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ESTIMATION OF THE SHORT CIRCUIT ACCIDENT PROBABILITY AT THE OVERHEAD ELECTRIC TRANSMISSION LINES

Об'єктом дослідження є імовірнісні характеристики виникнення короткого замикання (КЗ) на повітряних лініях електропередачі (ЛЕП) класів напруги 110 кВ і вище, відмова яких може призвести до розвитку аварії в електроенергетичній системі (ЕЕС). Імовірнісні характеристики виникнення КЗ на ЛЕП залежать від великої кількості факторів: довжини та траси проходження ЛЕП, класу напруги, погодних умов, кваліфікації персоналу, в віданні, управлінні та обслуговуванні якого знаходиться ЛЕП. Найбільш проблемними питаннями при оцінці імовірності виникнення КЗ на повітряних ЛЕП є виділення пошкоджуваності від КЗ із загальної статистики пошкоджень, кількісне врахування таких особливостей функціонування повітряних ЛЕП, як метеорологічні умови, рівень кваліфікації персоналу та технічний стан окремої одиниці обладнання.

В ході дослідження розроблено нечітко-статистичний підхід до оцінювання імовірності виникнення КЗ на повітряній ЛЕП з урахуванням її індивідуальних особливостей роботи, таких як кваліфікаційний рівень обслуговуючого персоналу, метеорологічні умови функціонування та технічний стан ЛЕП. Для визначення безумовної імовірності виникнення КЗ на повітряній ЛЕП використовуються статистичні дані щодо КЗ на лініях відповідного класу напруги. Технічний стан ЛЕП та метеорологічні умови функціонування кількісно оцінюються за нечіткими моделями, кваліфікаційний рівень персоналу визначається на стандартних інтервалах шкали Харрінгтона. Умовні імовірності стану функціонування ЛЕП визначаються за допомогою спрощеного нечіткого виводу, що дає можливість кількісної оцінки умовної імовірності при відсутності чітких аналітичних зв'язків між ознаками умов роботи ЛЕП.

Отримані за розробленим підходом результати рекомендовано використовувати в зачах ризик-орієнтованого управління ЕЕС для підвищення надійності функціонування шляхом зниження величини ризику розвитку системної аварії при виникненні КЗ в елементах ЕЕС. Також визначено обмеження на застосування розробленого підходу в задачах оцінювання імовірності відмови обладнання та організації ризик-орієнтованого управління.

Ключові слова: *коротке замикання, лінія електропередачі, технічний стан, рівень кваліфікації персоналу, метеорологічні умови, функції приналежності, еталонні матриці.*

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1. Introduction

In modern conditions of the electric power system (EPS), an important task is to ensure its reliable and efficient functioning. When solving this problem, it is necessary to take into account that a significant amount of equipment works beyond the standard operating life, and the level of qualification of operational and maintenance staff is not always sufficient. Also, starting in 2019, EPS operation, for example Ukraine, in a new electric energy market leads to an encumbrance of the electrical modes of its equipment.

The analysis of modern world approaches to the organization of effective and reliable management of the EPS shows the feasibility of using risk-oriented management, the main quantitative characteristic of which is risk [1]. Risk is the product of the probability of an accident and its consequences [2] and is a quantitative characteristic of the EPS reliability over a time interval.

One of the main causes of emergencies in the EPS is a short circuit (SC). So, according to [3], 65–85 % of all failures in the EPS are precisely the result of short-circuit. Thus, in the tasks of assessing the risk of an emergency in the EPS, it is important to assess the likelihood of SC in its elements. According to [4], the most vulnerable elements of the EPS are overhead electric transmission lines (ETL). It is on them that due to the fact that they are distributed in space, and not a concentrated object, up to 80 % of all SCs in the EPS occur.

2. The object of research and its technological audit

The object of research is the probabilistic characteristics of the SC occurrence on overhead electric transmission lines of voltage classes 110 kV and higher, the failure of which can lead to the development of an accident in the EPS. These characteristics are adjusted for each specific overhead ETL taking into account the individual conditions of its functioning. The probabilistic characteristics of the SC occurrence on ETL depend on a large number of factors: ETL length and route, voltage class, weather conditions, and the staff qualifications in whose charge, management and maintenance the ETLs are located. Statistical data on SC on ETLs usually take into account only the averaged indicators and the totality of these factors.

