UDC 621.31
DOI: 10.15587/1729-4061.2023.292253

IDENTIFYING THE INFLUENCE OF THE SYSTEM AND MODE CHARACTERISTICS ON THE POWER LOSS MODE BASED IN 110 kV POWER GRIDS

Temirbolat Akimzhanov
Doctor PhD, Senior Lecturer, Chief Specialist
Department of State Standards
Kazakhstan Institute of Standardization and Metrology
Mangilik El ave., 11, Astana, Republic of Kazakhstan, 010000

Yermek Sarsikeyev
Doctor PhD, Senior Lecturer, Head of Department*

Assemgul Zhantlessova
Doctor PhD, Senior Lecturer*

Serik Zhumazhanov
Candidate of Technical Sciences, Senior Lecturer
Department of Electric Power Engineering
L. N. Gumilyov Eurasian National University
Satpayeva str., 2, Astana, Republic of Kazakhstan, 010008

Zhanibek Baydulla
Master Degree in Smart Grid and Demand Management, Energy Audit
Limited Liability Partnership «Energy on Track»
Abylai Khan str., 37, Astana, Republic of Kazakhstan, 010000

Bibigul Issabekova
Doctor PhD, Associate Professor**

Zhanat Issabekov
Doctor PhD, Associate Professor**

Ali Mekhtiyev
Candidate of Technical Sciences, Professor*

Yelena Neshina
Corresponding author
Candidate of Technical Sciences, Head of Department
Department of Energy Systems
Abylkas Saginov Karaganda Technical University
Nursultan Nazarbayev ave., 56, Karaganda, Republic of Kazakhstan, 100027
E-mail: 1_neg@mail.ru

*Department of Operating Electra Equipment
S. Seifullin Kazakh Agro Technical Research University
Zhenis ave., 62, Astana, Republic of Kazakhstan, 010011

*Faculty of Computer Science
Toraighyrov University
Lomov str., 64, Pavlodar, Republic of Kazakhstan, 140008

In this paper, the object of the research is 110 kV power grids of three regions of the Republic of Kazakhstan: Astana city, Turkestan region and Shymkent city, as well as West Kazakhstan region.

Operators of the studied power grids have no idea about the real levels of voltage and current sinusoidality distortion coefficients, as well as about their relationship with other regime and system parameters of power grids. Similar problems may be faced by other grid companies that do not have the appropriate information and measurement infrastructure to monitor the modes of power grids in terms of voltage and current sinusoidality distortion.

In the course of the present study, using portable three-phase power quantity and quality analyzers, it was possible to make daily measurements of mode parameters in 41 110 kV transmission lines with a length of 5 to 120 km.

The results of measurements showed that in Astana city, the voltage quality is at a satisfactory level, but the distortion coefficient of sinusoidality of current reaches 39 % (the average level for 15 studied lines is 13.3 %) due to the high concentration of non-linear load of consumers. In the South of Kazakhstan, the voltage and current sinusoidality distortion coefficients are relatively moderate, but voltage drops are frequent (sometimes up to 10 % or more) due to the large distance between load centers and relatively high population density. In the power grids of Western Kazakhstan, voltage and current sinusoidality distortion coefficients have high levels (reach 14 % and 70 %, respectively) due to low network load with a large length of transmission lines.

The analysis makes it possible to trace the relationship of voltage and current sinusoidality distortion coefficients with such regional characteristics as population density, nature of loads, power losses, voltage and current levels

Keywords: electrical measurements, power losses, harmonic distortions, electric power, energy efficiency

Received date 08.09.2023
Accepted date 20.11.2023
Published date 29.12.2023

***How to Cite:** Akimzhanov, T., Sarsikeyev, Y., Zhantlessova, A., Zhumazhanov, S., Baydulla, Z., Issabekova, B., Issabekov, Z., Mekhtiyev, A., Neshina, Y. (2023). Identifying the influence of the system and mode characteristics on the power loss mode based in 110 kV power grids. Eastern-European Journal of Enterprise Technologies, 6 (8 (126)), 6–14. doi: https://doi.org/10.15587/1729-4061.2023.292253*

1. Introduction

Continuous growth of the Earth's population and energy consumption causes an increase in anthropogenic greenhouse gas emissions. In its Sixth Assessment Report, the International Panel on Climate Change reported that humanity has reached the highest levels of greenhouse gas emissions. Specialists believe that the continuation of such dynamics of

CO_2 emissions growth will inevitably lead to changes in the Earth's climate system and accompanying natural cataclysms.

The importance of the problem of climate change due to greenhouse gas emissions is evidenced by the UNO Resolution «Transforming Our World: The 2030 Agenda for Sustainable Development», according to which UN member states have assumed obligations to ensure environmental protection, as well as the Paris Agreement aimed at keeping the global average temperature below pre-industrial levels.

An important direction in the pursuit of carbon neutrality is the conservation of electricity. The efficiency of electricity utilization is determined by the efficiency of all links of the technological chain preceding its consumption: search, exploration and production of energy raw materials – its conversion into electrical energy – delivery to consumers, which is accompanied by energy losses.

