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STUDY OF EMERGENCY SITUATIONS ON HIGH AND ULTRA-HIGH VOLTAGE POWER LINES

High- and ultra-high-voltage overhead power lines are critical for maintaining a reliable electricity supply to industrial consumers and regional power systems in the Republic of Kazakhstan. The country's large geographic extent, coupled with harsh and highly variable climatic conditions, imposes additional demands on the stable operation of transmission networks. In recent years, there has been an upward trend in emergency events on transmission lines, resulting in power interruptions, economic damage and a decrease in the overall reliability of the power system. The present study focuses on a detailed analysis of emergency situations on high- and ultra-high-voltage power lines in the Republic of Kazakhstan in the period 2020–2024.

The study draws on the analysis and synthesis of statistical data on technological disturbances, records of relay protection and automatic reclosing performance, cartographic examination of the power supply system, and a review of regulatory and technical documents. The principal types of emergency events are distinguished, including conductor galloping with associated short circuits, icing, interphase arc flashovers initiated by birds, direct lightning impacts, and failures of polymer insulators. Special emphasis is placed on the role of meteorological conditions – strong winds, icing, and thunderstorm activity – in shaping both the frequency and the characteristics of accidents.

The study assesses automatic reclosing devices and demonstrates their key role in clearing transient faults and reducing the impact of emergencies.

The analysis also reveals the limitations of conventional relay protection systems in reliably distinguishing between electrical and mechanical faults. The paper substantiates the applicability of intelligent protection solutions based on fuzzy logic to enhance fault recognition accuracy and increase decision-making reliability. The proposed technical and organizational measures are aimed at improving the operational reliability of transmission lines and supporting the sustainable development of the power system of the Republic of Kazakhstan.

Keywords: high-voltage overhead power lines, emergency situations, conductor galloping, electric arc flashover, meteorological conditions, automatic reclosing, reliability of power systems.

Introduction

Power transmission lines (PTLs) play a key role in providing electricity to industrial enterprises in the Republic of Kazakhstan (RK). The country's extensive energy infrastructure includes high-voltage and ultra-high-voltage transmission lines that connect major regions and ensure the transmission of electricity between major energy facilities. However, in recent years, incidents of power line emergencies have become more frequent, significantly impacting the stability of the power supply [1].

Emergencies on power transmission lines can be caused by both natural factors (hurricanes, icing, lightning strikes) and man-made causes (equipment wear, operating errors, external damage). Analysis of these accidents is an important task for developing measures aimed at reducing the number of emergencies and minimizing their consequences [2].

This work is devoted to the study of emergency situations on high-voltage and ultra-high-voltage power lines in the Republic of Kazakhstan, since they are the most significant in the power supply of the Republic. The aim of the study is to identify the main causes of accidents, analyze their consequences, and develop recommendations for improving the reliability of power lines. Particular attention is paid to analyzing the current state of the infrastructure, as well as the impact of climatic conditions on power supply reliability.

Due to the growth of manufacturing enterprises in Republic, the load on the energy system will increase [2; 3]. The main objective of the work is to analyze emergency situations in high- and ultra-high-voltage systems and to substantiate the required set of technical solutions to improve the reliability and reduce the accident rate of the power supply system. To achieve this goal, it is necessary to solve the following tasks: analyze emergency situations; determine the influence of cause-and-effect relationships between climatic factors and the technical condition of the

transmission line structural elements on the occurrence of emergency situations; substantiate a set of measures and technical solutions to ensure increased reliability of the power supply system.

To achieve the stated goals and perform the tasks of investigating emergency situations on high-voltage and ultra-high-voltage power lines in the Republic of Kazakhstan, the following methods were used [4]:

1. Analysis and generalization of statistical data from publicly available sources;
2. Cartographic analysis of the power supply system;
3. Diagnostics of the technical condition of equipment;
4. Analysis of regulatory recommendations.

The use of an integrated approach and complementary methods made it possible to conduct a comprehensive study and develop well-founded proposals to reduce the risk of accidents on high-voltage and ultra-high-voltage power lines.

