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## Economic load intervals for selecting 10 kV cable cross-sections for agricultural consumers

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**Abstract.** District electric networks for agricultural purposes are characterized by a constant increase in loads. In these conditions, it is important to choose the correct parameters of power lines and, first of all, the cross-sections of overhead lines (overhead lines) and cable lines. There are technical possibilities to increase the capacity of overhead power lines, which can be carried out in the following ways: voltage regulation; reactive power compensation; replacement of existing wires with wires of a larger cross-section; load unbundling; transfer of the network to an increased voltage. Increasing the capacity of cable transmission lines by all of these methods is not possible due to their design features. Thus, due to the difficulties of increasing the capacity of cable lines and dynamically developing networks, the problem of choosing the optimal cable cross-section for lines with an ever-increasing load is becoming more acute. Currently, agricultural distribution electric networks have a constant increase in load. In these conditions, the correct choice of the parameters of cable lines and the residential cable line is of great importance. Due to the complexity of increasing the throughput of cable lines and dynamic networks, problems arise with the choice of optimal paths for wires and residential cables for agricultural lines.

### 1. Introduction

In the world and the Republic, special attention is paid to solving the problem of increasing the efficiency of agricultural production and implementing the food program. The successful solution of the tasks set for the reliable provision of agricultural production with the necessary amount of electricity requires further development of electric networks for agricultural purposes. In this regard, an important task is to increase the reliability of power supply to agricultural consumers using cable networks, improve methods for selecting elements of rural electric networks in the conditions of their development and reduce power losses in lines by applying their optimal parameters, which are used in the design, reconstruction, modernization, and operation of rural electric networks [1, 2, 3].



The purpose of the research is a study of the optimal development trend of rural electric networks using cable lines to improve the reliability of power supply to rural consumers and the development of an appropriate scale of standard cable cross-sections of rural electric networks.

Research problem:

determining the optimal development trend of the agricultural cable network due to the peculiarities of the cable line and the constant increase in a load of rural consumers.

study of the boundaries of economic load intervals for a given scale of cross-sections of cable cores, taking into account and without taking into account the influence of limiting conditions;

research and development of an appropriate scale of standard cross-sections of agricultural cables using the method of economic intervals.

The object of research is rural electric networks.

The subject of the research is the search for optimal parameters of low-voltage rural electric networks.

## 2. Methods

Recognition and the greatest application for solving this problem have received the method of economic intervals [4, 5]. However, it should be noted that mainly the economic load intervals were calculated and widely used to select the wires of overhead power lines. To select the cross-sections of cable cores of cable power lines, the economic current density is widely used to date, which does not meet the minimum cost condition. In this regard, it became necessary to determine the economic load intervals for the choice of cross-sections of cable conductors and related tasks.

## 3. Results and Discussion

When applying the method of economic intervals, boundaries of the economic intervals of the load are determined from the condition

$$3_i = 3_{i+1} \quad (1)$$

where  $3_i$  is the cost of a cable line with a cross-section of cable conductors  $F_i$ ;  $3_{i+1}$  is the same, with the cross-section of the cable veins  $F_{i+1}$ .

With regard to the definition of economic load intervals, the costs of cable power lines can be determined as follows [3].

$$3 = (E_H + p_a)K \frac{U_{\Pi} 10^{-5}}{U_H^2 \gamma F} \left[ S_1^2 + \sum_{t=2}^T (S_t^2 - S_{t-1}^2)(1 + E_{\text{Hnn}})^{1-t} \right] \quad (4)$$

An analysis of the technical and economic indicators of 10 kV cable power lines in rural areas showed that, following the conditions for the existence of economic intervals [6], all standard cable core sections have economic load intervals.

If the load throughout the entire period under review is constant and does not change in time.

