

Justification of the Causes of Mass Power Outages in Atyrau Electric Networks in January 2021

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Abstract. The article presents the results of studies to substantiate the causes of mass power outages at 220 kV high-voltage substations in Atyrau electrical networks in January 2021, during a period of dense fog and drizzling rain. The degree of contamination in the operation of external insulation of electrical equipment of 220 kV outdoor substations has been established based on laboratory results analyzes. The tests of IOS-110-1250T1 stress cone with natural pollution at fifty percent discharge voltage have been carried out. The qualitative and quantitative composition of collected rainwater components during the period of mass power outages has been determined. It has been established that the main cause of spark discharges and arc overlaps of external insulation of electrical equipment is their abnormal rapid contamination by conductive precipitation in the form of salt fog and drizzling rain. Natural sources of pollution of electrical networks with salt deposits and the likelihood of salt fogs are noted.

Keywords: electrical equipment, external insulation, electrical discharge, power outage, pollution degree, test, salt fog.

Introduction

In the period from January 10 to 22, 2021, at the facilities of Atyrau electrical networks of the Republic of Kazakhstan, there were massive emergency outages caused by arc overlaps of the external insulation of electrical equipment of overhead lines (OHL) and substations (SS). The largest number of outages (more than 80) occurred at 220 kV «Atyrau» substation, 220 kV «Inder» substation, 220 kV «Kulsary» substation, as well as 220 kV «Tengiz» substation. At the same time, arc overlaps of high-voltage insulators caused short circuits, triggering of relay protection and disconnection of outgoing power lines.

Electric (spark and arc) discharges on insulators of electrical equipment occur, as a rule, under adverse weather conditions [1]. On the above days, abnormal (for the winter period) weather conditions were recorded on the territory of Atyrau region: an increase in air temperature with drops near zero, high air humidity, fog, drizzling rain and melted snow.

«Salt» fogs, which cause strong spark discharges, represent the greatest danger to electrical networks and even arc overlaps of the outer insulation of high-voltage electrical equipment. Such salt fogs occur in areas of the seacoast every 5-7 years. They can move up to 100 km inland and are associated with certain weather conditions, including a colder flow in the air and temperature inversion [2, 3].

In literary references, there is practically no information about accidents in electrical networks associated with large-scale insulation overlaps in conditions of salt fog pollution. In some degree, this can be explained by the reluctance of energy companies to disclose information about accidents for commercial reasons or to maintain their image.

In the present case, massive outages at high-voltage substations led to significant interruptions in power supply of the enterprises and organizations in Atyrau region, discomfort for the population in the winter period and even claims against energy companies.

In the light of the above, the team of scientists of Almaty University of Power Engineering and Telecommunications named after G. Daukeyev with the participation of Gaivoronskiy A.S. (ass. prof. c.t.s, Federal State Budgetary Scientific Institution, Novosibirsk, Russia) conducted a research to substantiate causes of mass outages at 220 kV «Atyrau» substation, 220 kV «Inder» substation, 220 kV «Kulsary» substation, as well as 220 kV «Tengiz» substation in the period 10 to 22 January 2021.

Research methods

To establish causes of arc overlaps of electrical equipment insulators at the mentioned substations, studies have been carried out based on guidelines [4,

5]:

- assessment of likelihood of arc overlaps of the external insulation of electrical equipment due to their natural pollution;

- determination of fifty percent discharge voltage of the stress cone with natural pollution, which was operated during the period of mass accidents;

- analysis of the content of chlorides and sulfates in rainwater samples in the Atyrau region.

According to the accepted classification [4], there are two main types of pollution that can lead to overlapping of the external insulation of electrical equipment:

- type A: solid impurities containing an insoluble neutral component (sand, dust, clay, etc.) and a soluble component (salts), which ensures the conductivity of the pollution layer when moistened;

- type B: liquid conductive impurities (electrolytes) with a very low content of insoluble components or, in its absence, deposited on the insulation surface. This type of pollution is most often associated with coastal areas and is created by seawater or salt fog. Other sources of Type B pollution can be chemical emissions and acid rains.

The formation of type B contaminants, unlike type A, occurs quickly, especially under conditions of conductive salt fog. At the same time, after the termination of salt fog and drying of the insulation, its surface remains practically clean, the pollution does not accumulate.

The main pollution indicators of insulators by type A are [4]:

- equivalent density of salt deposits (EDSD), mg/cm²;

- density of insoluble deposits (DID), mg/cm².

