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## Reliability indicators of 10 kV cable lines in rural areas

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**Abstract.** Based on statistical data, the article analyzes and proposes a combination method for calculating the reliability indicators of power supply to agricultural consumers (equivalent duration of outages, frequency of failures and deliberate outages, recovery time) when using cable and overhead lines. It has been established that the reliability of rural cable lines is slightly higher than overhead and the use of cables in rural electric networks improves the reliability of power supply to consumers by eliminating failures, and also leads to an increase in the reliability of transformer substations by reducing the number of damage to transformers.

### 1. Introduction

Solving the problems of reliable provision of agricultural production with the necessary amount of electricity requires the further development of agricultural electrical networks, including the use of cable lines to improve the reliability of power supply to consumers and the quality of transmitted electricity. In this regard, an important task is to increase the reliability of power supply to agricultural consumers using cable networks and reduce the loss of electricity in cable lines through the use of their optimal parameters in the design of rural electric networks.

### 2. Methods

As an indicator of the reliability of electricity supply to agricultural consumers, the equivalent duration of outages [1], the value of which depends on the reliability indicators of network elements, and mainly transmission lines, is currently accepted. For distribution power lines (air and cable), this indicator can be determined by the formula:

$$T_p = \alpha_p l_p = (\omega\tau + \gamma_n v \vartheta) \quad (1)$$

where  $\alpha_p$  - is the specific equivalent line failure duration;  $l_p$  - total length of line sections, km;  $\omega, v$  - the specific frequency of failures and intentional outages, respectively, 1 / year\*km;  $\vartheta$  is the average time of one recovery and the average time of one line service (recovery after a deliberate shutdown), h;  $\gamma_n$  - coefficient taking into account the lesser severity of planned outages, equal to 0.33.

The values of indicators included in (1) are found by processing the statistical data of existing networks. However, due to the small number of cable lines (CL) in rural areas, the necessary statistical data on their reliability indicators are not available. In this regard, a combination method is proposed to determine the reliability indicators of cable lines in rural areas. The essence of this method lies in the fact that the indices of elemental reliability of CL in rural areas are determined indirectly by a



differentiated analysis of the reliability indices of other similar objects by certain attributes and the subsequent synthesis of the necessary indices with new quantitative characteristics and qualitative properties corresponding to new possible conditions.

### 3. Results and Discussion

From an analysis of the causes of damage to cable lines, it is obvious that all factors determining the magnitude of the CL failure rate in urban conditions will also occur in rural areas. However, the degree of influence of these factors on the indicator  $\omega$  as a whole will be different and, therefore, its significance for rural conditions will be different than for urban conditions.

The failure rate for cable lines in rural areas is proposed to be determined from the expression:

$$\omega = \omega_{\text{эл}} + \omega_{\text{мех}} \quad (2)$$

where  $\omega_{\text{эл}}$  is taken according to statistics for urban cable lines, and  $\omega_{\text{мех}}$  is taken from statistics on communication lines in rural areas.

There are significant difficulties in estimating the average recovery time. In this regard, in studies, the value of  $\tau$  was determined on the basis of analysis and synthesis of the components of the recovery time of urban cable and rural overhead power lines, taking into account the characteristics of rural networks[2].

The average recovery time CL in case of failures consists of the time required to locate damage  $\tau_{\text{лок}}$ , locate damage  $\tau_{\text{омп}}$ , repair fluid damage, test and turn on cable line  $\tau_{\text{вкл}}$ , i.e.

$$\tau = \tau_{\text{лок}} + \tau_{\text{омп}} + \tau_{\text{ликв}} + \tau_{\text{вкл}} \quad (3)$$

The localization time and the time of testing and switching on the line are determined by the network configuration and operating conditions and it can be assumed that they do not depend on the version of the power line. Therefore, the  $\tau_{\text{лок}}$  and  $\tau_{\text{вкл}}$  values were taken according to statistics for rural CL.

Unlike  $\tau_{\text{лок}}$  и  $\tau_{\text{вкл}}$ , the time for determining the location of damage  $\tau_{\text{омп}}$  and the time for eliminating damage  $\tau_{\text{ликв}}$  for cable lines differ significantly from  $\tau_{\text{омп}}$  и  $\tau_{\text{ликв}}$  for overhead lines and depend on the operating conditions and the terrain in which they are located.

As analysis has shown, the value of  $\tau$  depends on the ratio of electrical breakdowns and direct mechanical damage. The time spent on determining the location of damage during direct mechanical damage is much less, especially during electrical breakdowns, and they can be practically neglected. Therefore, the average recovery time for direct mechanical damage is also shorter.