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

then  $3_i$  and  $3_{i+1}$  in the expression (1) in accordance with (4) will take the form

$$3_i = (E_H + p_a)K_i + \frac{U_{\Pi} S^2 10^{-5}}{U_H^2 \gamma F_i} \quad (5)$$

$$3_{i+1} = (E_H + p_a)K_{i+1} + \frac{U_{\Pi} S^2 10^{-5}}{U_H^2 \gamma F_{i+1}} \quad (6)$$

Equating expressions (5) and (6) following condition (1) and solving the obtained equation with respect to the load, we obtain an expression for determining the boundaries of economic intervals for adjacent sections for the case that does not take into account the dynamics of load growth

$$S_{gr} = \sqrt{\frac{(E_H + p_a)(K_{i+1} - K_i)U_H^2\gamma F_{i+1}F_i 10^5}{U_{\Pi}(F_{i+1} - F_i)}} \quad (7)$$

From the expression (7) it can be seen that the sectors that determine the boundaries of the economic intervals of the load can be divided into two groups: constant and variable. The former include conductivity and standard sections  $F_i$  and  $F_{i+1}$ . The group of constant factors can also conditionally include the standard efficiency coefficient  $E_H$ , the rate of depreciation deductions  $p_a$  and the stress  $U_H$ . A completely different effect on the economic intervals of the load has a change in load over time. If the load growth is expressed relative to its value at the end of the billing period, then the boundary values of the economic loading intervals can be determined by the following expression

$$S_{rp} = \sqrt{\frac{(E_H + p_a)(K_{i+1} - K_i)U_H^2\gamma F_i F_{i+1} 10^5}{U_{\Pi}(F_{i+1} - F_i)A}} \quad (11)$$

where  $A$  - is the coefficient determined by the law of load growth.

The coefficient  $A$  is determined for the exponential, linear laws of load growth and load growth according to the law of a simply modified exponent.

When using coefficient  $A$ , the expression for the reduced costs of the power line for any law of load growth can be written as

$$3_i = (E_H + p_a)(K_0 + kF_i) + \frac{U_{\Pi}S_T^2 A 10^{-5}}{U_H^2\gamma F_i} \quad (12)$$

To determine the effect of various laws of load growth, the compared options should be comparable. Comparability conditions are provided if the compared growth laws give the same multiplicity of load growth. Therefore, the previously mentioned laws of load growth must be expressed in terms of the growth rate [7, 8, 9].

At  $t = T$ , the load growth factor for the exponential growth law is defined as

$$K_T^{\exists} = \frac{S_T}{S_0} (1 + k_{pr}^{\exists})^2 \quad (13)$$

for the linear law of load growth as

$$K_T^L = \frac{S_T}{S_0} (1 + k_{np}^L)^2 \quad (14)$$

Comparability conditions will be met if the load growth factors are determined from expressions (13) and (14) for a given magnitude of the load growth ratio as

$$k_{pr}^e = \exp\left(\frac{\ln \ln k_T}{T}\right) - 1 \quad (15)$$

$$k_{pr}^l = \frac{k_T - 1}{T} \quad (16)$$

Thus, changes in the boundaries of the economic intervals of the load are studied, depending on possible changes in the source information [10, 11].

Therefore, having determined the value of  $S_{rp}$  between the first and second sections from a series of nominal sections, there is a real opportunity to determine the boundaries of the economic load intervals for all other standard sections. The value of the coefficient  $\Delta S_i^*$  and  $\Delta 3_i^*$  are given in Table. 1.

**Table 1.**The values of the coefficients  $\Delta S_i^*$  and  $\Delta 3_i^*$

|                | Cable cross-section $F_i, \text{mm}^2$ |      |      |      |      |      |      |      |      |
|----------------|--|------|------|------|------|------|------|------|------|
|                | 16                                     | 25   | 35   | 50   | 70   | 95   | 120  | 150  | 185  |
| $\Delta S_i^*$ | 1.00                                   | 0.48 | 0.61 | 0.87 | 1.12 | 1.26 | 1.37 | 1.62 | 2.21 |
| $\Delta 3_i^*$ | 1.00                                   | 0.76 | 1.00 | 1.40 | 1.80 | 2.00 | 2.20 | 2.60 | 3.60 |

Let us consider the relationship between the difference in reduced costs not within the boundaries of the economic interval of the load for an arbitrary section of cable strands of the cable line and the difference in the reduced costs at the borders of the economic interval of the load for the first standard section of cable strands from the scale of nominal sections Mathematically, this can be expressed as follows

$$\Delta 3_i^* = \frac{3_{gri}^B - 3_{gri}^H}{3_{gr1}^H - 3_{gr1}^H} \tag{17}$$

Substituting the corresponding values into the expression (17) after the simplest transformations, we obtain

$$\Delta 3_i^* = \frac{[F_{i+1}(K_{i+1}-K_i)(F_i-F_{i-1})-F_{i-1}(K_i-K_{i-1})(F_{i+1}-F_i)](F_2-F_1)}{F_2(K_2-K_1)(F_{i+1}-F_i)(F_i-F_{i-1})} \tag{18}$$

Or, given expression (8), after the transformations, we can write

$$\Delta 3_i^* = \frac{F_{i+1}-F_{i-1}}{F_2} \tag{19}$$

Thus, it can be seen from expression (19) that the value  $\Delta 3_i^*$  is determined only by the ratio of the cross-sections from the scale of the nominal cross-sections of cable cores. The coefficient  $\Delta 3_i^*$  is given in Table 1.