Materials and methods

The research relies on a comprehensive analysis of emergency events on high- and ultra-high-voltage overhead power lines in the Republic of Kazakhstan over the period 2020–2024. As input data, publicly available statistics on technological disturbances and records of relay protection performance and automatic reclosing were used. The source data were classified by disturbance types (conductor galloping and short circuits, direct lightning impacts, interphase arc flashovers caused by birds, polymer insulator defects, overload-related outages) and by automatic reclosing outcome (successful/unsuccessful), which made it possible to evaluate both the dynamics of the failure rate and the effectiveness of protection operations.

To reveal cause-and-effect relationships, a comparative analytical method was employed. The impact of meteorological conditions (wind loads, icing, thunderstorm activity) and external influences on the probability of outages was assessed by comparing disturbance categories and their annual frequency. Additionally, cartographic analysis of the power supply system was used to account for the territorial characteristics of transmission line routes and the operating conditions of high-voltage networks, including segments located in remote and difficult-to-access areas. Diagnostics of the technical state of line components (conductors, insulator strings, fittings, towers and vibration dampers) was treated as a key factor in explaining failures related to wear, latent defects and material aging.

The diagnostic assessment was clarified as an integrated procedure combining visual inspection, analysis of relay protection and automatic reclosing data, thermal imaging of contact joints and insulator strings, and UAV inspection of line sections with limited accessibility. In assessing overhead line elements, attention was focused on the condition of conductors, fittings, polymer insulators, vibration dampers, towers, and grounding components. Thermal imaging was used

to identify local overheating associated with increased contact resistance, overloads, or leakage currents. UAV inspection made it possible to detect mechanical damage, corrosion, displacement of vibration dampers, defects in insulator strings, and foreign objects located near live parts. The assessment of polymer insulators was also related to the identification of partial discharge activity and visible signs of surface degradation, since these defects can gradually reduce insulation strength and increase the likelihood of emergency outages [5-7].

Regulatory and technical documents in force in the Republic of Kazakhstan were examined to link the observed disturbance types with existing operational requirements and protection principles. Based on this analysis, a set of technical measures to reduce the outage rate (including scheduled maintenance, vibration mitigation, meteorological monitoring and UAV-based inspections) was substantiated, and the use of fuzzy-logic decision-making elements in protection and automatic reclosing schemes was justified to improve the reliability of distinguishing between electrical and mechanical faults.

Results and discussions

The electric power system of the Republic of Kazakhstan uses overhead high-voltage transmission lines for the transmission of electricity. Operation of existing transmission lines and the design of new ones are carried out in accordance with regulatory requirements approved in the Republic of Kazakhstan [8].

Particular attention is paid to increasing the reliability and improving the operational characteristics of high-voltage power transmission lines, since their condition directly affects the stability of the power supply to industrial enterprises.

The most serious problem in the operation of power transmission lines is emergency situations, which can be caused by many factors [9].

Currently, in order to prevent the development of technological violations, complex protection systems are used.

The integrated substation protection system consists of:

- short circuit current protection;
- differential protection (one of the most accurate types of protection);
- against ground faults (implemented to protect power transmission lines when single-phase ground faults occur);
- distance protection (measures the impedance (resistance) of the line and determines the distance to the fault location);
- automatic reclosing devices (ARD);
- multi-stage protection with several levels (fast-acting and time-delayed);
- surge protection devices;
- overload protection (OLP);

If the emergency situation was short-lived and did not lead to serious consequences, the controlled section of the power line is connected to the power source and the automatic reclosing device is considered successful. The classification of emergency situations on high-voltage and ultra-high-voltage transmission lines from 2020 to 2024 is presented in Table 1.

Table 1 – Statistics of emergency situations on high-voltage and ultra-high-voltage power lines

Technological disturbances on power lines and reactions of the protection system	2020	2021	2022	2023	2024
The number of technological failures due to conductor galloping with subsequent restoration of the electrical circuit	3	2	2	3	1
The power line shutdown was a short circuit between the phase wire and the ground wire or a fall of the phase wire to the ground.	1	1	2	1	3
The number of direct lightning strikes on live wires of power transmission lines.	1	1	2	2	1
Interphase electric arcs caused by birds	9	7	3	5	6
Number of outages due to polymer insulator failure	1	1	2	2	2
Number of network overload outages	1				
Successful automatic reclosing devices	13	10	7	10	8
Unsuccessful automatic reclosing devices	3	2	4	3	5
Total number of technological violations	16	12	11	13	14

1. Analysis and generalization of statistical data on technological violations at high and extra-high voltage (2020–2024)

General analysis of the dynamics of technological disturbances :

From 2020 to 2024, the total number of power transmission line faults fluctuated between 11 and 16 per year. The lowest number of faults (12) was recorded in 2021, while the highest number (16 and 14, respectively) was observed in 2020 and 2024.

