STUDY OF WAYS OF MODERNIZATION OF THE CURRENT-CONDUCTING PART OF OVERHEAD POWER LINES

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Abstract

A study of ways to modernize the current-conducting part of overhead lines was conducted in order to increase the efficiency of electric energy transmission. A comparative analysis of technical and economic characteristics of AS, ACCR, AERO-Z wires was performed. According to the results of the comparison of AS, ACCR, AERO-Z wires, it follows that the factor that limits the scope of application of ACCR wire in Ukrainian electrical networks, even for spans with extremely high requirements for the characteristics of electrical energy transmission, is its high cost. Also, during the research, it was found that the AERO-Z wire is the most appropriate for introduction into Ukrainian electrical networks. Because the technical characteristics of this wire are better than the characteristics of AS wire and it has a relatively low cost compared to ACCR wire, and its special design is adapted to adverse climatic conditions that affect the characteristics of electrical energy transmission.

Keywords: overhead power line, current-carrying part, wire, electrical network, criterial method.

Problem setting. Overhead transmission lines (OTL), which are operated in Ukrainian electrical networks (EN), were designed and put into operation in the 70s of the last century. At that time, there were slightly different requirements for EN design. Thus, during EN design, OTL structures were chosen in such a way as to ensure close to minimum network throughput in order to ensure savings in metal and capital investments. As a result of this approach, there were limitations of EN bandwidth, which could not but affect the structural reliability of power transmission and the management of EN operating modes. Based on the above, it follows that during the design of EN, an important role is assigned to the selection of OTL wires. Currently, 11 brands of wires are used in the EM of Ukraine: in the system-forming networks – 4; in distribution networks - 7 [1, 2].

Under such conditions, attention should be paid to the fact that different cross-sections of both steel-aluminum (AS) and other conductors determine EN bandwidth, wire weight per unit of length, strength of OL structures, metal consumption, the size of investments and further operating costs . That is, those EN parameters that ensure mode and structural reliability of power transmission. Therefore, the modernization of the current-conducting part of the OTL should be based on new progressive developments of AS wires, which would satisfy such technical requirements as: reliability, survivability and durability; corrosion resistance; high adhesiveness; insensitivity to vibration during operation under the influence of adverse climatic factors; resistance to temperature effects of the environment; installation of insulating overlays on sections of wires, etc.

The purpose of the article. Conduct a study of ways to modernize the current-conducting part of overhead lines to substantiate the feasibility of their use in Ukrainian electrical networks in order to increase the efficiency of electrical transmission.

Basic research methods.

Analysis of steel-aluminum wires. Steel-aluminum (AS) wires are widely used in EN not only of Ukraine, but also in EN of foreign countries. This is explained by the low cost and good electrical and mechanical characteristics of AC wires [3 - 5].

For OTLs, which are operated in different climatic conditions, AS wires are produced with different cross-sections of the aluminum part and the steel core. This approach characterizes their strength and allows use under various operating conditions. Thus, in areas with an ice wall thickness of up to 20 mm, AS wires are used with a cross-section ratio of the aluminum part and the steel core equal to 6-8; with a greater thickness of the icicle wall, the lower limit of this ratio is 4.3. On the coast of seas, salt lakes, in industrial areas, where the current-conducting part of the PLE is destroyed by corrosion, it is recommended to use AS wires with a cross-section ratio of the aluminum part and the steel core equal to 6.1 - 6.25 [6].

The structural uniformity of AS wires for OTL has been preserved for a long time, only the parameters have changed - the diameters of steel cores and aluminum windings, their number in a winding, the ratio of steel and aluminum parts, the cross section of the conductor part, etc. But this does not satisfy the needs of EN to improve the efficiency of electric energy transmission.

Analysis of high-temperature wires. As an innovative solution to increase the efficiency of electric energy transmission in countries such as Japan, South Korea, Italy, and the USA, new high-temperature wires have been developed for OL power transmission with a long-term permissible operating temperature of up to 210 °C instead of standard AS wires designed for working temperature 70 °C [7, 8].