The most problematic issues in assessing the likelihood of SC on overhead ETL is the allocation of damage from a SC with general damage statistics, the quantitative consideration of such features of the functioning of overhead ETLs, such as meteorological conditions, the level of staff qualification and the technical condition of a single piece of equipment.

3. The aim and objectives of research

The aim of research is to develop a fuzzy-statistical approach to assessing the probability of SC occurrence on an overhead ETL under conditions of incompleteness and fuzziness of the initial information, which is the stochasticity of external processes that affect the state of the overhead ETL. According to the aim in the work the following objectives are solved:

1. Determination of the integral probability distribution functions of the SC occurrence on overhead ETLs based on available statistical data.
2. Development of a method for taking into account the individual characteristics and operating conditions of ETL in the conditions of fuzzy initial information and the absence of mathematical connections between state signs.
3. Modeling the probability of SC occurrence on an overhead ETL at a time interval with developed methods and functions.

4. Research of existing solutions of the problem

In [3, 5], statistical data on the number of SC occurrences on 110 (154) kV lines in a powerful EPS with a total line length of 6000 km are presented. These analytical dependencies are shown in graphical form in Fig. 1.

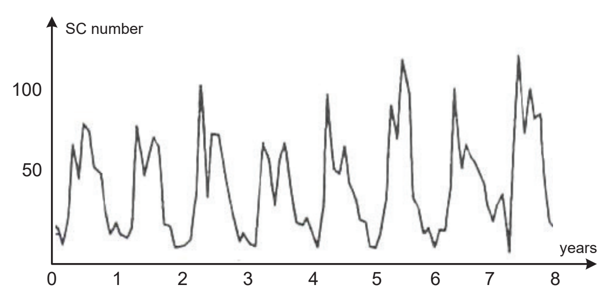

Fig. 1. The distribution of the SC number on 110 (154) kV overhead ETLs in a powerful electric power system for 8 years

These works also provide statistical data on the distribution of the SC number by months and years for overhead ETLs 220, 330 kV. But, in these studies, when determining the SC likelihood on ETL and predicting the levels of SC currents, ELS individual characteristics are not taken into account, namely their technical condition and the qualification level of the staff that serves them. The influence of climatic conditions is also carried out averaged in monthly statistics.

In [6], analytical methods are proposed for determining the residual life and the probability of failure of overhead ETLs, which use the averaged statistical parameters and do not take into account the individual operating conditions of the ETLs. Also, «failure» means any failure of ETL without highlighting a short circuit as a type of damage.

In [7, 8], the authors propose a fuzzy approach to determining the probability of failure of ETLs, taking into account individual characteristics, staff qualification level and meteorological conditions of ETLs, but the proposed approach also does not highlight the SC probability.

In [9, 10], a probabilistic model for assessing the risk of line disconnection is presented and statistics on accidents caused by weather conditions are presented, while ETL disconnections due to SC are also not highlighted. In [11, 12], the probabilistic characteristics of failures of overhead ETLs in wet snow and ice are given, but other factors affecting the reliability of operation of overhead ETLs are not considered.

From a literature review, it is possible to conclude that in modern systems for assessing the probability of SC occurrence on ETLs, the average statistics on their damage are mainly used. For reliable modeling of the development of an accident in a specific EPS in the case of SC on its overhead ETLs, it is necessary to develop methods that take into account their individual condition and operating conditions.

5. Methods of research

According to the statistical data [4, 5], the characteristics of the SC distribution on 110 (154) kV overhead ETLs per 100 km of length and the corresponding integral probability distribution function for SC determining are determined. Let's suppose that in the i-th month there are N_i SCs on the 110 (154) kV lines in the EPS. The total length of 110 (154) kV ETLs in the EPS is L kilometers. In this case, the relative number of SC in the i-th month per 100 km of ETL length is:

$$n_i = \frac{N_i \cdot 100}{L}. \quad (1)$$

The distribution function of the SC occurrence per 100 km of 110 kV ETLs is defined as:

$$f(t_i) = \frac{n_i}{N}, \quad (2)$$

where t_i – the time interval corresponding to the i-th month; N – the total SC number. The graph of the function $f(t)$, constructed from statistical data [4], is presented in Fig. 2.

