON Web Token (JWT) and this sensitive data is encrypted with Secure SharedPreferences and stored on the user's device. The JWT is validated on every API request that requires user authorization. However, user passwords are stored in the database after being passed through a hash function. Since hash functions are non-reversible (one-way) functions, the system administrator or a potential database attacker has no chance to access the plaintext of the passwords.

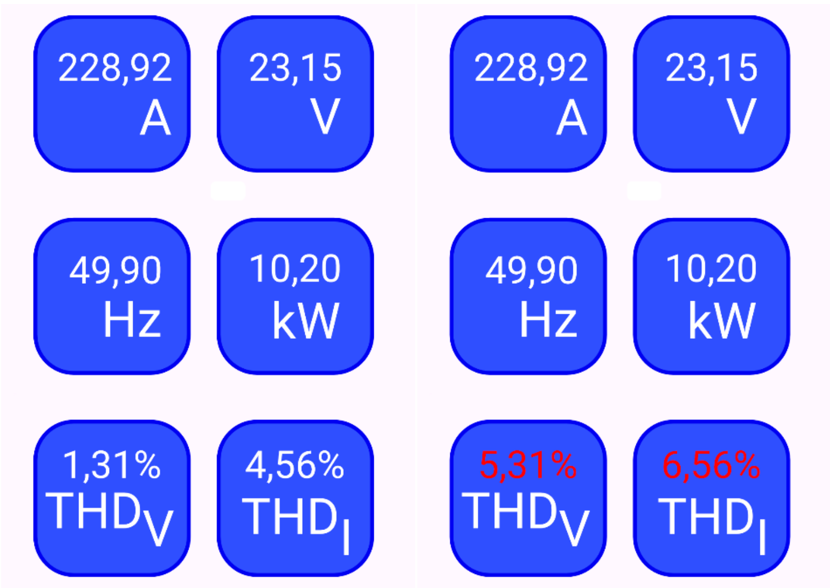
Admin Screen (AdminFragment/ChildViewController): Role-Based Access Control (RBAC) is used in the mobile application. There are two user roles: administrator and user. While users have limited privileges such as device control and reading logs, administrators have standard user privileges as well as extra privileges such as adding and deleting users and database management.

Device Control Screen (DeviceControlFragment/ChildViewController): This is the screen where users can view and control devices according to their authorizations registered in the database. Every operation to be performed on the devices is performed after the users' authorizations are checked. In addition, a JWT must be sent with each request and the backend must validate this token.

Graphic and Data Display (GraphicDataFragment/ChildViewController): It is the screen designed to examine the data obtained from the devices and sensors in the smart building automation system application set and to create graphics. The open source AnyChart library was used to convert the sensor data obtained from the database into graphics.

Under Device Sensor Graphs, it is possible to access the graphs created for devices such as temperature sensor, smoke sensor, wall socket, smart lamp that can be measured within the smart building automation system application set. The relevant graphs appear to the user primarily on a monthly basis. When any month is clicked, daily graphs are obtained, and similarly, when any day is clicked, hourly graphs are obtained.

Under the Power Analysis Data button, the system can display the total Volt, Amper, Hertz, kWh, THD_V and THD_I values of all currently active devices. In addition, the application can display warnings by checking the harmonic order values. Screenshots of the mobile application are presented in Figures 6 and 7.



(a) THD value is not out of the limitations (b) THD value is out of the limitations

