Economic interval analysis of loads for selection of cross-section surfaces of electrical transmission lines

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Abstract. In this article, the implementation of comprehensive measures for the use of modern approaches to the selection of the main parameters of the system in the development of the electric power industry of our Republic, including the development of methods for optimizing, updating and increasing the reliability of electric transmission networks, as well as the selection of the most optimal cross-sectional surface of the conductors of power transmission lines written about the problem and the widespread use of the method of economic intervals to solve this problem. In addition, the action strategy for the further development of the Republic of Uzbekistan in 2017-2021 defines the tasks of "... to reduce the energy and resource capacities of the economy, to widely introduce energy-saving technologies into production, which are implemented in accordance with the target parameters of reducing energy consumption in economic sectors,..." and these tasks. It has been reflected that determining the optimal parameters of electrical networks, carrying out theoretical and scientific work on increasing their reliability, and receiving appropriate recommendations for the design, construction, modernization and operation of rural electrical networks are considered to be one of the most important issues for implementation.

1 Introduction

The problem of choosing the optimal cross-sectional surface of power line conductors has always been a problem, and now a lot of attention is paid to this problem. To solve this problem, the method of economic intervals is widely used. Academician Budzko I.A., Venikov V.A., Levin M.S., Kholmsky V.G., Blok V.N., Efentev S.N., Zuev E.N., Suvorova I. developed the theoretical aspects of this method. A., Herkusov A.A., Freishteter V.P., Martyanov A.C., Varygina A.O., Fedotov A.I. and a number of other research scientists [1-8]. Subsequent studies have substantiated and refined this method both theoretically and practically.

2 The current state of the investigated problem

The availability and adequacy of economic intervals for wire and cable loads are shown in [9, 26]. If initially the economic range of the load was determined for static load, then in the process of determining them, the dynamics of load growth [10, 29] and the possibilities of reconstruction of power lines were taken into account [11-18].

However, it should be noted that mainly the economic ranges of loads are widely used in the calculation and selection of wires of overhead transmission lines. To date, economic current density is widely used to select cross-sectional areas of cable lines, but it does not meet the condition of minimum total costs. In this regard, it was necessary to determine the economic ranges of loads and the tasks associated with them in order to choose the cross-sectional surfaces of the cables [19-25].

3 Study of changes in economic load intervals

The limits of the economic range of the load are determined from the following condition [12]:

$$З_i = З_{i+1} \tag{1}$$

where $З_i$ is the total cost of the cable line with a cross-sectional area F_i, $З_{i+1}$ is the total cost of a cable line with a cross-sectional area F_{i+1}.

As for determining the economic intervals of loads, the total costs for cable lines are determined as follows. Capital investments in the construction of cable lines are usually made within one year. It is difficult to reconstruct the cable line to increase its carrying capacity, and because it is not useful during its service life, new capital costs are not included in it. Taking into

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account these characteristics of cable lines, the capital cost shown in the expression is written as follows:

$$E_M \sum_{t=1}^{T} K_t (1+E_{MK})^{\tau-t} = E_M K \qquad (2)$$

In this case, we assume that the costs are included in the first year of operation τ=1.

Due to the fact that capital funds do not change, depreciation expenses remain constant, in which we can write the following expression:

$$\sum_{t=1}^{T} (U_{at} - U_{a(t-1)})(1+E_{MK})^{1-t} = U_{a1} = p_a K \qquad (3)$$

Operating costs do not depend on the cross-sectional area of the cables and do not change over time. Therefore, they may not be taken into account when determining the economic intervals of loading. When determining the economic intervals of loads, the length of power lines is not important and is usually taken as 1 km.

Taking into account the above, as well as expressions (2) and (3), the expression for determining the total costs of the transmission line can be written as follows:

$$З = (E_M + p_a)K \frac{U_H 10^{-5}}{U_H^2 \gamma F}\left[S_1^2 + \sum_{t=2}^{T}(S_t^2 - S_{t-1}^2)(1+E_{MK})^{1-t}\right] \qquad (4)$$

The analysis of technical and economic indicators of cable lines in rural areas showed that all cross-sectional surfaces of cables have economic intervals in accordance with the conditions of availability of economic intervals of loads.

