Lightning activity in Yakutia and its impact on the networks of PJSC Yakutskenergo

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Abstract. It is shown that daily, seasonal and interannual variations in the number of lightning outages in the Central and Western energy district regions of Yakutia correspond to variations in lightning activity in the area where these networks are located. The annual number of lightning outages was from 35 to 65. The daily variation has the form of a one-period wave with a maximum at 19:00 local time and a minimum at 7:00 LT. In the total diurnal variation over 7 years around 7 LT, about two outages were observed, while at 19 LT the total number reached 25. The similarity of daily, annual, and interannual variations in lightning activity and the number of thunderstorm outages indicates the absence of special features in the discharges that lead to thunderstorm outages of high-voltage networks.

1. Introduction

Lightning discharges often cause power line failures. According to [1], more than 30% of blackouts in the USA are related to thunderstorms. Data of 250 lightning outages on high-voltage electrical networks 110-220 kV in the western and central power regions of Yakutia, for 2012-2018, provided by PJSC Yakutskenergo, are analyzed. Lightning activity in the Republic of Sakha (Yakutia) by means of the World Wide Lightning Location Network (WWLLN) data in 2009-2019 [2, 3] were analyzed. The positive cloud-to-ground lightning strokes (CG) [4] were analyzed according to the data of a single-point lightning direction finder Stormtracker manufactured by Boltek Co (Canada) with an effective observation radius of 480 km around the installation site. The device is in the city of Yakutsk and completely covers the territory of the Central Energy District. The lightning direction finder software allows evaluating lightning parameters such as the type of lightning (cloud-to-cloud, cloud-to-ground, compact intracloud discharge) and the sign of the transferred charge. Positive cloud-to-ground lightning stroke represents the highest probability of a shutdown of power transmission lines due to thunderstorm, since it carries a greater electric charge, have a longer discharge duration compared to negative CG-lightning stroke. However, the probability of occurrence of a positive CG discharge is in the range of about 15% of the total number of CG lightning strokes [5, 6].

This paper analyzes lightning activity on the territory of the Republic of Sakha (Yakutia) in 2009-2019, its daily and seasonal variations, variations in the duration of the thunderstorm season, the ratio of the number of discharges of various types.
2. **Analysis of lightning activity in Yakutia**

A map of the density of lightning discharges in Yakutia, corrected by the relative detection efficiency of the WWLLN system, is shown on the figure 1. The maximum lightning activity was observed in the southern and western zones of Yakutia, where the main high-voltage power lines of PJSC Yakutskenergo are located. The main power line network of the Western Energy District is located from Udachny, Aikhal to the south to Mirny, a cascade of Vilyui hydroelectric power plants and then to Lensk and Peleduy and reach the western zone of a high lightning activity. The ratio of 171 lightning outages in the Western and 79 in the Central power districts at high-voltage 110-220 kV electrical networks and 11 at the substations of the Vilyuysk hydroelectric power station cascade and 7 at the Yakutskaya GRES in 2012-2018 corresponds to the ratio of the density of lightning discharges. The interannual variations in the number of lightning discharges from 2009 to 2018 for three zones of Yakutia: northern 66-74 N, 105-160 E; southern 56-60N, 120-130E and western 60-64N, 110-120E is shown in figure 2. Quasi-oscillatory character of variations with a period of about 4 years can be noted. In general, for the territory of Yakutia, there is a positive trend in lightning activity, especially for the northern regions. The total lightning number over the entire area of Yakutia has increased 1.5 times over 10 years.

![Figure 1. Lightning discharges density in Yakutia in 2009-2019 with a resolution of 0.25x0.25 gr. (category / sq. km, logarithmic scale).](image)

The southern and western zones are characterized by the highest average long-term lightning density in Yakutia, and the increase in lightning activity in the zones did not exceed the 5-year average. Lightning activity in the northern regions increased in 2014 and 2015 more than 2 times the level from 5 previous years. Variations in lightning activity in Central Yakutia correlated with variations in lightning activity in the huge region with high lightning density, the center of which is in the valley of the Amur and Sungari rivers, caused by the summer monsoon. Variations in the annual total number of lightning strokes in Central Yakutia and entire Yakutia showed an oscillatory character with a period of 2-3 years. Based on the variations in the total number of lightning strokes per month, it can be assumed that the maximum intensity of lightning activity shifts from the beginning of the season to the end within 3-4 years.
3. Analysis of data on lightning outages in the Central and Western energy regions

Let us consider the changes in the start and end dates and duration of thunderstorm seasons during the period of 2009-2019 (figures 3 and 4). Note that the beginning of the thunderstorm season during this period shifted to earlier dates, and the end to later ones and, consequently, the duration of thunderstorm seasons increased. The start date of thunderstorm activity varies within 2 weeks, with the exception of 2015. The end time of the season shifts to later dates, which leads to an increase in its duration in the period under consideration.

Let us compare these interannual variations with the number of lightning outages on the networks of Yakutskenergo PJSC for 2012-2018, which are shown in figures 5.

