



UDC 628.5 (075.8)

ISTI 87.17.15

DOI 10.37238/2960-1371.2960-138X.2026.101(1).38

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ENSURING THE RELIABILITY OF HIGH-VOLTAGE POWER TRANSMISSION LINES IN ICE-COLOURED CONDITIONS

Annotation. This paper analyzes the current state of overhead power lines and the reasons for the decline in their reliability. The development of electrical systems aimed at improving the quality and reliability of power supply to consumers under conditions of ice and wind loads, their testing, analysis of efficiency and implementation in electric power systems is an urgent task in areas with a sharply continental climate and in conditions of unprecedented extreme climatic phenomena.

The purpose of the presented study is to identify the causes of emergency shutdowns of overhead power lines during ice formation and to evaluate the method of melting ice with current to prevent accidents in power systems. The results of the study include identifying the impact of ice formation on overhead power lines in the Republic of Kazakhstan and substantiating an effective method for melting ice for structural elements on power lines. The article discusses methods of combating ice formation, presents the results of long-term observations of climatic parameters affecting ice formation in the regions of the Republic of Kazakhstan, the efficiency of a device for melting ice using a short circuit method, analyzes the expected mechanical loads on wires, and determines the values of critical spans for selecting foundations for transmission line supports.

Keywords: power supply system safety, power outage, icing, reliability, de-icing methods, diagnostic methods, monitoring, frost deposits, overhead power transmission lines.

Introduction

One of the key objectives of modern power supply systems is the uninterrupted transmission of electricity from various generating stations to consumers. In Kazakhstan, overhead power transmission lines (OPTLs) serve as the primary means of electricity transportation. The reliability and efficiency of their operation directly depend on the condition of the electrical networks.

The aim of this study is to explore methods for ensuring the safe operation of overhead power transmission lines. The research examines the detection and prevention of potential threats to OPTLs, as well as the analysis of data collected from various devices and meteorological stations to minimize the impact of emergency situations. Based on the obtained data, measures are developed to enhance the reliability of power lines and mitigate the consequences of failures.

For reliable power supply during icing conditions, several key measures are necessary: identifying the processes leading to ice accumulation on power lines, conducting continuous monitoring of mechanical load changes, and implementing effective de-icing strategies to prevent accidents.

Severe winter conditions, including inaccessible terrain, short daylight hours, and the remoteness of certain areas, significantly hinder both the prevention and resolution of power line failures. Combined with wind and icing, particularly during the early stages of ice formation, these conditions often result in phenomena such as conductor twisting, vibrations, and oscillations, which generate dynamic loads. One of the most critical factors negatively impacting power supply reliability is the icing of various components of high-voltage overhead power transmission lines [1].

This study focuses on overhead power transmission lines used for their maintenance. These power lines operate under extremely harsh conditions, constantly subjected to cyclic loads caused by external factors affecting conductors, cables, joints, and supports. These factors include the self-weight of conductors, wind forces, ice accumulation, and temperature fluctuations. Ice and frost deposits (IFD) typically form over vast areas, affecting multiple transmission corridors simultaneously, further exacerbating emergency situations.



Inaccessible roads during winter, limited daylight, and the difficulty of reaching certain locations complicate both accident prevention and emergency response efforts. The combination of wind and icing, especially in the early stages of ice formation, often leads to conductor twisting, vibration, and galloping, creating additional dynamic loads and increasing the risk of system failures.

Materials and methods of research

The methodological basis of the study was the scientific works of domestic and foreign scientists in the field of ice formation and methods of combating it. To solve the problems and achieve the goal of studying the methods of combating ice, analytical methods and mathematical modeling were used. Processing of computer modeling data, measurement results and experiments was carried out in the Matlab package. Theoretical provisions are confirmed by the results of experimental studies and measurements on an experimental stand in the laboratory.