The city of Astana has a sharply continental climate, and variable frequency drives are used for effective control of heating and cooling systems. In addition, in the new part of the city there is a large amount of server equipment, which are also sources of higher current harmonics.

In recent decades, energy losses have been increasingly affected by the constant growth of nonlinear loads, primarily due to the increase in the share of power consumption by equipment for creating a comfortable microclimate. This causes an increase in the share of higher harmonic components of current and voltage in electrical networks. In addition to nonlinear loads, the sources of higher harmonics are nonlinearities of network elements and possible resonance modes of their operation. Higher current harmonics, in addition to reducing power quality, cause additional power losses. In order to develop methods to combat them, it is necessary to carry out targeted research into their nature in power grids.

2. Literature review and problem statement

In the paper [1], the problems of voltage and current higher harmonics in electric networks are considered. However, to date, engineers and scientists of the electric power industry have no idea about the real situation of this problem and whether it is worth paying attention to it. Since there are various methods of solution, which do not reveal the full picture of the influence of certain parameters on electrical energy losses.

The way to overcome these difficulties may be to conduct large-scale studies of non-sinusoidality of voltages and currents in electrical networks on 41 transmission lines with a nominal voltage of 110 kV and varying length from 5 to 120 km in three regions of the Republic of Kazakhstan: the city of Astana, Turkestan region and the city of Shymkent, West Kazakhstan region.

The paper [2] presents the research results for one region. All this suggests that it is advisable to conduct a study of the entire energy system of the Republic of Kazakhstan. One region is described, since it is difficult to explore all regions of the Republic of Kazakhstan due to long distances. The report [3, 4] shows that it is characterized by dependence on thermal power plants, which are often located far from the centers of consumption. This causes long distances of electricity transmission.

The paper [5] shows that the Republic of Kazakhstan is one of the largest suppliers of natural resources in the world due to its rich and easily accessible mineral resources. The work [6] shows that the country has a large number of energy-intensive enterprises, which include ferrous and non-ferrous metallurgy, energy resource extraction and other industrial enterprises. The paper [7, 8] presents the results of research on the scale of resource extraction, which are not without ultra-high losses and deterioration of power quality in power grids. In all these works, the effect of asymmetry on the loss of electrical energy was not considered, since this was not the goal of the authors.

According to the Republic of Kazakhstan Agency for Statistics [4], the level of electricity losses in the Republic of Kazakhstan in 2020 amounted to about 12.7 %, which is higher than the average for the countries of the European Union. There are several potential solutions to mitigate the problem of electricity losses in the power system of the Republic of Kazakhstan. The paper [9] shows that it is reasonable to invest in renewable energy sources, such as wind and solar power, which can generate electricity closer to consumption centers and reduce transmission distances. In the paper [10], a way to overcome these difficulties can be to improve the efficiency of existing transmission and distribution networks by modernizing equipment and implementing Smart Grid technologies.

In addition, one of the problems of electrical networks and systems is the presence of higher harmonic components of voltages and currents. Their sources in transit and distribution power grids are electrical receptors with nonlinear characteristics and nonlinearities of power grid elements. In the paper [8], the issues of combating higher harmonic components in power supply systems of large enterprises remained unresolved, higher harmonic components of current can penetrate into the electrical network due to inaccurate adjustment of filter compensating devices.

The research focused on revealing the influence of system and mode characteristics on the non-sinusoidality of voltages and currents in 110 kV electric networks represents a promising direction in the field of electric power engineering. Critical analysis of a number of cited sources emphasizes the relevance of this problem. These sources point to the importance of understanding the factors affecting power quality, especially in the context of the increasing use of electronic devices and non-linear loads.

Various studies in the electric power industry indicate an increase in non-sinusoidality in the voltages and currents of electrical networks. This fact calls for a more in-depth study of the factors contributing to such deviations from the sinusoidal shape of electrical parameters. Such analyses are an important step towards improving the energy efficiency and reliability of electric power systems in the context of modern power supply requirements. This will make it possible to develop effective methods of network and equipment management to minimize distortions and ensure stable power quality in 110 kV and higher networks.

All this allows us to assert that it is expedient to conduct a study on improving the efficiency and quality of electrical energy, reducing losses and harmonic distortions. This is crucial for ensuring the stability of the energy system of the Republic of Kazakhstan and increasing the competitiveness of its industrial sectors.

3. The aim and objectives of the study

The aim of the study is to identify the influence of changes in system and mode characteristics on the power loss mode based in 110 kV power grids. This will make it possible to increase the efficiency of electrical networks based on the results of evaluating the influence of power quality and regional factors on them.

To achieve this aim, the following objectives are accomplished:

– to carry out measurements of mode parameters in the investigated 110 kV electric networks;

– to process the obtained measurement results taking into account levels of voltages and currents, as well as the distortion coefficients of the sinusoidality of voltages and currents;

– to analyze the efficiency of modes of the power grids to give recommendations on how to improve them under the conditions of the factors affecting them.

4. Materials and methods

The object of the research is 110 kV power grids of three regions of the Republic of Kazakhstan: Astana city, South Kazakhstan region, and West Kazakhstan region.