First of all, we note that from 2012 to 2018 the increase in the number of lightning outages corresponds to an increase in both the total lightning activity in Yakutia and the observed increase in all three selected zones. The year of 2015 was characterized by the largest number of lightning outages. It is also characterized by significant lightning activity in Yakutia. And the decline in the number of lightning outages in 2016 corresponded to the decline in lightning activity. A sharp increase in the total lightning activity in 2017 was caused by an increase in thunderstorms in the northern and southern parts of Yakutia. In the western part there was a much smaller increase in total lightning stroke number, that determined a slight increase in lightning outages in the networks of Yakutskenergo PJSC in 2017 and a further increase in 2018 compared to 2016. The earliest onset of lightning outages was recorded on May 28, 2014, and the last on August 30, 2014. It was also the longest thunderstorm period with similar dates in 2014. The average seasonal variation assumes a peak in mid-summer lightning activity in July.
Figure 3. The number of days with a thunderstorm and the duration of thunderstorm seasons during the period of 2009-2019.

Figure 4. Variation in the timing of the beginning and end of thunderstorm seasons during 2009-2019.

Figure 5. Interannual variations in the number of lightning outages in the networks of the central and western power regions of PJSC Yakutskenergo.
However, the change in the seasonal variation of the total monthly lightning activity in Yakutia shows that there is a quasi-annual shift of the peak of activity from the beginning of the summer season (June) to its end (August) and back with a period of about 2-4 years. The daily variation of lightning outages in the networks of PJSC Yakutskenergo is shown in figure 6. The polynomial trend is presented as: 

\[ N = -0.01T^3 + 0.49T^2 - 4.99 + 16.53, \]

\[ R^2 = 0.8, \]

where \( N \) is lightning outages and \( T \) is a local time.

The daily variation in the number of lightning outages corresponded to the daily variation in the number of lightning strokes in Yakutia, shown in figure 7.

\[ \text{Figure 6. Daily variation of lightning outages of networks of PJSC Yakutskenergo.} \]

\[ \text{Figure 7. Seasonally averaged normalized daily variation of the number of lightning discharges.} \]

It can be noted that if in June the maximum is in the afternoon, then by August the maximum shifts towards the evening, and a second maximum appears at night. This maximum is determined by the lakes releasing the heat accumulated during the day to the atmosphere at night. In accordance with the diurnal variation of lightning activity, the number of lightning outages in different months at different hours of the day can also be expected.

Lightning outages are mainly caused by cloud-to-ground discharges. It should be considered that positive CG discharges have a peak current of about 10 times more than the peak current of negative...
CG discharges. Note that from 2009 to 2018 the share of negative CG discharges decreased, which means that the share of more dangerous positive CG discharges grew on average from 10% to 15%.

The share of the number of negative cloud-to-ground lightning strokes to the total number of lightning CG strokes over the area covered by observations varied on average about 80% for the season. On average, during a day with intense thunderstorm, the share of positive CG lightning is about 10%. The daily share reaches ~20% mainly at the end of June and the end of August. The share of positive CG lightning increased after the maximum total lightning activity in 70% of thunderstorm events with a duration of more than 2 hours over the considered territory in 2016-2017. According to WWLLN estimates, the distribution of lightning energies shifts to higher values after the maximum lightning activity, which probably corresponds to the more frequent occurrence of positive CG lightning strokes with high currents in the channel. When considering the entire array of available data from 2009 to 2019 the fact of an increase in the share of positive lightning after the stage of maximum thunderstorm activity is also confirmed in ~ 70% of cases of intense (more than 20 lightning per hour) and prolonged thunderstorms (more than 1 hour) at an hour resolution. The total number of positive CG lightning strokes most often was more than 50% of the maximum in the hour following this maximum. It is assumed that after the stage of maximum lightning activity associated with the active development of vertical processes inside the cloud, that processes attenuate, and due to horizontal processes, the positively charged upper part of the cloud is shifted relative to the lower negatively charged part of the cloud, thereby increasing the likelihood of favorable conditions for the positive CG lightning stroke. In addition, we note that “intercloud” short-range discharges are often inclined and it is their magnetic component that creates currents induced in neutrals, therefore they also pose a danger to electrical networks. The thunderstorm moves at an average speed of 44 km/h and has an average area 5000-10000 km² for Yakutia [6]. Hence, it is assumed that lightning strokes of one thunderstorm occurring within a radius of 10 km around the power transmission line can cause power line shutdowns within 1-2 hours, even during a thunderstorm moving across the line.

4. Conclusion
It is shown that daily, seasonal and interannual variations in the number of lightning outages in the Central and Western energy districts of Yakutia corresponded to variations in lightning activity in the area where these networks are located. The annual number of lightning outages is from 35 to 65. The daily variation has the form of a one-period wave with a maximum at 19:00 local time and a minimum at 7:00 LT. In the total diurnal variation over 7 years around 7 LT, about two outages were observed, while at 19 LT the total number reached 25. The similarity of daily, annual, and interannual variations in lightning activity and the number of thunderstorm outages indicates the absence of special features in the discharges that lead to thunderstorm outages of high-voltage networks.

Acknowledgment
This work supported by the Ministry of Education and Science of the Russian Federation, budgetary theme, AAAA-A21-121012000007-4.

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