2. Analysis of individual types of technological violations:

The phenomenon of conductor galloping, causing a short circuit, followed by the activation of protection and restoration of the electrical circuit, occurs annually, but the frequency of emergency shutdowns varies.

– In 2020 and 2023, 3 cases were registered, which is the maximum figure.

- In 2024, the lowest number of accidents was recorded (1 case).
- The overall reduction may indicate the effectiveness of the measures taken to combat conductor galloping, such as the installation of additional supports, the installation of damper spacers, the installation of interphase spacers, the installation of additional garlands, etc.

Short circuits between the current-carrying wire and the ground wire due to conductor galloping.

This type of violation has minor deviations:

- In 2022 and 2024, 2 cases were recorded.
- In 2020, 2021 and 2023 – 1 case each.
- In 2024, the number of such cases increased, which may indicate the need for further analysis of lightning protection design.

Direct lightning strikes on live wires

- In 2020 and 2021, 1 case was registered each.
- In 2022–2024, 2 cases were recorded annually.
- The increase in the number of lightning strikes may be due to changes in climate conditions or insufficient efficiency of lightning protection devices.

Interphase arc flashovers due to birds.

- In 2020, there were 9 cases, which is the maximum figure.
- In 2022, only 3 cases were recorded – the minimum level.
- In 2023–2024, a slight increase to 5–6 cases was noted.
- The introduction of additional protective measures (for example, the installation of bird protection devices) can partially reduce the frequency of such incidents.

Destruction of polymer insulators.

- The number of insulator destructions has gradually increased from 1 case in 2020 and 2021 to 2 cases in 2022–2024.

- The increase in the number of incidents may be due to the impact of external factors (ultraviolet radiation, high dynamic loads on insulator strings caused by gusts of wind, conductor galloping and ice deposits, aging of the material).

Exposure to high current load.

- The only registered case occurred in 2020.
- The absence of similar violations in subsequent years may indicate the correct operation of the power lines or the introduction of more efficient load management methods.

3. Analysis of successful and unsuccessful application of automatic reclosing (AR) on high and extra-high voltage power transmission lines in Republic of Kazakhstan.

Successful application of ARD allows to ensure:

- reducing the consequences of an emergency;
- reduction of operating costs;
- combination of the automatic reclosure control system with modern monitoring systems.

The main causes of technological failures on power transmission lines are:

1. Meteorological conditions: strong winds, storms, icing, thunderstorms, floods.
2. Mechanical damage to the elements of the power transmission line structure (falling trees, transport accidents, impact of unauthorized persons, design defects).
3. Technical faults : expiration of service life, hidden defects of overhead power line elements or construction deficiencies [5; 10].
4. A particular threat to high-voltage and ultra-high-voltage power lines is posed by adverse weather conditions, such as gusty winds, which cause conductors gallop and lead to mechanical damage to the elements of the power line structures and the shutdown of a section of the power supply system with successful or unsuccessful automatic reclosure.

Analysis of emergency situations on high and extra-high voltage power lines.