The measurement of EDSD and DID, as well as chemical analysis of contamination of external insulation of electrical equipment at substations 220 kV «Atyrau», 220 kV «Inder», 220 kV «Kulsary» and

220 kV «Tengiz» was carried out by LLP «Republican research center for the protection of atmospheric air», Atyrau.

The measurement method is adopted in accordance with [4]. The collection of impurities from the insulation surface was carried out from at least two units of electrical equipment at each substation. The impurities were collected by the swab method separately from rib top and bottom of the insulators. We examined 22 samples in all.

The EDSD and DID indicators 220 kV «Atyrau» SS, 220 kV «Inder» SS, 220 «Kulsary» SS and 220 kV «Tengiz» SS are shown in Figure 1. At the same time, the diagrams show the maximum values of contamination of external insulation electrical equipment of each substation separately.

The analysis of Figure 1 shows that the indicators of contamination on insulators vary in the range: EDSD = 0.0131-0.025 mg/cm² and DID = 0.022-0.06 mg/cm². The highest values of such indicators were observed at 220 kV «Kulsary» SS and 220 kV «Tengiz» SS which are located closer to the shores of the Caspian Sea (from the west) and salt marshes (from the east).

The degree of pollution (EDSD = 0.0019-0.0064 mg/cm² and DID = 0.01895-0.06276 mg/cm²) on the outer insulation of RVS-220 kV arrester with the 220 kV «Kulsary» SS was confirmed by the laboratory «Sibenergo diagnostics» (Novosibirsk, Russia).

To determine the classes of pollution degree in operation (PDO), the averaged values of EDSD and DID were plotted on typical nomograms [4], which are shown in Figure 2.

The diagrams in Figure 2 show that EDSD and DID indicators at the substations under consideration relate to very light (a) and light (b) pollution [4, 5]. This degree of contamination of insulators could not cause arc overlaps of the external insulation of electrical equipment and lead to massive outages in

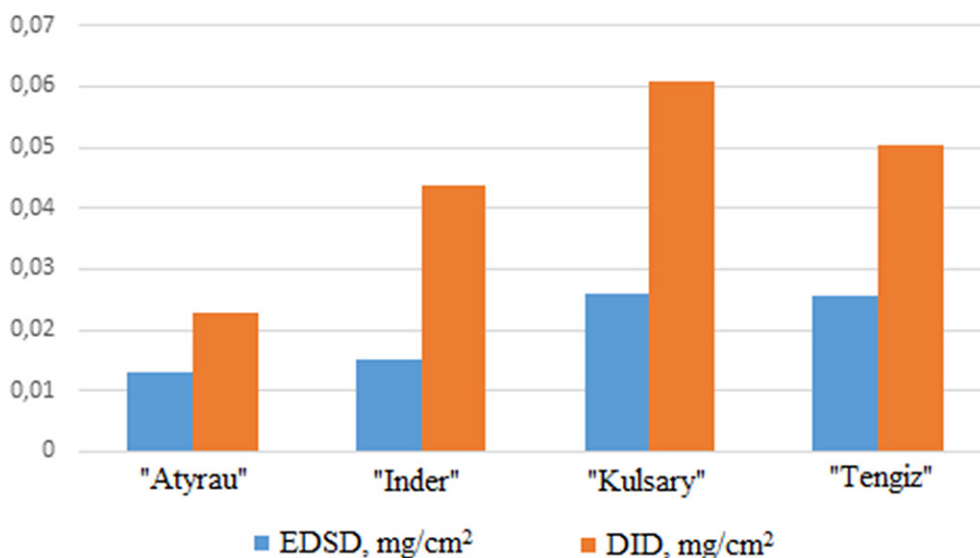
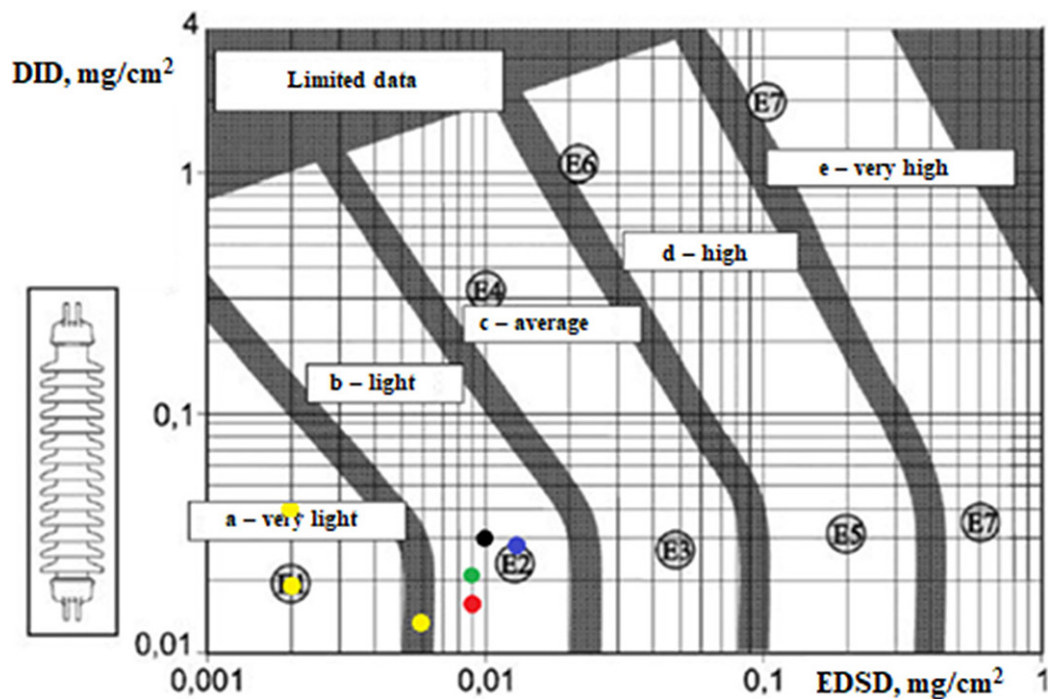