The main hypothesis of the study is the correlation between system and mode characteristics within the 110 kV electrical networks and their impact on the non-sinusoidal nature of voltages and currents. This study intends to explore how specific system and operational attributes relate to deviations from sinusoidal behavior in electrical networks operating at 110 kV.

The measurements in the electrical networks were conducted using three-phase power quality analyzers, specifically the C.A.8335 and C.A.8336 models from the KATRU and Energy On Track company, as well as the Fluke 437-ii and Fluke 434-ii devices owned by KATRU and KazStandard.

The applied power quality analyzers were pre-calibrated at KazStandard using the Three-Phase Power Standard, which consists of the calibration system comprising Fluke 6135A, 6105A (6106A) with an accuracy class of 0.007, and the Zera COM 3003 [DC] comparator with an accuracy class of 0.01. These devices are shown in Fig. 1.

Fig. 1. Calibration process of the power quality analyzer in the Laboratory of Electric Power and Energy at the Republic of Kazakhstan Institute of Standardization and Metrology

The measurements of operating parameters were carried out at 110/35/10 kV substations, specifically in the measurement circuits of the 110 kV power transmission lines. The measurements were conducted continuously over a 24-hour period with a 1-minute interval (Fig. 2).

Assumptions adopted in the work when using the frequency characteristics of the overhead line allow us to understand the dependence of the input conductances of the phases of the line on the frequency of the applied voltage. This makes it possible to evaluate the influence of frequency characteristics of the line on the harmonic composition of the current, that is, you can get the mathematical expectation of the coefficients of harmonic components for each phase and, according to the results, plot the spectral composition of the input voltages and currents.

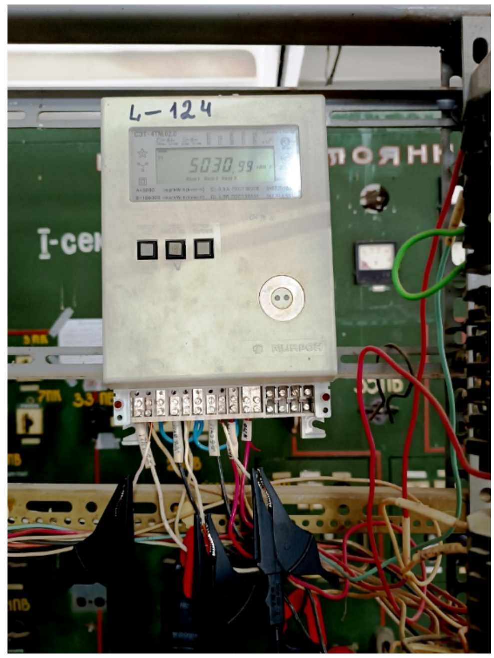

Fig. 2. Measurement of operating parameter connection of three-phase power quality analyzers to «L-124»

To solve the problems, the theory of matrix calculus, methods and techniques of mathematical modeling, methods of physical and computational experiments, comparison of survey results with the results of modeling were used.

The data of the overhead line parameters are initial for calculating the parameters of the system of telegraphic equations that allow calculating the change of voltages and currents along the length of the line [2].

The processing of experimental data is based on the concepts of probability theory and mathematical statistics. These include the concepts of the general population, sampling, empirical distribution function [2].

In the course of the study, various operating parameters were measured, but this paper focuses only on the voltage and current total harmonic distortions, as they succinctly provide an indication of the levels of higher harmonics [11, 12].

Measurement locations were selected based on such organizational and technical factors as the possibility of obtaining authorized access to the substation under study and the technical feasibility of connecting to the substation's measurement circuits.

The problems of ensuring proper quality and efficiency of electricity supply and functioning of the power grid were discussed with the engineering staff of the power grid companies.

Data on the length of transmission lines and levels of electricity losses were obtained directly from the administration of the power grid companies.

Understanding of the nature and levels of loads came as a result of many years of practical experience in energy auditing of various enterprises throughout the Republic of Kazakhstan.

Information on the territory of the surveyed regions and population density in them was taken from open sources on the Internet.

Processing of measurement results was carried out using MS Excel tabular processor. By means of generalization and visualization of the results of measurements of regime parameters, a direct analysis of distortion coefficients of sinusoidality of voltages and currents, as well as their relationship with the above-mentioned factors was carried out.

5. Results of research on total harmonic distortions of voltage and current in 110 kV electric networks

5. 1. Analysis of electric power losses based on instrumental measurements

The results of the study can be presented in the form of diagrams showing the minimum, average and maximum values of the distortion coefficients of sinusoidality of voltages and currents in the surveyed lines for a day, they clearly and concisely illustrate the levels of distortion that may be present in electrical grids.

As an example, Fig. 3 shows a daily plot of current total harmonic distortions in the phases of one of the investigated 110 kV transmission lines.

