Study of optimality of existing 10 kV overhead wire standard section scale

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Abstract. In the article, using the method of economic intervals using the principle of limiting the permissible increase in costs from the optimal ones, the existing scale of standard wire cross-sections of 10 kV lines was investigated and, as a result, it was established that the existing scale does not satisfy the conditions of optimality and a new scale was developed that satisfies the conditions of economy.

1 Introduction

For the optimal development of electrical networks, it is important not only to select the parameters of a network element from the existing standard scale of standard sizes, but also to optimize standard scales of equipment standard sizes or to check their optimality.

In accordance with the requirements set forth in [1], at the present time, the preferred are the scales of standard sizes, built with a constant step according to the principle of geometric progression. The existing standard scale for nominal wire cross-sections of overhead power transmission lines has an uneven pitch between adjacent cross-sections. According to [2], for wires of overhead power transmission lines 10 kV, the following standard cross-sectional scale is adopted in Uzbekistan: 16; 25; 35; fifty; 70; 95; 120; 150; 185; 240 mm^2. The ratio between adjacent sections here ranges from 1.56 to 1.23. That is, the standard scale of line cross-sections does not meet the requirements of [1] and therefore the question arises of compliance of the existing scale of line cross-sections with the requirements of optimality.

It should be noted that recently the question of the optimality of the existing scale of cable cross-sections for urban networks has been raised [1-6]. The issue of unification of electrical equipment (including cables) is being considered abroad [7-13].

Based on the analysis of methods for constructing optimal parametric series of electrical equipment [4, 5, 6] for constructing a parametric series of wire cross-sections intended for 10 kV overhead power lines, it is proposed to use the method of economic load intervals and the principle of limiting the permissible increase in costs from the optimal ones.

In this case, the boundaries of economic load intervals are determined from the condition:

$$З_i = З_{i+1}, \qquad (1)$$

where $З_i$ - costs for a line with a section F_i; $З_{i+1}$- - the same, at the section F_{i+1};

The costs are determined [9]:

$$З_i = (E_н + p_a)K_i + \frac{U_П S^2 10^{-5}}{U_н^2 \gamma F_i}, \qquad (2)$$

where $E_н$ - standard coefficient of efficiency of capital investments; p_a - depreciation rate; S - load, kVA; $U_н$- rated voltage, kV; -specific conductivity of conductive material, km/Ohm·mm^2; F_i- wire cross-section, mm^2; $U_П$- costs for reimbursement of electricity losses, sum / kV-th.

Research has established that investment in the construction of single voltage lines with high accuracy is approximated by a linear function of the form [3]:

$$K_i = K_0 + kF_i, \qquad (3)$$

where K_0- is a constant component of the cost, which does not depend on the cross-section of the wire; k - coefficient of appreciation.

If the load during the entire considered period is constant and does not change over time, i.e. . $S_t = S_{t-1} = S$, than $З_i$ in $З_{i+1}$ in expression (2) will take the form:

$$З_i = (E_н + p_a)K_i + \frac{U_П S^2 10^{-5}}{U_н^2 \gamma F_i}, \qquad (4)$$

$$З_{i+1} = (E_н + p_a)K_{i+1} + \frac{U_П S^2 10^{-5}}{U_н^2 \gamma F_{i+1}}, \qquad (5)$$

Equating expressions (4) and (5) in accordance with condition (1) and solving the resulting equation with respect to the load, we obtain an expression for determining the boundaries of economic intervals for adjacent sections:

$$S_{\text{гр}} = \sqrt{\frac{(E_{\text{н}}+p_a)(K_{i+1}-K_i)U_{\text{н}}^2\gamma F_{i+1}F_i 10^5}{U_{\text{п}}(F_{i+1}-F_i)}}, \tag{6}$$

If in expression (4) instead of the load we substitute its boundary value (6), then the costs are:

$$\text{З}_{\text{гр}i} = (E_{\text{н}}+p_a)\left[K_i + \frac{F_{i+1}(K_{i+1}-K_i)}{F_{i+1}-F_i}\right], \tag{7}$$

In the practice of design and scientific and technical research, it is accepted that two compared options are considered economically equivalent if their indicators differ by no more than 5%. This condition is the basis of one of the approaches to determining the optimal parametric series [7], which consists in the fact that the deviation of the actual costs when using the section from the standard scale from the optimal ones is 5% [14-25]:

$$\text{З}_{\text{ф}} = (1+\delta)\text{З}_{\text{э}}, \tag{8}$$

where δ is the deviation of the actual costs from the optimal ones (0.05).

