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POWER SYSTEMS DYNAMIC SIMULATION DEVELOPMENTS FOR POWER QUALITY MONITORING

MASTER THESIS

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I hereby affirm in that I provided the submitted master research thesis

POWER SYSTEMS DYNAMIC SIMULATION DEVELOPMENTS FOR POWER QUALITY MONITORING

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Freiberg, Germany,
15.05.23

Place, Date

Signature

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ABSTRACT

This Master's thesis addresses the critical issue of high harmonics impacting the power grid system's power quality, resulting in financial losses, equipment heats generation, transmission and distribution line problems, and electrical shock to end-users. These harmonics are especially problematic within industrial environments such as steel melting furnaces, where significant voltage and current volatility is observed. This study utilized real-time data measurement at the highest and lowest potential points within these furnaces. It developed MATLAB's dynamic simulation to accurately represent and analyze the sinusoidal waveform of fundamental harmonics and the distinctive harmonics generated within the power system's energy conversion process. This analysis adheres to the specifications outlined in the MNS 1778:2007 and IEEE 519-2014 standards, contributing to understanding and preserving power quality in energy dynamics. The gathered data was imported into Microsoft Excel for further processing and evaluation. MATLAB's Graphical User Interface simulated the harmonic oscillations and changes under varying load conditions. The preliminary findings reveal that the odd harmonics, particularly those not divisible by three, are causing substantial damage to the fundamental harmonics waveform, significantly impacting the electrical grid system. Given the current lack of current quality control or standardization in the MNS 1778:2007, it is crucial to integrate the IEEE 519-2014 standard's current quality control measures. Future research will delve into the differences in odd harmonics divided by three and not divided by three and develop strategies to filter them using a hybrid filtering system. Furthermore, the research anticipates implementing current harmonics or quality standards into the Mongolian electrical system, promoting electrical purity in the industrial and mining sectors.

CHAPTER 1. RESEARCH BACKGROUND

1.1. Overview

Research on power quality in Mongolia's energy and electrical engineering sector has been limited since the establishment of the energy and power grids in 1922. However, the extensive use of highly non-linear loads, such as high-capacity rectifiers, melting apparatuses, computers, and fluorescent lamps, has led to the generation of excessive reactive power and distorted current waveforms, resulting in poor power quality. Poor power quality can cause significant losses to industries, businesses, and the economy, and even pose a threat to human life in mission-critical applications and highly sensitive environments. Additionally, it can lead to equipment breakdowns, system failures, high energy bills, and payment penalties.

The power quality parameters involved include power frequency, voltage magnitude, flicker, voltage sags and swells, voltage interruptions, transient over-voltages, voltage unbalance, voltage and current harmonics, voltage inter-harmonics, mains signaling on the supply voltage, and rapid voltage changes. Harmonics and inter-harmonics are the key parameters that reduce power quality, and other parameters do not meet standards when these occur in power grid systems. Harmonic filters can mitigate the problem of harmonic waveform distortion, reduce thermal and electrical stress on the electrical infrastructure, and prevent harmonics-related reliability issues, leading to long-term energy efficiency and cost savings. Since modern electrical devices are mostly nonlinear, harmonic filters will play a vital role in ensuring better power quality.

1.2. Problem Description, Motivation, Research Objectives

The Erdenet Mining Corporation's mineral processing plant is a state-of-the-art facility that operates on a fully automated system. However, the use of semiconductor-based equipment has resulted in increased electricity consumption and a need for improved operational reliability and safety. Despite these challenges, the power quality of the plant's power systems has not yet been studied.

To address this gap in knowledge, this master's thesis research will focus on studying the behavior of power quality in the power systems of Erdenet Mining Corporation. The goal is to develop a dynamic simulation that will shed light on the factors that affect power quality and identify areas for improvement.

One of the key steps in improving power quality is to study load characteristics. By understanding how the plant's equipment consumes electricity, it will be possible to identify areas where energy efficiency can be improved. Once load characteristics have been studied, the next step will be to develop filters that can improve power quality in the energy systems.

Overall, this research has the potential to make a significant contribution to the field of mineral processing by improving the efficiency and reliability of power systems. By developing a better understanding of power quality, it will be possible to reduce energy consumption, improve safety, and enhance the overall performance of the Erdenet Mining Corporation's mineral processing plant and manufacture of steel balls.

1.3. Profile of organization:

Erdenet Mining Corporation was established in 1973 through a joint venture between Mongolia and Russia, with each country owning 50% of the company. Since then, EMC has played a pivotal role in Mongolia's development throughout the 20th century. The construction of the Erdenet plant marked the beginning of a remarkable journey for the corporation, which led to the establishment of Erdenet city, a mining-focused city with comprehensive infrastructure. This city has become a classic model for large-scale mining projects.

Today, EMC is the largest copper and molybdenum mining and concentrating company in Asia, processing an impressive 35 million tons of ore and extracting 37-40 million tons of ore annually. The company produces approximately 580.0 thousand tons of copper concentrate and about 5.0 thousand tons of molybdenum concentrate every year. EMC has established collaborations with leading mining experts from around the world, including Phelps Dodge, Inc.; Outokumpu Oyj, Finland; Bateman Engineering Ltd., Australia; Pacific Ore Technology Ltd., Australia; Brook Hunt & Associates Ltd., UK; KDEngineering, USA; and Samsung Corp., South Korea [1].

EMC's success can be attributed to its commitment to excellence and its ability to form strategic partnerships with industry leaders. The company's focus on innovation and sustainability has allowed it to maintain its position as a leader in the mining industry. With a strong track record of success and a commitment to responsible mining practices, EMC is poised to continue its growth and development well into the future.

1.4. Goal & Objective of the study

Dynamic simulations have been used by many researchers to study power quality of industrial power systems. However, dynamic simulations cannot define all parameters, and therefore require reference modeling and mathematical expression. This study aims to develop a dynamic simulation model using MATLAB Simulink and real-time data of existing power subsystems, with Microsoft Excel used for visualization and analysis of results.

The goal of this master's research is to develop a dynamic simulation model for analyzing power quality, with the following specific objectives:

- Review the most important parameters of power quality and investigate various simulation techniques.
- Develop an algorithm to determine the extent to which the power quality meets the requirements of MNS 1778-2007.
- Develop a dynamic simulation model to study power quality characteristics based on different loads such as processing plant and manufacture of steel balls.
- Analyze and compare the data obtained from the study cases including processing plant and manufacture of steel balls.

By accomplishing these objectives, the research will provide insights into power quality behavior and help improve the reliability and safety of the power systems at Erdenet Mining Corporation.

1.5. Outline

This thesis comprises five chapters.

- Chapter 1 introduces the main research topic and discusses the purpose of the study in a wider context.
- Chapter 2 provides a comprehensive study of key elements related to reliability and power quality, including power quality parameters, power systems, load characteristics, harmonics behaviors, and methods for developing dynamic simulations. The chapter also reviews various approaches for determining power quality, harmful harmonics, and constraints. Furthermore, it provides basic knowledge of modeling and simulation on MATLAB Simulink, and also includes a comparative study on power quality standards, introducing the MNS 1778-2007 standard.
- Chapter 3 studies on power quality parameters and its standards such as Nominal voltage and acceptable voltage values, steady-state voltage variation, voltage amplitude variation, flicker (voltage fluctuation), total harmonics distortion, individual harmonic order coefficient, supply voltage asymmetry inverse order, supply voltage asymmetry zero order, frequency deviation or variation, voltage dip or a sag, impulse voltage, and transient overvoltage.
- Chapter 4 investigates the development of an algorithm, flow chart, and block diagram for dynamic simulation in studying power quality, and presents the results of the dynamic simulation based on real-time data from different loads of the mineral processing plant. The chapter first determines modeling blocks based on load characteristics, followed by an explanation of simulation approaches with defined constraints. Then, the results obtained from simulations are analyzed and compared with different loads. Finally, harmful aspects are determined based on the simulation results, and several essential aspects are discussed.

- Chapter 5 discusses the research results based on the dynamic simulation and summarizes the research findings, presents conclusions, and provides recommendations for future research.

1.6. Conclusion of chapter one

This research effort represents a comprehensive attempt to examine power quality in the context of Mongolia's Erdenet Mining Corporation, particularly concerning the functioning of their mineral processing plant. The study recognizes the potential power quality issues inherent in a system heavily dependent on non-linear loads and seeks to mitigate them.

It is established that understanding the plant's load characteristics can pave the way for identifying areas where energy efficiency can be improved. This knowledge has been employed in developing harmonic filters, potentially enabling better power quality and, overall operational efficiency. Moreover, the study uses dynamic simulation and algorithmic models to illuminate power quality characteristics and behavior under varying load conditions.

The Erdenet Mining Corporation, a joint venture between Mongolia and Russia, plays a crucial role in Mongolia's development and operates as Asia's largest copper and molybdenum mining and concentrating company. The study's focus on improving the power quality within the organization can help reduce energy consumption, enhance safety protocols, and optimize the overall performance of the corporation's mineral processing plant.

The research provides a blueprint for a targeted approach to power quality improvement. Leveraging tools like MATLAB Simulink for dynamic simulation and Microsoft Excel for data visualization and analysis presents a viable path to enhance the power systems' reliability and safety. Further research and iterations of these models can potentially unearth additional avenues for power quality improvement and operational efficiency.

CHAPTER 2. RELIABILITY AND POWER QUALITY OF POWER SYSTEM

2.1. Background knowledge of reliability and power quality of power system

The development of Mongolia's energy sector, which is the backbone of the country's growth, began in 1922. The groundwork for the power systems was established in 1932, and the first thermal power plant was constructed in the same year, creating a complex fuel and power system. Currently, the energy sector operates 15 sources of renewable and convenient energy with a total installed capacity of 1277 MW, which supplies approximately 80% of the total consumption.

The mining industry is heavily reliant on advanced equipment with high capacity that utilizes microprocessor and logic-controlled, fully automated, and semiconductor-based techniques and devices. A small change in the steady state or transient state of the power grid system can negatively affect the operation of these technical devices and, consequently, the production process. Therefore, it is crucial to maintain high power quality to ensure optimal productivity and quality of the end products, as well as the smooth operation of technological processes and equipment.

One of the primary pieces of equipment in the mineral processing plant is the induction melting furnace, which is used for metal processing and producing steel balls for concentrators. However, the inductive properties of induction melting furnaces and step-down transformers can create harmonic pollutions and cause resonance in the power grid systems, which can degrade power quality.

As previously mentioned, power quality is essential for ensuring the smooth operation and productivity of the power plant, quality of the product, and overall efficiency of the technological process and equipment. It encompasses various factors such as voltage stability, frequency stability, waveform distortion, and power factor. Businesses and industries that rely heavily on electrical equipment and processes must monitor and maintain power quality to avoid equipment failure, production downtime, and safety hazards, ensuring the smooth and efficient operation of the equipment and processes. By prioritizing power quality, the mining industry can maximize productivity and efficiency while minimizing the risk of equipment failure and downtime.

An overview of research work on power system reliability and energy efficiency is reviewed.

- The research thesis entitled "Non-linear Mathematical Model and Methodology for Analyzing the Growth and Supply of Energy in Mongolia" focuses on power system reliability and energy efficiency, which is a critical area of study in Mongolia's energy economy. Specifically, the research aims to develop a non-linear mathematical model and methodology for analyzing the growth and efficiency of the power system. This includes evaluating the effectiveness of government investments in the energy sector, analyzing changes in fuel and energy consumption, and developing a mathematical model that considers uncertain conditions related to the use of primary energy resources. The ultimate goal of this research is to improve the structure of Mongolia's energy balance and increase the efficiency of its fuel and energy sector. By analyzing trends in fuel and energy consumption and modeling potential growth scenarios, researchers hope to identify strategies for improving the reliability and efficiency of the power system [2].

- The research thesis titled "Voltage Stability Assessment of Dubai Power Grid Using a Detailed Load Model" delves into the updated load model that is used to evaluate the voltage stability margin against the increasing use of power transmission resources, growing demand, and associated stress on available and planned active and reactive power resources. The existing Dubai Power Grid load model falls short in reflecting the actual system behavior following experienced disturbances. Therefore, having an accurate load model that can capture load behavior during system disturbances is crucial in voltage stability assessment. This thesis presents a detailed load model for Dubai Power Grid that has been validated against recorded disturbances. The load model is capable of accurately reflecting the system behavior during disturbances, which is essential in assessing voltage stability. With the growing demand for power transmission resources, it is imperative to have a reliable and accurate load model to ensure the stability of the power grid. The research conducted in this thesis provides valuable insights into the voltage stability assessment of Dubai Power Grid. The detailed load model presented in this thesis can be used to evaluate the voltage stability margin against the increasing use of power transmission resources and growing demand. This research is a significant contribution to the field of power engineering and can be used to improve the stability of power grids worldwide [3].
- The research topic at hand is focused on identifying the optimal alternative for utilizing local energy sources in the electricity supply of the Mongolian region. Specifically, we are evaluating the wind speed and personal power resources in the eastern and southern regions of Mongolia, in coordination with the working characteristics of modern wind energy equipment that stands at a height of 30-50 meters. The preliminary findings have allowed us to determine potential locations for large-scale wind power plants, as well as select asynchronous generators that can be used by independent low-power users. We are also developing methods for the recovery, control, and voltage adjustment of these generators, and introducing renewable energy resources into the renewable energy balance of the territory of Mongolia. Through our research, we have laid the foundation for the use of wind energy as a source of large-scale electrical power in Mongolia. Our findings will not only contribute to the sustainable development of the region but also serve as a model for other areas looking to incorporate renewable energy sources into their energy mix [4].

- The research project titled "Mathematical Model of Energy Sources and Consumption in Mongolia" has resulted in the development of an economic mathematical model. This model is designed to determine the consumption of coal, heat, and electricity based on the unique characteristics of energy consumption in Mongolia, along with key macroeconomic indicators. Through the development of this mathematical model, we have established a comprehensive understanding of the relationships between electricity consumption and function. This has enabled us to fully automate the transmission of information regarding consumer electricity consumption, optimize load distribution between power stations, and manage electricity load and consumption. Furthermore, the development of this model has allowed us to utilize automated mathematical models and computer software to facilitate calculation, research, and control. This has resulted in a more efficient and effective approach to energy consumption management in Mongolia. Overall, the Mathematical Model of Energy Sources and Consumption in Mongolia has provided valuable insights into the country's energy consumption patterns and has paved the way for more advanced and sophisticated energy management strategies [5].
- A mathematical model has been developed to determine the most cost-effective way to repair and maintain excavator electrical equipment. This model considers the delay in research work on the reliability of mine power supply. To achieve this, a comprehensive program for outage registration and short-circuit calculation was created, along with a new indicator for evaluating the reliability of the mine power supply system. This approach ensures that repairs and replacements are made efficiently and effectively, ultimately saving time and money [6].
- The research project titled "Simulation and Mitigation of Power Quality Disturbances on a Distribution System Using DVR" addresses power quality problems faced by power distribution systems in general, with a specific focus on analyzing an important distribution system. In this study, a dynamic voltage restorer (DVR) is connected to the 11kV utility feeder that supplies power to the Ipoh hospital to mitigate voltage sags that affect the operation of sensitive hospital loads. The results obtained from the DVR show that the voltage sags are reduced by bringing the supply voltage level to 100%. The simulated results were then verified for selected faults using theoretical methods [7].

In order to the review of above research thesis, it is imperative that we conduct research utilizing dynamic simulation techniques. This will allow us to gain a deeper understanding of the complex factors that impact power quality and develop more effective solutions to improve it. By studying the intricacies of power quality through research, we can enhance the reliability and efficiency of power systems, ultimately benefiting society as a whole.

2.2. Power quality of power systems

The increase in non-linear devices has led to more harmonic pollution in distribution systems, which can negatively affect power quality for sensitive electronic equipment. Standards have been set to limit pollution, but precise detection of sources is necessary for proper enforcement, which can be achieved through an optimization approach for sensor placement [8].

Power systems have changed, and traditional methods of transporting electricity are inadequate for deregulated systems. Customers buy the cheapest energy that meets their needs.

Power quality is a concern due to sensitive load equipment and the rise of distributed generators. Harmonic currents cause distortion and identifying sources of pollution is difficult.

Power quality parameters are critical for both electricity consumers and providers, as they determine the quality and reliability of energy supply. These parameters enable a quantitative assessment of energy consumption, transmission, distribution, and the characteristics of technological processes.

Power quality parameters can be broadly classified into the following categories:

- Transients (impulsive, oscillatory),
- Short-duration variations (Voltage Sag (Dip), Voltage Swell, Voltage Interruption),
- Long-duration variations (over-voltage, under-voltage, sustained interruption),
- Voltage Imbalance,
- Waveform Distortion (DC offset, harmonic (total harmonic distortion (THD), Inter-harmonics, Notching, Noise),
- Voltage Fluctuations (Flickers),
- Power Frequency Variations.

The standard establishes numerical values for these parameters, along with permissible limits and norms. However, strict compliance with electricity standards can be challenging due to sudden changes in electrical load. Therefore, the standard also defines the probability of exceeding quality standards.

The detection process is crucial in identifying power quality problems, using time-dependent techniques and predetermined thresholds. Two methods for detecting power system disturbances are identifying deviations from nominal waveform and using high pass/band pass filters to detect step changes or oscillations. The first method involves identifying any deviation of time-dependent RMS voltage/current magnitudes from the nominal waveform and detecting the disturbance start and end points by comparing the change in magnitude with a predetermined threshold. This method is used for detecting voltage dips, swells, and interruptions. The second method involves using high pass or band pass filters followed by detecting step changes or oscillations. These different methods for detecting disturbances in a power system, including the use of high pass or band pass filters and wavelet filters. These methods can detect the start and end points of disturbances by identifying significant sudden changes or singularities in the signal waveform.

Signal processing techniques are used to analyze detected disturbance signals in order to identify the type of disturbance that occurred by justifying the disturbance signal's features, leading to more accurate disturbance identification.

Disturbances are caused by the presence of harmonics pollution, which is a result of the increased use of non-linear devices in the system. The latest load equipment is highly sensitive to power quality disturbances, especially harmonic distortion.

There are various methods or techniques have been used to analyze the signals that are produced by the harmonics pollution and signal disturbances in distribution systems. These techniques are used to detect and identify the sources of the harmonic's pollution. Signal processing techniques are methods used to analyze and manipulate signals, which are electrical or electromagnetic representations of information. The signals being analyzed are those produced by the harmonics pollution in distribution systems. The techniques used to analyze these signals can include Fourier analysis, wavelet analysis, and time-frequency analysis, among others. These techniques are used to extract information from the signals, such as the frequency content, amplitude, and phase, which can then be used to identify the sources of the harmonic's pollution.

The following methods are to detect the harmonics pollution and signal disturbances.

- Fast Fourier Transform (FFT)
- Short-Time Fourier Transform (STFT)
- Wavelet Transforms
- Kalman Filters

The Total Harmonic Powers (THP) method is used to identify the harmonics pollution sources in this research study. This method is efficient and requires the network voltage and current values, which can be provided by the proposed monitoring system. The ability to apply the THP method on any distribution system has been scrutinized to confirm its validity for distribution systems. The THP method is used to identify the harmonics pollution sources, and its validity for distribution systems has been confirmed.

Fast Fourier Transform (FFT) is used for processing data in this research.

2.3. Power quality standards

Standards have been proposed to protect power systems from harmonics pollution, and responsible parties must pay for consequences. Power quality standards aim to protect utilities and end-user's equipment from voltage, current, or frequency deviations, which is necessary under deregulation to prevent disturbances in the system. Each country develops and implements its own standards and regulations for controlling the power quality of electricity. For example, the following organizations have developed the power quality standards:

- The Institute of Electrical and Electronics Engineers (IEEE),
- American National Standards Institute (ANSI),
- Electric Power Research Institute (EPRI)
- International Electrotechnical Commission (IEC)
- Russian Federation

There are three types of the power quality standards:

- IEEE Standards
- PQ Disturbances
- IEC Standards
- GOST Standards

European countries have the IEC 61000-4-30 standard and EN 50160 standard approved by the International Electrotechnical Commission, GOST 10913-2003 in Russia, and MNS1778:2007 in Mongolia.

It is clear that distribution organizations in our country are not giving enough attention to power quality and are not strictly adhering to the MNS1778:2007 standard. However, our State Professional Supervision Agency (SPA) has acted by developing the Electrical Facilities Regulations (BD 43-101-03) under the guidance of the Minister of Infrastructure. This regulation has been adapted from the Russian Electrical Installation Rules, as well as American and Swedish regulations for electrical installations, to suit the specific needs of our country.