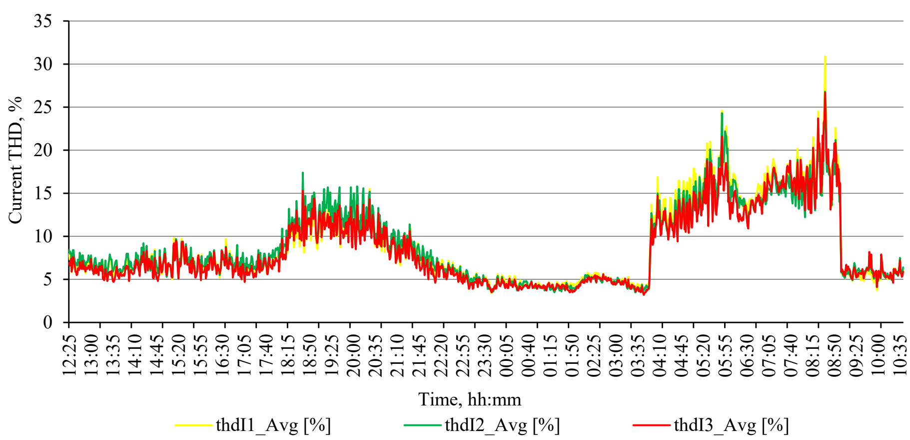

Fig. 3. Daily plot of current total harmonic distortion in one of the investigated 110 kV lines

Since the levels of current harmonic distortion are not regulated by any standards in the Republic of Kazakhstan, the method used to represent their levels in the investigated 110 kV lines was developed based on the objective of this paper, which is to assess the real situation with higher current harmonics in the 110 kV electrical networks of the Republic of Kazakhstan. Voltage harmonic distortions are presented in a similar manner, as it proved to be the most indicative.

Table 1 and Fig. 4 present the values of these indicators for the graph in Fig. 3, as well as the average daily current value.

In Fig. 4, the average value of the distortion coefficient k_{iavg} serves as a reference point to which most values during the day approach. The maximum value of k_{imax}=30.3 % in this case indicates a significant deviation from k_{iavg}=8.75 %, signaling an abnormal increase. In practice, it is often observed that the main reason for abnormally high levels of current distortion factors is low grid utilization. Thus, the average value of the current I_{avg}=23.13 A gives an indication of the network line loading.

Table 1

Data Representation for Diagram Generation

Line name	I_{avg}, A	k_{imax}, %	k_{iavg}, %	k_{imin}, %
L-124	23.13	30.3	8.75	3.2

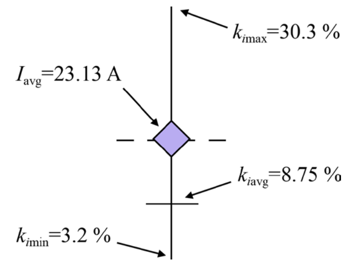

Fig. 4. Graphical illustration of Table 1

5. 2. Assessment of power quality in power grids

The values of the operating parameters in electrical networks depend on many interrelated system factors. Therefore, it is advisable to describe the electrical network under study and the nature of consumer loads.

Astana, the capital of the Republic of Kazakhstan, has a constantly evolving electrical network equipped with modern and efficient electrical equipment [13]. The network comprises 28 overhead and underground 110 kV lines, with a total length of 295 km. The lines experience a high degree of current loading. The city is home to numerous commercial and entertainment centers with modern climate control systems based on variable frequency drives, as well as a special economic zone hosting modern manufacturing facilities. This study covers 15 110 kV lines in the city (Fig. 5, 6).

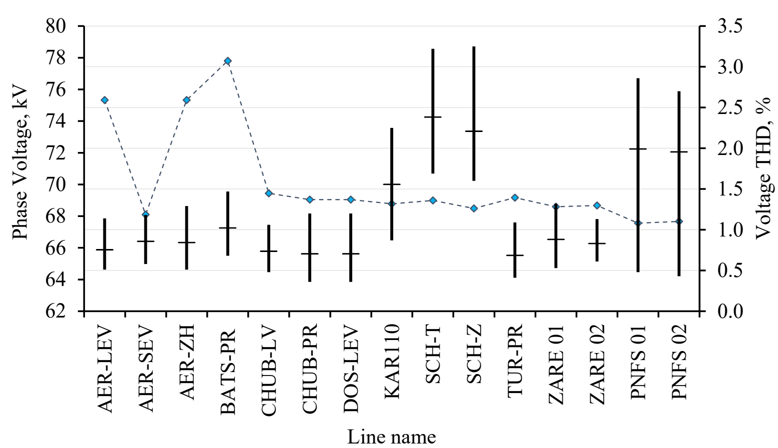

Fig. 5. Voltage harmonic distortion levels in the 110 kV electrical network of Astana