Fig. 6. Power analysis data screenshots

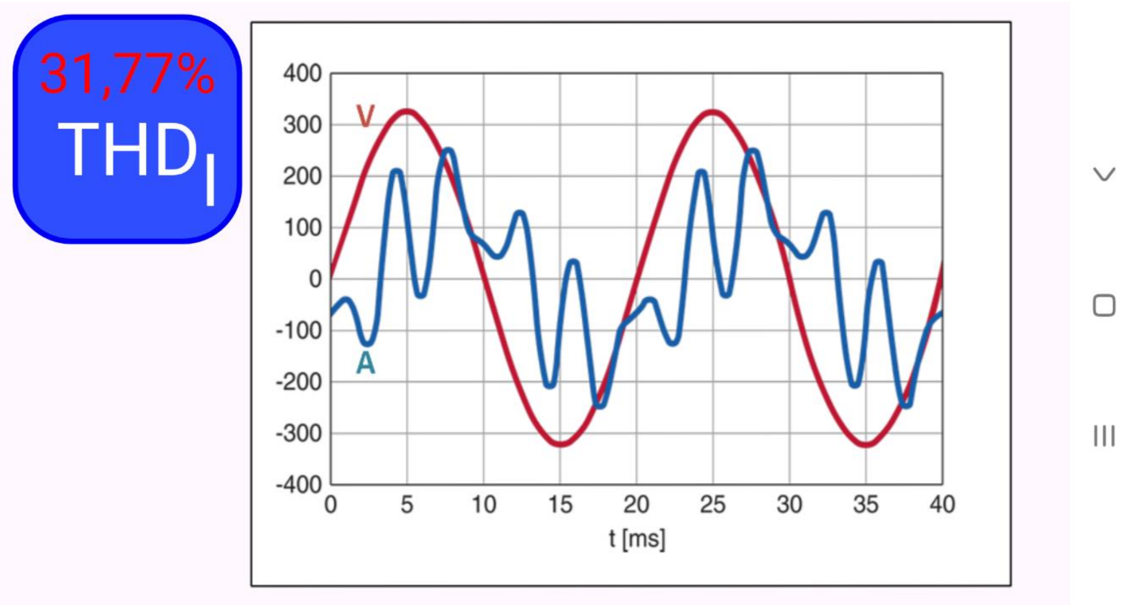


Fig. 7. Mobile application instant THD graph screenshot

Three different test environments were created for the designed mobile application. In the first of these, the mobile application was tested using different simulators in both Android Studio software development environment. In order to maximize compatibility, care was taken to ensure that the simulators had different screen sizes, different resolutions and different hardware specifications.

In the second test environment, many different usage scenarios were created using the devices and sensors in the smart building automation systems application set and each scenario was tested on the application.

Finally, the mobile application was tested with the help of Google Play Console software, which is the most frequently used test environment of the application markets of devices with Android operating system.

V. CONCLUSION

In this study, in order to contribute to the studies in the literature, harmonic measurements covering the entire system for smart building systems will be made and the negative effects of the results obtained on the network are examined. In this context, the relationship and interaction with harmonic distortions in the grid are investigated. Experimental setups representing smart building systems are composed of building automation systems, electronic load systems, automation systems, microprocessors. By using independent experimental sets, both the results obtained from individual measurements were evaluated and the measurements were repeated by creating a smart building system in which all systems work together. A mobile application was developed for remote monitoring of the measurements and it was aimed to monitor power quality parameters with a single application independent of the measurement instrument manufacturers. Widespread use is targeted with the mobile application covering all manufacturers.

The findings obtained from the study are shared below;

- The impact of smart building automation systems on power quality is not corrosive.
- According to the measurement results during different variations, harmonic distortion values are within the limits specified in the relevant standards.
- In the case of the widespread use of smart building automation systems in homes, the change characteristics of power quality parameters are emphasized.
- With the developed mobile application, it has become possible to remotely monitor the modules in smart building automation systems.
- With the instant monitoring of harmonic distortion limit values, fault monitoring is provided on system components.

- It has been observed that monthly, daily and hourly graphs can be monitored successfully and the mobile application is successful.
- As a result, it was determined that the mobile monitoring application can be used in reducing economic losses and planning maintenance works.

ACKNOWLEDGMENT

This study was funded by Scientific Research Projects Coordination Unit of Trakya University Project number: 2023-112.