Figure 1 – EDSD and DID indicators on insulators of 220 kV SS in Atyrau electrical networks



- EDSD / DID averaged indicators of samples at 220 kV «Atyrau» SS;
- EDSD / DID averaged indicators of samples at 220 kV «Kulsary» SS;
- EDSD / DID averaged indicators of samples at 220 kV «Tengiz» SS;
- EDSD / DID averaged indicators of samples at 220 kV «Inder» SS;
- EDSD / DID indicators of samples from the insulator of RVS-220 kV arrester at the «Kulsary» substation (LLC «Sibenergo diagnostics», Novosibirsk, Russia)

Figure 2 – Determination of PDO classes of type A by averaged values of EDSD and DID [4]

Atyrau electrical networks in January 2021.

In addition, the electrical equipment at the substations under consideration has a performance category along the creepage distance of at least II* (for a number of equipment – III and IV), which ensures its reliable operation with an average degree of pollution [6-9]. At the existing levels of light pollution of type A, the margin of insulation dielectric strength exceeds the permissible one by 1.5-2 times.

To determine the fifty percent discharge voltage in case of natural pollution, in accordance with [10, 11], laboratory tests of the IOS 110-1250T1 stress cone were carried out, taken out of service at the 220 kV «Atyrau» SS and delivered to the Test Center of high-voltage electrical equipment of the Branch of «JSC STC FGC UES» – Siberia research institute (Novosibirsk, Russia). Fragments of tests of this stress cone under conditions of artificial humidification are shown in Figure 3.

Table 1 shows the results of tests to determine the fifty percent discharge voltage of the mentioned stress cone with natural pollution in conditions of artificial humidification and changes in the applied voltage. In parentheses, you can see the conductivity values measured with a megohmmeter before testing.

After test No. 8, the experiments were stopped because of a sharp decrease in conductivity due to the washout of natural pollution.

The protocol and test results show that the fifty

percent discharge voltage of the IOS 110-1250T1 stress cone under natural pollution is 194 kV, which is 2.4 times higher than the normalized test insulation voltage of 80 kV [10].

Laboratory tests of insulators used at 220 kV «Atyrau» and «Kulsary» substations in the period from 10.01.2021 until 22.01.2021, in the Testing Center of high-voltage electrical equipment of the Branch of JSC «STC FGC UES» – Siberia research institute and the laboratory «Sibenergo diagnostics» confirm the absence of significant pollution of type A. They indicate that the overlapping of the external insulation of electrical equipment in Atyrau electrical networks in January 2021 were caused by pollution type B, that is, conductive precipitation in the form of salt fog and drizzling rain.

To determine the nature of pollution by type B, we analyzed the data of the Republican State Enterprise (RSE) «Kazhydromet» in Atyrau region, Information bulletins on the environment situation in the Republic of Kazakhstan for 2015-2019 and the protocols of «Analytical Laboratory for Environmental Protection» LLP on the study of rainwater samples taken in the moment of drizzling rain on January 11, 2021 from the surface of insulators at «Atyrau» Substation.