Between 2020 and 2024, Republic of Kazakhstan experienced various power line emergencies caused by strong winds and other factors, such as:

- The proximity of live wires to grounded parts of supports, causing an electric arc flashover due to gusts of wind. Such outages are usually accompanied by successful automatic reclosure [11].
- Vibrations of wires leading to mechanical damage to wires, Linear suspension and almost always with unsuccessful automatic reclosure.
- An electric arc flashover between a phase conductor and a ground wire caused by strong wind gusts and wire movement. Most often, such outages are successfully reclosed.
- Icing on power transmission lines in Republic of Kazakhstan, especially in winter, is one of the main causes of emergency outages. The country's climatic conditions – temperature fluctuations, high humidity, and wind loads – facilitate the formation of ice, which increases the load on wires and structures, threatening the integrity of transmission line components and the reliability of the power system. Such incidents are most often identified, and measures are taken to prevent emergency outages and damage to transmission line components.
- Electrochemical frost is a form of icing that occurs on power transmission lines (PTLs) as a result of a combination of electromagnetic processes and adverse weather conditions. In the Republic of Kazakhstan, this phenomenon is observed primarily during the cold season, especially in areas with high humidity and sudden temperature fluctuations. Measures taken are similar to those used for icing [6].

- Lightning strikes are a common cause of emergency outages on high-voltage and ultra-high-voltage power lines (HV/EVL) in Republic of Kazakhstan. Lightning can cause equipment damage, power outages, and even major grid failures. The number of such incidents from 2020 to 2024 reached 12 in the Karaganda region alone, demonstrating the vulnerability of power lines to this type of impact. To reduce the effect of lightning surges on power lines, regular inspection and repair of ground wires, lightning protection components, and grounding of poles are undertaken.

Justification of the use of fuzzy logic in the power transmission line protection system

Existing relay protection systems for high-voltage and ultra-high-voltage transmission lines have limitations related to their insufficient ability to accurately analyze the nature of fault situations. For example, a wire break that touches other phases or the ground causes a short circuit. However, due to the lack of an effective diagnostic mechanism, the automatic reclosure system may trip prematurely, even if the underlying cause of the fault has not been eliminated [12].

Furthermore, a wire break often creates a false arc fault, leading to an incorrect protection response. Existing circuits are unable to reliably distinguish a wire break from an arc fault, as sudden changes in current and voltage are often accompanied by electromagnetic interference, which the system interprets as a short circuit.

It's also worth noting the low information yield of traditional protection devices: their algorithms don't allow for a clear determination of the nature of a fault – whether electrical or mechanical. This significantly reduces the accuracy and effectiveness of fault localization. Therefore, there is a need to develop an improved protection system capable of performing a comprehensive analysis of network parameters, ensuring more accurate diagnostics and preventing reconnections in the event of unrepaired faults [7].

One way to improve the reliability of emergency diagnostics is to use diagnostic systems based on fuzzy logic. Fuzzy logic is used in protection systems for high-voltage and ultra-high-voltage substations, particularly in automatic reclosing and relay protection. Its use improves the accuracy and adaptability of protection systems in the face of intermittent damage to transmission line components [13].

Advantages of fuzzy logic:

- Possibility of processing uncertain or partially reliable information;
- Improving the reliability of accident classification (mechanical damage vs. electrical short circuit);
- Flexibility in deciding whether to file an automatic reclosing devices;
- Increased selectivity and reliability of automatic reclosing [13].

Table 2 – Simplified fuzzy rule base for automatic reclosing decision-making

Input condition	Fuzzy assessment	Decision for AR
High short-circuit current, short voltage dip, no mechanical defect detected	Transient electrical fault	Permit automatic reclosing
High current, conductor galloping, strong wind or icing	Mixed electrical-mechanical disturbance	Extend dead time before reclosing
Repeated trip after reclosing, thermal anomaly or visible conductor/insulator defect	Persistent fault	Block reclosing and require inspection
Lightning activity, single short-term disturbance, no repeated trip	Probable transient overvoltage	Permit single reclosing attempt
Polymer insulator degradation, leakage current signs or partial discharge indication	Insulation-related fault	Block reclosing and schedule diagnostics

Unlike conventional relay protection, which usually operates on fixed current and voltage thresholds, the fuzzy logic approach makes it possible to evaluate several uncertain factors at the same time. For instance, when a fault is accompanied by increased current, a voltage drop, strong wind and signs of conductor galloping, it should not automatically be treated as a temporary short circuit. In such a situation, the fuzzy rule base gives greater weight to the likelihood of mechanical damage and may recommend extending the dead time or blocking automatic reclosing. This helps prevent repeated reclosing when the fault has not yet been eliminated [11; 12].