An increase in the operating temperature and throughput of the PLE by more than 2 times required the solution of the following related problems that arose with this approach to the modernization of the conductive part of the PLE, namely: reducing the sag of the wire due to the use of materials with a halved reduction in its design coefficient of linear expansion; increasing breaking forces and reducing the mass of wires per unit length while maintaining high electrical conductivity. It is especially interesting that these problems are solved in the design of a high-temperature wire of the ACCR (Aluminum Conductor Composite Reinforced) type - an aluminum composite wire developed in the USA [9].

The ACCR wire is a typical example of the application of nanotechnology. The core of this wire, which is made of composite alloys based on high-purity aluminum (Al2O3), has high tensile strength and low coefficient of linear expansion and high electrical conductivity. Wraps of aluminum-zirconium metal wires are placed around the core. But, along with these characteristics, there are disadvantages of ACCR wire. One of the disadvantages of this wire stems from the properties of the composite itself, which is used to make the wire core. This is a rather fragile material, the properties of which lead to the fact that it is necessary to work with ACCR wire more carefully both during transportation and during installation.

Analysis of specially designed wires. During the design, an important factor that affects the final decision regarding the choice of EN design option is the climatic conditions in which the OTL will be operated. Thus, under adverse climatic conditions, which include strong winds, ice and frost deposits, snow accumulation, the mechanical characteristics of wires of a special design can become a decisive factor in their use. A valid example is the use of AERO-Z wire. The main feature of the AERO-Z wire, which was developed by the Nexans concern, Belgium, is the laying of conductive layers, the cross-section of which resembles the letter "Z". Such AERO-Z wire wrap surface is smooth and has slight helical grooves that occur between the upper limits of the Z-shaped wires. Due to this, the design of the AERO-Z wire is more compact compared to the AS wire and, with the same diameter, has a larger cross-section than aluminum. Such features contribute to the reduction of mechanical stress on the supports and allow to increase the useful conductive cross-section, which increases the operational and structural reliability of power transmission. Also, AERO-Z wire has increased torsional rigidity and therefore better resists ice and frost deposits on PL wires [10].

Technical - economic comparison of AS, ACCR, AERO-Z wires. Comparison of wires of the AS brand (Energoprom Cable Plant, Ukraine) [5], ACCR (3M™, USA) [9], AERO-Z (Nexans, Belgium) [10] was performed using the criterion method [11] for 1 km of single-circuit PLE 110 kV, provided that the maximum wire tension permissible under the Rules for electrical installations (REI) is reached - 45% of the breaking force, but no more than 42.5 kN [6].

During the comparative analysis, the technological supply of wires was not taken into account, but the requirements for the sag arrow, wire mass, maximum current, and minimum cost were made. Also, the cost of the same structural elements of the line was not taken into account, that is: supports, coupling linear fittings, insulators, protective fittings.

The determination of the cost of 1 km OL of 110 kV power line, taking into account the accepted assumptions, was carried out in conventional units (units) according to the formula:

$$B = B_1 + B_2 + B_3, \quad (1)$$

where B1 is the cost of 1 km of wire; B2 - cost of tensioning and supporting clamps for 1 km of 110 kV power line; B3 - the cost of installation work for 1 km of 110 kV power line.

The cost of wires B1 (f. 1) was not tied to a specific volume, conditions, period of delivery and depends on world prices for aluminum and exchange rates.

During the calculation of B2 (f. 1), the cost of the tensioning and supporting clamps was used directly. For the AS wire, the cost of traditional clamps was taken, and for the rest of the wires, the cost of special type clamps was used to ensure the maximum durability of the wire.

Calculation B3 (f. 1) is carried out without taking into account the costs of preparatory work, coordination, disconnection, transportation of materials to the object, emergency stock and other additional costs, which are specified at the stage of design and estimate documentation.