In line with decree No. 252 of December 18, 2003, which will be enforced from March 1, 2004, the activities of electricity distributors and consumers will be closely monitored. This is a significant step towards ensuring that power quality is maintained and that all parties involved in the distribution of electricity are held accountable for their actions. It is crucial that distribution organizations prioritize power quality and adhere to regulations to ensure the safety and reliability of our electrical infrastructure. The implementation of the Electrical Facilities Regulations is a positive step towards achieving this goal and will undoubtedly have a significant impact on the industry.

The regulations outlined in BD 43-101-03 do not specify the quality of electricity, but rather adhere to general provisions that apply to electrical equipment with a voltage above or below 1 kV. However, these provisions do not meet the requirements for the quality of electrical energy set for electronic equipment. To address this, the MNS 1778-2007 standard has established power quality norms that can be applied to contracts for the supply of electricity to consumers. These norms are used to determine the level of electromagnetic noise and noise from electricity consumers when designing and using standard norms and normative power grid projects.

In simpler terms, while BD 43-101-03 provides guidelines for electrical equipment, it does not address the specific quality of electricity needed for electronic equipment. To ensure that electronic equipment is receiving the necessary quality of electricity, the MNS 1778-2007 standard has established power quality norms that can be applied to contracts for the supply of electricity to consumers. These norms help to reduce electromagnetic noise and noise from electricity consumers, making it easier to design and use standard norms and normative power grid projects.

MNS1778:2007 recognizes that the main source of harmonic voltages is nonlinear loads located on the end-user side. This standard has been used for this research study.

2.4. Simulation of power system

Simulation of power systems is a crucial aspect in the planning and operation of electrical power systems. As power systems continue to expand and integrate new technologies, the simulation process has become increasingly complex. Therefore, obtaining significant simulation results has become a critical research focus within the field of electrical power engineering [9].

The developed models simulate various disturbances like voltage sag, swell, transient, harmonic, and flicker using default settings for simplicity and reproducibility. The models serve as basic building blocks for larger power systems and include line fault, induction motor starting, transformer energizing, capacitor bank energizing, lightning impulse, nonlinear load, and electric arc furnace models [7].

There are numerous simulation tools available for analyzing power systems, including MATLAB with Power System Toolbox, Power System Analysis Toolbox, and Simulink with SimPowerSystems blockset. By leveraging these powerful simulation tools, engineers and researchers can gai a deeper understanding of the complex phenomena that impact power systems. This knowledge can then be used to optimize system performance, improve reliability, and enhance overall efficiency. Whether you are working in academia, industry, or government, these simulation tools are essential for staying ahead of the curve in the rapidly evolving field of power systems engineering.

Simulation models were developed using MATLAB/Simulink with Graphical User Interface and programming of MATLAB to simulate power quality disturbances and observe their effects on the power system waveform. The models were designed with simplicity and reproducibility in mind and serve as building blocks for larger power systems.

2.5. Conclusion of chapter two

This chapter explores the increasingly complex field of power quality in power systems, particularly in relation to harmonic pollution caused by the rise of non-linear devices. This pollution can affect power quality, thus leading to challenges for sensitive electronic equipment. It discusses various power quality parameters such as transients, short-duration variations, long-duration variations, voltage imbalance, waveform distortion, voltage fluctuations, and power frequency variations. Methods for detecting these disturbances, such as deviation identification from nominal waveforms and high pass/band pass filters, are also discussed. Techniques to analyze the signals produced by harmonic pollution include Fourier analysis, wavelet analysis, and time-frequency analysis, among others.

Power quality standards are crucial to control and maintain power quality. These standards, which vary by country and organization, protect utilities and end-user's equipment from voltage, current, or frequency deviations. This chapter also highlights the need for strict adherence to these standards to ensure the reliability and safety of electrical infrastructure. In addition to the general regulations for electrical equipment, it is emphasized that specific standards are required to ensure the quality of electricity supplied to electronic equipment. Futhermore, the importance of power system simulation in understanding and managing the complex phenomena that impact power systems. With the aid of simulation tools like MATLAB and Simulink, it simulates power quality disturbances and their effects on the power system waveform.

In conclusion, power quality in power systems is a complex and crucial area, demanding careful management and adherence to power quality standards. Simulations, data analysis, and strict enforcement of regulations all play key roles in maintaining power quality, ensuring the reliability of the power supply, and preventing potential disruptions caused by harmonic pollution. As the use of non-linear devices continues to grow, these aspects will only become more critical in the future.

CHAPTER 3. STUDY ON POWER QUALITY PARAMETERS AND ITS STANDARDS

3.1. Power quality parameters

Power quality refers to a set of characteristics that are essential for ensuring the proper functioning of electrical equipment and systems. The quality of energy and its parameters are evaluated according to the Mongolian standard MNS 1778:2007. This standard provides guidelines for assessing the power quality and acceptable values of a single-phase or three-phase AC power supply system with a frequency of 50 Hz. However, it has been observed that in our country, distribution organizations do not always prioritize the quality, reliability, and continuity of electric energy and may not strictly comply with the provisions of this standard [10].

The norms established by this standard must be followed in all working modes of the electricity and power supply systems and may not be followed in the working modes depending on the following conditions:

- Extreme weather conditions and force major events (strong wind storm, flood disaster, earthquake, etc.);
- Unforeseeable events that occur independently of the service provider and the user (fire, explosion, military operations, etc.);
- Cases related to the elimination of the consequences of disasters caused by weather and other special and unexpected conditions.
- The norms established by this standard should be included in the technical conditions for the new connection of the CHP user to the network and the contract for the use of electricity between the CHP user and the supplier organization.

The norms set forth by this standard serve as a crucial tool in assessing the level of tolerance for electromagnetic side effects experienced by electricity consumers. Additionally, they help to determine the inductive electromagnetic side effects that may be introduced into the customer's network during the operation and design of the power line network.

The power quality standards of electricity and power systems within a customer's property must adhere to industry standards and other normative documents. These standards should not exceed the power quality standards established by this standard at the general point of electricity connections.

In cases where relevant normative documents are not available, the norms outlined in this standard are mandatory for electric energy consumers. From these guidelines, ensure that the power grid operates efficiently and effectively while minimizing any potential negative impacts on consumers.

Mongolian National Standards 2980:2003 and 1778:2007 specify detailed voltage quality conditions and stability requirements for the power grid and electricity. The central frequency stability and its deviation from the integrated network should be continuously recorded with a fluctuation of 50+0.2 Hz for 10 minutes according to the rules of technical operation. It is allowed to operate temporarily with a frequency variation of 50+0.4 Hz. However, these standards do not address high-frequency exposure, its harmful effects, or its limitations.

That is why each country develops and implements standards and norms suitable for its own country when it is necessarily comes up for controlling the quality of electricity. For instance, European countries have the IEC 61000-4-30 standard and EN 50160 standard approved by the International Electrotechnical Commission, while Russia has GOST 10913-2003 and Mongolia has MNS1778:2007.

The Mongolian National Standard 1778:2007 serves as the official document for regulating electric energy and ensuring electromagnetic compatibility of technical equipment. This standard is crucial in maintaining the safety and efficiency of electrical systems and devices in Mongolia. This provides the essential criteria and directions for producers, providers, and users of electrical equipment to ensure they meet the requisite standards for secure and dependable operation. Adhering to this standard is vital for enterprises and individuals who depend on electrical equipment for efficient and effective operation.

The twelve parameters of Mongolian National Standard 1778:2007 include:

1. Nominal voltage and acceptable voltage values Uy,
2. Steady-state voltage variation δUy;
3. Voltage amplitude variation δUt;
4. Flicker (voltage fluctuation) Pt;
5. Total harmonics distortion KU;
6. Individual harmonic order coefficient $K_{U(n)}$;
7. Supply voltage asymmetry inverse order K_{2U};
8. Supply voltage asymmetry zero order K_{0U};
9. Frequency deviation or variation Δf;
10. Voltage Dip or a Sag Δtп;
11. Impulse voltage U_{imp};
12. Transient overvoltage $K_{пер\ U}$.

1. <u>The nominal voltage and acceptable voltage value (Uy):</u> The nominal voltage and acceptable voltage values of electricity and power supply systems should be measured within a calculated predicted period of from 30 minutes to 24 hours.

2. <u>Steady-state voltage deviation (δUy):</u> It should adhere the following norm values:

- The acceptable limit for steady-state voltage deviation (δUy) should be within ±5 to ±10 percent deviation from the nominal supply voltage specified in the standard MNS 1778 for electricity and power supply systems at the end receiver of electric energy.

- The supply voltage values should be measured at regular intervals, such as every i-th voltage measurement, within a timeframe of 30 minutes to 24 hours.
- The calculation of the root mean square (RMS) voltage of the three-phase AC line, considering the fundamental frequency in positive sequences, shall be performed in real time using Equation (1).

Equation 1

$$U_{1(1)i} = \sqrt{\frac{1}{12}\left[\left(\sqrt{3}U_{AB(1)i} + \sqrt{4U_{BC(1)i}^2 - \left(\frac{U_{BC(1)i}^2 - U_{CA(1)i}^2}{U_{AB(1)i}} + U_{AB(1)i}\right)^2}\right)^2 + \left(\frac{U_{BC(1)i}^2 - U_{CA(1)i}^2}{U_{AB(1)i}}\right)\right]}$$

The line RMS voltage values with fundamental frequency at the i-th voltage measurement are denoted as $U_{AB(1)i}$, $U_{BC(1)i}$,$U_{CA(1)I}$. These values can be determined using Equation (2):

Equation 2

$$U_{1(1)i} = \frac{1}{3}\left(U_{AB(1)i} + U_{BC(1)i} + U_{CA(1)i}\right)$$

The inverse order of supply voltage unbalance should not exceed 6% of the line RMS voltage values with fundamental frequency when calculated using Equation (2) instead of Equation (1).

Steady-state voltage deviation is shown in Figure 1.

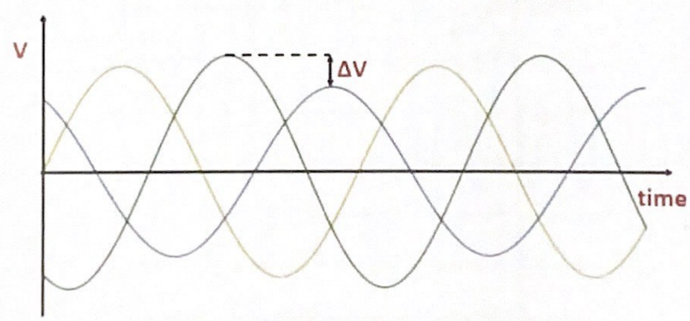


Figure 1. Steady-state voltage deviation

The average voltage value, obtained through real-time measurements at every i-th measurement within a one-minute time interval, can be calculated using Equation (3).

Equation 3

$$U_y = \sqrt{\frac{\sum_{i=1}^{N} U_i^2}{N}}$$

U_i represents the voltage at the i-th measurement, while U(1)i and U1(1)i represent the voltage values in volts (V) or kilovolts (kV). The steady-state voltage deviation can be calculated using Equation (4).

Equation 4

$$\delta U_y = \frac{U_y - U_{nom}}{U_{nom}} \cdot 100$$

U_{nom} – phase nominal voltage, [V, kV].

3. <u>Voltage variation:</u> It is defined by the following parameters:

- Voltage amplitude variation δUt,
- Flicker (voltage fluctuation) Pt.

The voltage amplitude variation shown in Figure *2*, denoted as δUt, can be calculated using Equation (5) and is expressed as a percentage.

Equation 5

$$\delta U_t = \frac{|U_i - U_{i+1}|}{U_{nom}} \cdot 100$$

U_i and U_{i+1} represent the maximum voltage values determined at each half period of the fundamental frequency and are measured in volts (V).

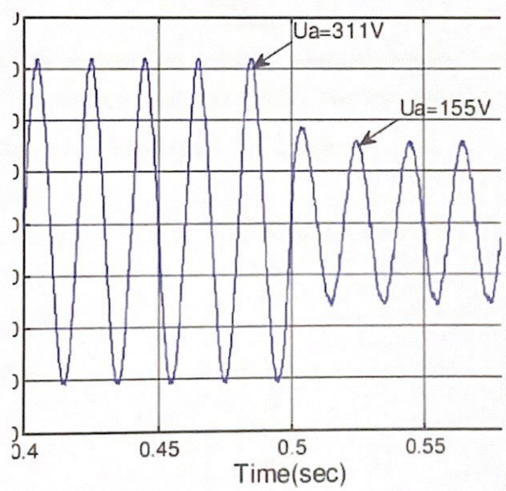


Figure 2. Steady-state voltage deviation

Flicker (voltage fluctuation) Pt is determined in accordance with the approved normative documents for the specific list of buildings and premises where tasks requiring high visual acuity are conducted. Flicker (voltage fluctuation) is shown in Figure 3.

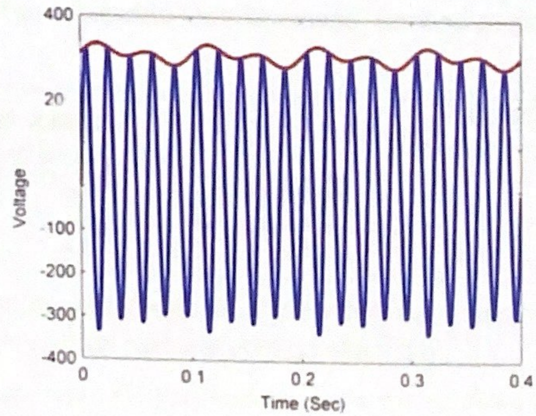


Figure 3. Flicker (voltage fluctuation)

4. Harmonic distortion: It is defined the following two parameters:

- Total harmonics distortion (THD) KU,
- Individual harmonic order coefficient $K_{U(n)}$.

Voltage amplitude variation δUt is calculated using Equation (6) and is expressed as a percentage when the total harmonic distortion (THD) does not exceed 5%.

Equation 6

$$\delta U_t = \frac{|U_{ai} - U_{ai+1}|}{\sqrt{2}U_{\text{НОМ}}} \cdot 100$$

U_{ai}, U_{ai+1} represent the maximum voltage values determined at each half period of the fundamental frequency and are measured in volts (V) or kilovolt (kV).

Voltage harmonic distortion is shown in Figure 4.

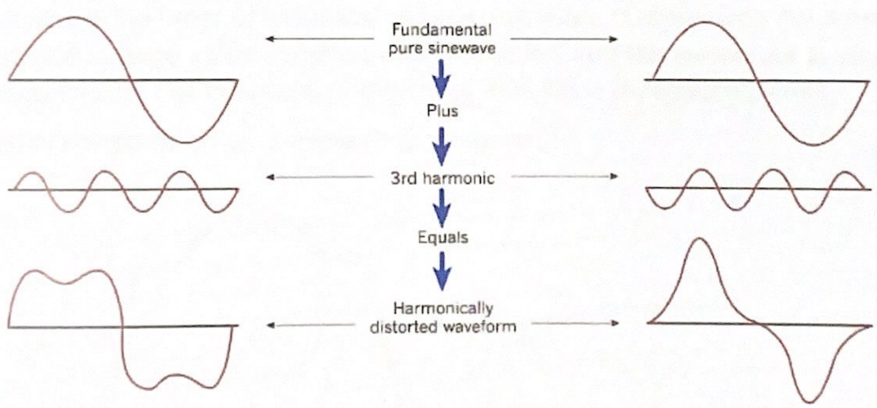


Figure 4. Voltage harmonic distortion

Table 1 provides the acceptable limits of voltage harmonic distortion at the general connection point for various nominal voltage electricity.

Table 1: The acceptable limits of voltage harmonic distortion expressed as a percentage

Nominal voltage, Depending on U_{nom} [kV]				Acceptable limits Depending on U_{nom} [kV]			
0.38	6-20	35	110-330	0.38	6-20	35	110-330
8.0	5.0	4.0	2.0	12.0	8.0	6.0	3.0

Table 2 provides the acceptable limits of Individual harmonic order at the general connection point for various nominal voltage electricity.

Table 2: The acceptable limits of Individual harmonic order expressed as a percentage and depending on U_{nom} [kV]

Odd harmonics not divided by 3	n*	5	7	11	13	17	19	23	25	> 25		
	0.38	6	5	4	3	2	2	1.5	2	0.2+	+1.3 x	x 25/n
	6-20	4	3	2	2	1.5	1	1	1	0.2+	+0.8x	x25/n
	35	3	3	2	2	1	1	1	1	0.2+	+0.6x	x 25/n
	110-330	2	1	1	1	0.5	0	0.4	0	0.2+	+0.2x	x25/n
Odd harmonics not divided by 3 **	n*	3	9	15	21	>21						
	0.38	5	2	0	0	0.2						
	6-20	3	1	0	0	0.2						
	35	3	1	0	0	0.2						
	110-330	2	0	0	0	0.2						
Even harmonics	n*	2	4	6	8	10	12	> 12				
	0.38	2	1	1	1	0.5	0	0.2				
	6-20	2	1	0	0	0.3	0	0.2				
	35	1	1	0	0	0.3	0	0.2				
	110-330	1	0	0	0	0.2	0	0.2				

*n represents the order of individual voltage distortion. ** represents the nominal acceptance voltage value corresponding to the 3rd and 9th harmonics in single-phase electricity. For three-phase electricity, this value is reduced by half.

Individual harmonic order is explaining in Figure 5.

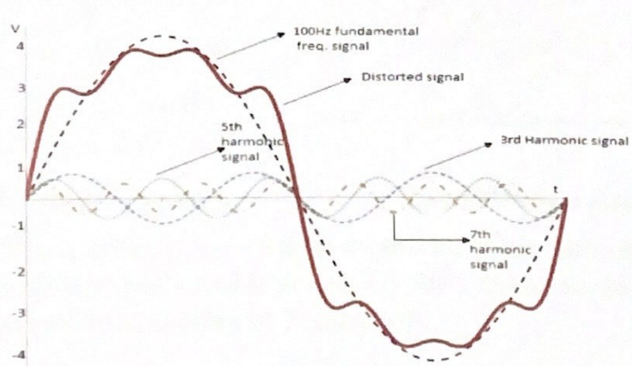


Figure 5. Waveform with individual harmonic order

The acceptable limits of the n-th individual harmonic order are calculated using Equation (7).

Equation 7

$$K_{U(n)\text{хяз}} = 1.5 \cdot K_{U(n)nom}$$

The acceptable value of the n-th individual harmonic order, $K_{U(n)\text{норм}}$, is determined by Table 2. If it is less than 0.2 percentage, it can be ignored.

If the maximum value of the voltage distortion coefficient, obtained from all measurements taken during a 24-hour period, does not exceed the acceptable limit values, and if the measurement values of the voltage distortion coefficient remain below the normal, acceptable value with a probability of 95 percent during the specified time period, the power quality of electricity, as determined by the voltage distortion coefficient, will be considered to meet the normative requirements of this standard at the general point of electricity connection.

The compliance of the measurement values with the normative requirements of the standard can also be assessed based on the total duration of exceeding the nominal acceptable limit values. If the total duration exceeding the nominal acceptable limit values does not exceed 5 percent of the specified time period or 1 hour and 12 minutes, and if it remains within the acceptable limit of 0 percent, then the power quality is considered to meet the normative requirements of this standard based on the voltage distortion coefficient of the sine wave.

5. Voltage asymmetry: The normal acceptable limit values for the voltage asymmetry coefficient in the negative sequence at the general connection point of electricity and the voltage asymmetry coefficient in the zero sequence at the general connection point of the four-wire electricity with a nominal voltage of 0.38 kV are 2.0 percent and 4.0 percent, respectively.

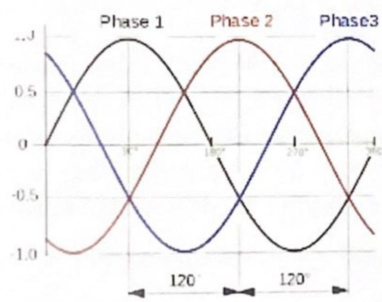


Figure 6. Voltage symmetry

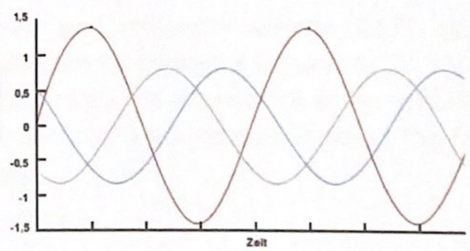


Figure 7. Voltage asymmetry

The RMS of $U_{AB(1)i}$, $U_{BC(1)i}$, $U_{CA(1)I}$ will be measured at the same time at each i-th measurement divided into equal time interval. RMS of $U_{AB(1)i}$, $U_{BC(1)i}$, $U_{CA(1)I}$ with negative sequence is calculated by Equation (8).

The RMS values of $U_{AB(1)i}$, $U_{BC(1)I}$ and $U_{CA(1)I}$ will be measured simultaneously at each i-th measurement, divided into equal time intervals. The RMS values of $U_{AB(1)i}$, $U_{BC(1)i}$, $U_{CA(1)I}$ for the negative sequence are calculated using Equation (8).