Based on the economic intervals of the load, the relative change in costs when deviating from the economic section to a larger or smaller standard is determined as

$$\delta_i^{\text{н}} = \frac{\text{З}_i^{\text{н}} - \text{З}_{i\text{э}}^{\text{н}}}{\text{З}_{i\text{э}}^{\text{н}}} \quad \text{and} \quad \delta_i^{\text{в}} = \frac{\text{З}_i^{\text{в}} - \text{З}_{i\text{э}}^{\text{в}}}{\text{З}_{i\text{э}}^{\text{в}}}, \tag{9}$$

The values of the costs $\text{З}_i^{\text{н}}$ and $\text{З}_i^{\text{в}}$ are determined by substituting in (7) the value of capital investments according to (3). After transformations we get:

$$\begin{aligned}\text{З}_i^{\text{н}} &= (E_{\text{н}}+p_a)[K_0 + k(F_{i-1}+F_i)] \\ \text{З}_i^{\text{в}} &= (E_{\text{н}}+p_a)[K_0 + k(F_i+F_{i+1})],\end{aligned} \tag{10}$$

If we conditionally take a number of wire cross-sections to be continuous, then for any given load it is possible to find the optimal wire cross-section $F_{\text{э}}$ corresponding to it, the use of which would ensure a minimum cost. This section is determined from the equality to zero of the partial derivative of function (2) with respect to the section. In this case, the optimal cross section is:

$$F_{\text{э}} = S_T\sqrt{\frac{U_{\text{п}}10^{-5}}{U_{\text{н}}^2\gamma(E_{\text{н}}+p_a)k}}, \tag{11}$$

The costs $\text{З}_{\text{э}}$, corresponding to this section are determined from expression (2) by substituting the optimal $F_{\text{э}}$ instead of F:

$$\text{З}_{\text{э}} = (E_{\text{н}}+p_a)K_0 + 2S_T\sqrt{\frac{kU_{\text{п}}10^{-5}}{U_{\text{н}}^2\gamma}}, \tag{12}$$

When substituting the boundary values of the load according to expression (6) into expression (11), we obtain economic sections corresponding to the boundary capacities $\text{З}_{\text{гр}i}^{\text{н}}$ и $\text{З}_{\text{гр}i}^{\text{в}}$.

$$F_{i\text{э}}^{\text{н}} = \sqrt{F_{i-1}F_i}, \quad F_{i\text{э}}^{\text{в}} = \sqrt{F_iF_{i+1}}, \tag{13}$$

The values of $\text{З}_i^{\text{н}}$ and $\text{З}_i^{\text{в}}$ are determined by substituting in (10) the boundary values of the load according to expression (6) and the values of economic sections according to (13). Under appropriate transformations, we obtain [26-29]:

$$\begin{aligned}\text{З}_i^{\text{н}} &= (E_{\text{н}}+p_a)\left[K_0 + 2k\sqrt{F_{i-1}F_i}\right] \\ \text{З}_i^{\text{в}} &= (E_{\text{н}}+p_a)\left[K_0 + 2k\sqrt{F_iF_{i+1}}\right],\end{aligned} \tag{14}$$

Taking into account expression (9) and (14), we find

$$\delta_i^{\text{н}} = \frac{\left(\sqrt{F_i}-\sqrt{F_{i-1}}\right)^2}{\frac{K_0}{k} + 2\sqrt{F_{i-1}F_i}} \quad \text{and} \quad \delta_i^{\text{в}} = \frac{\left(\sqrt{F_{i+1}}-\sqrt{F_i}\right)^2}{\frac{K_0}{k} + 2\sqrt{F_iF_{i+1}}}, \tag{15}$$

The value of the relative deviation of costs when deviating from the economic section is determined by the ratio of adjacent standard sections and the ratio of the constant component of the cost of the line K_0, which does not depend on the section and the coefficient of appreciation k.

Table 1 shows the results of calculating the values of relative changes in costs when deviating from the economic section for 10 kV overhead lines. Data analysis table. 1 shows that the value of the ratio K_0 / k varies within narrow limits - from 92.73 to 124.02 with the arithmetic mean of 116,62 and the mean square of 112,27.

From table. 1 it can be seen that the deviation of the actual costs from the economically optimal ones for the existing scale of standard wire cross-sections of 10 kV overhead lines varies within 0.004 ... 0.008 and it is an order of magnitude lower than the accepted 5%. These results indicate that the existing scale of nominal wire cross-sections does not correspond to the possible optimal range.