The scientific novelty of the work consists in conducting an analysis of emergency shutdowns of overhead power lines and assessing the electrothermal method, which consists in increasing the temperature of overhead power line wires with electric current under certain climatic conditions.

According to statistics, more than half of the cases of severe snowstorms occur in Akmola, North Kazakhstan, Kostanay and Karaganda regions. The area under consideration is characterized by the formation of ice and drizzle deposits during drizzle and fog at air temperatures from -2 to -5 °C, the density of deposits on wires is 0.25-0.6 g/cm³.

The calculation of the overhead power line for normal operation was made for a combination of the following conditions:

- highest temperature, no wind and ice;
- lowest temperature, no wind and ice;
- average annual temperature, no wind and ice;
- wires and cables are covered with ice, temperature with ice, no wind;
- wind with the estimated load on the wires, air temperature at standard wind pressure, no ice;
- wires and cables are covered with ice, temperature with ice, wind with ice on the wires 0.25W.

The following temperature values are accepted:

- average annual temperature 15°C;
- lowest temperature -40°C;
- highest temperature 40°C;
- temperature during icy conditions -5 °C;
- air temperature at standard pressure -5 °C.

When melting ice by short circuiting, on one side the heated line is disconnected from the power system and artificially short-circuited, and on the other side a power source is connected that can provide the required melting current.

Statistical analysis indicates that icing on overhead power transmission lines is closely linked to significant shortcomings in the design, construction, and operation phases, particularly in regions prone to ice formation [2]. This highlights the urgent need for specialized measures to prevent such issues. In most cases, power line failures occur in areas where ice melting is either completely absent or significantly delayed. This phenomenon is observed not only under high loads but also under conditions where loads do not reach the calculated design limits.

Operational experience in power systems confirms that preventing ice-related failures and significantly improving the reliability of overhead power transmission lines is only possible through the timely implementation of current-induced ice melting techniques [3].

An analysis of icing conditions on overhead power transmission lines reveals that a substantial portion of Kazakhstan's power grid is affected by localized icing. While some sections experience severe ice loads, others remain largely unaffected or do not encounter icing at all.

The total length of overhead power transmission lines in the Republic of Kazakhstan is presented in Table 1.

Table - 1 – Length of Overhead Power Transmission Lines in Kazakhstan

Voltage	Length, km
220 kV	14694
220 kV (within the dimensions of 330 kV)	1864,1
500 kV	8288
500 kV (within the dimensions of 1150 kV)	1421,3
Total	26267,3

Note: Compiled by the authors based on [3]



The failure of overhead power transmission lines can lead to severe consequences, which is why they must meet stringent strength and stability requirements to withstand various external forces affecting supports, conductors, cables, and fittings. The design and structural selection of power transmission lines are based on long-term climate data, including temperature variations, wind speed, mechanical strength characteristics, and the specific weight of ice in the construction zone.

Years of observation have provided comprehensive data on wind speeds and the icing process across nearly all regions of Kazakhstan, forming the basis for the development of climate zoning maps. However, operational experience with ice-melting devices (IMD) has revealed several technical limitations. These include the load capacity of power sources, the necessity of maintaining system frequency stability during IMD operation, and compliance with GOST standards regarding harmonic levels and voltage asymmetry at consumer busbars. Additionally, there is a risk of conductor overheating in power line sections not affected by icing, as well as the need to ensure that the ice-melting rate exceeds the rate of ice formation [4].

According to Kazakhstan’s climate zoning map, for heights up to 15 meters above ground level, the minimum dynamic wind pressure is set at no less than 40 daN/m² for transmission lines operating at 6–330 kV and no less than 55 daN/m² for 500 kV transmission lines (as shown in Table 2).

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An analysis of emergency power outages indicates that weather conditions are the primary contributing factor, while technical malfunctions play a secondary role [5,6]. However, structural defects can significantly complicate repair and restoration efforts.