Equation 8

$$U_{2(1)i} = \sqrt{\frac{1}{12}\left[\left(\sqrt{3}U_{AB(1)i} + \sqrt{4U_{BC(1)i}^2 - \left(\frac{U_{BC(1)i}^2 - U_{CA(1)i}^2}{U_{AB(1)i}} + U_{AB(1)i}\right)^2}\right)^2 + \left(\frac{U_{BC(1)i}^2 - U_{CA(1)i}^2}{U_{AB(1)i}}\right)\right]}$$

The normal acceptable limit values for voltage asymmetry in the negative sequence are calculated using Equation (9) and expressed as a percentage.

Equation 9

$$K_{2U_i} = \frac{U_{2(1)i}}{U_{1(1)i}} \cdot 100$$

$U_{2(1)i}$ represents the RMS voltage value of the three-phase AC system with fundamental frequency at the i-th measurement in the negative sequence, measured in volts (V) or kilovolts (kV). $U_{1(1)i}$ represents the RMS voltage value with fundamental frequency at the i-th measurement in the positive sequence, measured in volts (V) or kilovolts (kV).

6. <u>Supply voltage unbalance inverse order K_{2U}</u>: It can be determined by the following:

— $U_{2(1)I}$ can be determined by asymmetry components;

— $U_{2(1)I}$ can be determined by Equation (10).

Equation 10

$$U_{2(1)i} = 0.62(U_{max(1)i} - U_{min(1)i})$$

$U_{max(1)i}$, $U_{min(1)i}$ represent the maximum and minimum voltage RMS values measured at the i-th measurement with the fundamental frequency [V, kV]. In cases where the total harmonic distortion does not exceed 5% while calculating $U_{2(1)i}$, individual harmonic orders will be calculated instead of using the RMS voltage values between phase voltages.

K_{0U} can be calculated using Equation (11).

Equation 11

$$K_{0U} = \frac{U_{0(1)i}}{U_{nom\_ph}}$$

U_{nom_ph}– nominal phase voltage, [V, kV].

The power quality of the negative sequence voltage will meet the requirements of this standard at the general connection point of electricity if the maximum value of all measured negative sequence voltage asymmetry coefficients over a 24-hour period does not exceed the permissible limit and if the measured reverse sequence voltage asymmetry coefficients during the specified period do not exceed the normal, acceptable value with a 95 percent probability.

7. Frequency variation Δf: Frequency variation shown in Figure 8, represented by Δf, is a measure of the voltage's frequency deviation in the electricity supply. The acceptable limit values for frequency deviation are set at ± 0.2 Hz and ± 0.4 Hz.

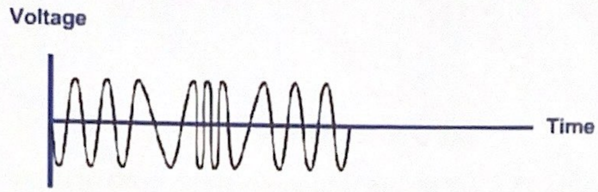


Figure 8. Frequency variation

To calculate the average frequency value, we consider N observations within a time interval of 20 seconds, as defined by Equation (12).

Equation 12

$$f_y = \frac{\sum_{i=1}^{N} f_i}{N}$$

To ensure accurate calculations, a minimum of 15 observations (N ≥ 15) is required. The frequency deviation (Δf) can be determined using Equation (13).

Equation 13

$$\Delta f = f_y - f_{nom}$$

F_{nom} – nominal frequency, Hz.

Assuming that at least 95 percent of all recorded frequency deviation values within 24 hours fall within the range specified by the nominal acceptable values, the power quality is deemed to satisfy this standard's requirements for frequency deviation.

The time the recorded values surpass the acceptable ones will be assessed to confirm conformity with this standard's requirements. In such cases, the cumulative time of measured values exceeding the acceptable limits should be at most 5% of the total measurement period, or one hour and twelve minutes. Furthermore, if no recorded values exceed 0%, the power quality is considered to fulfill this standard's frequency deviation requirements.

8. Voltage Dip or a Sag Δtп: The voltage dip or sag is defined by the duration of the voltage drop, and specific norms have been established for it. The acceptable limit for the duration of a voltage drop in electricity with a voltage of up to 20 kV is set at 30 seconds. The duration of the voltage drop to be mitigated through

relay automation is determined by the operating time of the relay protection and automation systems.

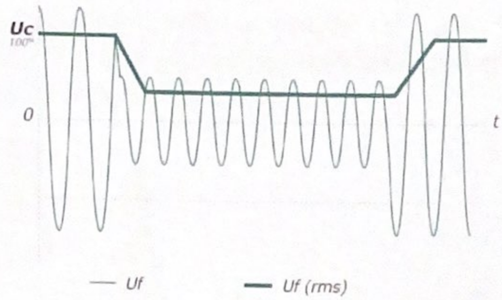


Figure 9. Voltage dip and sag

The duration of voltage drop Δtp is measured using the following procedure. First, identify the initial moment tn when the mean square value of the voltage curve sharply decreases below 0.9 Unom (nominal voltage). Then, determine the final moment tk when the voltage recovers to the rms value of 0.9 Unom. The duration of the voltage drop, tp, is calculated in seconds using Equation (14).

Equation 14

$$\Delta t_n = t_k - t_{\text{н}}$$

t_H, t_K - voltage dip and sag start and end time.

To calculate the voltage drop depth (δU_n), the minimum root mean square value of the voltage (U_{min}) is obtained from all the measured values. The calculation is performed using Equation (15), which expresses the voltage drop depth as a percentage

Equation 15

$$\delta U = \frac{U_{\text{ном}} - U_{\text{min}}}{U_{\text{ном}}} \cdot 100$$

In the equation, U_{max} represents the maximum root mean square value of the voltage, and U_{min} represents the minimum root mean square value of the voltage.

If the maximum duration of voltage dips measured during long-term observation (typically for a year) does not exceed the acceptable limit value, the power quality at the general point of connection is considered to meet the requirements of this standard regarding the duration of voltage dips.

9. Impulse voltage U_{imp}: The voltage pulse is represented by the pulse voltage parameter. The voltage value of short circuits and lightning impulses occurring in the electricity determines the impulse voltage (U_{imp}). The impulse voltage Uimp represents the maximum value of a sudden voltage change, with a pulse front duration not exceeding 5 milliseconds. The impulse voltage is measured in volts (V) or kilovolts (kV).

10. Transient overvoltage $K_{пер\,U}$: The transient overvoltage shown in Figure 10 is quantified by the transient overvoltage coefficient. This coefficient represents the magnitude of temporary voltage fluctuations occurring in the power network of the power supply organization within a duration of up to 5 milliseconds. The voltage amplitude (Ua) is measured during each half cycle of the main frequency and expressed in volts (V) or kilovolts (kV).

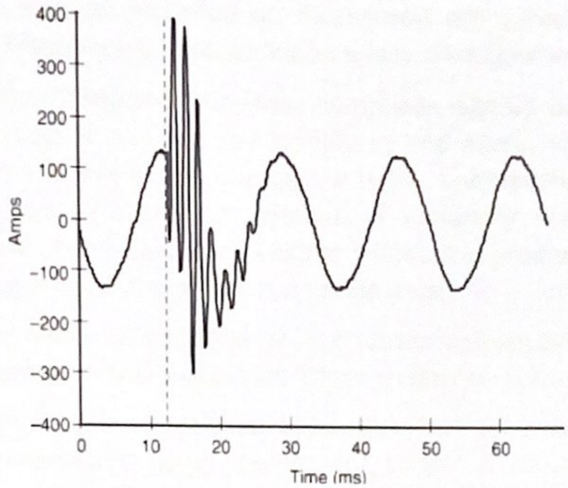


Figure 10. Transient overcurrent

The maximum value of Ua, denoted as Ua max, is determined from the measured voltage amplitude values. To mitigate the influence of switching pulses on the transient overvoltage coefficient, Ua max is calculated 0.04 seconds after the moment when it exceeds the 1.1 times the nominal voltage (Unom) level. The transient overvoltage coefficient is calculated using Equation (16):

Equation 16

$$K_{\text{пер}U} = U_{a\,max}/\sqrt{2}U_{\text{ном}}$$

The duration of transient overvoltage, denoted as Δ tпер, is defined in seconds. It is determined by recording two time instants: tn per, which is the moment when the voltage exceeds the level of 1.1 times the nominal voltage ($1.1U_{nom}$), and tk per, which is the moment when the voltage returns to the level of $1.1U_{nom}$. Δtk per is calculated using Equation (17), expressed in seconds:

Equation 17

$$\Delta t_{\text{пер}}U = t_{k\ \text{пер}} - t_{\text{н пер}}$$

3.2. Analyzing High Harmonic Frequencies: Methodology and Signal Processing

When measuring power quality and high harmonics, the output signal of the measuring instrument is an electrical signal that varies over time. These signals can be either phased or nonphased. However, simply observing the time variations of these signals on the oscilloscope screen may not provide useful information. The signals displayed on the screen are complex, consisting of multiple discrete frequencies that cannot be easily distinguished.

Extract the individual frequencies in these composite signals, and a methodology for signal processing is required. By identifying and analyzing each frequency component within the signal, we can gain a better understanding of the power line quality and identify potential sources of variability within the network. Therefore, the first crucial step in the signal processing process is to determine the frequencies present in the measured oscillations.

There are various methods available for high harmonic frequency analysis, each with its own advantages and limitations. These methods include:

Fourier Transform: This is a widely used technique that decomposes a signal into its frequency components using the Fourier series. It provides a frequency spectrum representation of the signal, showing the amplitudes and phases of the individual harmonics.

Wavelet Transform: Unlike the Fourier Transform, the wavelet transform allows for time-frequency analysis, providing information about frequency content at different time intervals. This can be useful for capturing transient or non-stationary harmonic phenomena.

Harmonic Analysis: This approach focuses specifically on identifying and characterizing harmonic components in the signal. It involves techniques such as harmonic estimation algorithms, spectrum analysis, and harmonic distortion calculation.

Spectral Analysis: Spectral analysis methods, such as the Fast Fourier Transform (FFT) or the Power Spectral Density (PSD) estimation, can provide detailed information about the frequency content of the signal, including the amplitudes and phases of different harmonics.

Choosing the method depends on the specific requirements of the analysis, the characteristics of the measured signal, and the desired level of accuracy. For that, consider the factors like resolution, computational complexity, and the ability to handle non-linear or non-stationary signals.

By applying these methodologies and analyzing the frequencies present in the measured oscillations, we can gain valuable insights into the power quality, identify harmonic distortions, and effectively address any issues or anomalies in the electricity.

When measuring power quality and high harmonics, the output signal of the measuring instrument is an electrical signal that varies over time. These signals can be either phased or nonphased. However, simply observing the time variations of these signals on the oscilloscope screen may not provide useful information. The signals displayed on the screen are complex, consisting of multiple discrete frequencies that cannot be easily distinguished.

As mentioned above, methodology for signal processing is required. By determining the frequencies present in the measured oscillations, we can better understand and interpret the quality of the power line and identify sources of variability within electricity. This step is crucial in the signal processing process.

With the advancement of discrete signal processing techniques, it is now easier to identify the multiple frequencies contained in a signal. The continuous analog signal from the measuring instrument is converted first into a digital signal using an analog-to-digital converter. This conversion allows for easy processing by digital electronics. The digital signal, consisting of discrete samples with equal time intervals, is then subjected to Fourier transform.

Through the Fourier transform, the digital signal's time function is transformed into a frequency function. This enables us to identify and analyze the individual frequencies present in the signal. The resulting frequency spectrum provides valuable insights into the harmonic content and power quality characteristics of the signal.

By applying the Fourier transform and other digital signal processing techniques, we can extract meaningful frequency information from the composite signals. This helps us to gain a comprehensive understanding of the power line's quality and effectively address any harmonic distortions or issues within electricity.

The signal obtained from frequency analysis proves highly valuable for analyzing power line fluctuations due to the extensive range of assessable parameters. In practical applications, vibration measurement signals manifest as intricate compositions with numerous frequencies, clearly identifiable within the frequency function. Consequently, the primary approach to identifying power line harmonics involves measuring its electrical, magnetic, or mechanical characteristics. This involves decomposing the continuous oscillations observed during measurement into a Fourier series, thereby enabling spectrum analysis extraction.

Spectral analysis is widely recognized as the primary approach for evaluating power quality, as it enables the detection of significant harmonic variations within the power grid. This section focuses on the Fourier transform and its application in extracting the spectrum of a signal. In 1807, Joseph Fourier, a renowned French mathematician, mathematically demonstrated that any periodic function is expressed as the sum of an infinite number of periodic functions.

Any periodic function $f(t)$ can be decomposed into a Fourier series using Equation (18)

Equation 18

$$f(t) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n cos(n\omega t + \varphi_n)$$

Here, n represents the harmonic index, ranging from $n = 1, 2, 3 ...$ and so on. $\frac{a_0}{2}$ is the constant term, a_n represents the amplitude of the nth harmonic, φ_n denotes the phase of the nth harmonic, and $\omega = 2\pi f$ represents the angular frequency.

Equation (18) is labeled with numbers indicating the harmonic order, such as the 1st harmonic, 2nd harmonic, and so on, based on the value of n. The fundamental harmonic, corresponding to $n = 1$, is commonly referred to as the "fundamental frequency," while the remaining harmonics are known as "higher harmonics." In the case where the frequency is denoted as $f = 1/T$ and the phase as $\varphi = 0$, Equation (18) can be decomposed in the following manner.

Equation 19

$$A_0 = \frac{A}{r} \qquad f_0 = 0 \cdot f$$

$$A_1 = \frac{2A}{\pi} \cdot \sin\left(\frac{\pi}{r}\right) \qquad f_1 = 1 \cdot f$$

$$A_2 = \frac{2A}{2\pi} \cdot \sin\left(\frac{2\pi}{r}\right) \qquad f_2 = 2 \cdot f$$

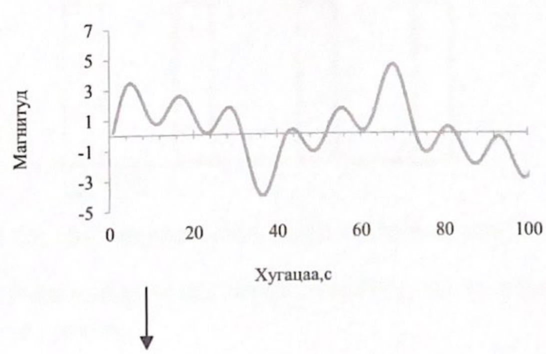
$$A_3 = \frac{2A}{3\pi} \cdot \sin\left(\frac{3\pi}{r}\right) \qquad f_3 = 3 \cdot f$$

$$\vdots \qquad \vdots$$

$$A_n = \frac{2A}{n\pi} \cdot \sin\left(\frac{n\pi}{r}\right) \qquad f_n = n \cdot f$$

The periodic function f(t) depicted in Figure 11(a) consists of the first three harmonic oscillations when decomposed using the Fourier series, as illustrated in Figure 11(b).

a)



b)

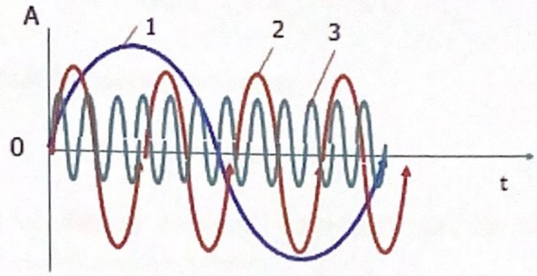


Figure 11. a) Periodic waveform and b) the decomposition of the periodic waveform into the 1st or fundamental, 2nd, and 3rd harmonics

A rectangular pulse is commonly referred to as a rectangular waveform. When a rectangular waveform is decomposed using a Fourier series, it yields the oscillation depicted in Figure 12 that showcases a rectangular wave and its corresponding spectrum. The rectangular wave represents a waveform characterized by alternating periods of high and low amplitude, while the spectrum displays the distribution of frequencies present in the rectangular wave

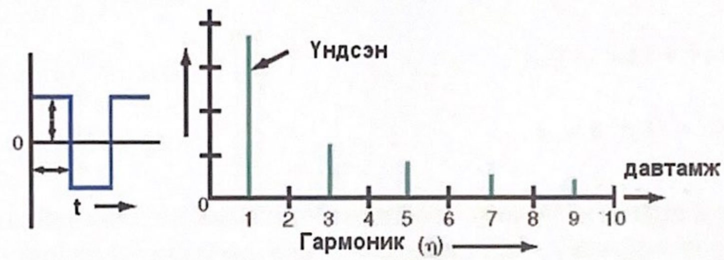


Figure 12. Rectangular waveform and its spectrum

Let's proceed with an example of harmonic calculation. Consider an rectangular pulse with a impulse period of 20 ms and one full period of 120 ms. We will perform harmonic calculations to draw the corresponding spectrum of the given rectangular pulse shown in Figure 13.

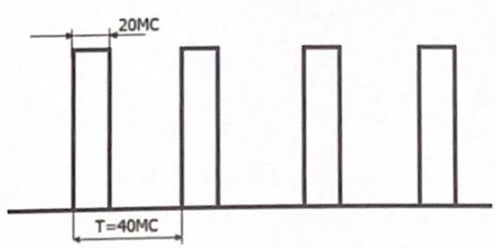


Figure 13. Rectangular pulse given in the example

Let's decompose the infinite series of continuous rectangular oscillations depicted in Figure 13 into a Fourier series.

The duty cycle of the rectangular pulse is defined as follows:

$$re = \frac{T}{\tau} = \frac{120\ ms}{20\ ms} = 6$$

To find the fundamental frequency, we have:

$$\frac{1}{T} = \frac{1000}{120} = 8.33\ \text{Гц}$$

The frequency and amplitude of each waveform can be determined using Equation (19), which is defined as follows:

$$A_0 = \frac{1}{6} = 0.17 \qquad f_0 = 0 \cdot 8.33 = 0$$

$$A_1 = \frac{2 \cdot 1}{3.14} \cdot \sin\left(\frac{\pi}{6}\right) = 0.32 \qquad f_1 = 1 \cdot 8.33 = 8.33$$

$$A_2 = \frac{2 \cdot 1}{2 \cdot 3.14} \cdot \sin\left(\frac{2\pi}{6}\right) = 0.28 \qquad f_2 = 2 \cdot 8.33 = 16.67$$

$$A_3 = \frac{2 \cdot 1}{3 \cdot 3.14} \cdot \sin\left(\frac{3\pi}{6}\right) = 0.21 \qquad f_3 = 3 \cdot 8.33 = 25$$

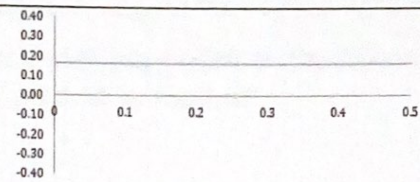
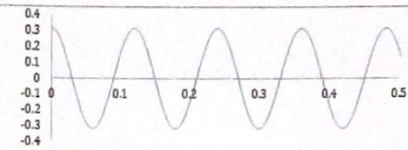
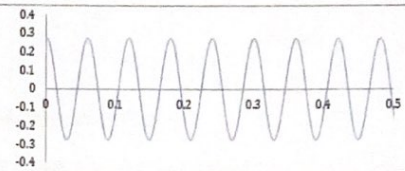
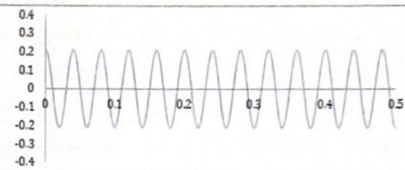
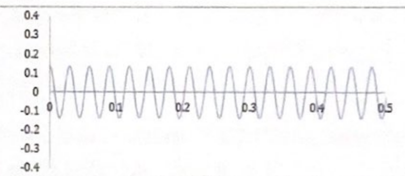
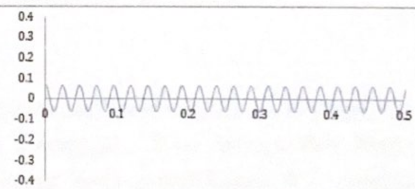
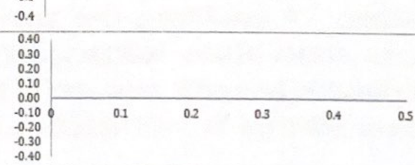
$$A_4 = \frac{2 \cdot 1}{4 \cdot 3.14} \cdot \sin\left(\frac{4\pi}{6}\right) = 0.14 \qquad f_4 = 4 \cdot 8.33 = 33.33$$

$$A_5 = \frac{2 \cdot 1}{5 \cdot 3.14} \cdot \sin\left(\frac{5\pi}{6}\right) = 0.06 \qquad f_5 = 5 \cdot 8.33 = 41.67$$

$$A_6 = \frac{2 \cdot 1}{6 \cdot 3.14} \cdot \sin\left(\frac{6\pi}{6}\right) = 0 \qquad f_6 = 6 \cdot 8.33 = 50$$

Based on this calculation, six waveforms have been determined. Table 3 displays the calculated results for each waveform, indicating their respective amplitudes and frequencies.