REFERENCES

[1] Regulations, IET Wiring; Seventeenth Edition. Requirements for Electrical Installations. BS7671-2008, 2008
[2] Škrbić, B.; Mikulović, J.; Šekara, T. Extension of the CPC Power Theory to Four-Wire Power Systems with Non-Sinusoidal and Unbalanced Voltages. Int. J. Electr. Power Energy Syst. 2019, 105, 341–350.
[3] Cai, G.; Wang, L.; Yang, D.; Sun, Z.; Wang, B. Harmonic Detection for Power Grids Using Adaptive Variational Mode Decomposition. Energies 2019, 12, 232.
[4] Hoon, Y.; Radzi, M.A.M.; Hassan, M.K.; Mailah, N.F. Control Algorithms of Shunt Active Power Filter for Harmonics Mitigation: A Review. Energies 2017, 10, 2038.
[5] Jain, S.K.; Singh, S.N. Exact Model Order ESPRIT Technique for Harmonics and Interharmonics Estimation. IEEE Trans. Instrum. Meas. 2012, 61, 1915–1923.
[6] Krein, P.T. Digital Control Generations—Digital Controls for Power Electronics Through the Third Generation. In Proceedings of the 7th International Conference on Power Electronics and Drive Systems, Bangkok, Thailand, 27–30 November 2007.
[7] Carpinelli, G.; Proto, D.; Russo, A. Optimal Planning of Active Power Filters in a Distribution System Using Trade-off/Risk Method. IEEE Trans. Power Deliv. 2017, 32, 841–851
[8] Moreno, I.M.; Medina, A.; Magana, R.C.; Lara, O.A. Noise Mitigation in Voltage and Current Waveforms in Harmonic Distortion Estimation. In Proceedings of the IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC), Ixtapa, Mexico, 8–10 November 2017.
[9] Bagheri, P.; Xu, W.; Ding, T. A Distributed Filtering Scheme to Mitigate Harmonics in Residential Distribution Systems. IEEE Trans. Power Deliv. 2016, 31, 648–656.
[10] Montoya, F.G.; Baños, R.; Alcayde, A.; Arrabal-Campos, F.M. Analysis of Power Flow under Non-Sinusoidal Conditions in the Presence of Harmonics and Interharmonics using Geometric Algebra. Int. J. Electr. Power Energy Syst. 2019, 111, 486–492.
[11] Camacho, A.; Castilla, M.; Miret, J.; Matas, J.; Guzman, R.; de Sousa-Pérez, O.; Martí, P.; de Vicuña, L.G. Control Strategies Based on Effective Power Factor for Distributed Generation Power Plants During Unbalanced Grid Voltage. In Proceedings of the 39th Annual Conference of the IEEE Industrial Electronics Society (IECON), Vienna, Austria, 10–13 November 2013.
[12] IEEE Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems; IEEE Standard 519-2014; The Institute of Electrical and Electronics Engineers (IEEE): New York, NY, USA, 2014.
[13] Rawa, M.J.H.; Thomas, D.W.P.; Sumner, M. Experimental Measurements and Computer Simulations of Home Appliances loads for Harmonic Studies. In Proceedings of the UKSim-AMSS 16th IEEE International Conference on Computer Modelling and Simulation, Cambridge, UK, 26–28 March 2014
[14] Islam, M.S.; Chowdhury, N.A.; Sakil, A.K.; Khandakar, A.; Iqbal, A.; Abu-Rub, H. Power Quality Effect of Using Incandescent, Fluorescent, CFL and LED Lamps on Utility Grid. In Proceedings of the First Workshop on Smart Grid and Renewable Energy (SGRE), Doha, Qatar, 22–23 March 2015.
[15] Gil-de-Castro, A.; Rönnberg, S.K.; Bollen, M.H.J.; Moreno-Muñoz, A. Study on Harmonic Emission of Domestic Equipment Combined with Different Types of Lighting. Int. J. Electr. Power Energy Syst. 2014, 55, 116–127.
[16] Dwyer, R.; Khan, A.K.; Mcgranaghan, M.; Tang, L.; Mccluskey, R.K.; Sung, R.; Houy, T. Evaluation of Harmonic Impacts from Compact Fluorescent Lights on Distribution Systems. IEEE Trans. Power Syst. 1995, 10, 1772–1779.
[17] Radmanesh, H.; Hosseinian, S.H.; Fathi, S.H. Harmonic Study in Electromagnetic Voltage Transformers. In Proceedings of the IEEE International Symposium on Industrial Electronics, Hangzhou, China, 28–31 May 2012
[18] Grady, W.M.; Santoso, S. Understanding Power System Harmonics. IEEE Power Eng. Rev. 2001, 21, 8–11.
[19] Filho, E.M.V.; Ribeiro, M.M.; Salomé, P.G.; Ribeiro, P.F. Influence of Harmonic Distortion in Current Transformer. In Proceedings of the 17th International Conference on Harmonics and Quality of Power (ICHQP), Belo Horizonte, Brazil, 16–19 October 2016.
[20] Ciocia, A.; Mazza, A.; Russo, A.; Spertino, F.; Enescu, D. Experimental investigations to characterize power quality of AC supplied thermoelectric refrigerators. In Proceedings of the 52nd International Universities Power Engineering Conference (UPEC), Heraklion, Greece, 28–31 August 2017.