Calculations of the value of displacement of the boundary values of the load were carried out under the condition δ = 0.05. For clarity, the calculation results are shown in Fig. 1 (thick lines). There are also presented the economic load intervals for the existing wire cross-sections of 10 kV overhead lines (thin lines).

Table 1

The magnitude of the relative changes in costs when deviating from the economic section

Section mm^2	The relative change in costs for K_0/k							
	97,22	118,90	92,73	115,92	124,02	120,91	112,27	116,62
16	0,0073	0,0063	0,0075	0,0064	0,0061	0,0062	0,0066	0,0064
25	0,0054	0,0047	0,0055	0,0048	0,0046	0,0047	0,0049	0,0048
35	0,0074	0,0066	0,0076	0,0067	0,0064	0,0065	0,0068	0,0067
50	0,0078	0,0071	0,0080	0,0072	0,0069	0,0070	0,0073	0,0071
70	0,0073	0,0068	0,0074	0,0068	0,0066	0,0067	0,0069	0,0068
95	0,0047	0,0044	0,0048	0,0044	0,0043	0,0044	0,0045	0,0044
120	0,0046	0,0043	0,0046	0,0044	0,0043	0,0043	0,0044	0,0043
150	0,0043	0,0041	0,0043	0,0041	0,0040	0,0040	0,0041	0,0041
185	0,0069	0,0066	0,0070	0,0067	0,0066	0,0066	0,0067	0,0066

From Fig. 1, it follows that taking into account the permissible 5% deviation of actual costs from economic costs makes it possible to abandon the use of some sections from the standard series, which confirms the relevance and legitimacy of raising the question of the expediency of the existing scale of nominal cross-sections of 10 kV overhead lines and the need to develop a new scale. satisfying the conditions of efficiency [30-31].

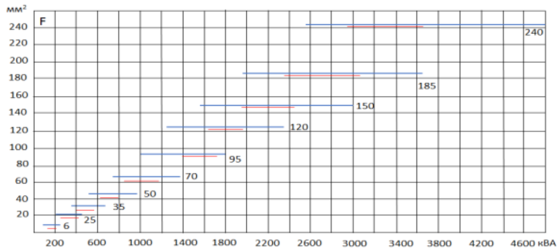

Fig. 1. Change in economic load intervals at δ = 0.05.

Currently, it is recommended to build a standard series of standard sizes with a constant step according to the principle of geometric progression [3]. Then you can write.

$$\frac{F_{i+1}}{F_i} = q$$

Or the step size of the scale is determined by:

$$q = \left[(1+\delta) + \sqrt{(1+\delta)^2 - \left(1 + \frac{K_0\delta}{kF_0}\right)}\right]^2 \qquad (16)$$

From the obtained expression (17), it can be seen that the size of the scale step is determined only by the value of the relative change in costs when deviating from the economic section and the ratio of the constant component of the line cost, which does not depend on the section, to the coefficient of rise in the cost of the line, as well as on the initial section of the scale. The dependence of the increment of the scale on the change in the initial section of the F_0 scale and the ratio K_0 / k is shown graphically in Fig. 2. The curve in fig. 2.constructed at δ = 0.05 and K_0 / k = 112.27 [32-39].

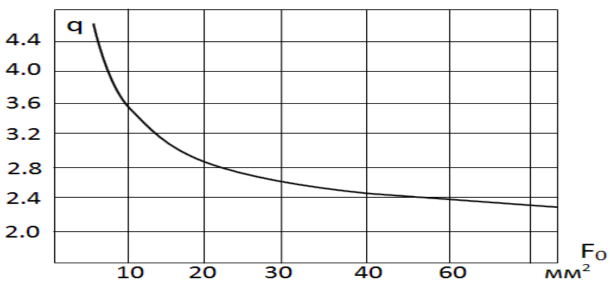

Fig. 2. Dependence of the scale step from change $\frac{K_0}{k}$, F_0, and δ

In this case, the step size of the cable cross-section scale is equal to 3.48; 2.97 and 2.63, respectively, for initial sections of 10.16 and 25 mm^2. In this case, instead of 8 standard sections, it turns out to be possible to use only three sections. In this case, after rounding off the scale of sections, they take the form: 10, 35, 120 mm^2; 16, 50, 150 mm^2; 25, 70, 150 mm^2 [40-47].

2 Conclusions

Thus, the existing parametric range of nominal cross-sections of 10 kV wires does not satisfy the conditions for optimal use of lines and contains an overestimated number of cross-sections. In this case, the optimal parametric series of 10 kV wire cross-sections with an initial cross-section of 25 mm^2 is 25; 70; 150 mm^2.

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