Study of reliability indicators of cable lines in rural areas

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Abstract. In this article, the investigation of the power supply system's reliability in our Republic, particularly focusing on the cable lines utilized in rural power networks, is highlighted as a pressing concern within the energy sector today. A crucial task in addressing this issue successfully involves researching the reliability metrics of existing cable lines, specifically self-contained insulated conductors in rural power networks with dynamic variable loads, and formulating pertinent recommendations. The reliability indicators of cable lines in rural areas were assessed using a comprehensive method that integrates modern approaches and the latest advancements in science and technology. The method's superiority over others is grounded in scientific principles. Furthermore, factors influencing the reliability metrics of cable lines in rural power networks, such as cable line failures, are systematically categorized.

1 Introduction

Currently, the equivalent duration of interruptions is used as an indicator of reliability of electricity supply to agricultural consumers [1,2,3], its value depends on the reliability indicators of network elements, mainly power transmission lines. It should be noted that high-quality implementation of construction-assembly works and operation, that is, compliance with the requirements of instructions and regulations, increases the reliability indicators of cable lines. This is the basis for the use of indicators of cable networks performed according to the requirements of the instructions and the rules of technical operation of consumer electrical devices (RTOCED) in determining the calculation indicator of the frequency of cable line interruptions in rural areas [4,5,6].

The average recovery time of a cable line depends on the repair time, which in turn is determined by the status of the damaged line in the network scheme (the line is reserved or not reserved, the category of consumers) [7,8].

In this article, since the reliability of the elements of the cable line is determined, the average recovery time should not indicate the backup capabilities of consumers (in this case, the repair of the line may begin after a certain time after the damage, and the recovery time will be longer than the repair time), but only take into account the time spent on the elimination of the damage and the operation of the line is needed [9,10].

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2 Materials and methods

In separate data sources, the frequency of preventive tests is given in relation to the length of the line. This is a convenient indicator, and according to the method of determining the equivalent comparative duration of interruptions, it is necessary to obtain its contents in relation to the length of the power transmission line [11-15]. To get the indicator of the frequency of preventive tests per 1 km of length, it is necessary to recalculate according to this expression:

$$\nu = f_{o'ch}\frac{1}{l_s} \tag{1}$$

where $f_{o'ch}$- the frequency of preventive tests for the line section, test/year; l_s- the average length of the tested section of the cable line, km.

Currently, the equivalent duration of interruptions is used as an indicator of the reliability of electricity supply to consumers of rural electricity networks. For distribution power lines (overhead and cable), this indicator is determined by the following expression:

$$T_h = \alpha_{sol} \cdot l_{um} = (\omega\tau + \gamma_r \nu \vartheta) \tag{2}$$

where α_{sol} - relative equivalent duration of interruptions in lines; l_{um} - total length of line sections, km; ω, ν - respectively, the relative frequency of interruptions and preliminary shutdowns, 1/yr.km; τ, ϑ - the average time of one recovery and maintenance of the line (recovery after previous outages), hours; γ_r - the coefficient that takes into account the consequences of planned interruptions, equal to 0,33.

In this regard, a combination method was proposed to determine the reliability of cable lines in rural areas. The essence of this method is that the reliability indicators of cable lines in rural areas are indirectly determined by differential analysis of the reliability indicators of other similar objects according to certain characteristics and by synthesizing the indicators in new conditions. The values of the indicators included in the expression are found by processing the statistical data of the current networks. However, due to the scarcity of cable lines in rural areas, the necessary statistical data on their reliability indicators are not available (Figure 1).

