Probabilistic Evaluation of Lightning-Protection in Overhead Transmission Lines

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Abstract – Traditionally, insulation coordination of power system apparatus relies on deterministic approaches where some conservative voltage stresses are defined and the insulation levels are then adjusted using protective ratios and margins. In the case of lightning stresses, this could easily lead to overinsulation or overdesign and subsequently to an increase in the cost of equipment. On the other hand, insufficient insulation could lead to power system failures with disastrous technical and economic consequences. In this paper we present a formalized method for predicting the lightning-related failure rate of power system equipment. In the probabilistic approach to insulation coordination of power system apparatus we quantify the expected risk of failure under lightning stresses to enable an economically optimized design.

Key words – lightning protection, the transmission line, overstrain, dangerous curve parameters, volt-second characteristic.

I. The models of calculating of reliability

After having estimated the number of strokes, the second step is to evaluate the lightning-related risk of failure of a power system apparatus. This is a component reliability problem, for which a risk formulation had been proposed in the IEC 71-2 insulation coordination standard [1] as follows:

$$P_f = \int_0^{\infty} f_U(u) \cdot F(u) du, \qquad (1)$$

where $f_U(.)$ is the probability density function of the lightning overvoltages stressing the apparatus and $F(.)$ is the probability distribution function of its withstand voltage.

The term 'risk' may be used in the sense of the probability with which the damage should be expected, as discussed in the preceding sections. For practical purposes this term has been replaced in the recent standard [4] by the related value of losses resulting from lightning damage and expressed by the product NPL, so the expression representing the risk can be simplified to the form

$$R \approx NPL = \sum_{X=A}^{Z} N_X P_X L_X = \sum_{X=A}^{Z} R_X, \qquad (2)$$

where N is the annual number of dangerous events (lightning flashes) influencing a structure or its equipment, P is the probability of damage to the structure or its equipment due to one event, L is the consequent loss due to a damage relative to the total value of humans and goods of the object to be protected, $N_X P_X L_X$ are the values of N, P and L selected for the risk distinguished component, R_X is the common symbol for the risk component, and X, A and Z are the symbols for the common respective risk components [5].

Risk analysis can also be formed on a full charge flash of lightning. Assuming the instantaneous voltage $u_A(t)$ and the instantaneous current $i_A(t)$ of the arrester terminal during the lightning discharge are known, the released energy in the arrester at the time instant t can be computed by [6]

$$W = \int_0^t u_A(t) \cdot i_A(t) dt. \qquad (3)$$

By comparing the released energy W with the arrester energy absorption capability E_R, the time instant t_a when the released energy W becomes greater than E_R could be determined. Then, the total lightning charge released until the occurrence of the arrester failure can be estimated by

$$Q_a = \int_0^{t_a} i(t) dt, \qquad (4)$$

where Q_a is the electrical charge of lightning channel and $i(t)$ is the lightning current.

The peak current magnitude of the equivalent single wave of flash is equal to the peak current of the first stroke I_p; then Q_a is also a function of I_p. If the arrester failure, for any given value of I_p, occurred at instant t_a, it will occur for all the great values of magnitude as well. Once the minimum value of electrical charge sufficient to cause the arrester failure is computed for each current magnitude I_p, a lightning limiting curve D can be determined, in which above is the region with the probability of arrester failure. Having the limiting curve D, the probability of arrester failure can be given by [6]

$$R = \int_D w(I_p, Q_a) dI_p dQ_a, \qquad (5)$$

where $w(I_p, Q_a)$ is the joint probability distribution function of I_p and total charge Q_a.

II. The Results of Research

Algorithms for calculating the probability for transmission line can be reduced to a single algorithm which is based on the use of n-fold integral over the region D of the density distribution $f(\vec{x})$ n – dimensional vector random variables.

$$p = \oint \ldots \oint f(\vec{x}) \prod_{k=1}^{n} dx_k, \qquad (6)$$

where $\vec{x}$ must be accept as a vector of random variables that determines lighting strength object, as well as a D – field region of these values at which the violation occurs insulation strength (hazardous area parameters).

In connection with the above expression (6) for the probability p infringement strength insulation in one lightning strike and random values of all the variables that determine the reliability of lightning protection facility to implement numerical integration, represented as:

$$p = \sum_{x_n} \Delta F(x_n) \ldots \cdot \sum_{x_k} \Delta F(x_k) = \prod_{k=1}^{n} \sum_{x_k} \Delta F(x_k), \qquad (7)$$

where $\Delta F(x_k)$ – the probability of getting k-th random variable at a given interval, as corresponds to the distribution function $F(x_k)$ on the edges of a given interval. Numerical integration, respectively (7) is realized by varying the value in cell belonging to the field of hazardous settings. Equation (7) is valid for independent random variables but it can be used for correlated variables, to use conditional distribution laws.