Currently, the following measures are being taken to reduce the number of emergency situations on 500 kV power transmission lines:

1. Carrying out scheduled work:

Conducting inspections and repairs of power transmission line equipment.

Checking the technical condition of wires, supports, insulators and other elements of the power transmission line structure.

Trimming trees and shrubs near power lines.

Checking the technical condition of guy wires and adjusting their tension.

Particular attention is paid to monitoring the technical condition of the vibration dampers on the wires and cables.

Vibration dampers are widely used to combat vibration phenomena. Vibrations of wires and cables on power transmission lines can occur due to wind loads, the properties of the wire and cable themselves, temperature fluctuations, and other factors. Republic of Kazakhstan climatic conditions, including strong winds

in the steppe regions and significant temperature fluctuations, require a special approach to this problem. Displacing vibration dampers from their intended location can damage the wire or cable, reduce its service life, and lead to accidents [14].

Experimental studies of power transmission lines show that timely installation and scheduled adjustment of vibration dampers allows:

- reduce the frequency of damage to overhead power line elements by 20–30 %;
- reduce costs for repair and maintenance of power lines;
- extend the service life of wires and supporting structures.

The proposed measures should be viewed as elements of a single preventive reliability program rather than as separate technical actions. Their effectiveness depends on the combined use of mechanical protection, regular condition monitoring and more accurate decision-making in relay protection systems. For example, the installation of vibration dampers and their periodic adjustment can reduce damage to overhead line components by about 20–30 %. UAV inspection makes it possible to examine remote sections of transmission lines more quickly and to identify defects such as corrosion, damaged fittings, shifted dampers, faulty insulator strings and hazards caused by birds. Thermal imaging control complements these measures by detecting overheating areas associated with poor contacts, leakage currents or overloads. Thus, the preventive value of the proposed approach is reflected not only in a reduction in outages, but also in the timely detection and localization of defects before they lead to emergency situations [6; 7].

2. Meteorological monitoring:

Climate monitoring technologies enable the prediction of adverse weather conditions. Timely preventative maintenance reduces the risk of emergencies during severe storms, icing and other natural phenomena [15].

3. Use of modern technologies:

Installation of automatic shutdown and protection systems that quickly respond to faults. Implementation of modern technologies for diagnosing the condition of wires and supports, such as thermal imaging cameras.

High-voltage and ultra-high-voltage power lines in the Republic of Kazakhstan occupy vast territories, often passing through hard-to-reach regions, such as mountainous areas and water resources of Republic of Kazakhstan, where ground inspections are difficult. Maintaining the operational condition of power transmission lines requires regular monitoring and timely detection of damage. Traditional inspection methods, such as visual inspection from the ground, are not always effective and require significant time and resources. In recent years, aerial inspections using light aircraft and unmanned aerial vehicles (drones) have become particularly popular. The high inspection speed allows for inspection of large sections of lines in a relatively short period of time and in a completely safe manner.

A drone equipped with specialized equipment: a high-resolution camera, a thermal imager and a geographic positioning sensor, allows it to detect:

- damage to wires and localization of damage;
- corrosion of supports;
- using thermography means, establish the fact of an electrical leak and localize the location of the accident;
- places in the design of transmission line elements with elevated temperatures caused by overload or malfunction.

To successfully utilize modern diagnostic technologies for electrical power system components, it is necessary to regularly train employees in modern methods of rapid response and troubleshooting using modern technologies.

Conducting training on safety and emergency prevention.

In 2020–2024, the annual number of technological disturbances ranged from 11 to 16 cases. This variation shows that emergency events did not follow a stable pattern and were influenced by both climatic conditions and operational factors. At the same time, the increase in the number of outages with successful automatic reclosures demonstrates the effectiveness of the protection systems in place and their good technical condition. To further reduce accidents, it is necessary to continue introducing modern protection systems, developing meteorological monitoring and diagnostic systems, and training personnel. Implementing these measures will improve the reliability of the power system and reduce the number of accidents. By implementing the above-mentioned program, the impact of accidents on the country's economy can be minimized.