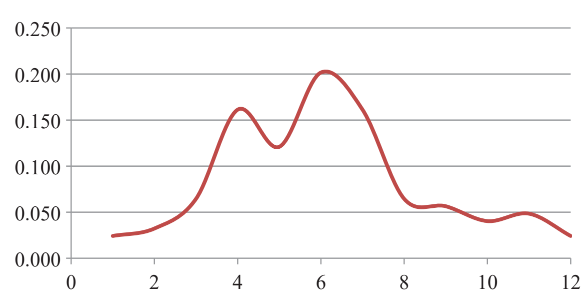

Fig. 2. Dependence $f(t)$ for 110 (154) kV overhead ETLs

The cumulative distribution function of the SC occurrence per 100 km of 110 (154) kV ETLs is determined by the following expression:

$$F(t_i)=\int_{t=0}^{T} f(t)\cdot dt. \qquad (3)$$

The graph of the integral function $F(t)$ is shown in Fig. 3.

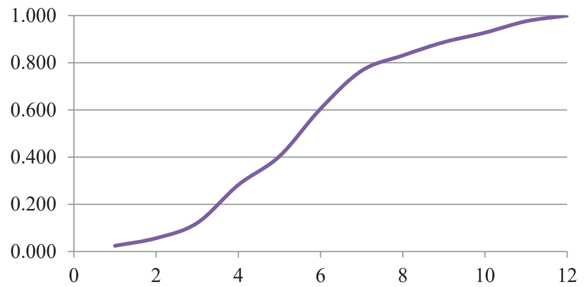

Fig. 3. Integral dependence $F(t)$ for 110 (154) kV overhead ETLs

To assess the SC likelihood on an overhead ETL over the time interval, let's introduce the following events:

H_1 – event, which means the SC occurrence on an overhead ETL of length L on a time interval Δt;

H_2 – event indicating the SC absence on an overhead ETL of length L over a time interval Δt.

Then the unconditional probability of the SC occurrence on the ETL in the time interval is determined directly from the function $F(t)$:

$$p(H_1)=\left(F(t_2)-F(t_1)\right)\cdot\frac{L}{100}. \qquad (4)$$

Since events H_1 and H_2 are a complete group of incompatible events, then:

$$p(H_2)=1-p(H_1).$$

Consideration of individual characteristics and operating conditions of ETL. The probability of SC occurrence in the time interval Δt depends on the individual characteristics and operating conditions of the ETL, such as:

– ETL technical condition at a time t_1;
– staff qualification level under the authority and control of which there is an ETL;
– meteorological conditions for the considered time interval.

To assess the individual characteristics and operating conditions of power lines, let's introduce the following event:

B – an event consisting in the fact that at the point t_1 in time the overhead ETL has a certain technical condition S. Staff qualification level at the given moment is R. And the meteorological conditions at the time of observation are determined by M.

Then it is possible to determine the following conditional probabilities:

1) $p(B/H_1)$ – the conditional probability of the event B upon the occurrence of the event H_1 (or the probability of confirming the hypothesis «SC on ETL at a time interval Δt» with signs S, P, M, characterizing the state and working conditions of the ETL under consideration).

2) $p(B/H_2)$ – the conditional probability of the event B upon the occurrence of event H_2 (or the probability of confirming the hypothesis «SC on ETL at a time interval Δt» with signs S, P, M, characterizing the state and working conditions of the ETL under consideration).

In this case, the probability of SC occurrence in the time interval on the ETL, taking into account its condition and operating conditions, is determined by the Bayes formula:

$$p(H_1/B)=\frac{p(H_1)\cdot p(B/H_1)}{p(H_1)\cdot p(B/H_1)+p(H_2)\cdot p(B/H_2)}. \qquad (5)$$

This raises the question of determining conditional probabilities $p(B/H_1)$ and $p(B/H_2)$.