We select a coordinate vector $\vec{x}$ values, which form the object in isolation strain $u(t)$ of random shapes. This parameters of wave of lightning current are I, a, τ the instantaneous value of the operating voltage u_0 at the time of the lightning discharge, the distance l space lightning from the object defending distance b from the place of lightning into the ground to the axis line, which is taken into account in the interaction induced stresses. We group them into a single vector and formula (7) can be rewritten as follows:

$$p = \sum_{l} \Delta F(l) \cdot \sum_{b} \Delta F(b) \cdot \sum_{I} \Delta F(I) \times \\ \times \sum_{A} \Delta F(A) \cdot \sum_{\tau} \Delta F(\tau) \cdot p(u, u_0), \quad (8)$$

where $p(u)$ – the probability of violation of strength isolation facility under the influence of the voltage $u(t)$, formed by the components of the vector at fixed values.

This mathematical model was implemented by software. To simplify the data preparation to the calculation of parameters of the experiment, presenting the results in a convenient form was designed interface.

When you run the program before the user opens the main window (Fig.1). That hosts the control buttons and display screen incoming information.

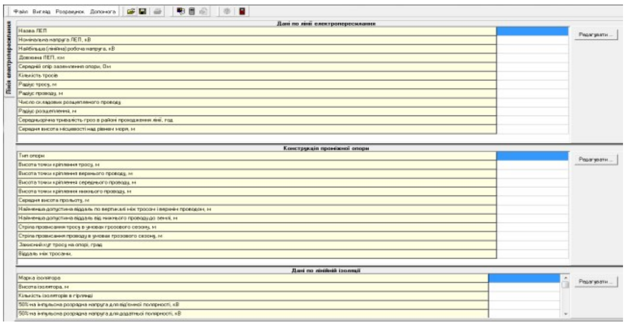

Fig. 1. The main window

Calculation of results are displayed in graphical form and contain three blocks of information, "Volt-second characteristic", "Dangerous Curves at impact parameters of resistance" and "Dangerous Curves options when struck in the rope" (Fig.2). We note that the user can choose the graphs represent different coordinates in coordinates A = f(I) i PA = f(PI). The result window also contains a block that displays information about the specific number of transmission line outages when lightning strikes in the wire, resistance wire, and the total number of specific storm outages and the absolute number of storm outages.

Conclusion

In the article the analysis of existing mathematical models to helps determine the reliability of lightning protection schemes. Existing models can only consider a limited number of random factors that determine the stability of the stormy objects displayed on the accuracy and reliability of performance optimization of difficult wires. As a result of the research was created a generalized mathematical model, which is implemented by software. Taking into account all the random variables that define lighting staunch object, we developed methods of calculation provide adequate compliance and natural processes.

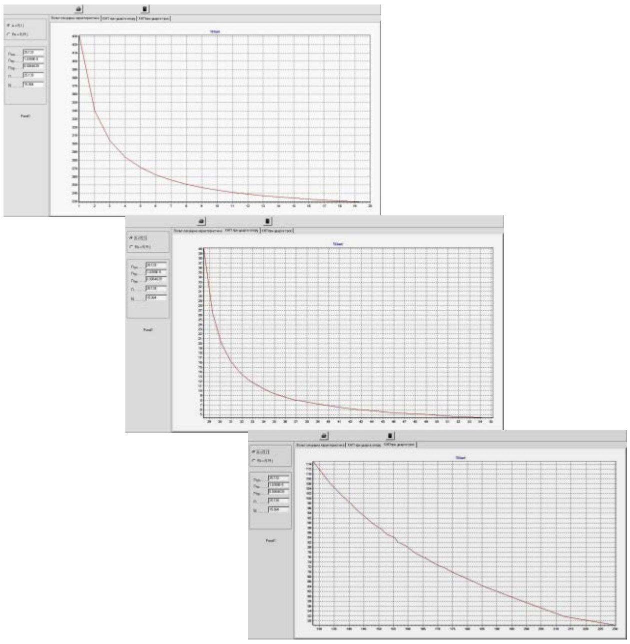

Fig. 2. Results of calculation of transmission line lightning protection

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