Table - 2 – Wind Pressure Parameters at H < 15 m Above Ground

Wind zones of Kazakhstan	Wind pressure, up to N/m(wind speed, m/s) with recurrence		
	Once every 5 years	Once every 10years	Once every 15years
I	27(21)	40(25)	55(30)
II	35(24)	40(25)	55(30)
III	45(27)	50(29)	55(30)
IV	55(30)	65(32)	80(36)
V	70(33)	80(36)	80(36)
VI	85(37)	100(40)	100(40)

Note: Compiled by the authors based on [5,7]

An analysis of emergency power outages indicates that weather conditions are the primary contributing factor, while technical malfunctions play a secondary role. However, structural defects can significantly complicate repair and restoration efforts.

Among the technical causes of failures, the most common issues include damage to insulators, line fittings, cables, conductors, and supports. The leading cause of support structure failures is corrosion of underground fastening elements [6,7]. In Kazakhstan, the most frequent reasons for power line outages are conductor and insulator damage, icing, and wire breakage.

The typical mass of ice accumulation on electrical conductors and cables is determined based on a cylindrical deposit formation with a density of 0.9 g/cm³ (Figure 1).



Figure - 1 – Typical ice formation on a power transmission line conductor
Compiled by the authors based on [2]



In 2021, wet snow on the support insulators of a 220kV substation in the Atyrau region caused a fire [5]. On March 13, 2021, due to freezing rain, hurricane-force gusts, and conductor icing, the 220 kV transmission lines "Kantau – GNPS" and "Shymkent – Mirgalimsai" were stopped due to the collapse of support insulators.

For the further development of the energy sector in the Republic of Kazakhstan, it is essential to consider the experience and challenges faced by foreign energy transmission organizations. In their study [6], scientists from the People's Republic of Bangladesh—Rahman K.M.D.J., Munni M.M., and Khan S.—analyzed the largest transmission line accidents worldwide, examining the number of affected individuals, recovery time, and causes of power outages from 1975 to 2015. Another study by researchers from the Republic of Colombia [7] presents global data on accidents that occurred between 2005 and 2016, classifying incidents based on their causes and economic consequences. However, these studies do not propose methods or strategies for reducing accident rates.

One of the methods for monitoring ice formation involves video recording the sagging of power transmission lines. The corresponding measurement post includes the following components: an optical marker, a temperature sensor, a video camera, a weather station, and a data processing unit. The primary communication channel is a cellular network. When a cellular network failure occurs, the information is transmitted through local systems in two directions, while the next system establishes a communication session with a cellular operator. Each local subsystem contains both hardware and software algorithm components. As a result, all collected and transmitted data is sent to a server, where it is processed and stored.

Results and discussion

The study determined the values of specific mechanical loads on 220-110 kV overhead power line wires, determined the values of critical spans, and calculated the loads. The efficiency of overhead power line operation in icy conditions was substantiated by reducing the overall span, increasing the height of supports, using composite and high-temperature wires, and increasing the cross-section or diameter of the wire of existing lines. Various schemes of ice-melting rectifier units were considered to develop measures to increase the efficiency of overhead power line operation in areas most susceptible to climatic influences.

The transmission of electrical energy from power plants or substations to consumers is carried out through power transmission lines, primarily overhead lines, which are an integral part of the power system. Additionally, overhead transmission lines utilize grounding wires for lightning protection. One of the key elements of a transmission line is the electrical conductor [8].

The most effective method for protecting against icing is ice melting, as it allows for the rapid removal of ice. When designing overhead power transmission lines, it is recommended to implement ice melting measures for lines with voltages up to 220 kV, especially if the route is located in an icing-prone area or in regions where lines frequently and significantly oscillate [8,9].