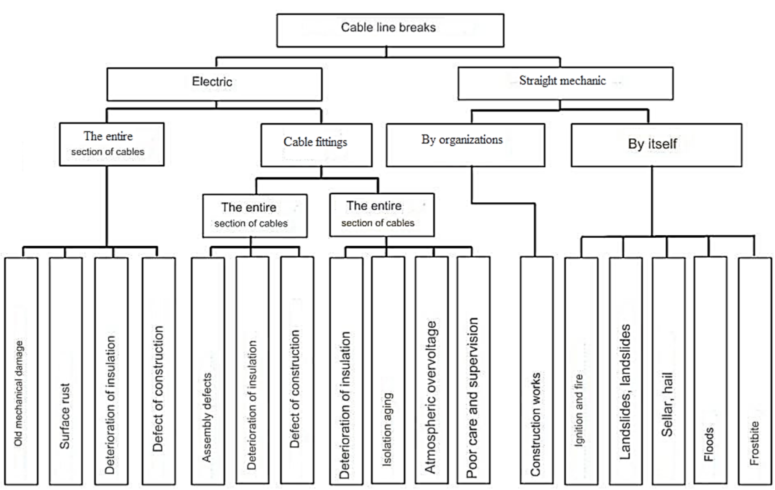

Fig. 1. Classification of cable line breaks.

In order to determine the factors that determine the frequency of breaks in cable lines in rural areas, they were initially classified (Figure 1). According to the classification, urban and rural cable networks are divided into electrical and mechanical. Power outages mainly occur due to the breakdown of the electrical strength of the insulation of the line elements.

They are characterized by the gradual development of insulation defects under the influence of an electric field, eventually leading to insulation perforation. The group of mechanical damages includes mechanical damages that lead to disconnection of cable lines as a result of their impact. They are mainly caused by various organizations and residents carrying out complex works on cable lines under working voltage.

The frequency of power outages (ω_{el}) will not depend on the transmission conditions of the cable line path. The main causes of power outages include old mechanical damage, insulation wear, manufacturing defects, and atmospheric overvoltages.

The analysis of the causes of cable line breaks showed that mechanical damage is significantly dependent on the conditions of cable laying and cable line path.

Thus, it is recommended to determine the frequency of interruptions of cable lines in rural areas from the following expression:

$$\omega = \omega_{el} + \omega_{mex} \tag{3}$$

where ω_{el} the value is derived from urban cable line statistics, ω_{mex} the value is derived from urban and rural network line statistics.

There are serious difficulties in calculating the average recovery time. In this regard, τ the value of the research was determined based on the analysis and synthesis of the components of the recovery time of urban cable lines and rural power lines, taking into account the characteristics of rural networks.

The average recovery time of the cable line in the event of a break consists of the following: the time required to locate the damageτ_{lok}, the time to identify the location of the damage τ_{shja}, the time to eliminate the damage τ_{bar} and the time to test and connect the cable line $\tau_{sin.va.ulash}$, i.e.

$$\tau = \tau_{lok} + \tau_{shja} + \tau_{bar} + \tau_{sin.va.ulash} \tag{4}$$

The times for locating faults, testing the line and connecting the line to the network are determined by the configuration of the line and the operating conditions and can be assumed to be independent of the execution option of the transmission line. Therefore, the values of τ_{lok} and $\tau_{sin.va.ulash}$ are taken based on the statistical data of rural air lines.

The time of damage detection τ_{shja} and damage elimination time τ_{bar} for cable lines depends on their operating conditions and the area where they are located.

So the value of can be determined from the following equation:

$$\tau = \frac{\omega_{el}}{\omega}\tau_{el} + \frac{\omega_{mex}}{\omega}\tau_{mex} \tag{5}$$

where τ_{el} - the average recovery time during power outages; τ_{mex}- average recovery time in case of mechanical breakdowns.

In addition, the values of τ_{el} and τ_{mex} are determined from the expression (4) the values of ω_{el} and ω_{mex} are determined from the calculation indicators obtained for rural areas.

The following expression is proposed to determine the value of the average service time for cable lines:

$$\vartheta = k_k \cdot \vartheta_{ish.chiq} + (1 - k_k)\vartheta_m \tag{6}$$

Where k_k - the coefficient indicating the ratio of the number of interruptions during preventive tests to the total number of preventive tests; $\vartheta_{ish.chiq}$ ϑ_m - average service time in case of failure during preventive testing; mean service time in a successful prevention trial.