If the load during the considered period is constant and does not change over time

$$S_t = S_{t-1} = S$$

then according to (4) $З_i$ and $З_{i+1}$ in expression (1) take the following form:

$$З_i = (E_M + p_a)K_i + \frac{U_H S^2 10^{-5}}{U_H^2 \gamma F_i} \qquad (5)$$

$$З_{i+1} = (E_M + p_a)K_{i+1} + \frac{U_H S^2 10^{-5}}{U_H^2 \gamma F_{i+1}} \qquad (6)$$

Equating expressions (5) and (6) in accordance with condition (1) and solving the obtained equation with respect to the load, we find the expression for determining the limits of the economic intervals for the interconnected cross-sectional surfaces for the case where the load growth dynamics is not taken into account.

$$S_{чег} = \sqrt{\frac{(E_M + p_a)(K_{i+1} - K_i)U_H^2 \gamma F_{i+1} F_i 10^5}{U_H (F_{i+1} - F_i)}} \qquad (7)$$

As can be seen in expression (7), the sectors that determine the limits of the economic intervals of the load can be divided into two groups: fixed (constant) and variable. The first includes specific permeability and standard cross-sectional areas F_i and F_{i+1}. The group of constant factors can be conditionally included E_M - standard coefficient of efficiency, p_a - standard coefficient of amortization output and U_H - nominal voltage.

The economic intervals of the load have a completely different effect on the time variation of the load. If the growth of the load is expressed in relation to the value at the end of the accounting period, then the limit values of the economic load intervals can be determined by the following expression [12].

$$S_{чег} = \sqrt{\frac{(E_M + p_a)(K_{i+1} - K_i)U_H^2 \gamma F_{i+1} F_i 10^5}{U_H (F_{i+1} - F_i) A}} \qquad (8)$$

where A is the coefficient that determines the law of growth of the load.

The value of the coefficient A is determined by expressions (10) - (15), respectively, in relation to the exponential, linear, simple modified exponential laws of load growth and the saw-shaped description of the load.

The obtained expression (8) differs from the similar expression (7) only by the part $A^{-\frac{1}{2}}$ in order to take into account the load growth dynamics. If the expression (7) is taken as a basis, then the expressed part of $A^{-\frac{1}{2}}$ is actually the relative values of the limit of economic load intervals. We call them displacement coefficients and denote them by k_c . During the study, they are determined according to the corresponding value of A as follows:

$$k_c = A^{-\frac{1}{2}} \qquad (10)$$

$$A^Э = (1+k_{ўc})^{2(1-T)} + \left[1-(1-k_{ўc})^{-2}\right] \times \sum_{t=2}^{T}(1+k_{ўc})^{2(t-T)}(1+E_{MK})^{1-t} \qquad (11)$$

$$A^Ч = (1+k_{ўc})^{-2} + (1+k_{ўc})^2 + \sum_{t=2}^{T}(1+k_{ўc})^{2(t-T)}(1+E_{MK})^{1-t} \qquad (12)$$

$$A^{МЭ} = \left[1-(1-\frac{1}{k_T})m\right]^2 + \sum_{t=2}^{T}\left\{\left[1-(1-\frac{1}{k_T})m^t\right]^2 - \left[1-(1-\frac{1}{k_T})m^{t-1}\right]^2\right\} \times (1+E_{MK})^{1-t} \qquad (13)$$

$$
\begin{aligned}
A^{AЭ} &= (1+k_{\breve{y}c})^{2(t-\tau_M)} + \left[1-(1+k_{\breve{y}c})^{-2}\right]\times \\
&\times \sum_{t=2}^{t_{p1}} (1+k_{\breve{y}c})^{2(t-t_{p1})}(1+E_{MK})^{1-t} + \\
&+ \left[k_{p1}^2(1+k_{\breve{y}c2})^{2(t_{p1}-t_{p2}+1)} - 1\right]\times(1+E_{MK})^{1-t_{p1}} + \\
&+ k_{p1}^2\left[1-(1+k_{\breve{y}c})^{-2}\right] \sum_{t=t_{p1}+2}^{t_{p2}} (1+k_{\breve{y}c2})^{2(t-t_{p2})}(1+E_{MK})^{1-t} + \\
&+ \left[k_{p1}^2(1+k_{\breve{y}c3})^{2(t_{p2}-T+1)} - k_{p1}^2\right](1+E_{MK})^{1-t_{p2}} + \\
&+ k_{p2}^2\left[1-(1+k_{\breve{y}c3})^{-2}\right] \sum_{t=t_{p2}+2}^{T} (1+k_{\breve{y}c3})^{2(t-T)}(1+E_{MK})^{1-t}
\end{aligned}
\qquad (14)
$$