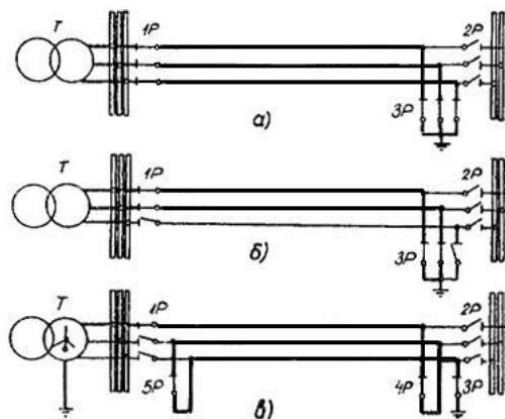
For 330 kV and 500 kV lines in certain regions, as well as for 35–220 kV lines in Zone III, where ice formation occurs, the decision to implement ice melting is based on technical and economic feasibility, considering the potential energy supply disruptions to consumers. Ice melting is primarily planned for transmission lines built under standards that do not comply with current regulatory requirements [10].

The electricity required for the ice melting program is supplied to the largest substations of the power system, located in areas with high ice accumulation. Ice melting begins as soon as the ice-wind load on the conductor reaches a predetermined value. To meet this requirement, for all conductors grouped under the ice melting mode, the direction of ice accumulation relative to the actual load and the transmission line route is taken into account. This means that for certain conductors, melting must begin in advance. The sequence of ice melting is determined based on consumer priority and the availability of backup power sources.

The minimum time required for the power transmission network is 12 hours for networks above 110 kV and 8 hours for 35 kV networks, which should be sufficient for ice melting on all overhead lines [10].

To reduce the costs of ice melting on overhead lines with bundled conductors, the lines are constructed using spacers between insulators. The distance between the spacers must be sufficient to prevent phase conductors from coming into contact with each other during uneven ice melting.

As a rule, the ice melting system should be activated within 1.0 hour after the dispatcher receives the ice melting signal. During ice melting by short-circuiting, the heated conductor is grounded at one end, while the other end is supplied with voltage sufficient to create the necessary current for melting (Figure 2).



a - three-phase short circuit; b - two-phase short circuit; c - "snake" scheme

Figure - 2 – Ice melting scheme using short-circuit method

Complied by the authors based on [2]

Therefore, the sequence of all tasks related to the installation of the ice melting scheme and the implementation of measures ensuring its rapid completion must be determined in advance. The assembly of the ice removal scheme is carried out using remotely controlled switching devices (circuit breakers, disconnectors) and, in some cases, manually operated devices. Temporary connections assembled using bolts, loops, overlays, or short circuits are not allowed.

Ice melting can be performed using three-phase, two-phase, and single-phase short circuits with conductors of all phases connected in series.

The three-phase short-circuit method is simple and convenient, as ice melting occurs simultaneously on all phases. When using the two-phase short-circuit method, the de-icing process must first be applied to two phases and then to three phases in combination with one of the already de-iced conductors.

Conclusion

The research results indicate that the implementation of such equipment will improve the energy efficiency of combating icing on power transmission lines and reduce the number of failures caused by ice accumulation.

The key methods and measures used to prevent icing-related accidents have been analyzed, leading to the development of efficiency standards for equipment designed to prevent ice formation on transmission lines.

The selection of the anti-icing mechanism and its placement has been justified, considering the span structure design and attachment method. Additionally, the experience in developing, installing, and operating systems in icing-prone areas has been analyzed and summarized to enhance the effectiveness of anti-icing measures for transmission lines and reduce energy losses.

Icing prediction data enables the system to forecast the development of icing with a certain probability and provide corresponding recommendations to substation personnel.

Gratitude

This study was supported by a contractual project with KEGOC, Kazakhstan Electricity Grid Operating Company, as part of the development of methods and devices for de-icing power lines. The authors are grateful to the company's management and staff for providing materials and consulting services during the writing process.