All parameters on which the probabilities $p(B/H_1)$ and $p(B/H_2)$ depend, are fuzzy quantities that are not subject to a formalized description. There are also no analytical links between them. Under such initial conditions, it is advisable to propose a fuzzy approach to determine the influence of the state and conditions of the ETL on the SC probability:

$$p(B/H_1)=\varphi_1(S,\ P,\ M); \qquad (6)$$

$$p(B/H_2)=\varphi_2(S,\ P,\ M). \qquad (7)$$

There are a number of fuzzy inference methods that allow to get a reliable quantitative result with fuzzy source data. These methods include:

– Mamdani method;
– Sugeno method;
– Zadeh fuzzy conclusion;
– simplified fuzzy conclusion.

Among the listed methods, according to [2, 7], the least dependent on the quality of the initial information and the qualifications of experts there is a simplified fuzzy *conclusion*.

Simplified fuzzy inference method. The algorithm of the simplified method of fuzzy inference is presented in [7]. Let conditional probabilities be and can be on one of five intervals:

– P1 – very low [0; 0.2);
– P2 – low [0.2; 0.36);
– P3 – average [0.36; 0.64);
– P4 – high [0.64; 0.8);
– P5 – very high [0.8; 1].

Probabilities $p(B/H_1)$ and $p(B/H_2)$ are characterized by the following input signs of links to the SC occurrence:

1) β_1 = «technical condition of the power transmission line»;
2) β_2 = «meteorological conditions»;
3) β_3 = «staff qualification level».

Input features are described by the following fuzzy terms:

1) β_1 = «technical condition of the power transmission line»: β_{11} = «Good», β_{12} = «Average», β_{13} = «Bad»;
2) β_2 = «meteorological conditions»: β_{21} = «Favorable», β_{22} = «Average», β_{23} = «Unfavorable»;
3) β_3 = «staff qualification level»: β_{31} = «High», β_{32} = = «Average», β_{33} = «Low».

Fuzzy terms are determined by the membership functions of the output values of the models for assessing the ETL state, weather conditions and staff level.

Based on the set of features that affect the probability of SC occurrence on an overhead ETL β, fuzzy inference rules are formulated that determine the matrix of standard conditional probabilities $p(B/H_1)$ and $p(B/H_2)$.

Let's consider in more detail the approaches to determining the parameters by which the probabilities $p(B/H_1)$ and $p(B/H_2)$ are estimated.

ETL technical condition. Overhead ETL technical condition is determined by the fuzzy model of the power line [8]. A quantitative assessment of the technical condition is the residual resource of the power transmission line, which varies from 0 (the resource is completely exhausted) to 1 (a completely new and serviceable line).

Weather conditions. Meteorological conditions in the considered time interval are estimated using a fuzzy model presented in [13]. The initial quantitative assessment is the meteorological situation, which is determined in the range from 0 (completely favorable) to 1 (completely unfavorable).

Staff qualification level. The qualification level of the operational and operational staff serving the ETL under consideration depends on factors such as work experience and level of training (technical, psychological, etc.). By the combination of these factors, the staff level can be assessed as «low», «medium» and «high» [13]. This allows to build fuzzy terms to assess the staff qualification level at standard intervals of the Harrington scale (Fig. 4) [14].

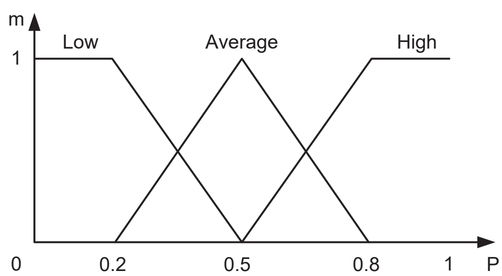

Fig. 4. Fuzzy terms for assessing staff qualifications

The reference matrices of intervals of conditional probabilities $p(B/H_1)$ and $p(B/H_2)$ are determined by expert estimates and are given in Tables 1, 2.