Table 3: Amplitude and frequency of each waveform

Harmonic Number	Amplitude	Frequency	Graph
0th	$A_0 = 0.17$	$f_0 = 0$	
First	$A_1 = 0.32$	$f_1 = 8.33$	
Second	$A_2 = 0.28$	$f_2 = 16.67$	
Third	$A_3 = 0.21$	$f_3 = 25$	
Forth	$A_4 = 0.14$	$f_4 = 33.33$	
Fifth	$A_5 = 0.06$	$f_5 = 41.67$	
Sixth	$A_6 = 0$	$f_6 = 50$	

The summation of the waveforms is shown in Figure 14.

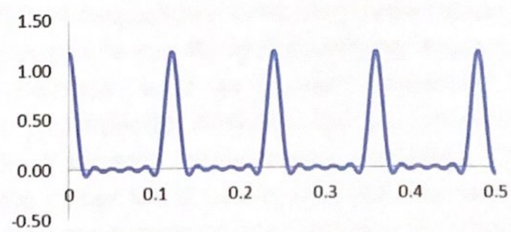


Figure 14. summation of the waveforms

As can be seen from Figure 14, this sum of oscillations looks similar to a series of rectangular pulses. Therefore, the number of oscillations that appear in Fourier series decomposition of rectangular oscillations is equal to the number of fillings.

If these oscillations decomposed by Fourier series are plotted on the frequency axis by amplitude, the spectrum shown in Figure 15 is obtained.

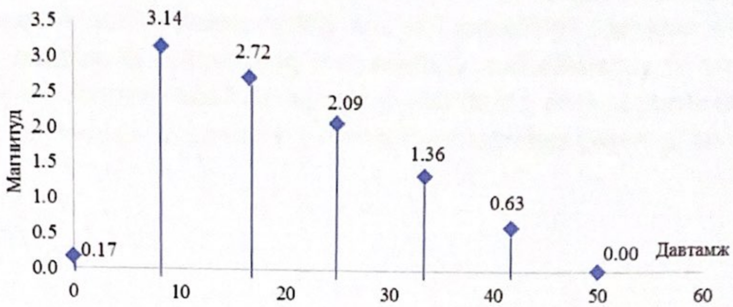


Figure 15. Rectangular pulse spectrum

The spectrum is obtained by performing a Fourier transformation on the complex fluctuations of the measured data using the research method's instrumentation. In certain cases, the power spectral density is employed, which is calculated as the square of the magnitude in the frequency domain. To conduct frequency analysis, the threshold division method (also known as thresholding) involves dividing the magnitude of the power spectral density by a constant value. The specific constant value used for division depends on the magnitude of the frequency domain observed in the original Fourier transform.

In MATLAB, the fft command is used to perform the Fourier transform, and the hanning window function is often applied prior to the transform.

3.3. Conclusion of chapter three

Analyzing power quality and high harmonic frequencies is crucial for the efficient and safe operation of electrical networks. The Mongolian National Standard 1778:2007 provides key guidelines and parameters for assessing power quality, including nominal voltage and acceptable voltage values, steady-state voltage deviation, and various harmonic indicators. Ensuring adherence to these standards is critical for the safety and effectiveness of electrical systems and devices in Mongolia.

The power quality measurements' output signals, which vary over time, contain multiple discrete frequencies. Analyzing these frequencies is fundamental to understanding power line quality and identifying sources of variability in the network. Various methods, such as Fourier Transform, Wavelet Transform, Harmonic Analysis, and Spectral Analysis, can be utilized to decompose these signals into their frequency components, thereby providing a deeper understanding of the power line's quality and allowing for the identification and resolution of any harmonic distortions or anomalies. The choice of the appropriate methodology depends on the specific requirements of the analysis, the characteristics of the measured signal, and the desired accuracy level. The conversion of continuous analog signals into digital signals facilitates the application of these methodologies, with the Fourier Transform serving as a key tool in transforming the time function of a digital signal into a frequency function. This process allows for the extraction of valuable frequency information, providing insights into the signal's harmonic content and power quality characteristics.

Overall, ensuring power quality and mitigating high harmonic frequencies are crucial aspects of maintaining the reliability and efficiency of an electricity network. They require carefully applying standards and sophisticated signal processing techniques to effectively monitor and address potential issues.

CHAPTER 4. DEVELOPMENT OF POWER QUALITY DYNAMIC SIMULATION

4.1. Algorithm of power quality dynamic simulation

Power system dynamic simulation is a critical tool for analyzing and comprehending the behavior of power systems under varying conditions and disturbances. It plays a vital role in assessing power system stability, transient responses, and power quality issues. By simulating the dynamic behavior of power systems, engineers can evaluate system performance, identify potential problems, and develop effective control strategies.

Dynamic simulation involves modeling the components of a power system, such as generators, transmission lines, transformers, and loads, using mathematical equations and algorithms. These models capture the dynamic characteristics and interactions among the different elements, allowing for the study of system response during transient events, fault conditions, and control actions.

Power quality analysis is an essential aspect of dynamic simulation. Dynamic simulation enables engineers to evaluate the impact of power quality disturbances on the system and identify appropriate mitigation measures. In simpler terms, power system dynamic simulation is a tool that helps engineers understand how power systems behave under different conditions. It allows them to identify potential problems and develop solutions to ensure that the system operates efficiently and effectively.

By modeling the different components of a power system, engineers can study how the system responds to different events and disturbances, such as power outages or equipment malfunctions. This helps them to develop strategies to mitigate the impact of these events and ensure that the system remains stable and reliable.

The power quality dynamic simulation has been developed the following software:

- MATLAB programming
- MATLAB Simulink
- MATLAB Guide | Graphical user interfaces (GUIs)

The power quality dynamic simulation is developed based on the Mongolian National Standard MNS 1778-2007.

The Matlab Simulink software is widely used in modern engineering science to develop the dynamic model of electric power quality. The dynamic design of this model emphasizes ease-of-use, simplicity, and a versatile interface for input data that can be easily imported from Windows environment applications. By entering measurement data into this model and analyzing it, researchers and technicians can quickly draw conclusions about the quality of electric power in the area. This is crucial because it provides an opportunity to prevent equipment damage and take measures to improve quality indicators.

In today's fast-paced world, it is essential to have tools that can quickly and accurately assess the quality of electric power. The dynamic model of electric power quality developed on Matlab Simulink software is one such tool. Its user-friendly interface and ease-of-use make it an ideal choice for researchers and technicians alike. By analyzing measurement data, this model can provide valuable insights into the quality of electric power in the area. This, in turn, can help prevent equipment damage and improve quality indicators.

Figure 16 illustrates the block diagram depicting the structure of dynamic simulation used for determining power quality parameters.

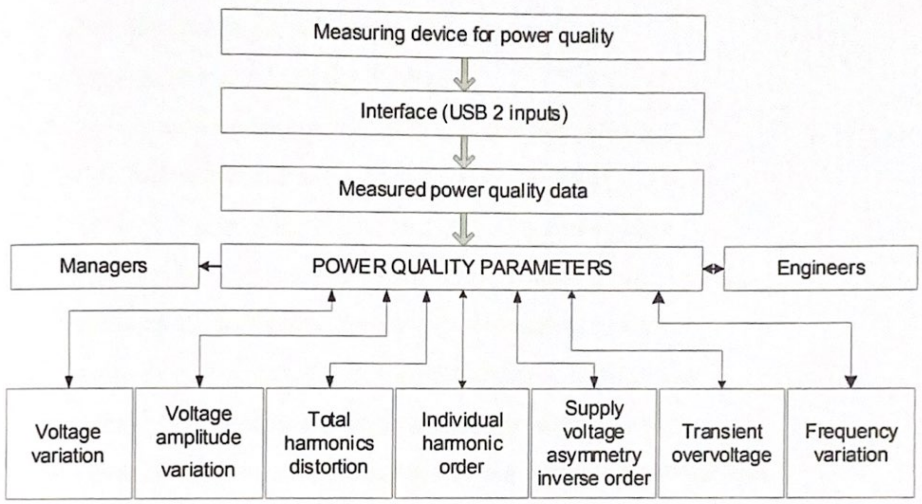


Figure 16. Block diagram for dynamic simulation

Processing measurement data in a dynamic model offers various possibilities, including:

Monitoring the power supply for consumers requiring high-quality electricity.

Utilizing it for ongoing research on electric energy quality.

Using it for training purposes related to electric energy quality.

Analyzing and comparing measurement results by selecting electric energy quality indicators.

The dynamic model is selected based on parameters defined by electric power quality standards, such as voltage fluctuation, higher harmonics content, and non-sinusoidal coefficients. It can efficiently analyze a power supply database with a range of 60-2460 rows and 120-480 columns in a short processing time.

The dynamic model processes the following values at each moment during the measurement period:

- Voltage of each phase (220 ± 10% V).
- Neutral voltage.
- Current of each phase.
- Neutral current.
- Frequency (50 ± 5% Hz).
- Distortion caused by non-sinusoidal current in each phase.
- Distortion caused by non-sinusoidal nature of neutral current.
- Distortion caused by non-sinusoidal voltage in each phase.
- Distortion caused by non-sinusoidal voltage of the neutral.
- 2nd-49th harmonic of the current in each phase.
- 2nd-49th harmonic of each phase voltage.
- 2nd-49th harmonic of the neutral.

The dynamic model outputs the following processed values:

- 2nd-25th harmonic value of each phase voltage.
- Value of the 2nd-25th harmonic of the neutral voltage.
- Value of the 2nd-25th harmonic of the current in each phase.
- Value of the 2nd-25th harmonic of the neutral current.
- Value of non-sinusoidal voltage distortion in each phase.
- Value of non-sinusoidal distortion in the neutral current.
- Value of non-sinusoidal distortion in the current of each phase.
- Value of non-sinusoidal distortion in the neutral current.
- Comparison of the sinusoidal form of the current with the theoretical curve.
- Comparison of the sinusoidal form of the voltage with the theoretical curve.
- Creation of a histogram displaying the content of higher harmonics.

The algorithm for developing dynamic simulation for power quality parameters is depicted in Figure 17, a dynamic simulation is developed based on this algorithm.

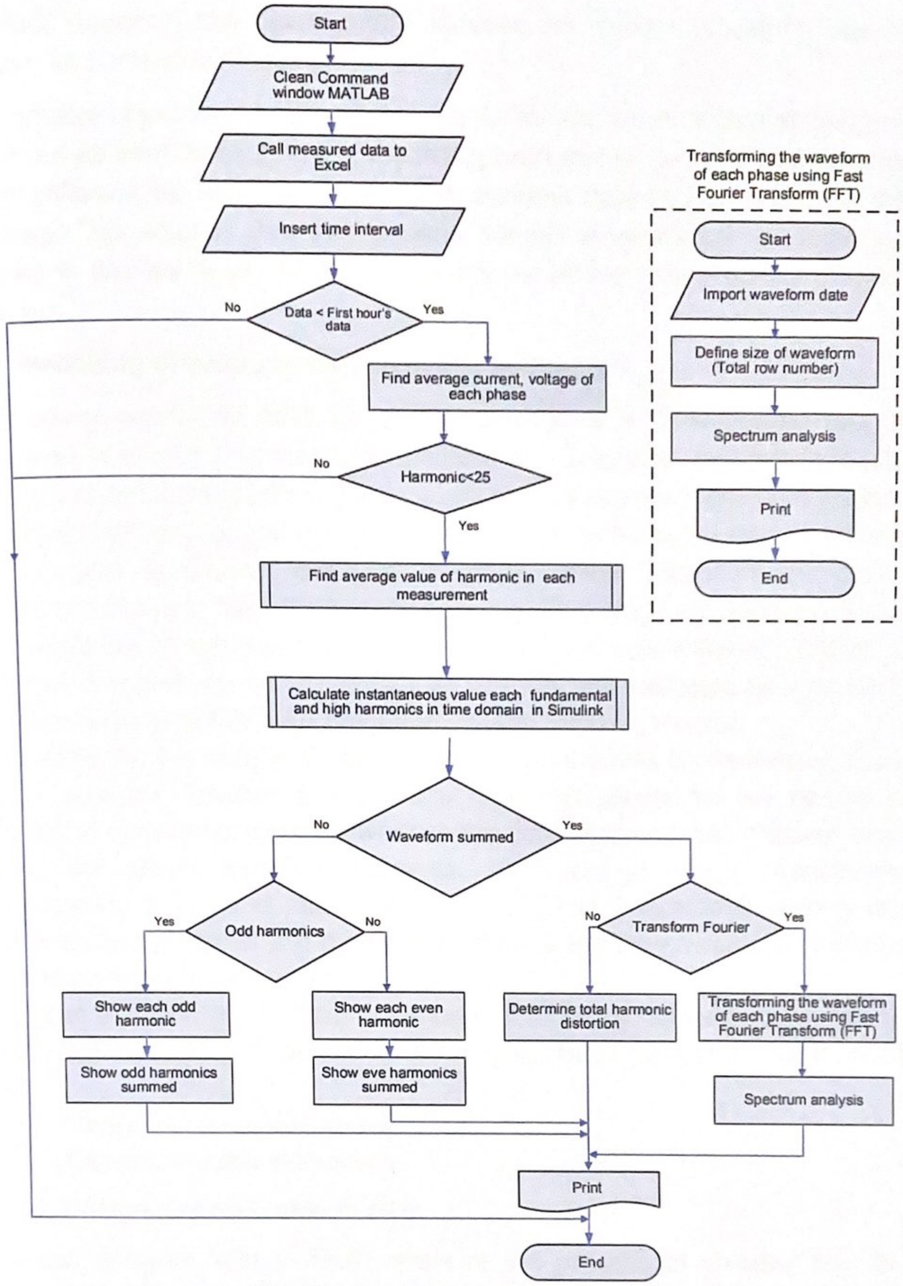


Figure 17. Algorithm for developing power quality parameters

When constructing a block diagram for a dynamic model aimed at determining the quality of electric energy, several considerations are taken into account. These include mathematical processing of input parameters, interfaces for displaying results, and compliance with relevant standards and requirements for evaluating output parameters. The dynamic model provides flexibility in terms of the method and format of inputting information regarding quality indicators of electric energy. Researchers have the freedom to make their own choices and conduct research and development focused on quality indicators, standard values, and operational modes.

The primary objective is to establish a highly flexible structure that allows for the input of data from measuring and recording instruments, devices, and commonly used software, as well as the ability to transmit data model results to these sources. This ensures that the resulting numerical values can be extensively utilized in diverse engineering calculations pertaining to the quality of electric energy.

4.2. Modelling of power quality dynamic simulation

The power quality dynamic simulation process is a multi-faceted task that leverages MATLAB programming, Simulink, and Graphical User Interface (GUI). This computational procedure is principally divided into two significant stages.

The first step involves the design of the software skin via the GUI. In essence, this pertains to creating the user interface, which represents the point of interaction between the user and the software. This stage includes planning the software's layout and aesthetic aspect, ensuring it is user-friendly, intuitive, and efficient. A well-designed GUI enhances usability and facilitates user interaction with the underlying MATLAB programming and Simulink models.

Subsequently, the second phase of the process focuses on developing models within Simulink. *Simulink* is a powerful tool that allows for the design and simulation of dynamic systems, which in this context are related to power quality. Here, the power system's elements, such as generators, transformers, transmission lines, and loads, are modeled. The interactions among these elements under normal and disturbed conditions are then simulated to evaluate their impacts on power quality.

One can examine power system performance and dynamics through this two-stage process, ultimately shedding light on potential power quality issues. Stages are:

- Design software skin in GUI
- Develop models in Simulink

4.2.1. Design software skin in GUI

"Design software skin in GUI" refers to the process of creating the visual appearance and layout of a software application's graphical user interface (GUI). It involves designing and customizing the elements such as buttons, menus, dialog boxes, and other graphical components that users interact with when using the software. The term "software skin" refers to the overall visual theme or style applied to the GUI. It includes the selection of colors, fonts, icons, and other graphical elements that determine the look and feel of the software.

Designing the software skin in the GUI involves considering factors such as usability, aesthetics, branding, and user experience. The goal is to create an intuitive and visually appealing interface that enhances the user's interaction with the software, making it easy to navigate, understand, and perform tasks [11].

So, designing the software skin for dynamic simulation of power quality in GUI encompasses the visual design and layout considerations for creating an attractive and user-friendly graphical interface for a software application.

The design of skin for dynamic simulation of power quality is shown in Figure 18-Figure 19.

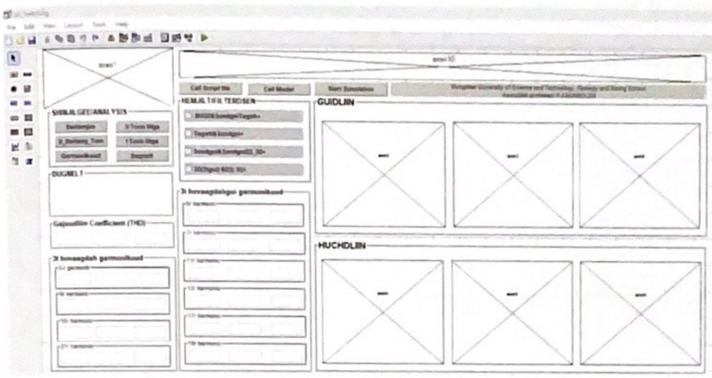


Figure 18. Designing skin of dynamic simulation

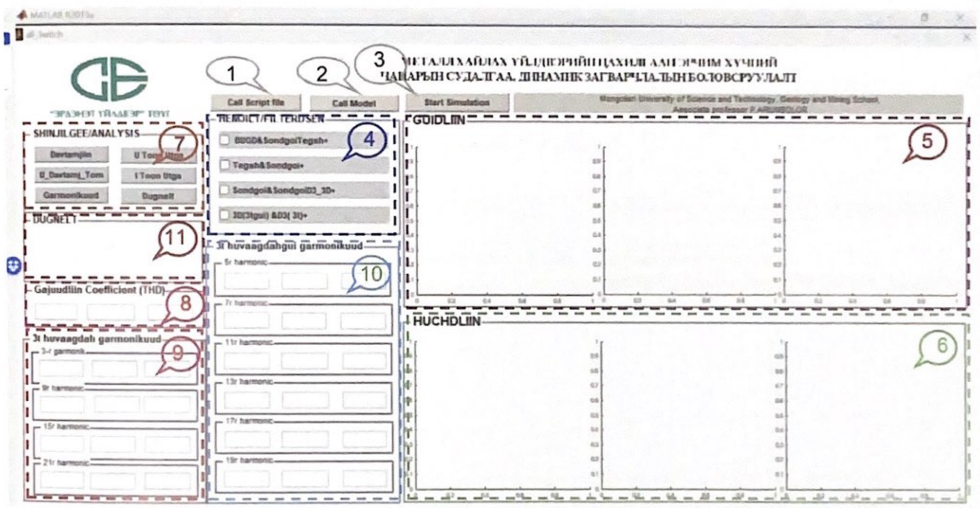


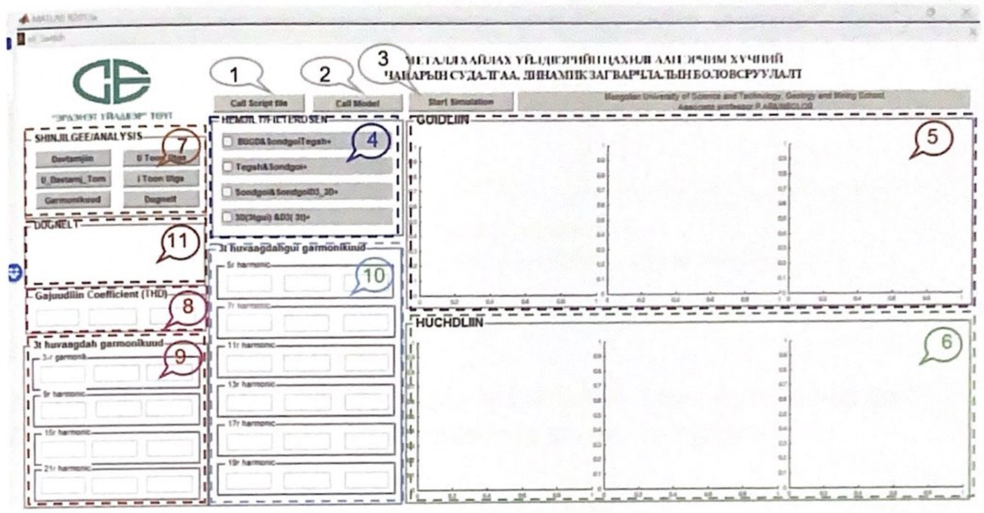
Figure 19. Skin of dynamic simulation

From Figure 19, the dynamic simulation is consisted of the following 11 blocks.