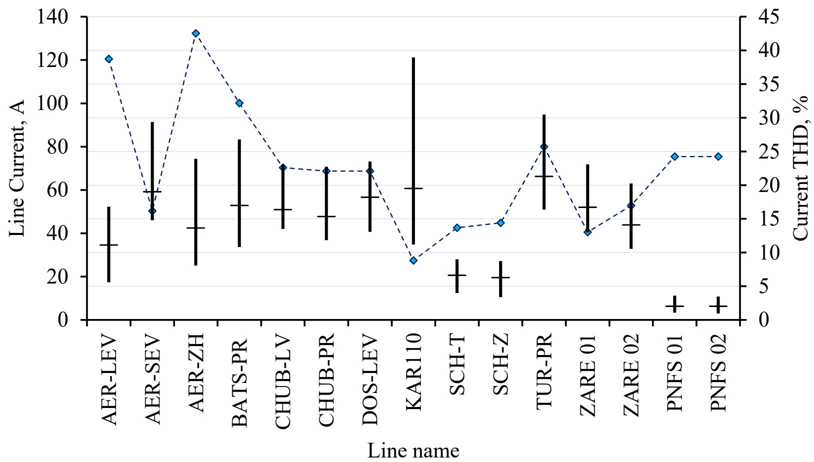

Fig. 6. Current harmonic distortion levels in the 110 kV electrical network of Astana

Under the «Astana» column, we can observe that high population density, electricity transmission volumes, and nonlinear loads contribute to a high level of current waveform distortion in the urban network.

South Kazakhstan Region. The electrical network of the Republic of Kazakhstan Southern Region is located in the area of 116,280 km^2, and electricity is supplied to remote areas through 70 overhead 110 kV power lines with a total length of 1,568 km. This region is characterized by high dynamics of development and population growth, which poses challenges in maintaining adequate voltage levels in remote areas. It is worth noting that the volume of transmitted electrical energy through these power grids increased by nearly 25 % during the period from 2017 to 2021. The main proportion of the load is residential, but there are also industrial consumers. This study covers 13 110 kV power lines (Fig. 7, 8).

The southern region experiences voltage drops and significant power losses due to relatively high population density and large distances between load centers and electricity generation.

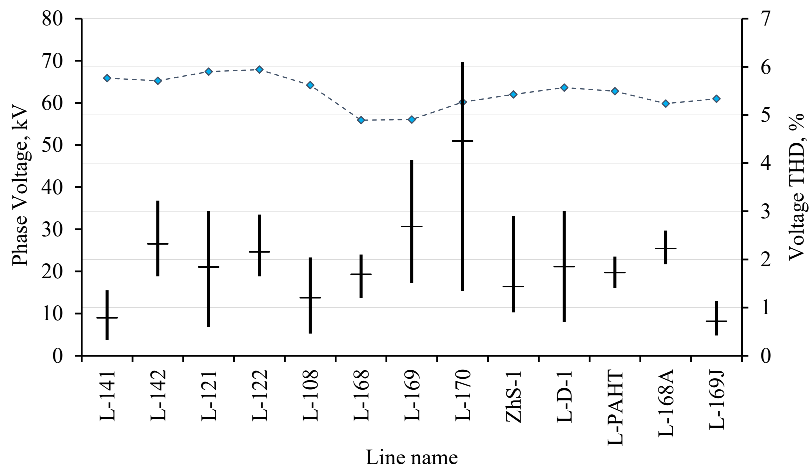

Fig. 7. Voltage harmonic distortion levels in the 110 kV electrical network of the South

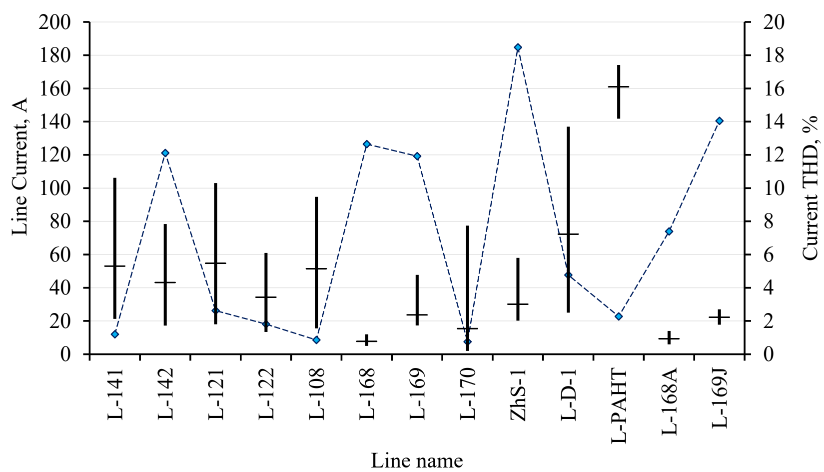

Fig. 8. Current harmonic distortion levels in the 110 kV electrical network of the South

West Kazakhstan region. The electrical network of this region is located on a vast area of 151,339 km^2, in which electricity is supplied by 67 110 kV overhead lines with a total circuit length of 2216 km. The network in this region experiences low congestion due to the sparse population density, and a subset of the 110 kV lines are operated at 35 kV. The load profile is a mix of industrial and residential. In the region, approximately 50 % of natural gas in the Republic of Kazakhstan is extracted, yet despite this, the electrical networks constantly face a deficit in the budget for modernization. In the course of the current study, measurements were conducted on 13 lines with a voltage of 110 kV (Fig. 9, 10).

The Western region is characterized by very low population density and extensive electricity transmission distances, resulting in low network loading and, consequently, relatively high levels of voltage and current waveform distortion.