$$
\begin{aligned}
A^{AЧ} &= (1+k_{\breve{y}c}t_{p1})^{-2} + \\
&\left[(1+k_{\breve{y}c1})^2 + k_{\breve{y}c}\sum_{t=2}^{t_{p1}} \begin{matrix}(2+2k_{\breve{y}c1}t-k_{\breve{y}c1})\times \\ \times(1+E_{MK})^{1-t}\end{matrix}\right] + \\
&k_{p1}^2(1+k_{\breve{y}c2}t_{p2})^{-2}\times \\
&\times\left\{\begin{matrix}\left[1+k_{\breve{y}c2}(t_{p2}+1)\right]^2 + \\ +(1+E_{MK})^{-t_{p1}} + \\ +k_{\breve{y}c2}\sum_{t=t_{p1}+2}^{t_{p2}}(2+2k_{\breve{y}c2}t-k_{\breve{y}c2})(1+E_{MK})^{1-t}\end{matrix}\right\} + \\
&+k_{p1}^2(1+k_{\breve{y}c3}T)^{-2}\times \\
&\times\left\{\begin{matrix}\left[1+k_{\breve{y}c3}(t_{p2}+1)\right]^2 + \\ +(1+E_{MK})^{-t_{p2}} + k_{\breve{y}c3}\times \\ \times\sum_{t=t_{p2}+2}^{T}(2+2k_{\breve{y}c3}t-k_{\breve{y}c3})(1+E_{MK})^{1-t}\end{matrix}\right\} - \\
&-(1+E_{MK})^{-t_{p1}}\left[1+k_{p1}^2(1+E_{MK})^{t_{p1}-t_{p2}}\right]
\end{aligned}
\qquad (15)
$$

The analysis of the expressions for determining the displacement coefficient shows that they do not depend on the cross-sectional area of the cables and are actually determined by the relative load growth factor (multiplier of the load growth) and the calculation period. Using the coefficient A, the expression of the total costs of the power line for any law of load growth can be written as follows.

$$
З_i = \left(E_M + p_a\right)\left(K_0 + kF_i\right) + \frac{U_H S_T^2 A 10^{-5}}{U_H^2 \gamma F_i} \qquad (16)
$$

To determine the effect of different laws of load growth on displacement coefficients, the compared options should be equal. If the compared growth laws give the same multiple of load growth, then the comparison conditions are satisfied. Therefore, it is necessary to express the previously mentioned laws of load growth with the growth factor.

For the law of exponential growth, the load growth factor at t=T is determined as follows:

$$
k_T^{Э} = \frac{S_T}{S_0}(1+k_{\breve{y}c}^{э})^2 \qquad (17)
$$

Similarly for the linear law of load growth

$$
k_T^{Ч} = \frac{S_T}{S_0}(1+k_{\breve{y}c}^{Ч})^2 \qquad (18)
$$

If the load growth factor is determined from expressions (17) and (18), then the comparison conditions are fulfilled.

A given load factor:

$$
k_{\breve{y}c}^{э} = \exp\left(\frac{\ln k_T}{T}\right) - 1 \qquad (19)
$$

$$
k_{\breve{y}c}^{Ч} = \frac{k_T - 1}{T} \qquad (20)
$$

For the load to grow according to a simple modified exponential law

$$
\ln m = \frac{\ln 0{,}05 S_T - \ln(1{,}05 S_T - S_0)}{T}
$$

or considering $k_T = S_T / S_0$,

$$
\ln m = \frac{\ln 0{,}05 - \ln\left(1{,}05 - \dfrac{1}{k_T}\right)}{T} \qquad (21)
$$

In order to study the influence of different laws of load growth on the displacement coefficient, appropriate calculations were carried out. The calculation results are presented in graphs 1-2.

The value of the displacement coefficient depends significantly on the law of growth of the load, the value of the multiple growths of the load and the calculation period T.

The length of the calculation period has a different effect on the value of the drift coefficients. In the linear law of load growth and any duration of the calculation period, the displacement coefficient is less than the exponential one, and the difference between them increases as the duration T increases.

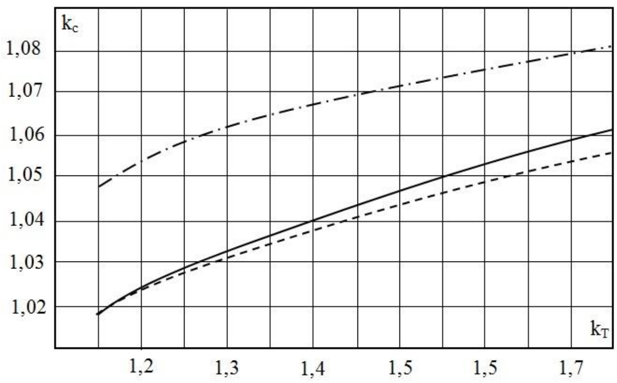
This difference increases as the load increases.