In accordance with the data of «Analytical Laboratory for Environmental Protection» LLP, the above rainwater has contained chloride ions (59.59%)

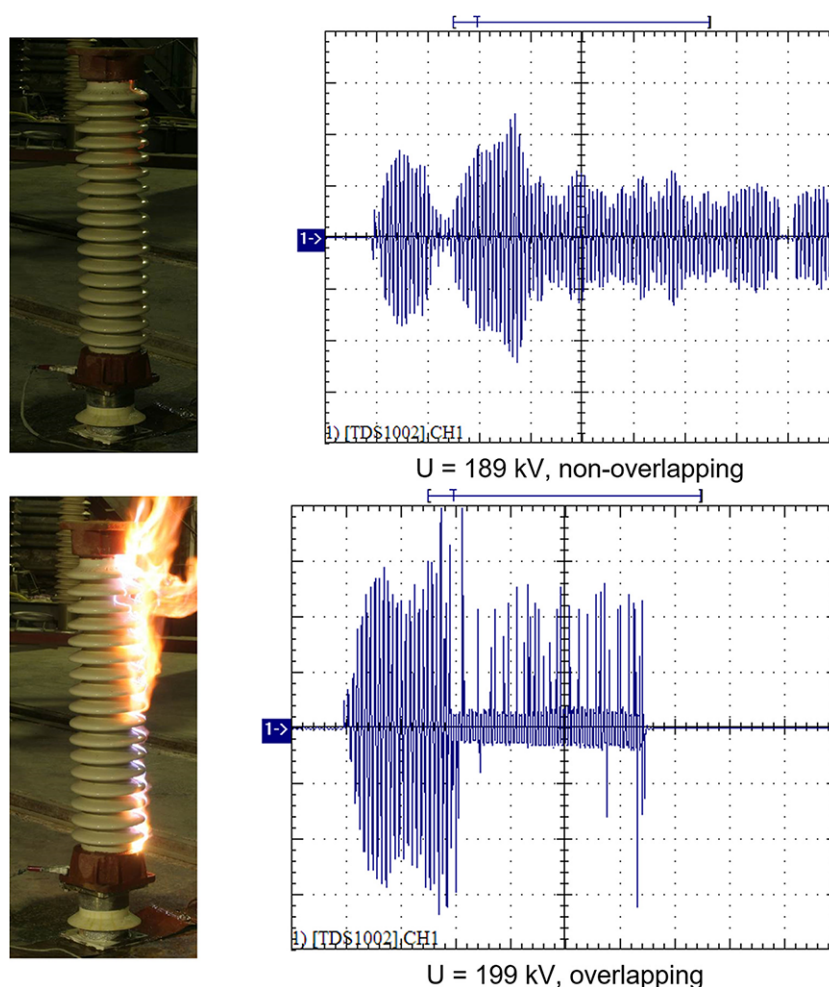


Figure 3 – Fragments of tests of the IOS 110-1250T1 stress cone in conditions of artificial humidification

Table 1 – Test of stress cone IOS 110-1250T1 with natural pollution in conditions of artificial humidification

No of test	Applied voltage, kV	Amplitude of leakage current along the pollution layer, mA	Superficial electric test conductivity, G, μS	Specific superficial electric conductivity, Gsp., μS	Overlapping (+), non-overlapping (-)
1	109	10	0,06 (0,14)	0,26	-
2	139	9	0,05 (0,11)	0,21	-
3	169	22	0,09 (0,14)	0,38	-
4	199	102	0,36 (0,13)	1,54	+
5	189	86	0,32 (0,22)	1,37	-
6	199	114	0,41 (0,40)	1,75	+
7	189	35	0,13 (0,33)	0,56	-
8	199	40	0,14 (0,29)	0,60	-

and sulfate ions (39.73%). In this case, the pH value = 7.85 of the specified sample of natural water has corresponded to the pH of seawater, the mineral composition of which is predominantly sodium chloride.

It is known that the presence of salts of strong electrolytes (NaCl , Na_2SO_4 , etc.) in humid air leads to their hydration and a significant increase in electrical conductivity [12].

Table 2 shows summary data on the concentrations of chlorides and sulfates in the rainwater of Atyrau region in recent years [13].

The analysis shows that the concentration of electrolyte ions in rainwater at the time of mass emergency outages (January 2021) significantly exceeds the average concentrations of these ions for 2015-2019: chlorides – by 3.7 times and sulfates – by 1.5 times.