5. 3. Analyzing the level of power losses in power grids

Table 2 presents the most significant characteristics of the investigated electrical networks. The data from Fig. 5–10 were averaged and also included in Table 2 for reference.

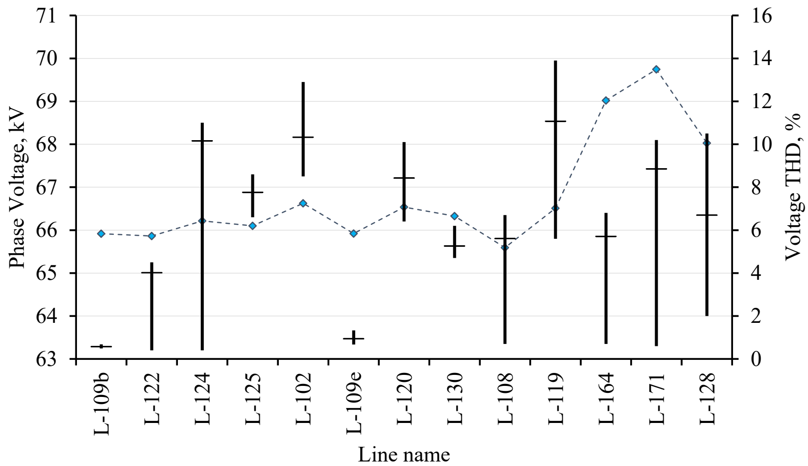

Fig. 9. Voltage harmonic distortion levels in the 110 kV electrical network of the West

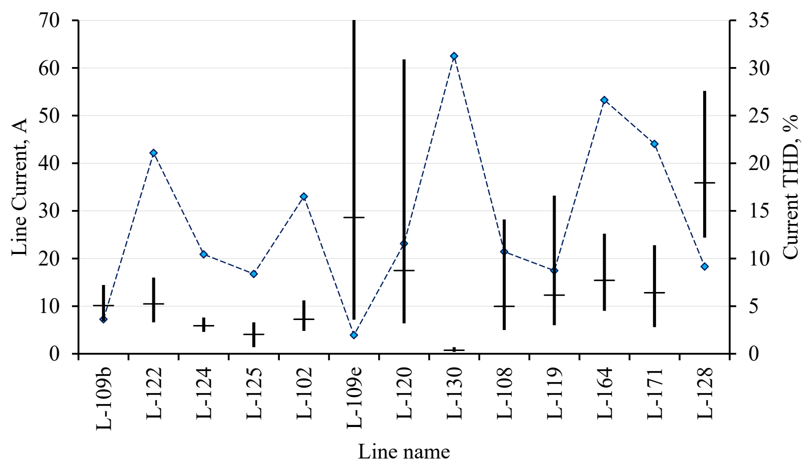

Fig. 10. Current harmonic distortion levels in the 110 kV electrical network of the West

Table 2

Characteristics of the Investigated Electrical Networks and Regions

Parameter	Regions		
	Astana	South Kazakhstan region	West Kazakhstan region
Year	2019	2021	2022
Region area, km^2	797	116,280	151,339
Population density in the region, people/km^2	1485.54	17.00	4.36
Total length of 110 kV lines, km	281.61	1,568.74	2,216.00
Volume of transmitted electricity per year, mln. kWh	3,813.61	3,796.15	1,220.38
Nature of loads	nonlinear	residential	industrial and residential
Electricity losses in the network, %	9.88	16.02	14.27
V_{avg}, kV	70.13	62.47	66.80
I_{avg}, A	69.99	69.92	28.02
k_{vavg}, %	1.21	1.93	6.57
k_{iavg}, %	13.30	4.46	6.58

Table 2 shows that the studied power grids are very different from each other both in their topology and system parameters, as well as in the nature of loads and modes.

The measurements were conducted during winter when electricity consumption is at its peak, and the influence of weather conditions was considered. The measurements were taken over a 24-hour period (a full day). Additionally, the region's area and population density were taken into account to gain a more comprehensive understanding of the overall picture.

High levels of harmonics can lead to equipment overheating, a reduction in its operational lifespan, and malfunctions in the operation of sensitive electronic devices used by consumers.

6. Discussion of experimental results to determine the effect of higher voltage and current harmonics on electrical networks

Fig. 3 shows that the sinusoidality distortion factor can vary over a wide range, for example, from 3.2 % to 30.3 %, with an average value of 8.75 %. Thus, daily measurements of sinusoidality distortion coefficients can be represented graphically by these three values (Fig. 4), which is very useful when illustrating data for multiple lines in an electrical network (Fig. 5–9). To try to find the relationship between voltage level and voltage non-sinusoidality, and between line loading level and current non-sinusoidality, the average values of voltages and currents are included in the plots of Fig. 4–9.

According to Fig. 5, it can be seen that the non-sinusoidality of voltages in the 110 kV electrical network of Astana is at an acceptable level, but pay attention to the lines SCH-T and SCH-T, as well as lines PNFS01 and PNFS02. If we refer to Fig. 6, we can see that these lines are characterized by sufficient loading and low level of distortion of sinusoidality of current. Referring to the data obtained in the course of the energy audit of the electric networks of Astana city, we can say that these lines are the longest, and the place of measurements is located far from nonlinear loads. Referring to Table 2, we can say that the voltage quality and power losses in Astana are at a relatively satisfactory level. However, attention is drawn to the high level of distortion coefficients of sinusoidality of currents, the average level of which is 13.3 %.