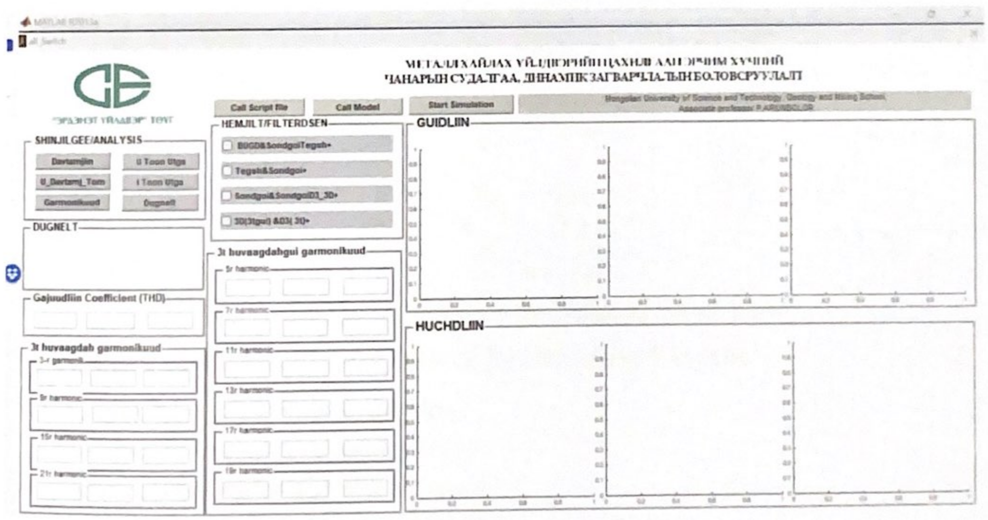
Block 1: Button to call script file,
Block 2: Button to call Model,
Block 3: Button to Start Simulation
Block 4: Select button the following options:

- All harmonics,
- even and odd harmonics,
- odd harmonics that are divided by three,
- odd harmonics not divided with filters.

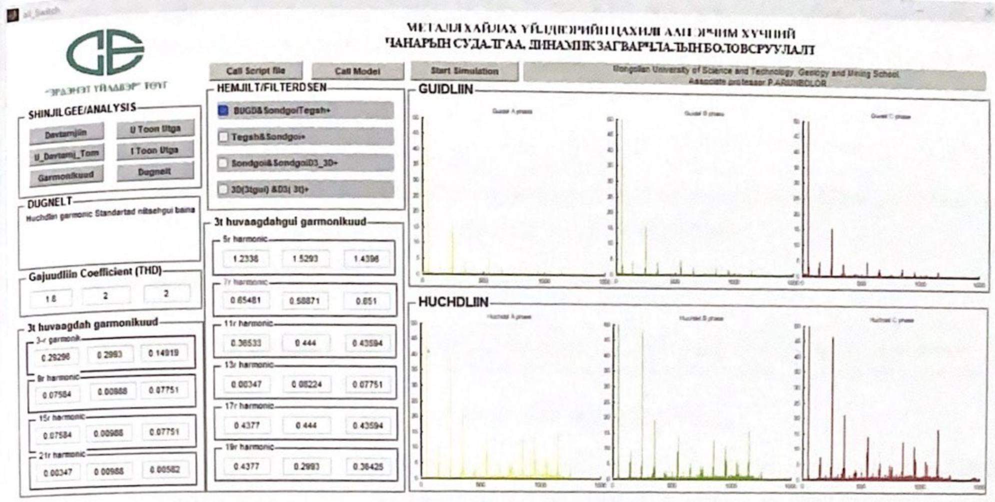
Block 5: Frequency spectrum of current
Block 6: Frequency spectrum of voltage
Block 7: Select the following type of analysis
Block 8: Show the total harmonic distortion
Block 9: Show odd harmonics divided by three
Block 10: Show odd harmonics not divided by three
Block 11: Conclude based on MNS 1778:2007



Skin of dynamic simulation



Before running the simulation



After running the simulation

Figure 20. Dynamic simulation for studying power quality

4.2.2. Develop models in Simulink

The dynamic simulation power quality parameters have been developed On MATLAB Simulink. The dynamic simulation is shown in Figure 21.

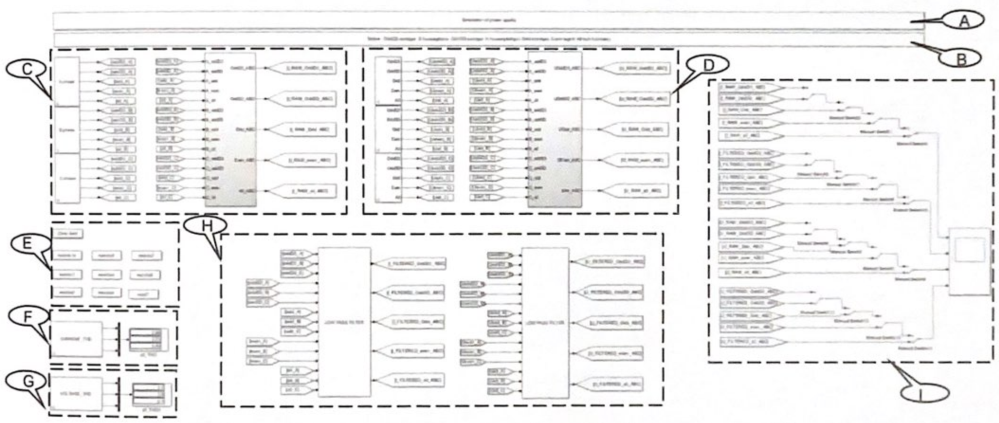


Figure 21. Dynamic simulation for analyzing power quality

The dynamic simulation is consisted of the following 8 blocks:

A. Block for calling the script files
B. Block for explaining terminology
C. Block models for current harmonics
D. Block models for voltage harmonics
E. Block calling the measured data
F. Block for current total distortion harmonic
G. Block for voltage total distortion harmonic
H. Block for filtering
I. Block for switching (all, odd, even, odd divided by 3, odd not divided by 3).

A. Block for calling the script files is for running "Simulation of power quality" Figure 22. The dynamic simulation is run when click on the name "Simulation of power quality"

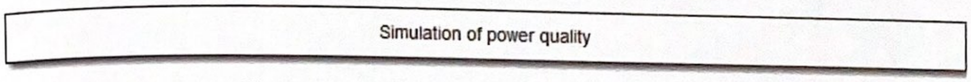


Figure 22. Run button the dynamic simulation

B. Block for explaining terminology is shown in Figure 23.

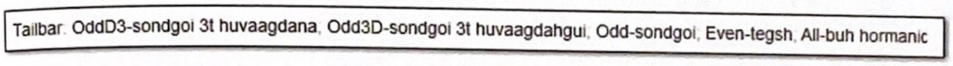


Figure 23. Block for explaining terminology

C. Block models for current harmonics is consisted of three phases. A phase model is shown in Figure 24. Rest two phases are the same with A phase model. However, phases are different by 120^0. Phases Model of A phase is shown in Figure 25.

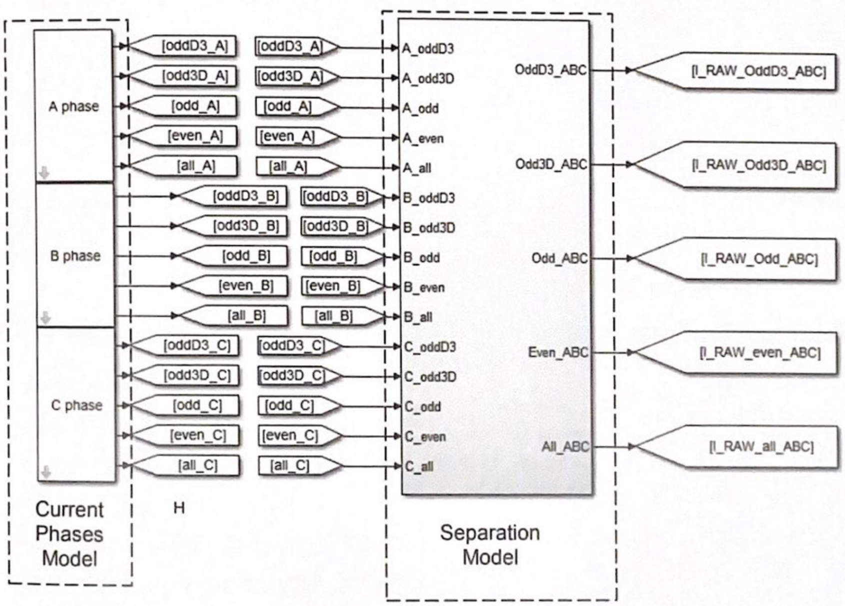


Figure 24. Block models for current harmonics of A phase

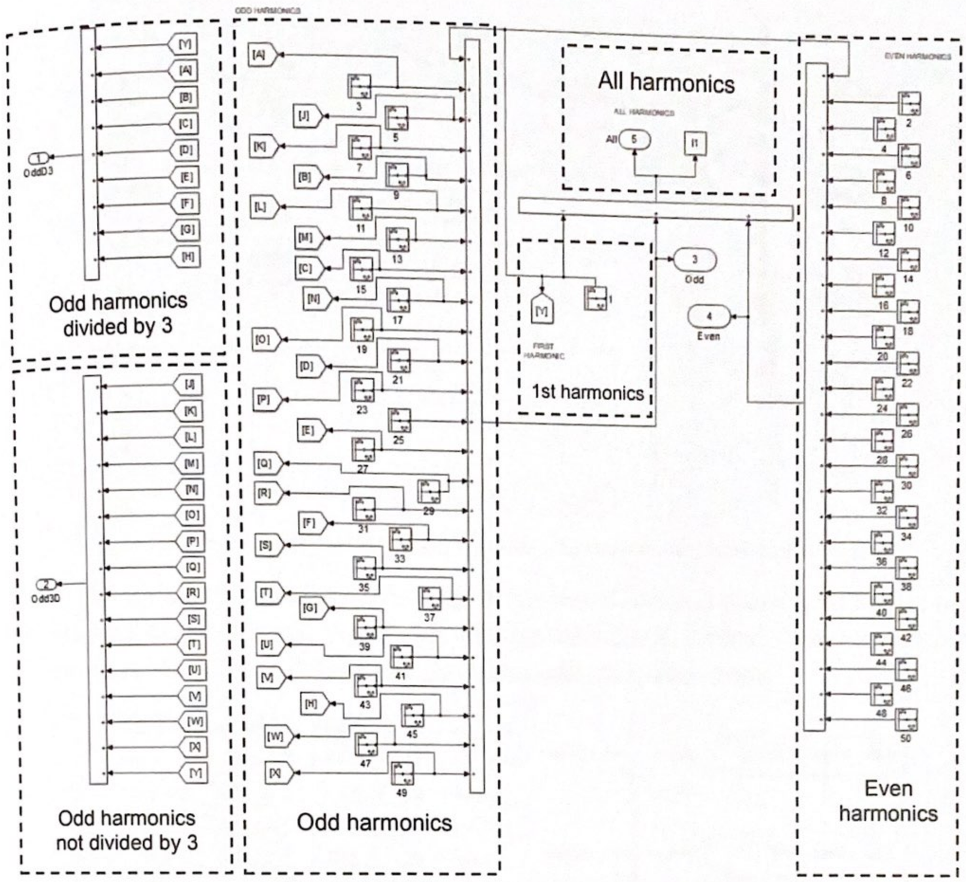


Figure 25. Phases Model of Block model for current harmonics

Phases Model of the block model for current harmonics has the following blocks:

- All harmonics
- First harmonics
- Even harmonics
- Odd harmonics
- Odd harmonics divided by three
- Odd harmonics not divided by three

Separation Model is shown in Figure 26.

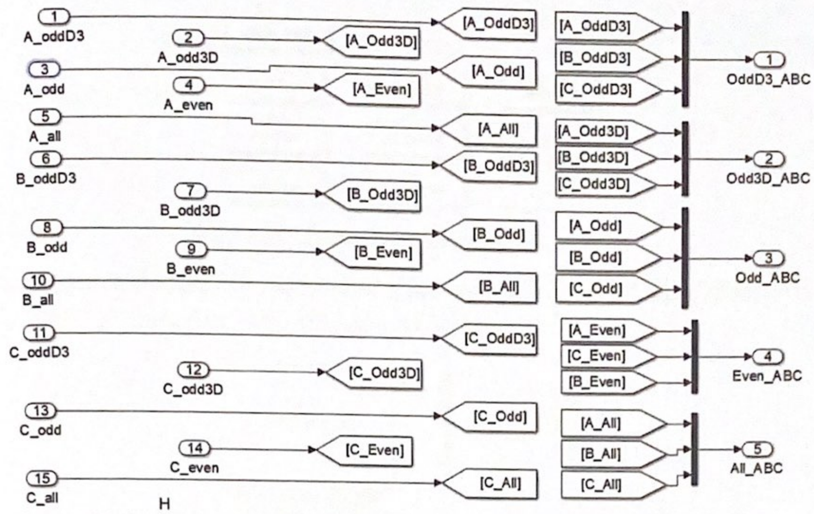


Figure 26. Separation model of block models for current harmonics of A phase

D. Block models for voltage harmonics is consisted of three phases and structure is the same with the block models for voltage harmonics. A phase model is shown in Figure 27. Rest two phases are the same with A phase model.

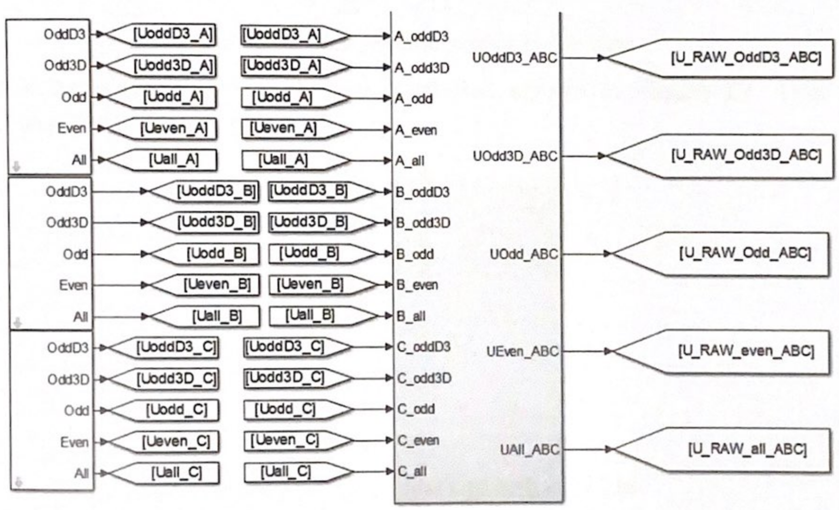


Figure 27. Phases Model of Block model for voltage harmonics

Phases Model and Separation Model of block model for voltage harmonics are the same with Block model for current harmonics. So, the Phases Model and Separation Model of block model for voltage harmonics do not show here.

Measured data is given to the dynamic simulation. The sample time is 0.00001 of the measured data.

E. Block calling the measured data is shown in Figure 28

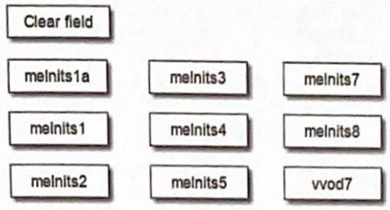


Figure 28. Block calling the measured data

F. Block for current total harmonic distortion is called as THD and shown in Figure 29. This block shows the THD of each phase.

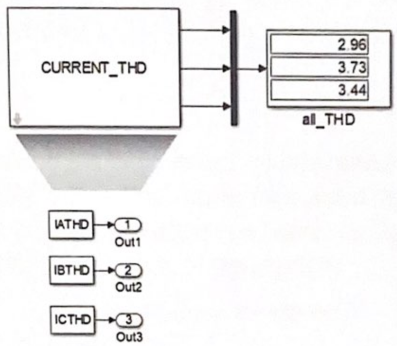


Figure 29. Current total harmonic distortion

G. Block for voltage total distortion harmonic shown in Figure 27. This block shows the THD of each phase.

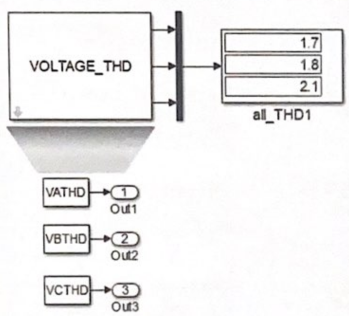
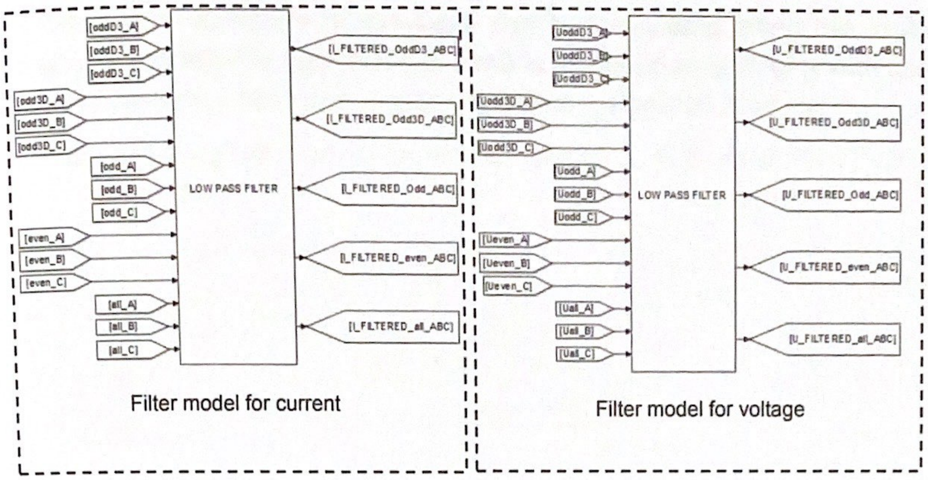


Figure 30. Voltage total harmonic distortion

H. Block for filtering is shown Figure 31. The THD is higher than the standard and not in the range of the power quality parameters. The the power system should be satisfied the standard of power quality, so the block for filtering is modeled shown in Figure 31 and is consisted of the filter model for current and the filter model voltage.



The filter model for current and the filter model voltage shown in Figure 32 are the same model but the data is different. The filter model for current run based on the measured current data and the filter model for voltage run based on the measured voltage data. The core (basic) model of the filter shown in Figure 33 in.

Figure 31. Block for filtering

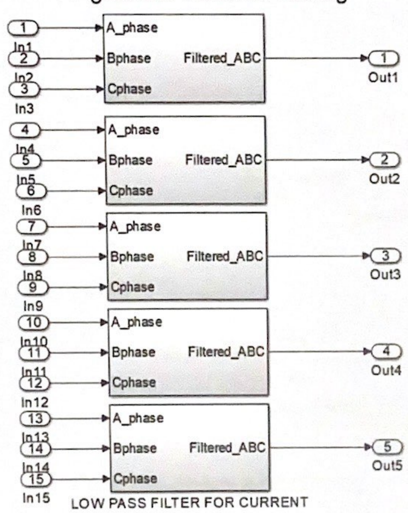


Figure 32. Filter model for current and voltage

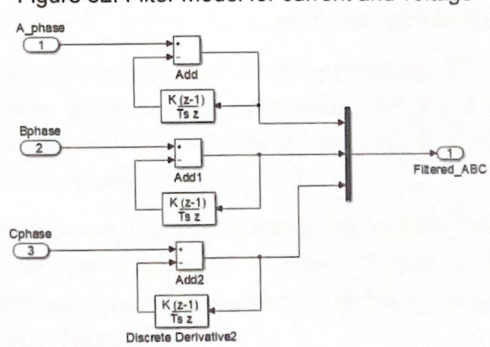


Figure 33. Filter model for voltage

The discrete-time derivative of the input can be calculated using this block. However, it is important to note that this block is designed to work only with fixed sample rates and may not function properly within a triggered subsystem.