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А. Бегимбетова, Ф. Жандаулетова, А. Абикенова, Т. Бейсекова, Е. Тыщенко
КӨКТАЙҒАҚ ШӨГІНДІЛЕРІ ЖАҒДАЙЫНДА ЖОҒАРЫ ВОЛЬТТЫ ЭЛЕКТР БЕРУ
ЖЕЛІЛЕРІНІҢ СЕНІМДІЛІГІН ҚАМТАМАСЫЗ ЕТУ

Аннотация. Бұл жұмыста электр желілерінің қазіргі жағдайына және олардың сенімділігінің төмендеу себептеріне талдау жасалды. Зерттеу нәтижелері Қазақстан Республикасындағы электрберудің әуе желілеріне мұз түзілуінің әсерін анықтау және электр беру желілеріндегі конструкция элементтері үшін мұзды балқытудың тиімді әдісін негіздеу болып табылады. Көктайғарак - жел жүктемелерінің әсер ету жағдайында тұтынушыларды электр мен жабдықтаудың сапасы мен сенімділігін арттыруға бағытталған электротехникалық жүйелерді әзірлеу, оларды сынақтан өткізу, электр энергетикалық жүйелерде тиімділікті талдау және енгізу күрт континенттік климаты бар аймақтарда және бұрын-соңды болмаған экстремалды климаттық құбылыстар жағдайында өзекті міндет болып табылады. Ұсынылған Зерттеудің максаты-мұздану кезінде әуе электр желілерінің авариялық сөну себептерін талдау және электр жүйесінің апаттарының алдын алу үшін ток индукцияланған мұзды балқыту әдісін бағалау. Жұмыста күресу әдістері қарастырылған мұз түзілуімен, Қазақстан Республикасының өңірлерінде мұз түзілуіне әсер ететін Климаттық параметрлерді көпжылдық байқаулардың нәтижелері, қысқа тұйықталу тәсілімен мұзды балқыту құрылғысының тиімділігі, сымдарға күтілетін механикалық жүктемелерді талдау ұсынылды, сындарлы аралықтардың мәндері анықталды ЭБЖ үшін тіректердің іргетасын таңдау.

Кілт сөздер: электр мен жабдықтау жүйелерінің қауіпсіздігі, апат, мұзқату, сенімділік, мұзды еріту әдістері, диагностикалық әдістер, бақылау, мұздақты шөгінділер, әуеэлектр беру желісі.

Бегимбетова А., Жандаулетова Ф., Абикенова А., Бейсекова Т., Тыщенко Е.
ОБЕСПЕЧЕНИЕ НАДЕЖНОСТИ ВЫСОКОВОЛЬТНЫХ ЛИНИЙ ЭЛЕКТРОПЕРЕДАЧ В
УСЛОВИЯХ ГОЛОЛЕДНЫХ ОТЛОЖЕНИЙ

Аннотация. В данной работе произведен анализ современного состояния воздушных линий электропередач и причины снижения их надежности. Результаты исследования заключаются в выявлении влияния гололедообразования на воздушные линии электропередач в Республике Казахстан и обосновании эффективного метода плавки гололеда для элементов конструкции на линиях электропередач. Разработка электротехнических систем, направленных на повышение качества и надежности электроснабжения потребителей в условиях воздействия гололедно-ветровых нагрузок, их апробация, анализ эффективности и внедрения в электроэнергетических системах является актуальной задачей в зонах с резко-континентальным климатом и в условиях беспрецедентных экстремальных климатических явлений.

Цель представленного исследования заключается в анализе причин аварийных отключений воздушных линий электропередач во время обледенения и оценке метода токоиндуцированного плавления льда для предотвращения аварий энергосистемы. В работе рассмотрены способы борьбы с



гололедообразованием, представлены результаты многолетних наблюдений климатических параметров, влияющих на гололёдообразование в регионах Республики Казахстан, эффективность устройства плавки гололеда способом короткого замыкания, анализа ожидаемых механических нагрузок на провода, определены значения критических пролетов для подбора фундамента опор для ЛЭП.

Ключевые слова: безопасность систем электроснабжения, авария, обледенение, надежность, методы плавки гололеда, методы диагностики, контроль, изморозившее отложения, воздушная линия электропередач.