By virtue of the above reasoning, the value of  $\tau$  can be determined from the expression:

$$\tau = \frac{\omega_{\text{эл}}}{\omega} \tau_{\text{эл}} + \frac{\omega_{\text{мех}}}{\omega} \tau_{\text{мех}} \quad (4)$$

where  $\tau_{\text{эл}}$  - average recovery time for electrical failures;  $\tau_{\text{мех}}$  - average recovery time for mechanical failures;

Moreover, the values of  $\tau_{\text{эл}}$  и  $\tau_{\text{мех}}$  are determined by the expression (3), and  $\omega_{\text{эл}}$  - according to the calculated indicators obtained for rural areas.

To determine the value of  $\vartheta$ , the following formula is proposed:

$$\vartheta = \kappa_{\text{п}} \vartheta_{\text{п}} + (1 - \kappa_{\text{п}}) \vartheta_{\text{у}} \quad (5)$$

where  $\kappa_{\text{п}}$  - coefficient showing the ratio of the number of breakdowns during preventive tests to the total number of preventive tests;  $\vartheta_{\text{п}}$  - average breakdown time during routine testing;  $\vartheta_{\text{у}}$  - average maintenance time for a successful preventive test.

The values of  $\kappa_{\text{п}}$  и  $\vartheta_{\text{у}}$  are taken from the statistical data for urban cable networks, and the value of  $\vartheta_{\text{п}}$  is taken equal to the average recovery time.

The proposed method allows you to determine the estimated reliability indicators of cable lines in rural areas. The indicators are set on the basis of data on electrical damage and their elimination in urban electrical networks and mechanical damage to cable lines in rural areas. Hence the interpretation of the method as combinational. The combination of reliability indicators of various objects is made using the methods of analysis and synthesis in inextricable unity.

The failure rate was calculated in accordance with expression (2). The component of the frequency of failures from electrical damage is determined based on the analysis of statistical data on failures of existing cable networks. An analysis of the technical causes of failures of urban cable lines [5] showed that they will also occur for agricultural cable lines.

As can be seen from the above analysis, a number of opposing factors will influence the number of CL failures in rural areas compared to urban ones, some of which will reduce it. Unfortunately, due to the lack of statistics on rural CL, it is not possible to quantify the impact of these factors. Therefore, when calculating the failure rate, component  $\omega_{\text{эЛ}}$  is adopted based on statistics on urban cable network failures.

From the analysis of the failure rate of cable lines it follows that its value is 2 ... 6 failures per 100 km per year, with 50% of failures due to direct mechanical damage to the cables. Thus, the value of  $\omega_{\text{эЛ}}$  for cable lines in rural areas can be taken equal to 1 ... 3 failures per 100 km per year with an average value of 2 open / 100 km.year. Considering that the damage caused by fires and the transfer of networks to high voltage is on average about 4%, the indicator  $\omega_{\text{эЛ}}$  for rural cable networks was assumed to be from 0.96 to 2.88 with an average value of 1.9 open / 100 km. year.

The failure rate component  $\omega_{\text{mex}}$  was determined in accordance with the proposed methodology according to the statistics of district communication lines in rural areas and the value  $\omega_{\text{mex}}$  was assumed to be equal to 0.13 off / 100 km.year on average for Uzbekistan.

Therefore, the failure rate for agricultural cable lines in accordance with formula (2) lies in the range of 1.09 ... 3.01 open / 100 km.year with an average value of 2.03 open / 100 km.year.

Thus, in accordance with expression (3), the average recovery time for electrical damage lies in the range:

$$\tau_{\text{эЛ}} = (1,5 \dots 2) + (2 \dots 8) + 9 + (0,5 \dots 1) = 13 \dots 20 \text{ h.}$$

With mechanical damage, the average recovery time is shorter than with electrical damage, since the location of the damage is already known. The localization time is also shorter, since there is no need to find the damaged area. This time can be taken equal to 1 hour. Thus, the average recovery time for mechanical damage is 10.5 ... 11 hours.

Therefore, based on expression (4), the average recovery time is

$$\tau = \frac{1,9}{2,03} (13 \dots 20) + \frac{0,13}{2,03} (10,5 \dots 11) \approx 12,9 \dots 19,5 \text{ h}$$

The specific equivalent duration of outages is greatly influenced by the frequency of intentional outages and the average service time, which characterizes the number and duration of planned outages of cable lines.