As a result of determining the characteristics of the input quantities, conditional probability vectors are formed $p(B/H_1)$ and $p(B/H_2)$ – $\beta_{K1}=\{\beta_{1K1}, \beta_{2K1}, \beta_{3K1}\}$, $\beta_{K2}=\{\beta_{1K2}, \beta_{2K2}, \beta_{3K2}\}$. The membership functions of fuzzy terms determine the membership values of each feature to its fuzzy terms and form matrices of conditional probabilities $p(B/H_1)$ and $p(B/H_2)$ (Tables 3, 4).

To determine which of the reference probabilities the probabilities belong to $p(B/H_1)$ and $p(B/H_2)$, the following fuzzy inference algorithm is implemented:

1) the logical union operation is performed according to the minimization rule for the matrix S_K and each of the reference matrices $S_1...S_5$;

2) the comparison index I_i, $i=1,...5$ is determined, which determines the proximity of the matrix S_K to each of the reference matrices $S_1...S_5$:

$$I_i = \frac{\sum_{j=1}^{3} \mu_{S_K \cap S_j}(\beta_{iK})}{\sum_{j=1}^{3} \mu_{S_j}(\beta_{ij})}; \quad (8)$$

3) the comparison index with the maximum value determines to which of the reference states the actual fuzzy probability of SC occurrence belongs:

$$S_K \in S_E = \{S_i | \max I_i\}. \quad (9)$$

Table 1

Reference conditional probability matrices $p(B/H_1)$

$\mu(\beta_i)$ \ β_i	β_1	β_2	β_3
S_1 – very low			
$\mu_1(\beta_i)$	1	1	1
$\mu_2(\beta_i)$	0	0	0
$\mu_3(\beta_i)$	0	0	0
S_2 – low			
$\mu_1(\beta_i)$	1	0	1
$\mu_2(\beta_i)$	0	1	0
$\mu_3(\beta_i)$	0	0	0
S_3 – average			
$\mu_1(\beta_i)$	0	0	0
$\mu_2(\beta_i)$	1	1	1
$\mu_3(\beta_i)$	0	0	0
S_4 – high			
$\mu_1(\beta_i)$	0	0	0
$\mu_2(\beta_i)$	0	0	1
$\mu_3(\beta_i)$	1	1	0
S_5 – very high			
$\mu_1(\beta_i)$	0	0	0
$\mu_2(\beta_i)$	0	0	0
$\mu_3(\beta_i)$	1	1	1

Table 2

Reference conditional probability matrices $p(B/H_2)$

$\mu(\beta_i)$ \ β_i	β_1	β_2	β_3
S_1 – very low			
$\mu_1(\beta_i)$	0	0	0
$\mu_2(\beta_i)$	0	0	0
$\mu_3(\beta_i)$	1	1	1
S_2 – low			
$\mu_1(\beta_i)$	0	0	0
$\mu_2(\beta_i)$	0	1	0
$\mu_3(\beta_i)$	1	0	1
S_3 – average			
$\mu_1(\beta_i)$	0	0	0
$\mu_2(\beta_i)$	1	1	1
$\mu_3(\beta_i)$	0	0	0
S_4 – high			
$\mu_1(\beta_i)$	0	1	1
$\mu_2(\beta_i)$	1	0	0
$\mu_3(\beta_i)$	0	0	0
S_5 – very high			
$\mu_1(\beta_i)$	1	1	1
$\mu_2(\beta_i)$	0	0	0
$\mu_3(\beta_i)$	0	0	0

Table 3

Conditional probability matrices $p(B/H_1)$

$\mu(\beta_i)$ \ β_i	β_1	β_2	β_3
$\mu_1(\beta_i)$	$\mu_1(\beta_{1K1})$	$\mu_1(\beta_{2K1})$	$\mu_1(\beta_{3K1})$
$\mu_2(\beta_i)$	$\mu_2(\beta_{1K1})$	$\mu_2(\beta_{2K1})$	$\mu_2(\beta_{3K1})$
$\mu_3(\beta_i)$	$\mu_3(\beta_{1K1})$	$\mu_3(\beta_{2K1})$	$\mu_3(\beta_{3K1})$