The average time of the preventive test consists of the time of operational $\vartheta_{o'r}$ preparation of the cable line for the test ϑ_{op}, the time of testing the cable line ϑ_{sin} and the time of connecting the line ϑ_{ulash}, i.e.

$$\vartheta_{o'r} = \vartheta_{op} + \vartheta ulash_{sin} \tag{7}$$

If there is an interruption during the preventive test, then the average time ϑ_p is the time of operational preparation of the cable line for the test ϑ_{op}, the time of testing and determining the location of the interruption ϑ_{suja}, the time of damage removal ϑ_{shy}, the time of retesting $\vartheta_{qay.sin}$ and the time of connecting the line ϑ_{ulash}, i.e.

$$\vartheta_p = \vartheta_{op} + \vartheta_{suja} + \vartheta_{shy} + \vartheta ulash_{qay.sin} \tag{8}$$

The frequency of interruptions is calculated according to the expression (2). The component of the frequency of interruptions due to electrical damage is determined based on the analysis of statistical data on interruptions of existing cable networks. An analysis of the technical reasons for outages in urban cable lines has shown that they also occur in cable lines in rural areas.

3 Results and discussion

For rural cable lines, it will be necessary to redistribute the damage ratio in their various elements. This can be explained by the following considerations.

Cable damage due to cable laying defects, old mechanical damage and soil corrosion is reduced, and damage to cable sheaths and protective coverings is also reduced. Factors that reduce damage to protective coatings and cable sheaths are as follows: the rural cable line route is usually free of slag, broken glass, construction waste and similar factors, in urban conditions, the cable laying depth is large and therefore the probability of damage is reduced, the bends in the route of cable lines laid in pipes are relatively will be less.

The results of calculating the reliability indicators of cable lines in rural areas are presented in Table 1. Here are also similar figures of airlines for comparison.

Table 1. Reliability indicators of cable lines.

Reliability indicators	Power transmission lines	
	Air	Cable
Breakdown frequency ω, shutdown/km.year	$\frac{0.05\ldots0.25}{0.15}$	$\frac{0.01\ldots0.03}{0.02}$
Average recovery time τ, hours/off	$\frac{3.5\ldots7.5}{5.5}$	$\frac{12.9\ldots19.5}{16.2}$
Pre-exit frequency ν, exit/km.year	$\frac{0.05\ldots0.25}{0.15}$	$\frac{0.29\ldots0.34}{0.31}$
Average service time ϑ, hours/off	$\frac{3.5\ldots7.5}{5.5}$	$\frac{1.6\ldots7.2}{4.0}$
Relative equivalent shutdown durationα_n, hours/km.year	$\frac{0.2\ldots0.5}{1.1}$	$\frac{0.31\ldots1.39}{0.75}$

The explanation is as follows. The figure shows the range of indicators, and the denominator shows the average value.

Analysis of the data in Table 1 shows that the cable line failure frequency is on average lower than the cable linearization failure frequency. The average recovery time of cable lines is about 3 times longer than that of overhead lines. The frequency of pre-discharge of cable lines is slightly higher than the additional costs, and the average time of service of cable lines is slightly lower. It should be noted that the component of the exact equivalent duration of cable line outages related to accidents is the same for overhead lines, 2,5-3 times less than the component of overhead lines, and the content associated with scheduled outages is 1,5 times more.

The relative equivalent lifetime of overhead line outages in rural areas is 1,4 times longer than that of cable lines. This is due to a significant reduction in cable line breaks. In this case, the following should be considered. Operational experience shows that for cable lines that are not exposed to the atmosphere, the probability of failure of two lines at the same time is very small. Therefore, the reliability of the circuit made with cable networks is much higher than that of aerial networks.

4 Conclusion

A combined method was proposed based on the analysis of reliability indicators of other objects with similar characteristics and conditions, and later synthesis of these indicators. As a result of research, it was found that the reliability of rural cable lines is much higher than that of overhead lines. The estimated average equivalent duration of interruption of rural cable lines is 0,75 hours per year (with a range of 0,3 to 1,5 hours). The use of cable lines in rural power networks allows to increase the reliability of electricity supply to consumers. In this case, the effect of increased reliability is provided by eliminating the malfunctions caused by the influence of weather and wind. The use of cable lines in rural areas increases the reliability of 35/10 kV and 10/0,4 kV transformer substations and reduces the number of damages to transformers and other equipment of substations due to external overvoltage.

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