An analysis of power line accidents in Republic of Kazakhstan shows that the main causes of accidents include icing, wire vibration, lightning strikes, equipment wear and tear, and external factors (strong winds, interference from unauthorised persons). To improve the reliability of power lines, reconstruction is required, taking into account changes in weather conditions, with the introduction of modern technologies (insulation and linear suspension fittings, support structures) and the development of new approaches to diagnosing and monitoring the condition of power lines.

Research into emergency situations on power lines in the Republic of Kazakhstan is a promising, knowledge-intensive area that could help to improve the reliability of power lines and the energy system as a whole.

Conclusions

Based on the analysis of emergency situations on high-voltage and ultra-high-voltage power lines in the Republic of Kazakhstan for 2020–2024, the following key conclusions were formulated:

1. The study of emergency events on high- and ultra-high-voltage overhead transmission lines in the Republic of Kazakhstan for 2020–2024 revealed that outages were mainly caused by conductor galloping, ice accumulation, interphase arc flashovers, direct lightning strikes, failures of polymer insulators and mechanical damage to line elements. The impact of these causes increases when severe climatic conditions coincide with the deterioration or unsatisfactory technical condition of overhead line components.

2. An analysis of the operation of automatic reclosing devices demonstrated their high effectiveness in eliminating short-term faults. The increase in the percentage of successful automatic reclosing operations confirms the correct operation of the existing relay protection systems. However, the increase in unsuccessful reclosings indicates the need to refine the algorithms for detecting and recognizing fault conditions.

3. It has been revealed that traditional relay protection systems have a number of limitations related to insufficient selectivity and the lack of reliable differentiation between electrical and mechanical line faults. This leads to an increased likelihood of erroneous reclosing and repeated tripping.

4. It has been shown that the use of intelligent protection systems based on fuzzy logic is justified, as they allow for the uncertainty of input parameters to be taken into account, improve the accuracy of recognizing emergency conditions, and make more informed decisions about performing automatic reclosing.

5. The effectiveness of a set of preventive measures, including scheduled preventive maintenance, monitoring the technical condition of overhead power line elements, installation of vibration dampers, development of meteorological observation systems and the use of unmanned aerial vehicles for diagnosing hard-to-reach sections of the line route, is demonstrated.

6. It has been established that a further reduction in the frequency of accidents and an increase in the reliability of the power supply in the Republic of Kazakhstan are achievable through a comprehensive approach that combines the modernization of protection systems, the adaptation of line design solutions to changing climatic conditions, the introduction of digital monitoring tools, and the systematic improvement of the qualifications of operating personnel.

The implementation of the proposed technical and organizational solutions will improve the reliability of high-voltage and ultra-high-voltage power lines, reduce economic losses from emergency outages, and promote the sustainable development of the energy system of the Republic of Kazakhstan.

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ЖОҒАРЫ ЖӘНЕ ӨТЕ ЖОҒАРЫ КЕРНЕТТІ ЭЛЕКТР БЕРУ ЖЕЛІЛЕРІНДЕГІ ТӨТЕНШЕ ЖАҒДАЙЛАРДЫ ЗЕРТТЕУ

Әуедегі жоғары вольтты және аса жоғары вольтты электр желілері Қазақстан Республикасындағы өнеркәсіптік тұтынушылар мен аймақтық электр желілерін сенімді электрмен жабдықтауды қамтамасыз ету үшін өте маңызды. Елдің кең географиялық аумағы, қатал және өте өзгермелі климаттық жағдайлармен бірге, электр беру желілерінің тұрақты жұмысына қосымша талаптар қояды. Соңғы жылдары электр желілерінің істен шығу санының арту үрдісі байқалды, бұл электр қуатының үзілуіне, экономикалық шығындарға және электр жүйесінің жалпы сенімділігінің төмендеуіне әкелді. Бұл зерттеу 2020 жылдан 2024 жылға дейін Қазақстан Республикасындағы жоғары вольтты және аса жоғары вольтты электр желілеріндегі істен шығулардың егжей-тегжейлі талдауын ұсынады.