I. Block for switching (all, odd, even, odd divided by 3, odd not divided by 3) is shown in Figure 34.

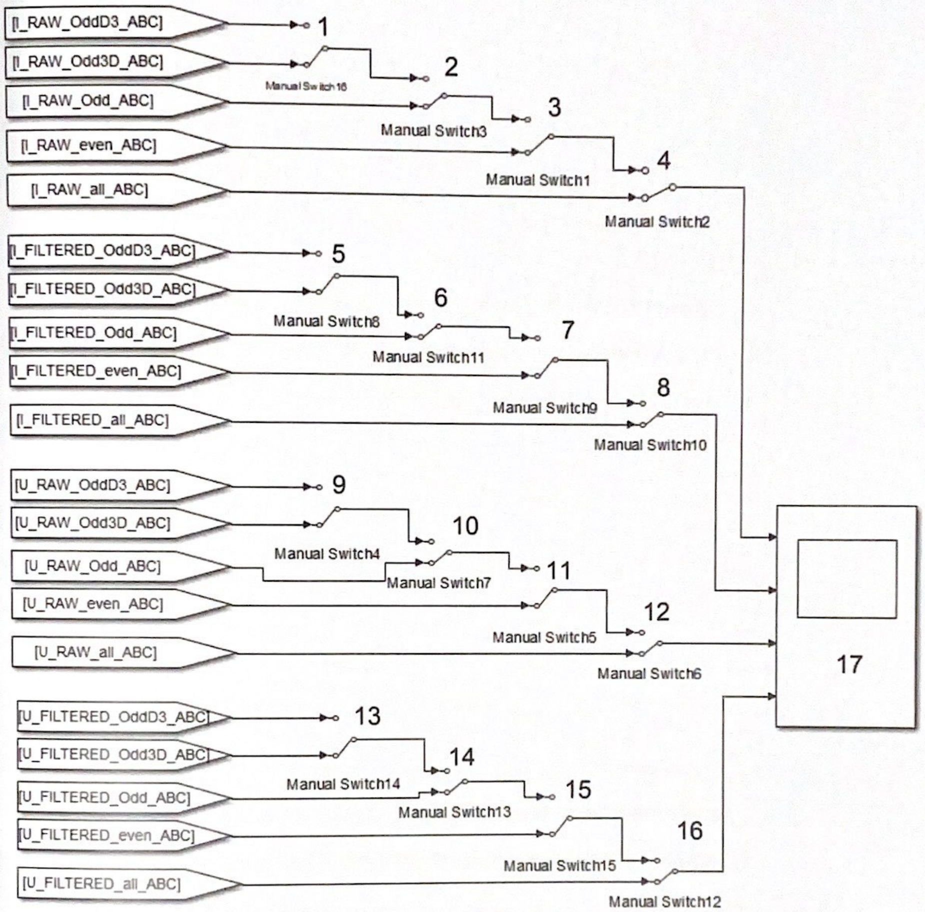


Figure 34. Block for switching

The modelling block for switching has 16 switches and 1 scope. There are four levels such as all, even, odd divided by 3, and odd not divided by 3.

16, 12, 8 and 4 switches are connected to all harmonics, 15, 11, 7 and 3 switches are connected to either even or odd harmonics, 14,10, 6 and 2 switches are connected to odd harmonics divided by 3 and 13, 9, 5 and 1 switches are connected to odd not harmonics divided by 3.

The 17-scope is for showing the results that the waveforms are all, even, odd divided by 3, and odd not divided by 3. From Figure 34-38, 1 is the current waveform, 2 is the filtered current waveform, 3 is the voltage waveform, and 4 is the filtered voltage waveform.

The graph of waveforms with all harmonics is shown Figure 35.

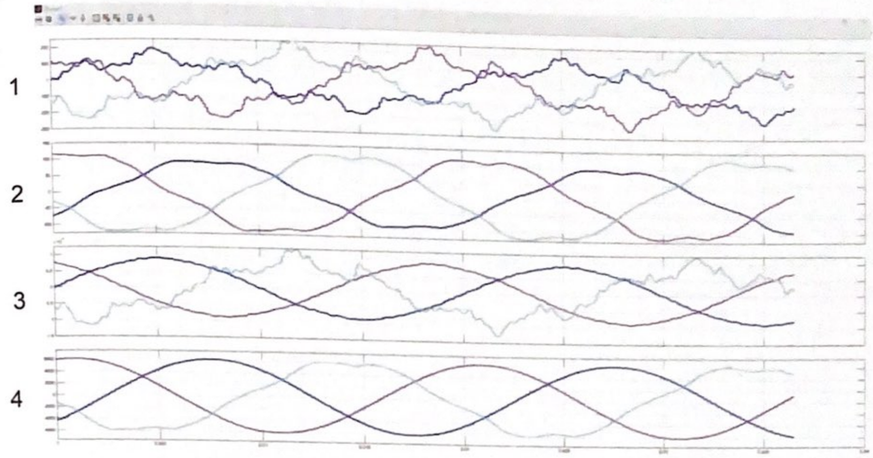


Figure 35. Graph of waveform with all harmonics

The graph of waveforms with even harmonics is shown Figure 36.

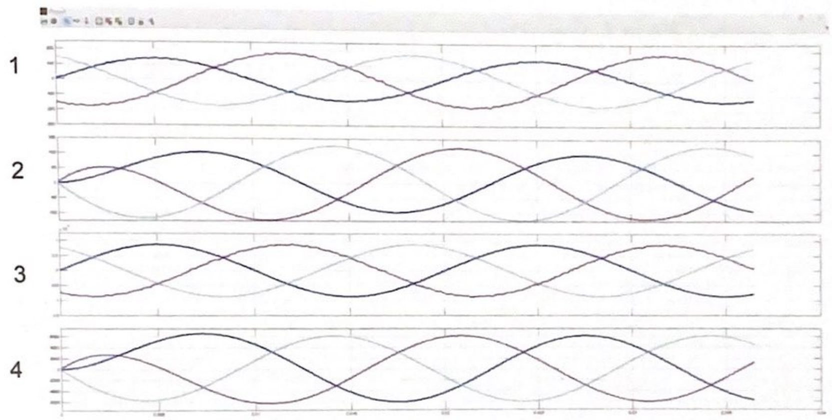


Figure 36. Graph of waveform with even harmonics

The graph of waveforms with odd harmonics is shown Figure 37.

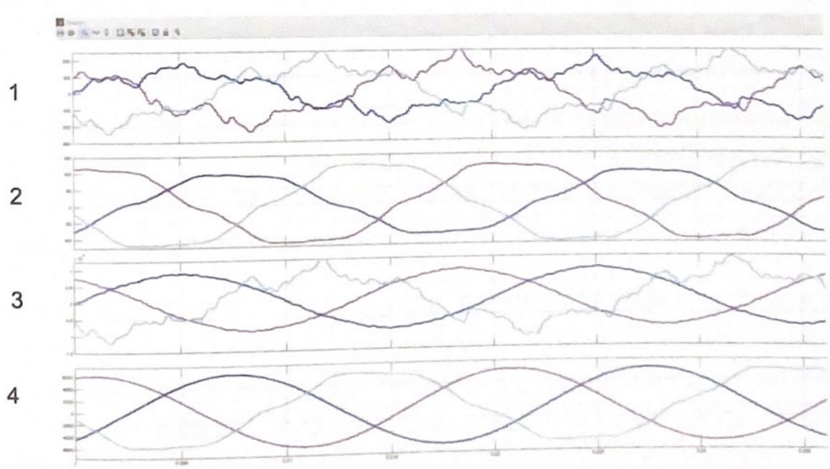


Figure 37. Graph of waveform with odd harmonics

The graph of waveforms with odd harmonics divided by three is shown in Figure 38.Figure 38. Graph of waveform with odd harmonics

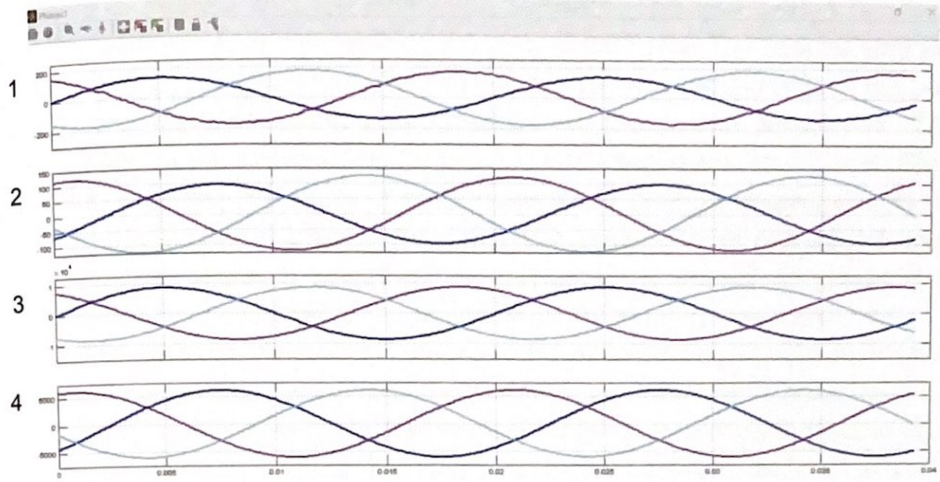


Figure 38. Graph of waveform with odd harmonics divided three

The graph of waveforms with odd harmonics not divided by three is shown in Figure 39.Figure 38Figure 38. Graph of waveform with odd harmonics

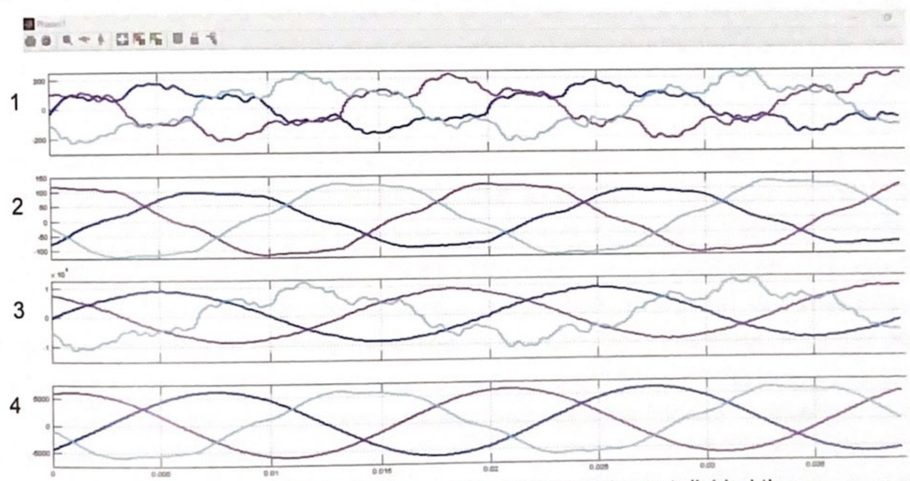


Figure 39. Graph of waveform with odd harmonics not divided three

From Figure 34-38, the total harmonic distortion of the odd harmonics not divided by three is higher than the odd harmonics divided by three and even harmonics. Therefore, we have to focus on the odd harmonics not divided by three.

4.3. Conclusion of chapter four

In conclusion, the power quality dynamic simulation is a crucial tool for understanding and analyzing the behavior of power systems under varying conditions and disturbances. By modeling the components of a power system using MATLAB programming, Simulink, and a Graphical User Interface (GUI), engineers can simulate and evaluate the system's dynamic behavior, including its stability, transient responses, and power quality issues. The simulation process involves two main steps. The first step is to design the software skin in the GUI, which includes creating a user-friendly and visually appealing interface for users to interact with the simulation software. The GUI design focuses on usability, aesthetics, and enhancing the user experience. The second step is the development of models in Simulink, where the various components of the power system are modeled using mathematical equations and algorithms. These models capture the dynamic characteristics and interactions among the different elements, enabling the study of system response during transient events, fault conditions, and control actions. Power quality analysis is an essential aspect of the simulation, allowing engineers to evaluate the impact of power quality disturbances on the system and identify appropriate mitigation measures.

The dynamic simulation process and its modeling in Simulink provide valuable insights into power system performance, identifying potential issues, and developing effective control strategies. It allows for evaluating power quality parameters, such as voltage fluctuation, harmonics content, and non-sinusoidal coefficients, based on the Mongolian National Standard MNS 1778:2007. The simulation results can be used for ongoing research, training, and decision-making on power quality.

The GUI and Simulink models facilitate the input of measurement data, the analysis of frequency spectra, the calculation of total harmonic distortion, and the visualization of waveforms. These tools enable engineers to monitor power supply quality, study different types of harmonics, and compare measurement results against power quality standards. By leveraging the power quality dynamic simulation, engineers can develop effective strategies to improve power system reliability, prevent equipment damage, and ensure compliance with power quality standards. While the simulation process provides valuable insights, it is important to note that real-world power systems may have additional complexities and variations that cannot be fully captured in the simulation models. Regular power quality measurements and assessments in real-world conditions are necessary to complement the simulation results and ensure power systems' optimal performance and reliability.

In conclusion, the power quality dynamic simulation, supported by MATLAB programming, Simulink, and GUI, is a valuable tool for analyzing and improving power system performance and quality. It allows engineers to understand the behavior of power systems under different conditions, identify potential issues, and develop effective solutions to ensure reliable and high-quality power supply.

CHAPTER 5. RESULT DISCUSSIONS

The results of the power system dynamic simulation are discussed in this chapter. Two different types of load measurements are used to determine harmonic behavior based on electric loads. One type involves measuring electric motors, while the other involves measuring an induction furnace.

5.1. Results of induction furnaces data (no loads)

The induction furnace voltage's total harmonic distortion has an impact on the power distribution system, and it is influenced by the load for metal melting. Induction furnaces are characterized by non-linear loads, which result in high harmonics in both voltage and current. These elevated harmonics can give rise to various issues, including triggering overcurrent protection, causing harmonic resonance, damaging capacitor banks, overheating transformer cores, degrading cable insulation, reducing equipment lifespan, burning motor stator windings, overloading neutrals, damaging generators, and more. Consequently, the induction furnace has a detrimental effect on the electrical power system.

The waveform and harmonic measurements were performed on the induction furnace without a compensator when it was at 0% load or unloaded, as illustrated in Figure 40 and **Error! Reference source not found.**.

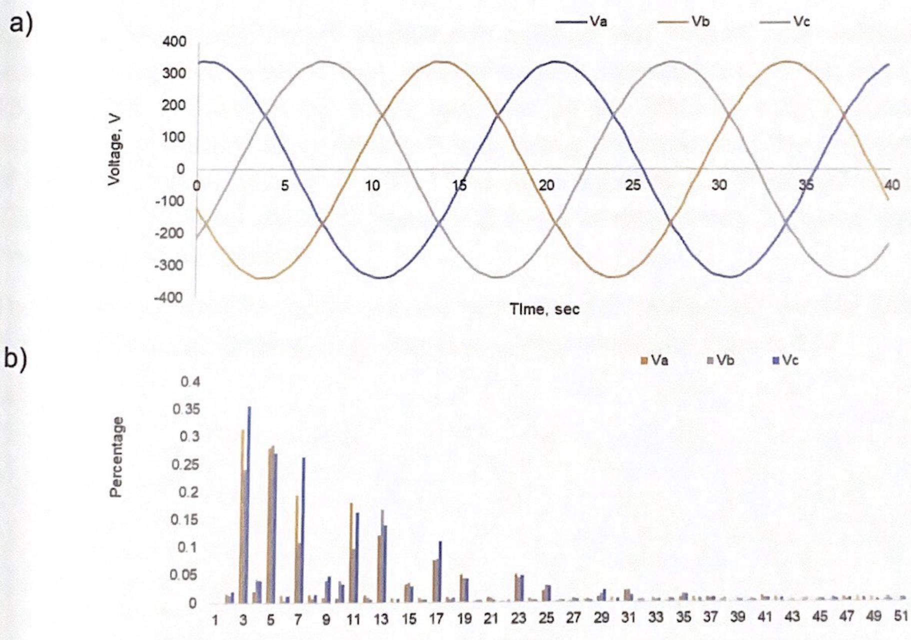
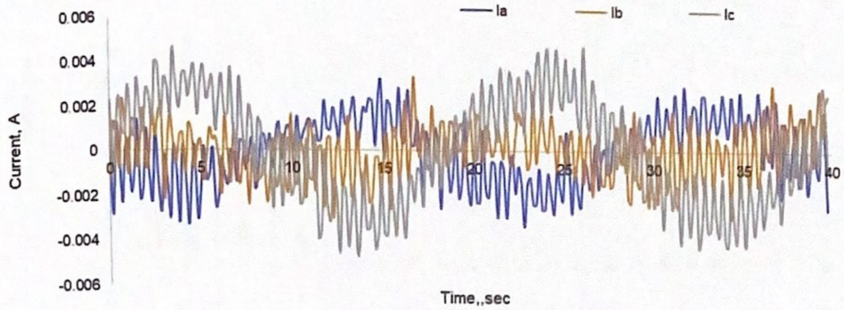


Figure 40. Measurement without load and without compensator, a) voltage sin waveform, b) voltage harmonics

a)



b)

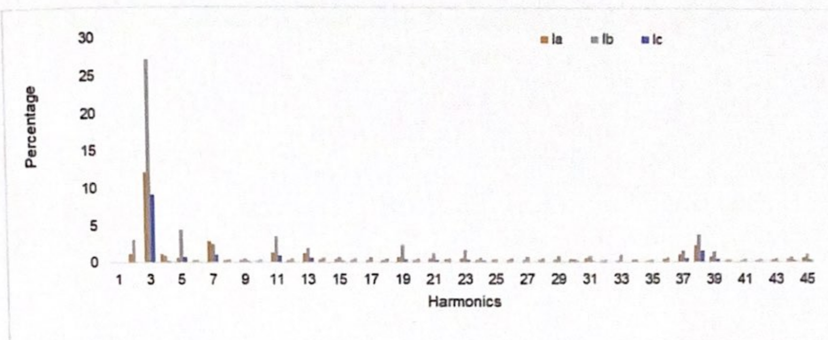
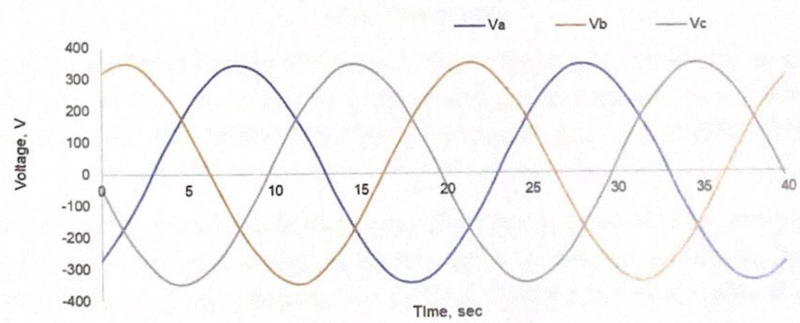


Figure 41. Measurement without load and without compensator, a) current sin waveform, b) current harmonics

Based on Figure 40-**Error! Reference source not found.**, the voltage sine waveform appears to be normal, and the specific harmonics (3, 5, 11, 13, 17, 23, 25, and 29) are within the limits specified by the MNS1778:2007 standards. However, the current sine waveform is severely distorted, and the 3rd harmonic of the current accounts for 27.18%. This value exceeds the threshold set by the IEEE STD 519-1992 standard, indicating that it is excessively high and does not meet the required criteria.

The waveform and harmonic measurements were performed on the induction furnace with a compensator as depicted in Figure 42 and Figure 43.

a)



b)

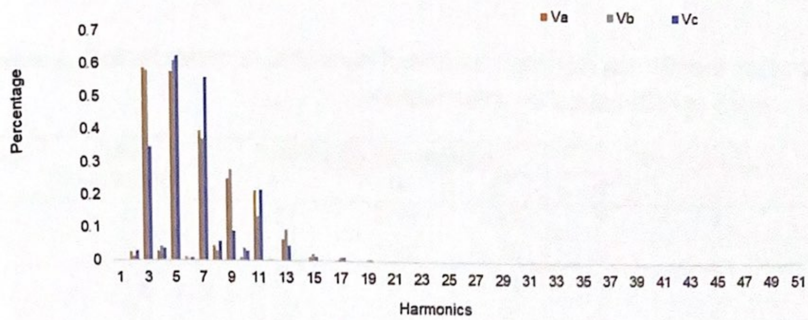
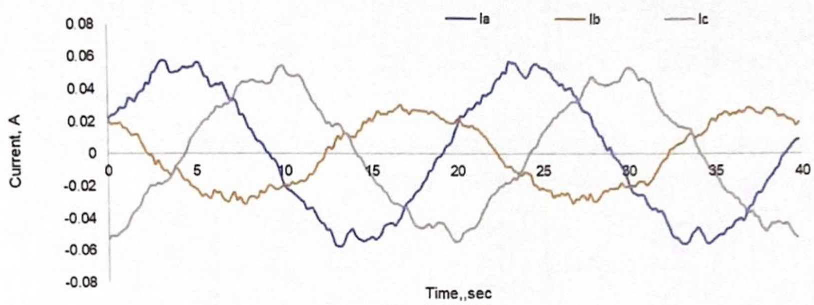


Figure 42. Measurement without load and with compensator, a) voltage sin waveform, b) voltage harmonics

a)



b)

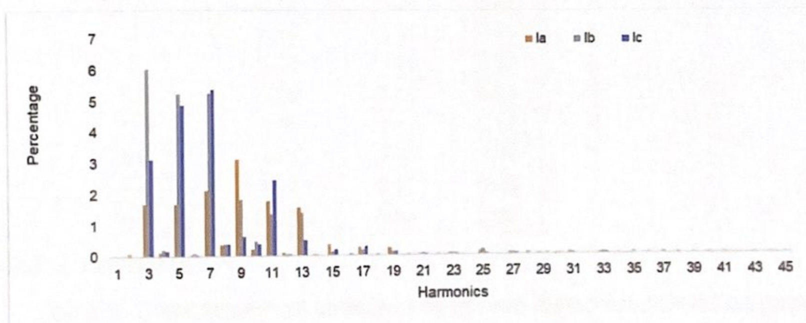


Figure 43. Measurement without load and with compensator, a) current sin waveform, b) current harmonics

Based on Figure 42and Figure 43Figure 40, the voltage sine waveform appears to be normal, and all the harmonics of voltage and current waveform are within the limits specified by the MNS1778:2007 standards and IEEE STD 519-1992 standard.