As can be seen from Fig. 7, the level of voltage sinusoidality distortion is at an acceptable level, except for line L-170. According to the data obtained during the energy audit of the power networks of the South, line L-170 is part of the ring power network and is characterized by low load (Fig. 8). Fig. 8 shows that the higher the load of the line, the lower the distortion of sinusoidality, however, due to the high load of the electrical networks of the South, the voltages in them are lower than in the electrical networks of Astana (Fig. 5) and the West (Fig. 8).

The results obtained in the 110 kV electrical networks of Astana indicate a high voltage quality, especially considering the low value of the sinusoidal distortion coefficient k_{vavg}, which is only 1.21 % (Table 2). However, it should be noted that the distortion coefficients of currents k_{iavg} have a relatively high level, amounting to 13.30 %. From the data in Table 2, it can be concluded that due to the high population density, high transmission volumes and non-linear loads contribute to a high level of current waveform distortion in the urban network.

According to experimental data, the network's loss level is 9.88 % (Table 2), which is higher than the 6 % reported in the energy sector review [4]. This indicates higher losses in the electrical networks than expected, possibly suggesting inefficient resource utilization.

In the South Kazakhstan region, low voltage levels at nodes and high line loads in the electrical network are observed (Table 2), with losses of 16.02 %. As measurements showed, the sinusoidal distortion coefficients of voltages and currents in the South's electrical network are relatively low, with k_{vavg}=1.93 % and k_{iavg}=4.46 %, and do not raise concerns.

As a result, voltage drops and significant power losses occur in the Southern region due to the relatively high population density and large distances between load and power generation centers.

Losses in the electrical networks in the Western region amount to 14.27 % (Table 2). Voltage levels in the electrical network are low, and the loading levels on transit lines are also low. The distortion coefficients of voltages and currents in the West's electrical network have the worst characteristics, with k_{vavg}=6.57 % and k_{iavg}=6.58 %. This situation is likely due to the 110 kV lines with low load, generating reactive power flows and causing resonance processes in the 110 kV electrical networks.

The Western region is characterized by very low population density and long transmission distances, which results in low network utilization and, as a consequence, relatively high levels of voltage and current waveform distortion.

When operating the power network, the company's administrative and engineering staff may not even be aware of the levels of higher harmonic components of voltages and currents and other mode parameters that can be the cause of false relay protection operation, deterioration of transmission capacity, errors in metering, overheating of equipment and shortening the service life of electrical equipment. Comparative analyses, as in this paper, provide insight into the characteristics of the electrical network that lead to quality problems in the functioning of the electrical network.

Limitations of this study include the coverage of only three regions of the Republic of Kazakhstan. Due to the complexity of organizing large-scale studies, the present studies covered only three regional grid companies, but there may be other variations of grid companies with other system and regime properties. Also, not all 110 kV lines are covered in the present studies for reasons such as lack of metering circuits on some lines, weather conditions not allowing access to some substations and other organizational constraints.

The shortcomings of this study involve an incomplete picture. It should be noted that this study is based on daily measurement data using three-phase power quality analyzers. Equipping grid companies with in-house instruments for recording voltage and current harmonics and other important parameters would greatly facilitate data collection and improve the quality of analyses of transmission and distribution efficiency; however, such a system is too expensive for some companies.

In the future, the research can be expanded by investigating other regions of Kazakhstan to obtain a more comprehensive view.

Challenges that may be encountered include the need for collaboration with various stakeholders to access information and resources.

The need for other grid companies to survey the mode properties of their networks can contribute to the quality of the analysis by expanding the data to be analyzed. In this case, it will be easier to achieve co-operation and mutual understanding on the way to achieve results. Also, data for a longer period of operation can be obtained if the grid companies have appropriate voltage and current quality recorders.

7. Conclusions

1. Instrumental measurements of operational parameters were conducted to determine the electrical power quality indicators, which included 24-hour measurements carried out on 41 power transmission lines with a nominal voltage of 110 kV and varying lengths from 5 to 120 km in three regions of Kazakhstan: Astana city, Turkestan region, Shymkent city, and West Kazakhstan region. The measurements made it possible to gain access to the necessary data for investigating the mode properties and non-sinusoidality in electric grids of regions with different load, geographic and demographic characteristics.

2. Illustration of measurement results is an important task, especially when it is necessary to process data on a large number of lines. For example, the graphs show the key problems of regional power grids: in Astana, strong distortion of sinusoidality of currents with normal other mode characteristics; in the South, strong voltage drop associated with high line load, but the distortion of sinusoidality is acceptable; in the West, heterogeneity of modes causes a high level of distortion of sinusoidality of voltages and currents. It is worth noting that according to the Law on Energy Saving and Efficiency Improvement, every five years it is necessary to conduct energy audits of power grids, which makes it possible to monitor the dynamics of changes in their efficiency, including in case of implementing recommendations to improve modes.