[21] Wang, Y.; Yong, J.; Sun, Y.; Xu, W.; Wong, D. Characteristics of Harmonic Distortions in Residential Distribution Systems. IEEE Trans. Power Deliv. 2017, 32, 1495–1504.
[22] Silva, F.B.; Vanço, W.E.; Gonçalves, F.A.S.; Junior, C.A.B.; Carvalho, D.P.; Neto, L.M. Experimental Analysis of Harmonic Distortion in Isolated Induction Generators. IEEE Lat. Am. Trans. 2016, 14, 1245–1251.
[23] Yong, J.; Chen, L.; Chen, S. Modeling of Home Appliances for Power Distribution System Harmonic Analysis. IEEE Trans. Power Deliv. 2010, 25, 3147–3155.
[24] Locci, N.; Muscas, C.; Sulis, S. Detrimental Effects of Capacitors in Distribution Networks in the Presence of Harmonic Pollution. IEEE Trans. Power Deliv. 2007, 22, 311–315
[25] Mazin, H.E.; Xu, W.; Huang, B. Determining the Harmonic Impacts of Multiple Harmonic-producing Loads. In Proceedings of the IEEE Power and Energy Society General Meeting, San Diego, CA, USA, 24–29 July 2011.
[26] Munir, M.S.; Li, Y.W.; Tian, H. Improved Residential Distribution System Harmonic Compensation Scheme Using Power Electronics Interfaced DGs. IEEE Trans. Smart Grid 2016, 7, 1191–1203.
[27] Tran, T.V.; Chun, T.W.; Lee, H.H.; Kim, H.G.; Nho, E.C. Control Method for Reducing a THD of Grid Current at Three-phase Grid-Connected Inverters under Distorted Grid Voltages. J. Power Electron. 2013, 13, 712–718.
[28] Farhoodnea, M.; Mohamed, A.; Shareef, H.; Zayandehroodi, H. An Enhanced Method for Contribution Assessment of Utility and Customer Harmonic Distortions in Radial and Weakly Meshed Distribution Systems. Int. J. Electr Power Energy Syst 2012, 43, 222–229.
[29] Ujile, A.; Ding, Z. A Dynamic Approach to Identification of Multiple Harmonic Sources in Power Distribution Systems. Int. J. Electr Power Energy Syst. 2016, 81, 175–183
[30] Electromagnetic Compatibility (EMC)—Part 3-2: Limits—Limits for Harmonic Current Emissions (Equipment Input Current ≤ 16 A per Phase). IEC Standard 61000-3-2; International Electrotechnical Commission (IEC): Geneva, Switzerland, 2018.
[31] Stolojescu-Crisan, C., Crisan, C., & Butunoi, B. P. (2021). An IoT-based smart home automation system. Sensors, 21(11), 3784.
[32] Gunge, V. S., & Yalagi, P. S. (2016). Smart home automation: a literature review. International Journal of Computer Applications, 975(8887-8891).