The measurements of individual harmonic distortions, both without being divided by three, with and without a compensator, were conducted when the induction furnace was unloaded, as presented in Table 4, *Table 5*,*Table 8*, *Table 9*.

Similarly, the measurements of individual harmonic distortions, divided by three, with and without a compensator, were taken when the induction furnace was unloaded, as indicated in 1-Satisified; (0) – Unsatisfied.

Table 6, *Table 7*, *Table 10*,*Table 11*.

Table 4. Comparation of individual harmonic distortion not divided be three with compensator no loads (voltage measurement)

Harmonics	MNS 1778:2007	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
5	6	0.57	5.23	4.87	1	1	1
7	5	0.40	5.25	5.38	1	1	1
11	3.5	0.21	1.35	2.44	1	1	1
13	3	0.07	1.41	0.52	1	1	1
17	2	0.00	0.18	0.31	1	1	1
19	1.5	0.00	0.13	0.12	1	1	1
23	1.5	0.00	0.05	0.07	1	1	1
25	1.5	0.00	0.17	0.06	1	1	1
29	1.3	0.00	0.04	0.06	1	1	1

1-Satisified; (0) – Unsatisfied.

Table 5. Comparation of individual harmonic distortion not divided be three compensator no loads (current measurement)

Harmonics	IEEE STD 519:2014	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
5	4	1.70	5.23	4.87	1	(0)	(0)
7	4	2.12	5.25	5.38	1	(0)	(0)
11	2	1.79	1.35	2.44	1	1	(0)
13	2	1.56	1.41	0.52	1	1	1
17	1.5	0.26	0.18	0.31	1	1	1
19	1.5	0.26	0.13	0.12	1	1	1
23	0.6	0.08	0.05	0.07	1	1	1
25	0.6	0.12	0.17	0.06	1	1	1
29	0.6	0.05	0.04	0.06	1	1	1

1-Satisified; (0) – Unsatisfied.

Table 6. Comparation of individual harmonic distortion divided be three with compensator no loads (voltage measurement)

Harmonics	MNS 1778:2007	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
3	6	0.59	6.04	3.13	1	1	1
9	5	0.25	1.84	0.62	1	1	1
15	3.5	0.01	0.12	0.21	1	1	1
21	3	0.00	0.08	0.06	1	1	1
27	2	0.00	0.09	0.06	1	1	1
33	1.5	0.00	0.08	0.06	1	1	1
39	1.5	0.00	0.06	0.02	1	1	1
45	1.5	0.00	0.05	0.03	1	1	1
51	1.3	0.00	0.08	0.03	1	1	1

1-Satisified; (0) – Unsatisfied.

Table 7. Comparation of individual harmonic distortion divided be three with compensator no loads (current measurement)

Harmonics	IEEE STD 519:2014	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
3	4	1.69	6.04	3.13	1	(0)	1
9	4	3.13	1.84	0.62	1	1	1
15	2	0.38	0.12	0.21	1	1	1
21	2	0.07	0.08	0.06	1	1	1
27	1.5	0.07	0.09	0.06	1	1	1
33	1.5	0.05	0.08	0.06	1	1	1
39	0.6	0.02	0.06	0.02	1	1	1
45	0.6	0.02	0.05	0.03	1	1	1
51	0.6	0.03	0.08	0.03	1	1	1

1-Satisified; (0) – Unsatisfied.

Table 8. Comparation of individual harmonic distortion not divided be three without compensator no loads (voltage measurement)

Harmonics	MNS 1778:2007	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
5	6	0.28	4.41	0.71	1	1	1
7	5	0.19	2.49	1.09	1	1	1
11	3.5	0.18	3.48	0.93	1	1	1
13	3	0.12	1.95	0.68	1	1	1
17	2	0.08	0.71	0.16	1	1	1
19	1.5	0.05	2.35	0.49	1	1	1
23	1.5	0.05	1.66	0.38	1	1	1
25	1.5	0.02	0.41	0.12	1	1	1
29	1.3	0.01	0.90	0.17	1	1	1

1-Satisified; (0) – Unsatisfied.

Table 9. Comparation of individual harmonic distortion not divided by three without compensator no loads (current measurement)

Harmonics	IEEE STD 519:2014	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
5	4	0.66	4.41	0.71	1	(0)	1
7	4	2.87	2.49	1.09	1	1	1
11	2	1.34	3.48	0.93	1	(0)	1
13	2	1.23	1.95	0.68	1	1	1
17	1.5	0.31	0.71	0.16	1	1	1
19	1.5	0.80	2.35	0.49	1	(0)	1
23	0.6	0.51	1.66	0.38	1	(0)	1
25	0.6	0.31	0.41	0.12	1	1	1
29	0.6	0.30	0.90	0.17	1	(0)	1

1-Satisified; (0) – Unsatisfied.

Table 10. Comparation of individual harmonic distortion divided be three without compensator no loads (voltage measurement)

Harmonics	MNS 1778:2007	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
3	6	0.31	27.18	9.20	1	1	1
9	5	0.01	0.52	0.26	1	1	1
15	3.5	0.03	0.71	0.23	1	1	1
21	3	0.01	1.26	0.38	1	1	1
27	2	0.00	0.72	0.15	1	1	1
33	1.5	0.01	1.11	0.18	1	1	1
39	1.5	0.00	1.46	0.45	1	1	1
45	1.5	0.00	1.18	0.37	1	1	1
51	1.3	0.00	0.87	0.17	1	1	1

1-Satisified; (0) – Unsatisfied.

Table 11. Comparation of individual harmonic distortion divided be three without compensator no loads (current measurement)

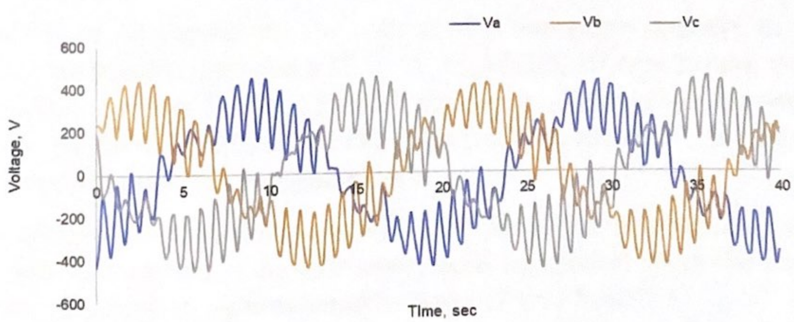
Harmonics	IEEE STD 519:2014	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
3	4	12.16	27.18	9.20	(0)	(0)	(0)
9	4	0.37	0.52	0.26	1	1	1
15	2	0.41	0.71	0.23	1	1	1
21	2	0.53	1.26	0.38	1	1	1
27	1.5	0.34	0.72	0.15	1	1	1
33	1.5	0.28	1.11	0.18	1	1	1
39	0.6	0.78	1.46	0.45	(0)	(0)	1
45	0.6	0.62	1.18	0.37	(0)	(0)	1
51	0.6	0.48	0.87	0.17	1	(0)	1

1-Satisified; (0) – Unsatisfied.

5.2. Results of induction furnaces data (Full loads)

The waveform and harmonic measurements were performed on the induction furnace without a compensator when it was at 100% load or fully loaded, as illustrated in Figure 44 and Figure 45.

a)



b)

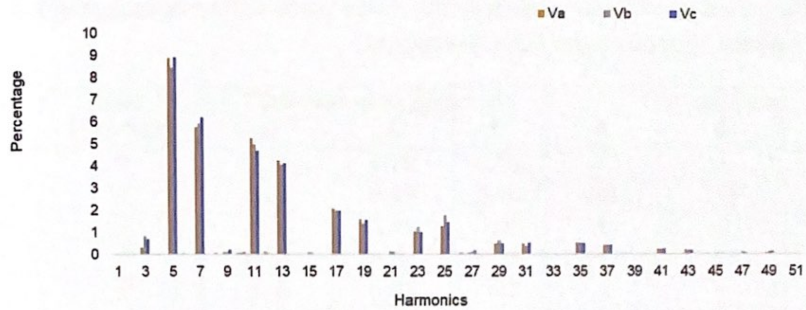


Figure 44. Measurement full load and without compensator, a) voltage sine waveform, b) voltage harmonics

a)

b)

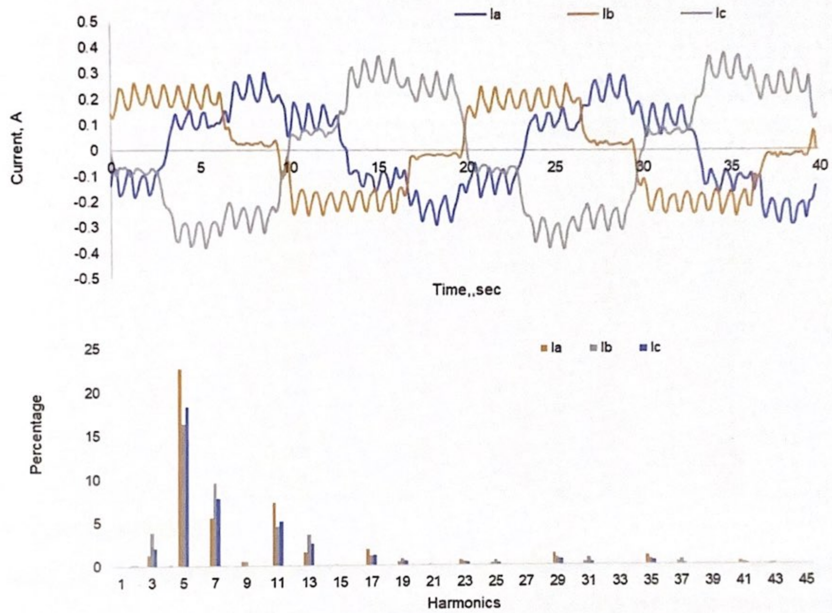


Figure 45. Measurement full load and without compensator, a) current sine waveform, b) current harmonics

Based on Figure 44-Figure 45, the voltage sine waveform appears to be not normal, and the specific harmonics (3, 5, 11, 13, 17, 23, 25, and 29) are more the limits specified by the MNS1778:2007 standards. This value exceeds the threshold set by the IEEE STD 519-1992 standard, indicating that it is excessively high and does not meet the required criteria.

The measurements of individual harmonic distortions, both without being divided by three, with and without a compensator, were conducted when the induction furnace was fully loaded, as presented in Table 12 and Table 13.

Similarly, the measurements of individual harmonic distortions, divided by three, without a compensator, were taken when the induction furnace was unloaded, as indicated in Table 14and Table 15*Table 7*.

Table 12. Comparation of individual harmonic distortion not divided be three without compensator full loads (voltage measurement)

Harmonics	MNS 1778:2007	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
5	6	5.52	4.79	5.83	1	1	1
7	5	5.03	5.60	5.44	(0)	(0)	(0)
11	3.5	2.16	1.97	2.40	1	1	1
13	3	0.75	0.89	0.75	1	1	1
17	2	0.46	0.40	0.47	1	1	1
19	1.5	0.24	0.29	0.22	1	1	1
23	1.5	0.18	0.14	0.17	1	1	1
25	1.5	0.10	0.13	0.09	1	1	1
29	1.3	0.08	0.05	0.07	1	1	1

1-Satisified; (0) – Unsatisfied.

Table 13. Comparation of individual harmonic distortion not divided be three without compensator full loads (current measurement)

Harmonics	IEEE STD 519:2014	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
5	4	22.70	16.36	18.37	(0)	(0)	(0)
7	4	5.60	9.60	7.86	(0)	(0)	(0)
11	2	7.33	4.55	5.12	(0)	(0)	(0)
13	2	1.59	3.63	2.56	1	(0)	(0)
17	1.5	1.94	1.12	1.19	(0)	1	1
19	1.5	0.44	0.79	0.57	1	1	1
23	0.6	0.65	0.44	0.34	(0)	1	1
25	0.6	0.32	0.66	0.30	1	(0)	1
29	0.6	1.41	0.88	0.75	(0)	(0)	(0)

1-Satisified; (0) – Unsatisfied.

Table 14. Comparation of individual harmonic distortion divided be three without compensator full loads (voltage measurement)

Harmonics	MNS 1778:2007	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
3	6	0.32	3.91	2.11	1	1	1
9	5	0.13	0.52	0.13	1	1	1
15	3.5	0.05	0.11	0.07	1	1	1
21	3	0.05	0.10	0.05	1	1	1
27	2	0.08	0.13	0.06	1	1	1
33	1.5	0.03	0.05	0.04	1	1	1
39	1.5	0.00	0.01	0.00	1	1	1
45	1.5	0.01	0.05	0.02	1	1	1
51	1.3	0.03	0.07	0.03	1	1	1

1-Satisified; (0) – Unsatisfied.

Table 15. Comparation of individual harmonic distortion divided be three without compensator full loads (current measurement)

Harmonics	IEEE STD 519:2014	Total harmonic distortion			Comparations		
		A	B	C	A	C	B
3	4	1.32	3.91	2.11	1	1	1
9	4	0.51	0.52	0.13	1	1	1
15	2	0.21	0.11	0.07	1	1	1
21	2	0.16	0.10	0.05	1	1	1
27	1.5	0.05	0.13	0.06	1	1	1
33	1.5	0.05	0.05	0.04	1	1	1
39	0.6	0.01	0.01	0.00	1	1	1
45	0.6	0.03	0.05	0.02	1	1	1
51	0.6	0.08	0.07	0.03	1	1	1

1-Satisified; (0) – Unsatisfied.

5.3. Conclusion of chapter five

The power system dynamic simulation results focused on analyzing the harmonic behavior based on load measurements from two different sources: electric motors and an induction furnace. This conclusion summarizes the findings and comparisons made for unloaded and fully loaded scenarios without a compensator.

For the induction furnace without a load, it was observed that the voltage waveform appeared normal, while the current waveform exhibited severe distortion. The 3rd harmonic of the current exceeded the threshold specified by the IEEE STD 519-2014 standard, indicating unsatisfactory performance. However, when introducing a compensator, the voltage and current waveforms improved, and all harmonics complied with the standards.

Comparisons of individual harmonic distortions were conducted for unloaded and fully loaded conditions, considering harmonics divided and not divided by three. When a compensator was present, all harmonic distortions satisfied the standards. Some harmonics exceeded the specified limits without a compensator, particularly at full load.

Discussion:

The analysis of the induction furnace data revealed the detrimental effects of non-linear loads on power quality. The presence of high harmonics in both voltage and current waveforms can lead to several issues, such as overcurrent protection triggers, harmonic resonance, damage to capacitor banks, transformer core overheating, cable insulation degradation, reduced equipment lifespan, motor stator winding burnout, overloaded neutrals, and generator damage.

The measurements demonstrated that introducing a compensator significantly improved power quality, reducing harmonic distortions and bringing the waveforms within acceptable limits. However, without a compensator, the induction furnace operation at full load resulted in higher harmonic distortions, indicating the need for mitigation measures. The comparison of individual harmonic distortions revealed that most harmonic components satisfied the relevant standards when a compensator was present. However, some harmonics exceeded the limits without a compensator, especially under full load conditions. These findings emphasize the importance of compensators or other corrective measures to mitigate harmonic distortions and ensure compliance with power quality standards.

It is crucial to note that the results obtained from dynamic simulations provide valuable insights into power system behavior and power quality issues. However, they should be complemented with real-world measurements and assessments to validate the simulation results and ensure practical implementation.

In conclusion, the power system dynamic simulation results highlight the impact of non-linear loads, such as induction furnaces, on power quality. The introduction of compensators can significantly improve power quality by reducing harmonic distortions. The comparison of harmonic distortions underscores the importance of mitigating measures to ensure compliance with power quality standards, particularly under full load conditions. Real-world measurements and assessments are essential for validating simulation results and guiding the implementation of effective power quality improvement strategies.

CONCLUSION AND FUTURE WORKS

The dynamic model of electric power quality monitoring has proven to be a valuable and effective tool for ensuring the reliable operation of electrical systems. Its versatility, user-friendly nature, and high level of accuracy make it an indispensable asset for researchers and technicians in the field of electrical engineering.

The development of a dynamic simulation model using MATLAB Simulink, based on real-time data from existing power systems, has been a significant focus of this research. The study has specifically examined power quality characteristics in various load scenarios, such as processing plants and the manufacturing of steel balls and melting furnaces, using the dynamic simulation model for analysis and comparison. Through this research, it has been discovered that the levels of odd harmonics, when not divided by three, exceed the allowable limits specified in the MNS 1778-2007 standard. Consequently, future research should focus on the development of filters tailored to specific loads in order to address this issue effectively.

1. Negative Sequence Harmonics (e.g., 5th, 11th): The most significant effect of these harmonics is that they produce a counter torque in induction motors, causing them to overheat and reduce efficiency. These harmonics can also cause malfunctions in power electronic devices and protection relay malfunctions and contribute to the creation of audible noise (humming) in transformers and motors.
2. Positive Sequence Harmonics (e.g., 7th, 13th): These harmonics can result in the saturation of transformers, causing them to overheat. The seventh harmonic, for example, can have a detrimental impact on capacitor banks, as it may cause resonance, leading to high voltages and currents, overheating, and potential failure. Negative and positive sequence harmonics can cause power electronic devices and protection relay malfunctions.

In general, all harmonic distortions can lead to a decrease in the power factor, increased energy losses in the distribution system, and increased operational costs. They interfere with the operation of sensitive electronic equipment and cause communication errors in data transmission systems. In addition, power quality issues related to harmonics lead to premature equipment failure and increased maintenance costs. Therefore, various methods are used to mitigate these harmonics, including passive filters, active filters, hybrid filters and careful system design and operation to avoid resonance conditions. The result is to reduce the harmonic distortion to acceptable levels to maintain the quality and reliability of the power system. The identified need for load-dependent filters serves as a direction for future research endeavors in the field of power quality.

By developing and implementing such filters, it will be possible to mitigate the excessive odd harmonics and ensure compliance with relevant standards.