3. Based on the analysis of the level of electrical power losses in the Republic of Kazakhstan's electrical networks, factors influencing these losses were identified, and recommendations for their reduction were provided:

– for the capital of the Republic of Kazakhstan, it is strongly recommended to implement and apply IEEE STD 519-2014 to mitigate their negative impact on the reliability and efficiency of the electrical network, given the high concentration of nonlinear consumer loads in electrical power networks with the coefficient of sinusoidal distortion k_{vavg}=1.21 %, the coefficient of distortion of currents k_{iavg}=13.30 %;

– for the South Kazakhstan region, solutions to address voltage loss of 16.02 % and increase the electrical network's capacity involve annual modernization efforts, especially since this region experiences a high number of sunny days throughout the year. Additionally, it is recommended to increase the capacity of solar power stations to relieve the main grid;

– losses in the power grids of the Western region reach 14.27 %. The worst characteristics of voltage and current distortion coefficients are observed in the power grids of this region: k_{vavg}=6.57 % and k_{iavg}=6.58 %. The Western region is characterized by low population density and significant intervals between transmission lines, which leads to low grid utilization and, consequently, to relatively high levels of voltage and current waveform distortion. To improve the situation in the power grids of the West Kazakhstan region, it is proposed to use shunt reactors to control reactive power flows generated by high-voltage lines with low loads.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

This research is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant AP09058186 on the topic «Development of a methodology and computer program for determining additional losses of electrical energy during its transportation and distribution in the electrical network»).

Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Velinov, E., Petrenko, Y., Vechkinzova, E., Denisov, I., Ochoa Siguencia, L., Gródek-Szostak, Z. (2020). «Leaky Bucket» of Kazakhstan's Power Grid: Losses and Inefficient Distribution of Electric Power. Energies, 13 (11), 2947. doi: https://doi.org/10.3390/en13112947
2. Zhantlessova, A., Zhumazhanov, S., Akimzhanov, T., Issabekova, B., Issabekov, Z., Mekhtiyev, A., Neshina, Y. (2023). Instrumental Research on the Voltage Harmonic Distortion Coefficient in the Modern 110 kV Urban Electric Network. International Journal on Energy Conversion (IRECON), 11 (2), 56. doi: https://doi.org/10.15866/irecon.v11i2.22979
3. Assembayeva, M., Egerer, J., Mendelevitch, R., Zhakiyev, N. (2019). Spatial electricity market data for the power system of Kazakhstan. Data in Brief, 23, 103781. doi: https://doi.org/10.1016/j.dib.2019.103781
4. Kazakhstan 2022. Energy Sector Review. International Energy Agency. Available at: https://iea.blob.core.windows.net/assets/fc84229e-6014-4400-a963-bccea29e0387/Kazakhstan2022.pdf
5. Papyrakis, E., Parcero, O. J. (2022). The psychology of mineral wealth: Empirical evidence from Kazakhstan. Resources Policy, 77, 102706. doi: https://doi.org/10.1016/j.resourpol.2022.102706
6. Ugwuagbo, E., Balogun, A., Olajube, A., Omeje, O., Awelewa, A., Abba-Aliyu, S. (2021). Experimental data on power quality assessment at point of common coupling of a steel mill to an electric power grid. Data in Brief, 39, 107681. doi: https://doi.org/10.1016/j.dib.2021.107681

7. Bamigbola, O. M., Ali, M. M., Oke, M. O. (2014). Mathematical modeling of electric power flow and the minimization of power losses on transmission lines. Applied Mathematics and Computation, 241, 214–221. doi: https://doi.org/10.1016/j.amc.2014.05.039
8. Norouzi, H., Abedi, S., Jamalzadeh, R., Rad, M. G., Hosseinian, S. H. (2014). Modeling and investigation of harmonic losses in optimal power flow and power system locational marginal pricing. Energy, 68, 140–147. doi: https://doi.org/10.1016/j.energy.2014.02.010
9. Panda, D. K., Das, S. (2021). Smart grid architecture model for control, optimization and data analytics of future power networks with more renewable energy. Journal of Cleaner Production, 301, 126877. doi: https://doi.org/10.1016/j.jclepro.2021.126877
10. Ali, A. O., Elmarghany, M. R., Abdelsalam, M. M., Sabry, M. N., Hamed, A. M. (2022). Closed-loop home energy management system with renewable energy sources in a smart grid: A comprehensive review. Journal of Energy Storage, 50, 104609. doi: https://doi.org/10.1016/j.est.2022.104609
11. EN 50160:2010. Voltage characteristics of electricity supplied by public electricity networks. Available at: https://standards.iteh.ai/catalog/standards/clc/18a86a7c-e08e-405e-88cb-8a24e5fedde5/en-50160-2010#Text
12. 519-2014 – IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems. doi: https://doi.org/10.1109/ieeestd.2014.6826459
13. Raihan, A., Tuspekova, A. (2022). Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions: New insights from Kazakhstan. World Development Sustainability, 1, 100019. doi: https://doi.org/10.1016/j.wds.2022.100019