Since the information contained in the value indicators (f. 1) is variable, which leads to its incompleteness and complicates the process of comparing wires. Therefore, the criterion method was chosen for the comparative analysis. The advantage of the criterion method is the determination of the optimal values of the objective function; optimization parameters; assessment of the stability of the function to changes in parameters around the minimum point; study of the sensitivity of the solution to the problem when the source information changes. The criterion method is based on the theory of similarity and allows to minimize the polynomial of the species [11]:

$$Y_{(x)} = \sum_{i=1}^{m_1} A_i \prod_{j=1}^{n} x_j^{\alpha_{ij}}, \; x_j \geq 0, \qquad (2)$$

where A_i are positive generalized constants that have a deterministic or probabilistic character depending on the conditions of the task and represent initial information about the object; x_j – optimization parameters, positive variables; α_{ij} – degree indicators, real numbers; m_1 - is the number of terms in the polynomial; n - is the number of independent parameters.

Restrictions imposed on individual variables x_j and their complexes are presented in the form of polynomials similar to (f. 2):

$$q_K(x) = \sum_{i=m_{K+1}}^{m_{K+1}} A_i \prod_{j=1}^{n} x_j^{\alpha_{ij}} \leq 1. \qquad (3)$$

A necessary condition for the existence of a conditional minimum of a function, taking into account all restrictions, is the requirement of canonicality of the function, which is understood as the fulfillment of the following relation:

$$M - п - 1 = 0, (M = п + 1), \qquad (4)$$

where M - is the total number of terms in the polynomial and constraints.

Algorithms of the criterion method make it possible to find optimal and quantitative economic relations of the object both with given and incomplete initial information in the conditional unit [11].

The characteristics of wires, which were taken into account during the comparative analysis [5, 9, 10], and the results of calculating the cost of 1 km of 110 kV OL by the criterion method are given in the table. 1.

Table 1

Comparison of AS, ACCR, AERO-Z wires

Technical and economic indicators	AS 240/32	ACCR 270-T16	AERO-Z 366-2Z
Long-term permissible current of the wire, A	605	1331	771
The maximum temperature of the wire, °C	70	210	70
Weight of the wire, kg/km	1313	967	1014
Boom sag at T=max, m	10,1	9,9	9,9
Comparison of the cost of 1 km of the 110 kV OL, units	1	Will increase by 4.8 times	will increase by 1.9 times

As follows from the table. 1, ACCR wire has a significant increase in current carrying capacity at a lower weight compared to AS and AERO-Z wires, but a relatively high price compared to these wires, which does not allow the use of ACCR wire in Ukrainian ENs for economic reasons. Analyzing the possibility of using ACCR and AERO-Z wires (table 1) spans with unfavorable climatic conditions, which include strong winds, ice-frost deposits, sticking snow, it makes sense to give preference to AERO-Z wire. Because its permissible current load is greater than the continuous current load of the AS wire, and the cost of the wire is lower than that of the ACCR wire. But the decisive circumstance for making a decision regarding the use of AERO-Z wire is definitely its design, which is more adapted to adverse climatic conditions that affect the characteristics of the transmission of electrical energy.

Thus, despite the better, compared to other wires, technical indicators of the ACCR wire, the factor that limits the scope of its application even for pro-lots with extremely high requirements for the characteristics of the transmission of electrical energy is its extremely high cost.

Conclusion.

The article analyzed the technical and economic characteristics of AS, ACCR, AERO-Z wires and performed a comparative analysis, which made it possible to justify the feasibility of using these brands of wires in Ukrainian electrical networks in order to increase the efficiency of electric energy transmission due to the modernization of the current-conducting part of the lines.

Based on the results of the conducted research, it follows that the AERO-Z conductor is the most appropriate for introduction into Ukrainian electrical networks. Because the technical characteristics of this wire are better than the characteristics of AC wire and it has a relatively low cost compared to ACCR wire, and its special design is adapted to adverse climatic conditions that affect the characteristics of electrical energy transmission.

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