APPENDIX: MAIN SCRIPT CODES

```
function varargout = all_Switch(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @all_Switch_OpeningFcn, ...
                   'gui_OutputFcn',  @all_Switch_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
function all_Switch_OpeningFcn(hObject, eventdata, handles, varargin)
clc;
axes(handles.axes1);
imshow('erdenet.png');
handles.output = hObject;
guidata(hObject, handles);
axes(handles.axes10);
imshow('Annotation.png');
handles.output = hObject;
guidata(hObject, handles);
function varargout = all_Switch_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;
function pushbutton1_Callback(hObject, eventdata, handles)
open_system('GuidelHuchdelNegtegsenMODEL');
sim('GuidelHuchdelNegtegsenMODEL.mdl');
function pushbutton_startstop_Callback(hObject, eventdata, handles)
myAB=get(hObject,'String');
tuluv=get_param(bdroot,'simulationstatus');
if strcmp(myAB,'Start Simulation')
    if strcmp(tuluv,'stopped')
    set_param(bdroot,'simulationcommand','start')
    end
    set(handles.pushbutton_startstop,'String','Stop Simulation');
elseif strcmp(myAB,'Stop Simulation')
    if strcmp(tuluv,'running')
        set_param(bdroot,'simulationcommand','stop')
    end
    set(handles.pushbutton_startstop,'String','Start Simulation');
end
function checkbox_switch_Callback(hObject, eventdata, handles)
sw_value=get(hObject,'Value');
if sw_value==0
    set_param([bdroot '/Manual Switch17'], 'sw','0')%Manual Switch17
else
    set_param([bdroot '/Manual Switch17'],'sw','1')%
end
```

```
assignin('base','startstop_hObject',handles.checkbox_switch)
function slider_Gain_Callback(hObject, eventdata, handles)
slider_AB=get(hObject,'Value');
Val=num2str(slider_AB*20-10);
set_param([bdroot '/Gain'],'Gain',Val);
set(handles.edit_Gain,'String',Val);
tuluv=get_param(bdroot,'simulationstatus');
if strcmp(tuluv,'running')
   set_param(bdroot,'simulationcommand','update');
end
function slider_Gain_CreateFcn(hObject, eventdata, handles)
if isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor',[.9 .9 .9]);
end
function edit_Gain_Callback(hObject, eventdata, handles)
function edit_Gain_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
function checkbox2_Callback(hObject, eventdata, handles)
sw_value=get(hObject,'Value');
if sw_value==0
   set_param([bdroot '/Manual Switch2'], 'sw','0')%BUGD&SondgoiTegsh+
   set_param([bdroot '/Manual Switch10'], 'sw','0')%BUGD&SondgoiTegsh+
   set_param([bdroot '/Manual Switch6'], 'sw','0')%Huchdel
   set_param([bdroot '/Manual Switch12'], 'sw','0')%Huchdel
else
   set_param([bdroot '/Manual Switch2'],'sw','1')%
   set_param([bdroot '/Manual Switch10'],'sw','1')%
   set_param([bdroot '/Manual Switch6'],'sw','1')%
   set_param([bdroot '/Manual Switch12'],'sw','1')%
end
assignin('base','startstop_hObject',handles.checkbox2)
function checkbox3_Callback(hObject, eventdata, handles)
sw_value=get(hObject,'Value');
if sw_value==0
   set_param([bdroot '/Manual Switch1'], 'sw','0')%Tegsh&Sondgoi+
   set_param([bdroot '/Manual Switch9'], 'sw','0')%Tegsh&Sondgoi+
   set_param([bdroot '/Manual Switch5'], 'sw','0')%Huchdel
   set_param([bdroot '/Manual Switch15'], 'sw','0')%Huchdel
else
   set_param([bdroot '/Manual Switch1'],'sw','1')%
   set_param([bdroot '/Manual Switch9'],'sw','1')%
   set_param([bdroot '/Manual Switch5'],'sw','1')%
   set_param([bdroot '/Manual Switch15'],'sw','1')%
end
assignin('base','startstop_hObject',handles.checkbox3)
function pushbutton3_Callback(hObject, eventdata, handles)
f0=50;assignin('base','f0',f0);
dv=10000;R=50*10^3; assignin('base','dv',dv);
C=1/(2*pi*R*f0);T=R*C; assignin('base','T',T);
data=load('ALAMO_Harmonics.txt'); assignin('base','data',data);
irms=data(1,1:3);assignin('base','irms',irms);
vrms=data(1,4:6);assignin('base','vrms',vrms);
I1harmonics=data(2:50,1)';assignin('base','I1harmonics',I1harmonics);
I2harmonics=data(2:50,2)';assignin('base','I2harmonics',I2harmonics);
I3harmonics=data(2:50,3)';assignin('base','I3harmonics',I3harmonics);
V1harmonics=data(2:50,4)';assignin('base','V1harmonics',V1harmonics);
V2harmonics=data(2:50,5)';assignin('base','V2harmonics',V2harmonics);
V3harmonics=data(2:50,6)';assignin('base','V3harmonics',V3harmonics);
```

```
THDIrms=[2.96,3.73,3.44];assignin('base','THDIrms',THDIrms);
THDVrms=[1.7,1.8,2.1];assignin('base','THDVrms',THDVrms);
function pushbutton4_Callback(hObject, eventdata, handles)
cla(handles.axes2);cla(handles.axes3);cla(handles.axes6);
cla(handles.axes4);cla(handles.axes5);cla(handles.axes8);
function checkbox4_Callback(hObject, eventdata, handles)
sw_value=get(hObject,'Value');
if sw_value==0
   set_param([bdroot '/Manual Switch'], 'sw','0')%Tegsh&Sondgoi+
   set_param([bdroot '/Manual Switch8'], 'sw','0')%Tegsh&Sondgoi+
   set_param([bdroot '/Manual Switch4'], 'sw','0')%Huchdel
   set_param([bdroot '/Manual Switch14'], 'sw','0')%Huchdel
else
   set_param([bdroot '/Manual Switch'],'sw','1')%
   set_param([bdroot '/Manual Switch8'],'sw','1')%
   set_param([bdroot '/Manual Switch4'],'sw','1')%
   set_param([bdroot '/Manual Switch14'],'sw','1')%
end
assignin('base','startstop_hObject',handles.checkbox4)
function checkbox5_Callback(hObject, eventdata, handles)
function checkbox6_Callback(hObject, eventdata, handles)
function checkbox7_Callback(hObject, eventdata, handles)
function checkbox8_Callback(hObject, eventdata, handles)
function checkbox9_Callback(hObject, eventdata, handles)
function checkbox10_Callback(hObject, eventdata, handles)
function pushbutton6_Callback(hObject, eventdata, handles)
dataFFT=load('ALAMO_FFT.txt'); assignin('base','dataFFT',dataFFT);
i1= [dataFFT(:,1)  dataFFT(:,2)];assignin('base','i1',i1);
i2= [dataFFT(:,1)  dataFFT(:,3)];assignin('base','i2',i2);
i3= [dataFFT(:,1)  dataFFT(:,4)];assignin('base','i3',i3);
v1= [dataFFT(:,1)  dataFFT(:,5)];assignin('base','v1',v1);
v2= [dataFFT(:,1)  dataFFT(:,6)];assignin('base','v2',v2);
v3= [dataFFT(:,1)  dataFFT(:,7)];assignin('base','v3',v3);
HorLimI=1500; assignin('base','HorLimI',HorLimI);

axes(handles.axes2);
plot(i1(:,1),i1(:,2),'y');
title('Guidel A phase');
axis([0 HorLimI 0 inf]); box off;

axes(handles.axes3);
plot(i2(:,1),i2(:,2),'g');
title('Guidel B phase');
axis([0 HorLimI 0 inf]); box off;

axes(handles.axes6);
plot(i3(:,1),i3(:,2),'r');
title('Guidel C phase');
axis([0 HorLimI 0 inf]); box off;

axes(handles.axes4);
plot(v1(:,1),v1(:,2),'y');
title('Huchdel A phase');
axis([0 HorLimI 0 inf]); box off;

axes(handles.axes5);
plot(v2(:,1),v2(:,2),'g');
title('Huchdel B phase');
axis([0 HorLimI 0 inf]); box off;
```

```
axes(handles.axes8);
plot(v3(:,1),v3(:,2),'r');
title('Huchdel C phase');
axis([0 HorLimI 0 inf]); box off;

function pushbutton7_Callback(hObject, eventdata, handles)
function pushbutton9_Callback(hObject, eventdata, handles)
function pushbutton8_Callback(hObject, eventdata, handles)
function checkbox14_Callback(hObject, eventdata, handles)
sw_value=get(hObject,'Value');
if sw_value==0
   set_param([bdroot '/Manual Switch10'], 'sw','0')%Manual Switch17
else
   set_param([bdroot '/Manual Switch10'],'sw','1')%
end
assignin('base','startstop_hObject',handles.checkbox14)
function checkbox15_Callback(hObject, eventdata, handles)
function checkbox16_Callback(hObject, eventdata, handles)
function checkbox17_Callback(hObject, eventdata, handles)
function checkbox18_Callback(hObject, eventdata, handles)
function checkbox19_Callback(hObject, eventdata, handles)
function checkbox11_Callback(hObject, eventdata, handles)
function checkbox12_Callback(hObject, eventdata, handles)
function checkbox13_Callback(hObject, eventdata, handles)
function edit3_Callback(hObject, eventdata, handles)
function edit3_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
function edit4_Callback(hObject, eventdata, handles)
function edit4_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit5_Callback(hObject, eventdata, handles)
function edit5_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit6_Callback(hObject, eventdata, handles)
function edit6_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit12_Callback(hObject, eventdata, handles)
function edit12_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit11_Callback(hObject, eventdata, handles)
function edit11_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
```

```
function edit10_Callback(hObject, eventdata, handles)
function edit10_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit7_Callback(hObject, eventdata, handles)
function edit7_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit8_Callback(hObject, eventdata, handles)
function edit8_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit9_Callback(hObject, eventdata, handles)
function edit9_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit40_Callback(hObject, eventdata, handles)
function edit40_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit39_Callback(hObject, eventdata, handles)
function edit39_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit38_Callback(hObject, eventdata, handles)
function edit38_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit34_Callback(hObject, eventdata, handles)
function edit34_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit33_Callback(hObject, eventdata, handles)
function edit33_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit32_Callback(hObject, eventdata, handles)
function edit32_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function edit16_Callback(hObject, eventdata, handles)
function edit16_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit15_Callback(hObject, eventdata, handles)
function edit15_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit14_Callback(hObject, eventdata, handles)
function edit14_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit22_Callback(hObject, eventdata, handles)
function edit22_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit21_Callback(hObject, eventdata, handles)
function edit21_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit20_Callback(hObject, eventdata, handles)
function edit20_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit28_Callback(hObject, eventdata, handles)
function edit28_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit27_Callback(hObject, eventdata, handles)
function edit27_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit26_Callback(hObject, eventdata, handles)
function edit26_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit17_Callback(hObject, eventdata, handles)
function edit17_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function edit18_Callback(hObject, eventdata, handles)
function edit18_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit19_Callback(hObject, eventdata, handles)
function edit19_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit23_Callback(hObject, eventdata, handles)
function edit23_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit24_Callback(hObject, eventdata, handles)
function edit24_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit25_Callback(hObject, eventdata, handles)
function edit25_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit29_Callback(hObject, eventdata, handles)
function edit29_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit30_Callback(hObject, eventdata, handles)
function edit30_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit31_Callback(hObject, eventdata, handles)
function edit31_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit35_Callback(hObject, eventdata, handles)
function edit35_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit36_Callback(hObject, eventdata, handles)
function edit36_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function edit37_Callback(hObject, eventdata, handles)
function edit37_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit41_Callback(hObject, eventdata, handles)
function edit41_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit42_Callback(hObject, eventdata, handles)
function edit42_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit43_Callback(hObject, eventdata, handles)
function edit43_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit52_Callback(hObject, eventdata, handles)
function edit52_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit51_Callback(hObject, eventdata, handles)
function edit51_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit50_Callback(hObject, eventdata, handles)
function edit50_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit47_Callback(hObject, eventdata, handles)
function edit47_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit48_Callback(hObject, eventdata, handles)
function edit48_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit49_Callback(hObject, eventdata, handles)
unction edit49_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
```

```
function edit46_Callback(hObject, eventdata, handles)
function edit46_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit45_Callback(hObject, eventdata, handles)
function edit45_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit44_Callback(hObject, eventdata, handles)
function edit44_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function checkbox20_Callback(hObject, eventdata, handles)
sw_value=get(hObject,'Value');
if sw_value==0
   set_param([bdroot '/Manual Switch3'], 'sw','0')%Tegsh&Sondgoi+
   set_param([bdroot '/Manual Switch11'], 'sw','0')%Tegsh&Sondgoi+
   set_param([bdroot '/Manual Switch7'], 'sw','0')%Huchdel
   set_param([bdroot '/Manual Switch13'], 'sw','0')%Huchdel
else
   set_param([bdroot '/Manual Switch3'],'sw','1')%
   set_param([bdroot '/Manual Switch11'],'sw','1')%
   set_param([bdroot '/Manual Switch7'],'sw','1')%
   set_param([bdroot '/Manual Switch13'],'sw','1')%
end
assignin('base','startstop_hObject',handles.checkbox20)
function checkbox21_Callback(hObject, eventdata, handles)
function checkbox22_Callback(hObject, eventdata, handles)
function checkbox23_Callback(hObject, eventdata, handles)
function edit53_Callback(hObject, eventdata, handles)
function edit53_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit54_Callback(hObject, eventdata, handles)
function edit54_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit55_Callback(hObject, eventdata, handles)
function edit55_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function pushbutton10_Callback(hObject, eventdata, handles)
data=load('ALAMO_Harmonics.txt'); assignin('base','data',data);
I1hms=data(2:50,1)';assignin('base','I1hms',I1hms);
I2hms=data(2:50,2)';assignin('base','I2hms',I2hms);
I3hms=data(2:50,3)';assignin('base','I3hms',I3hms);
V1hms=data(2:50,4)';assignin('base','I1hms',V1hms);
```

```
V2hms=data(2:50,5)';assignin('base','I2hms',V2hms);
V3hms=data(2:50,6)';assignin('base','I3hms',V3hms);
HorLimH=50; assignin('base','HorLimH',HorLimH);

axes(handles.axes2);bar(I1hms,'y');title('Guidel A phase');axis([0 HorLimH 0 inf]); box off;
axes(handles.axes3);bar(I2hms,'g');title('Guidel B phase');axis([0 HorLimH 0 inf]); box off;
axes(handles.axes6);bar(I3hms,'r');title('Guidel C phase');axis([0 HorLimH 0 inf]); box off;

axes(handles.axes4);bar(V1hms,'y');title('Huchdel A phase');axis([0 HorLimH 0 inf]); box off;
axes(handles.axes5);bar(V2hms,'g');title('Huchdel B phase');axis([0 HorLimH 0 inf]); box off;
axes(handles.axes8);bar(V3hms,'r');title('Huchdel C phase');axis([0 HorLimH 0 inf]); box off;

function edit71_Callback(hObject, eventdata, handles)
function edit71_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit72_Callback(hObject, eventdata, handles)
function edit72_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit73_Callback(hObject, eventdata, handles)
function edit73_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit68_Callback(hObject, eventdata, handles)
function edit68_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit69_Callback(hObject, eventdata, handles)
function edit69_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit70_Callback(hObject, eventdata, handles)
function edit70_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function pushbutton11_Callback(hObject, eventdata, handles)
dataFFT=load('ALAMO_FFT.txt'); assignin('base','dataFFT',dataFFT);
i1= [dataFFT(:,1)  dataFFT(:,2)];assignin('base','i1',i1);
i2= [dataFFT(:,1)  dataFFT(:,3)];assignin('base','i2',i2);
i3= [dataFFT(:,1)  dataFFT(:,4)];assignin('base','i3',i3);
v1= [dataFFT(:,1)  dataFFT(:,5)];assignin('base','v1',v1);
v2= [dataFFT(:,1)  dataFFT(:,6)];assignin('base','v2',v2);
v3= [dataFFT(:,1)  dataFFT(:,7)];assignin('base','v3',v3);

HorLimBig=1500; assignin('base','HorLimBig',HorLimBig);
```

```
VerLimBig=50; assignin('base','VerLimBig',VerLimBig);

axes(handles.axes2);
plot(i1(:,1),i1(:,2),'y');
title('Guidel A phase');
axis([0 HorLimBig 0 VerLimBig]); box off;

axes(handles.axes3);
plot(i2(:,1),i2(:,2),'g');
title('Guidel B phase');
axis([0 HorLimBig 0 VerLimBig]); box off;

axes(handles.axes6);
plot(i3(:,1),i3(:,2),'r');
title('Guidel C phase');
axis([0 HorLimBig 0 VerLimBig]); box off;

axes(handles.axes4);
plot(v1(:,1),v1(:,2),'y');
title('Huchdel A phase');
axis([0 HorLimBig 0 VerLimBig]); box off;

axes(handles.axes5);
plot(v2(:,1),v2(:,2),'g');
title('Huchdel B phase');
axis([0 HorLimBig 0 VerLimBig]); box off;

axes(handles.axes8);
plot(v3(:,1),v3(:,2),'r');
title('Huchdel C phase');
axis([0 HorLimBig 0 VerLimBig]); box off;

function pushbutton12_Callback(hObject, eventdata, handles)
data=load('ALAMO_Harmonics.txt'); assignin('base','data',data);
THDIrms=[32.31,32.28,32.26];assignin('base','THDIrms',THDIrms);
THDVrms=[1.8,2.0,2.0];assignin('base','data',THDVrms);
set(handles.edit10,'String',num2str(THDVrms(1)));
set(handles.edit11,'String',num2str(THDVrms(2)));
set(handles.edit12,'String',num2str(THDVrms(3)));
set(handles.edit26,'String',num2str(data(3,4)));
set(handles.edit27,'String',num2str(data(3,5)));
set(handles.edit28,'String',num2str(data(3,6)));
set(handles.edit46,'String',num2str(data(5,4)));
set(handles.edit44,'String',num2str(data(5,5)));
set(handles.edit45,'String',num2str(data(5,6)));
set(handles.edit14,'String',num2str(data(9,4)));
set(handles.edit15,'String',num2str(data(9,5)));
set(handles.edit16,'String',num2str(data(9,6)));
set(handles.edit47,'String',num2str(data(7,4)));
set(handles.edit49,'String',num2str(data(7,5)));
set(handles.edit48,'String',num2str(data(7,6)));
set(handles.edit53,'String',num2str(data(15,4)));
set(handles.edit54,'String',num2str(data(15,5)));
set(handles.edit55,'String',num2str(data(15,6)));
set(handles.edit50,'String',num2str(data(11,4)));
set(handles.edit51,'String',num2str(data(11,5)));
set(handles.edit52,'String',num2str(data(11,6)));
set(handles.edit77,'String',num2str(data(13,4)));
set(handles.edit78,'String',num2str(data(13,5)));
```

```
set(handles.edit79,'String',num2str(data(13,6)));
set(handles.edit82,'String',num2str(data(17,4)));
set(handles.edit81,'String',num2str(data(17,5)));
set(handles.edit80,'String',num2str(data(17,6)));
set(handles.edit83,'String',num2str(data(19,4)));
set(handles.edit84,'String',num2str(data(19,5)));
set(handles.edit85,'String',num2str(data(19,6)));
set(handles.edit74,'String',num2str(data(21,4)));
set(handles.edit75,'String',num2str(data(21,5)));
set(handles.edit76,'String',num2str(data(21,6)));

function edit76_Callback(hObject, eventdata, handles)
function edit76_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit75_Callback(hObject, eventdata, handles)
function edit75_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit74_Callback(hObject, eventdata, handles)
function edit74_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit85_Callback(hObject, eventdata, handles)
function edit85_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit84_Callback(hObject, eventdata, handles)
function edit84_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit83_Callback(hObject, eventdata, handles)
function edit83_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit82_Callback(hObject, eventdata, handles)
function edit82_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit81_Callback(hObject, eventdata, handles)
function edit81_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function edit80_Callback(hObject, eventdata, handles)
function edit80_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit79_Callback(hObject, eventdata, handles)
function edit79_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit78_Callback(hObject, eventdata, handles)
function edit78_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit77_Callback(hObject, eventdata, handles)
function edit77_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function pushbutton13_Callback(hObject, eventdata, handles)
data=load('ALAMO_Harmonics.txt'); assignin('base','data',data);
THDIrms=[32.31,32.28,32.26];assignin('base','THDIrms',THDIrms);
THDVrms=[1.8,2.0,2.0];assignin('base','data',THDVrms);
set(handles.edit10,'String',num2str(THDIrms(1)));
set(handles.edit11,'String',num2str(THDIrms(2)));
set(handles.edit12,'String',num2str(THDIrms(3)));
set(handles.edit26,'String',num2str(data(3,1)));
set(handles.edit27,'String',num2str(data(3,2)));
set(handles.edit28,'String',num2str(data(3,3)));
set(handles.edit46,'String',num2str(data(5,1)));
set(handles.edit44,'String',num2str(data(5,2)));
set(handles.edit45,'String',num2str(data(5,3)));
set(handles.edit14,'String',num2str(data(9,1)));
set(handles.edit15,'String',num2str(data(9,2)));
set(handles.edit16,'String',num2str(data(9,3)));
set(handles.edit47,'String',num2str(data(7,1)));
set(handles.edit49,'String',num2str(data(7,2)));
set(handles.edit48,'String',num2str(data(7,3)));
set(handles.edit53,'String',num2str(data(15,1)));
set(handles.edit54,'String',num2str(data(15,2)));
set(handles.edit55,'String',num2str(data(15,3)));
set(handles.edit50,'String',num2str(data(11,1)));
set(handles.edit51,'String',num2str(data(11,2)));
set(handles.edit52,'String',num2str(data(11,3)));
set(handles.edit77,'String',num2str(data(13,1)));
set(handles.edit78,'String',num2str(data(13,2)));
set(handles.edit79,'String',num2str(data(13,3)));
set(handles.edit82,'String',num2str(data(17,1)));
set(handles.edit81,'String',num2str(data(17,2)));
set(handles.edit80,'String',num2str(data(17,3)));
set(handles.edit83,'String',num2str(data(19,1)));
set(handles.edit84,'String',num2str(data(19,2)));
set(handles.edit85,'String',num2str(data(19,3)));
set(handles.edit74,'String',num2str(data(21,1)));
set(handles.edit75,'String',num2str(data(21,2)));
set(handles.edit76,'String',num2str(data(21,3)));
```

```
unction pushbutton14_Callback(hObject, eventdata, handles)
et(handles.text13,'string','Huchdliin garmonic Standartad niitsehgui baina');
```

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