Table 4

Conditional probability matrices $p(B/H_2)$

$\mu(\beta_i)$ \ β_i	β_1	β_2	β_3
$\mu_1(\beta_i)$	$\mu_1(\beta_{1K2})$	$\mu_1(\beta_{2K2})$	$\mu_1(\beta_{3K2})$
$\mu_2(\beta_i)$	$\mu_2(\beta_{1K2})$	$\mu_2(\beta_{2K2})$	$\mu_2(\beta_{3K2})$
$\mu_3(\beta_i)$	$\mu_3(\beta_{1K2})$	$\mu_3(\beta_{2K2})$	$\mu_3(\beta_{3K2})$

To determine the quantitative value of the output variable $p(B/H_1)$, or $p(B/H_2)$, let's assume that the ratio of the comparison index I_{out} to the sum of the maximum comparison indices of the output terms determines the confidence degree in the conclusion.

With a large number of comparison indices, the arithmetic mean value of all indices of mistrust should be taken as the degree of distrust.

With this approach, the quantitative value of the output variable S_n is determined by the following expressions:

$$p(B/H_1)=S_{out-l1}+\Delta S_{out1}\frac{I_{out1}}{I_{out1}+\sum_{i=1}^{n}I_{i1}\Big/n}, \qquad (10)$$

$$p(B/H_2)=S_{out-l2}+\Delta S_{out2}\frac{I_{out2}}{I_{out2}+\sum_{i=1}^{n}I_{i2}\Big/n}, \qquad (11)$$

where S_{out-l1}, S_{out-l2} – the lower boundary of the interval of the output term, which is defined as a solution; $\Delta S_{out1}=S_{out-l1}-S_{out-l1}$, $\Delta S_{out2}=S_{out-l2}-S_{out-l2}$ – the width of the interval of the output term, which is defined as a solution.

6. Research results

Let's consider an 154 kV overhead ETL of the Dnipro electric power system (control name: L10, substation DniproGES-1 – Solonianska substation, length L=42 km). And let's determine the probability of its failure in the time interval Δt=2 months of the largest thunderstorm activity (April-May).

Using the integral distribution function of the SC occurrence on the 110 (154) kV lines (Fig. 3), let's determine the unconditional probability of the SC occurrence on the ETL in the time interval Δt=2 months. $F(t_1)=0.121$, $F(t_2)=0.403$:

$$p(H_1)=\left(F(t_2)-F(t_1)\right)\cdot\frac{L}{100}=$$
$$=\left(0.403-0.121\right)\frac{42}{100}=0.119; \qquad (12)$$

$$p(H_2)=1-p(H_1)=1-0.119=0.881. \qquad (13)$$

The technical condition of the overhead ETL L10 is determined by the fuzzy model presented in [8] according to the following parameters:

– relative electrical load: $E=0.9$;
– supports defectiveness coefficient: $K_{DS}=0.4$;
– insulators defectiveness coefficient: $K_{DI}=0.2$;
– wire defectiveness coefficient: $K_{DW}=0.5$.

The technical condition (residual life) of the L10 line is:

$$\beta_1=\varphi_T(E,K_{DS},K_{DI},K_{DW})=$$
$$=\varphi_T(0.9;\,0.4;\,0.2;\,0.5)=0.68. \qquad (14)$$

Meteorological conditions in the considered period are described by the following quantitative characteristics:

– average wind load: $W=7$ m/s;
– ice load: $I=0$ mm;
– relative intensity of the thunderstorm: $S=10$ days/month;
– average air temperature: $T=12$ °C.

According to the fuzzy model [15], the meteorological situation in the region of operation of the L10 overhead line is determined:

$$\beta_2=\varphi_M(W,I,S,T)=\varphi_M(7;0;10;12)=0.27. \qquad (15)$$

Staff qualification level is determined by fuzzy terms presented in [15] and is:

$$\beta_3=\mu(P)=0.75. \qquad (16)$$

According to the developed standard matrices (Tables 1, 2), matrices of conditional probabilities $p(B/H_1)$ and $p(B/H_2)$ are formed (Tables 5, 6).