In accordance with the proposed methodology, the frequency of deliberate outages was determined on the basis of statistical data of urban cable lines and prospective data on the lengths of cable line sections in rural areas. The analysis of statistical data on the planned preventive tests CL in urban conditions [1-4] showed that their frequency is 1.0 ... 1.2 isp / lin.year. The analysis of the "Development schemes for the distribution of 10 kV distribution networks for agricultural areas of electric networks" executed in the cable version showed that the average length of cable line sections in rural areas is about 3.5 km. Thus, in accordance with expression (6), the frequency of deliberate trips is

$$\nu = (1,0 \dots 2,0) \frac{1}{3,5} = 0,29 \dots 0,34 \text{ isp/km.year.}$$

The value of the average service time was determined in accordance with the expression (5). The average service time for a successful test according to the data for urban CL [1-4] is 1 ... 2 hours. The value of the  $\kappa_{\text{n}}$  coefficient varies between 0.055 ... 0.3 with an average value of 0.175. In accordance with the methodology, the average service time in the event of a breakdown during a preventive test can be taken equal to the average recovery time, i.e.  $n = 12.9 \dots 19.5$  hours with an average of 16.2 hours

Thus, the average service time in accordance with expression (5) is:

$$\vartheta = (12,9 \dots 0,3) \cdot (12,9 \dots 19,5) + (0,945 \dots 0,7) \cdot (1 \dots 2) = 1,65 \dots 7,25 \text{ h}$$

The average value of  $\vartheta$  is

$$\vartheta = 0,175 \cdot 16,2 + (1 - 0,175) \cdot 1,5 = 4,0 \text{ h}$$

Given the necessary components obtained, the specific equivalent duration of outages was calculated in accordance with expression (1). The results of calculating the reliability indicators of cable power lines in rural areas are given in table. 1. Here, for comparison, similar indicators of overhead lines are given according to [5-7].

**Table 1.** Reliability indices of overhead and cable lines 10 kV

Reliability indicators	Power lines	
	Aerial	Cable
Failure rate $\omega$ , fail/km.year	$\frac{0,05 \dots 0,25}{0,15}$	$\frac{0,01 \dots 0,03}{0,02}$
Average recovery time $\tau$ , h/fail	$\frac{3,5 \dots 7,5}{5,5}$	$\frac{12,9 \dots 19,5}{16,2}$
Frequency of intentional outages $\nu$ , fail/km.year	$\frac{0,05 \dots 0,25}{0,15}$	$\frac{0,29 \dots 0,34}{0,31}$
Average service time $\vartheta$ , h/fail	$\frac{3,5 \dots 7,5}{5,5}$	$\frac{1,6 \dots 7,2}{4,0}$
Specific equivalent outage duration $\alpha_p$ , h/km.year	$\frac{0,2 \dots 0,5}{1,1}$	$\frac{0,31 \dots 1,39}{0,75}$

**Note.** The numerator shows the range of indicators denominator - average

Data analysis table. 1 shows that the failure rate of CL is on average an order of magnitude lower than the failure rate of AL. The average recovery time for CL is approximately 3 times longer than for overhead lines. The frequency of intentional blackouts CL is slightly higher than overhead, and the average time for servicing cable lines is slightly lower. It should be noted that the component of the specific equivalent duration of cable line outages associated with emergency outages is 2.5-3 times less than the same component for overhead lines, and the component associated with planned outages is 1.5 times more.

The specific equivalent duration of outages in rural areas is approximately 1.4 times that of cable lines. This is due to the significantly lower failure rate of cable lines.

In accordance with the principles of a systematic approach, it is necessary to consider the reliability of other elements of the cable network. Switching to cable networks will affect the reliability of transformer substations, and in the first place, transformers themselves. Analysis of the reliability of transformers in rural distribution networks [8-12] showed that one of the main reasons for their failure is lightning surges. It is obvious that the use of cable lines in agricultural distribution networks will significantly reduce the number of transformer damage for this reason, which will accordingly reduce the total number of failures of rural substations. According to [13-14], in air networks of 6-10 kV, up to 21.0% of transformers are damaged due to lightning overvoltages, while in cable networks only 3.57%. According to the data of Uzenergoengineering JSC, in the 6 - 10 kV air network, lightning overvoltages cause 26% of transformer damage, and only 3% in cable. Moreover, it is noted that the damage to transformers in air networks is about 10 times higher than in cable ones. This is due to the frequent exposure of transformers to lightning surges, a large number of short circuits on overhead lines of 0.38 kV, etc. This conclusion is confirmed by foreign data. According to in Germany for the observation period 2000-2010. the failure rate of 10 kV transformers is 0.207, 20 kV - 0.419, 30 kV - 0.686 per 100 transformers per year. In Poland, the failure rate of transformers 2–

20 kV is two times lower than that of transformers 30–40 kV [15]. In Austria, the number of transformer failures in the 20 and 30 kV network in 2001–2002. amounted to about 3 per 100 transformers per year, and in the 10 kV network - 0.55 ... 0.36 [10–16].

#### 4. Conclusions

1. As a result of studies, it was found that the reliability of rural cable lines is slightly higher than overhead and the average calculated specific equivalent duration of disconnection of rural cable lines is 0.75 hours / km.year with a change in the range from 0.3 to 1, 5 h / km
2. The use of CL in rural electric networks can improve the reliability of power supply to consumers by eliminating failures from icy-wind effects and leads to increased reliability of transformer substations of 35/10 kV and 10 / 0.4 kV by reducing the number of transformers and other equipment of substations damage due to lightning overvoltages.

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