Table 2 – Concentration of chloride and sulfate ions in rainwater in Atyrau region

Ions	2015	2016	2018	2019	2021 (during the accident)
Chlorides,%	21,13	13,60	10,92	18,06	59,59
Sulfates, %	19,90	19,30	31,86	32,20	39,73

Discussion of the results

Based on the analysis of the rainwater sample and the prevailing weather conditions during this period, it can be concluded that in January 2021 in Atyrau region periodically (from 10 to 11 January 2021 and from 15 to 17 January 2021), liquid conductive precipitation fell, containing a high concentration of chlorides and sulfates. These precipitations saturated the air with the smallest particles of salt (salt fog) in the regions of Atyrau electrical networks. As a result, conditions were created for a sharp increase in the electrical conductivity of humid air: 9.86 times for chlorides and 3.9 times for sulfates, which led to massive arc overlaps of the external insulation of electrical equipment. Outages occurred at almost all substations in Atyrau region. The largest number of outages occurred at overhead lines and substations in the immediate vicinity of the Caspian Sea coast, at a distance of 5-40 km.

Findings and conclusion

The current state of contamination of the external insulation of electrical equipment at 220 kV «Atyrau»,

«Inder», «Kulsary» and «Tengiz» substations corresponds to the class of light pollution according to [4] and does not pose a danger to the operation of the equipment.

The reason for overlapping insulation of electrical equipment and massive outages at 220 kV «Atyrau», 220 kV «Inder», 220 kV «Kulsary» and 220 kV «Tengiz» substations, in particular, in the period from 10 to 11 January 2021 and January 15-17, 2021, abnormal rapid type B insulation pollution should be considered conductive precipitation in the form of salt fog and drizzle.

Natural and technology-related factors can be the probable reasons for the excess concentration of chlorides and sulfates in the atmosphere. Type B pollution is most often associated with the presence of nearby seacoasts, salt lakes or salt marshes.

In Atyrau region, there are many natural and industry-related sources of environmental pollution with salt deposits, which, with a high degree of probability, could contribute to the formation of salt fog at the facilities of Atyrau electrical networks in January 2021 [14-16].

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Атырау электр тораптарындағы 2021 жылдың қаңтар айындағы жаппай ажыратулар себептерін негіздеу

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Аңдатпа. Мақалада 2021 жылдың қаңтарында қалың тұман және бұрқасын жауған жаңбыр кезінде Атырау қаласының электр желілерінің 220 кВ қосалқы станцияларындағы жоғары вольтты қосалқы станциялардағы жаппай ажыратулар себептерін негіздеу бойынша зерттеулердің нәтижелері берілген. Зертханалық талдаулар нәтижелері бойынша 220 кВ қосалқы станцияларының ашық қосалқы станцияларының электр жабдықтарының сыртқы оқшауламасының жұмысындағы ластану дәрежесі белгіленді. Табиғи ластануы бар ИОС-110-1250Т1 тіректі изоляторының разрядтық кернеуінің елу пайыздық мәнінде сынақтар жүргізілді. Жаппай ажыратулар кезеңінде жиналған жаңбыр суының құрамдас бөліктерінің көлемдік және сапалық құрамы анықталды. Электр жабдығының сыртқы оқшаулауының ұшқындық разрядтарының және доғалық беттік тесілудің негізгі себебі олардың тұзды тұман және жаңбыр түріндегі электрлік өткізгіштікке ие жауын-шашынмен жылдам және шектен тыс ластануы екені анықталды. Электр тораптарының тұзды шөгінділермен ластануының табиғи көздері және тұзды тұманның ықтималдығы атап өтілді.

Кілт сөздер: электр жабдықтары, сыртқы оқшаулама, электр разряды, ажырату, ластану дәрежесі, сынақ, тұзды тұман.

Обоснование причин массовых отключений в Атырауских электрических сетях в январе 2021 года

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Аннотация. В статье приведены результаты исследований по обоснованию причин массовых отключений на высоковольтных подстанциях ПС-220 кВ Атырауских электрических сетей в январе 2021 года, в период густого тумана и морозящего дождя. На основе результатов лабораторных анализов установлены степени загрязнения в эксплуатации внешней изоляции электрооборудования открытых подстанций ПС 220 кВ. Проведены испытания опорного изолятора ИОС-110-1250Т1 с естественным загрязнением на пятидесятипроцентное значение разрядного напряжения. Определен качественный и количественный состав компонентов дождевых вод, собранных в период массовых отключений. Установлено, что основной причиной искровых разрядов и дуговых перекрытий наружной изоляции электрооборудования является аномальное быстрое загрязнение их проводящими осадками в виде соляного тумана и морозящего дождя. Отмечены природные источники загрязнения электрических сетей солевыми отложениями и вероятности возникновения соляных туманов.

Ключевые слова: электрооборудование, наружная изоляция, электрический разряд, отключение, степень загрязнения, испытание, соляной туман.

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