Зерттеуде статистикалық деректерді талдау және технологиялық бұзылулардың қысқаша мазмұны, релелік қорғаныс және автоматты қайта жабу жұмысының жазбалары, электрмен жабдықтау жүйесінің картаға түсіру зерттеуі және нормативтік-техникалық құжаттаманы қарау пайдаланылды. Төтенше жағдайлардың негізгі түрлері анықталды, соның ішінде қысқа тұйықталулармен бірге жүретін өткізгіштердің кернеуі, мұздану, құстардың әсерінен фазалық доғаның пайда болуы, найзағайдың тікелей соққылары және полимер оқшаулағыштарының істен шығуы. Төтенше жағдайлардың жиілігі мен сипаттамаларын қалыптастырудағы метеорологиялық жағдайлардың – қатты желдің, мұзданудың және найзағай белсенділігінің рөліне ерекше назар аударылды.

Зерттеу автоматты қайта жабу құрылғыларын бағалайды және олардың өтпелі процестерді жоюдағы және апаттардың салдарын азайтудағы негізгі рөлін көрсетеді. Талдау сонымен қатар дәстүрлі релелік қорғаныс жүйелерінің электрлік және механикалық ақауларды сенімді түрде ажыратудағы шектеулерін анықтайды. Мақалада ақауларды тану дәлдігі мен шешім қабылдау сенімділігін арттыру үшін анық емес логикаға негізделген интеллектуалды қорғаныс шешімдерінің қолданылуы негізделеді. Ұсынылған техникалық және ұйымдастырушылық шаралар электр беру желілерінің пайдалану сенімділігін арттыруға және Қазақстан

Республикасының энергетикалық жүйесінің тұрақты дамуын қолдауға бағытталған.

Кілтті сөздер: жоғары кернеулі әуе электр жеткізу желілері, апаттық жағдайлар, сымдардың тербелісі, электр доғалық айқасу, метеорологиялық жағдайлар, автоматты қайта қосу, энергия жүйесінің сенімділігі.

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ИССЛЕДОВАНИЕ АВАРИЙНЫХ СИТУАЦИЙ НА ЛИНИЯХ ЭЛЕКТРОПЕРЕДАЧИ ВЫСОКОГО И СВЕРХВЫСОКОГО НАПРЯЖЕНИЯ

Воздушные высоковольтные и сверхвысоковольтные линии электропередачи имеют решающее значение для обеспечения надежного электроснабжения промышленных потребителей и региональных энергосистем Республики Казахстан. Большая географическая протяженность страны в сочетании с суровыми и крайне изменчивыми климатическими условиями предъявляет дополнительные требования к стабильной работе передающих сетей. В последние годы наблюдается тенденция к увеличению числа аварийных ситуаций на линиях электропередачи, приводящих к перебоям в электроснабжении, экономическому ущербу и снижению общей надежности энергосистемы. Настоящее исследование посвящено детальному анализу аварийных ситуаций на высоковольтных и сверхвысоковольтных линиях электропередачи в Республике Казахстан в период 2020–2024 годов.

В исследовании использованы данные анализа и обобщения статистических данных о технологических нарушениях, записи о работе релейной защиты и автоматического повторного включения, картографическое исследование системы электроснабжения, а также обзор нормативно-технической документации. Выделены основные типы

аварийных событий, включая скачки проводников с сопутствующими короткими замыканиями, обледенение, межфазные дуговые пробои, вызванные птицами, прямые удары молнии и отказы полимерных изоляторов. Особое внимание уделено роли метеорологических условий – сильного ветра, обледенения и грозовой активности – в формировании как частоты, так и характеристик аварий.

В исследовании оцениваются устройства автоматического повторного включения и демонстрируется их ключевая роль в устранении переходных процессов и снижении последствий аварий. Анализ также выявляет ограничения традиционных релейных систем защиты в надежном различении электрических и механических неисправностей. В статье обосновывается применимость интеллектуальных решений защиты на основе нечеткой логики для повышения точности распознавания неисправностей и надежности принятия решений. Предложенные технические и организационные меры направлены на повышение эксплуатационной надежности линий электропередачи и поддержку устойчивого развития энергосистемы Республики Казахстан.

Ключевые слова: высоковольтные воздушные линии электропередач, аварийные ситуации, пляска проводов, электродуговое перекрытие, метеорологические условия, автоматическое повторное включение, надежность энергосистем.

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