Table 5

Conditional probability matrix $p(B/H_1)$ for overhead ETL L10

$\mu(\beta_i)$ \ β_i	β_1	β_2	β_3
$\mu_1(\beta_1)$	0	0.767	0
$\mu_2(\beta_2)$	0.4	0.233	0.167
$\mu_3(\beta_3)$	0.6	0	0.833

Table 6

Conditional probability matrix $p(B/H_2)$ for overhead ETL L10

$\mu(\beta_i)$ \ β_i	β_1	β_2	β_3
$\mu_1(\beta_i)$	0	0.233	0
$\mu_2(\beta_i)$	0.4	0.767	0.167
$\mu_3(\beta_i)$	0.6	0	0.833

The probabilities $p(B/H_1)$ and $p(B/H_2)$ are determined using the expressions (8)–(11), the following fuzzy inference algorithm is implemented:

$$p(B/H_1)=S_{out-l1}+\Delta S_{out1}\frac{I_{out1}}{I_{out1}+\sum_{i=1}^{n}I_{i1}\Big/n}=$$
$$=0.36+0.16\cdot0.22=0.395; \qquad (17)$$

$$p(B/H_2)=S_{out-l2}+\Delta S_{out2}\frac{I_{out2}}{I_{out2}+\sum_{i=1}^{n}I_{i2}\Big/n}=$$
$$=0.64+0.16\cdot0.18=0.667. \qquad (18)$$

By the Bayes formula (5), the probability of SC occurrence on 154 kV L10 overhead ETL of the Dnieper EPS is determined for $\Delta t = 2$ months:

$$p(H_1/B) = \frac{p(H_1)\cdot p(B/H_1)}{p(H_1)\cdot p(B/H_1) + p(H_2)\cdot p(B/H_2)} = \\ = \frac{0.119\cdot 0.395}{0.119\cdot 0.395 + 0.881\cdot 0.675} = 0.073. \quad (19)$$

The result shows that the probability of SC occurrence on the L10 line during a thunderstorm is below the average due to good technical condition and a high level of staff.

7. SWOT analysis of research results

Strengths. Compared with previous methods and models for assessing the probability of SC occurrence on overhead ETLs, an approach has been developed that allows for objectively existing individual features of the operation of a single power line to be taken into account. This will allow to effectively use the approach in the tasks of assessing the risk of an emergency in the EPS in the event of a SC in it.

Weaknesses. The disadvantage of the proposed approach is the complexity of its use and the low reliability of the final result in the absence of representative statistical information on SC on the equipment in question or the absence of experts of sufficient qualifications able to reasonably construct the membership functions of fuzzy terms and reference matrices.

Opportunities. Using the developed approach in the tasks of risk-based management of the EPS will make it possible to make effective decisions to reduce the risk of an accident in the EPS in the conditions of incomplete initial information and to increase the reliability of its operation.

Threats. Application of the proposed approach in conditions of low qualification of experts can lead to erroneous decisions and actions in the implementation of risk-oriented management of EPS.

8. Conclusions

1. The cumulative probability distribution functions of the SC occurrence on an overhead ETL are determined, which makes it possible to form a general set of events for power lines of different voltage classes and also to determine the unconditional probabilities of occurrence and absence of SC on ETL in the time interval.

2. A method is developed for assessing the probability of SC occurrence in an overhead ETL over a time interval that takes into account statistical information about the functioning of power lines of a certain voltage class, takes into account their length, technical condition, operating conditions and the staff level. This method allows to take into account the uncertainties associated with the lack of analytical relationships between features that affect the probability of SC occurrence on power lines and the quality of a number of features.

3. Simulation of the probability of SC occurrence on an overhead ETL on a time interval with the developed methods and functions has been carried out. The obtained result allows to identify the probability of ETL failure due to SC occurrence from the total set of power line failures and to assess the risk of SC occurrence on power line. According to this assessment, it is possible to develop measures to reduce the risk (for example, improving the technical condition by replacing and modernizing power transmission line equipment, increasing the staff qualification level, etc.) and developing an emergency in the EPS.

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