According to the simple modified exponential law, the coefficient of displacement is larger with the growth of the load and the short duration of the calculation period, decreases with the increase of the calculation period, and becomes smaller compared to the exponential growth of the load. The characteristic of the change of the displacement coefficient with respect to the change of the multiple growth of the load is approximately the same as the change of the calculation period [27, 28].

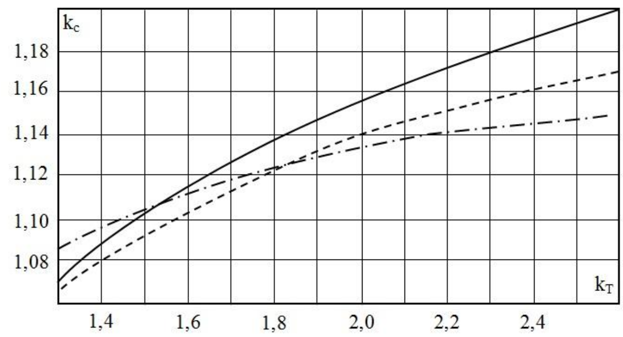
4 Influence of different laws of load growth on the shear coefficient

Analysis of shift coefficients in the change of the load in the saw-shaped description: their value shows the dependence of the laws of growth of loads between reconstructions, the coefficient of growth of the load, the value of the coefficient of distribution of loads, the time of reconstruction and the duration of the accounting period. In comparable conditions, the coefficient $k_c^{э.ўс}$ is always greater than $k_c^{ўс.ч}$. The large number of variable parameters does not allow to build appropriate relationships.

In all possible cases, the shift factor is always greater than one. Thus, when choosing cross-sectional areas of cables for lines whose load does not change over time, the limits of economic intervals of loads are always greater than those of lines whose load changes.



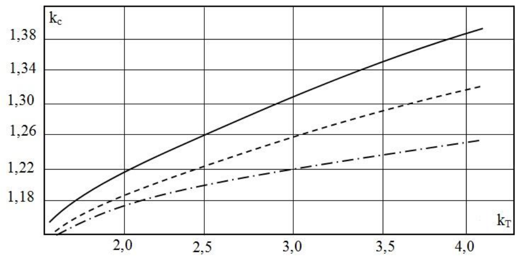
a)



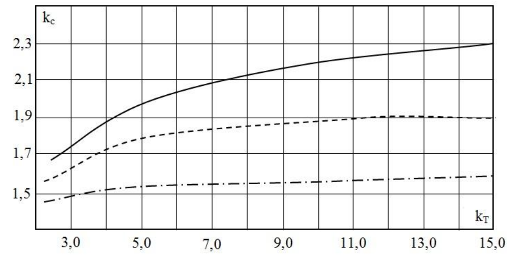
b)

—— $k_c^{э}$; – – – $k_c^{ч}$; –·– $k_c^{м.э}$;

Fig.1. a) T=5 years; b) T=10 years; Dependence of the change of displacement coefficients on k_T



a)



b)

—— $k_c^{э}$; – – – $k_c^{ч}$; –·– $k_c^{м.э}$;

Fig.2. a) T=15 years; b) T=30 years; Dependence of the change of displacement coefficients on k_T

The upper limit of the displacement coefficient is limited by the permissible load currents in the cable. If we take the value of the long-term permissible load current [13, 28] of the cables with the appropriate cross-sectional area, the upper limit of the economic range established for the case of constant loads, we get the values of the technically maximum permissible displacement coefficients. Studies have shown that their value is from 1.76 to 4.47, and with the increase of the cross-sectional area of the cables, the allowable displacement coefficient decreases [30-33, 14, 20].

5 Conclusion

The analysis of the values of the coefficient of displacement k_c shows that its value is 1.735 for the accounting period of 20 years with an increase in the load by 12% per year according to the exponential law. Thus, taking into account the dynamics of restrictions on long-term permissible loading, the choice of cross-sectional areas of cables in the economic intervals of loading is practically not affected.

The case is more complicated considering the limit on the allowable voltage drop. Economic loading intervals do not take this limitation into account. Therefore, after choosing the cross-sectional area of the cables for economic load intervals, it is necessary to check the selected cross-sectional area according to the permissible voltage loss.

Thus, it is possible to determine the limits of the economic intervals of the load, without taking into account the change of the load over time, and using the shift coefficients of the limits of the economic intervals, the limits of the economic intervals can be determined for any law of growth of the loads.

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