Studies have shown that the results obtained on the dynamic optimization model can also be considered as economic load intervals for the choice of cable conductor cross-sections. The only difference is that the model allows you to take into account the influence of limiting conditions.

A comparison of the load boundaries obtained on the optimization model with the economic load intervals showed the following. When removing restrictions on long-term permissible current loads and allowable voltage loss, the load boundaries determined by almost coincide with the economic intervals of the load, the optimization model, for any duration of the calculation period. This is seen from the data table 2 and 3.

**Table 2.**The upper bounds of the economic intervals of the calculation load

| Section, $\text{mm}^2$ | Billing period, years |      |      |      |
|------------------------|-----------------------|------|------|------|
|                        | 10                    | 15   | 20   | 30   |
| 16                     | 269                   | 310  | 363  | 513  |
| 25                     | 441                   | 507  | 594  | 839  |
| 35                     | 569                   | 655  | 767  | 1086 |
| 50                     | 944                   | 1087 | 1272 | 1798 |
| 70                     | 1169                  | 1346 | 1575 | 2227 |
| 95                     | 1456                  | 1675 | 1954 | 2772 |
| 120                    | 2009                  | 2312 | 2707 | 3826 |

|     |      |      |      |      |
|-----|------|------|------|------|
| 150 | 2417 | 2782 | 3257 | 4604 |
| 185 | 2856 | 3291 | 3853 | 5445 |

The tables 2 and 3 show the calculation results for the following initial data  $l = 1 \text{ km}$ ;  $\cos \varphi = 0,85$ ;  $U_{\Pi} = 295 \text{ sum/kW} \cdot h$ ;  $x = 0,08 \text{ ohm/km}$ ;  $U_H = 10 \text{ kV}$ . The amount of investment was taken according to [5-8]. For calculations, an average relative annual load increase of  $k_{pr} = 0.075$  (the law of load growth is exponential) was adopted [12, 13].

**Table 3.** The upper boundaries of the economic intervals of the load model

| Section, mm <sup>2</sup> | Billing period, years |      |      |      |
|--------------------------|-----------------------|------|------|------|
|                          | 10                    | 15   | 20   | 30   |
| 16                       | 268                   | 311  | 361  | 525  |
| 25                       | 443                   | 503  | 594  | 831  |
| 35                       | 567                   | 658  | 765  | 1051 |
| 50                       | 948                   | 1095 | 1274 | 1795 |
| 70                       | 1170                  | 1346 | 1572 | 2232 |
| 95                       | 1453                  | 1672 | 1954 | 2801 |
| 120                      | 2009                  | 2315 | 2718 | 3852 |
| 150                      | -                     | 2781 | 3250 | 4596 |
| 185                      | -                     | -    | 3865 | 5472 |

**Table 4.** Economic load intervals according to the optimization model, taking into account limiting conditions

| Section, mm <sup>2</sup> | Billing period, years |      |      |      |
|--------------------------|-----------------------|------|------|------|
|                          | 10                    | 15   | 20   | 30   |
| 16                       | 268                   | 311  | 361  | 394  |
| 25                       | 443                   | 503  | 595  | 613  |
| 35                       | 567                   | 651  | 765  | 832  |
| 50                       | 948                   | 1095 | 1189 | 1269 |
| 70                       | 1175                  | 1346 | 1572 | 1751 |
| 95                       | 1453                  | 1672 | 1954 | 2145 |
| 120                      | -                     | 2308 | 2570 | 5122 |
| 150                      | -                     | 2781 | 3101 | 6347 |
| 185                      | -                     | -    | 3674 | 7310 |

From the data table 2 and 3 it can be seen that for any billing period, the boundaries of economic intervals coincide. The existing discrepancies are explained by the accuracy of the calculations, since when calculating the optimization model the load boundaries to save machine time were determined with an accuracy of 5 kVA. Based on this comparison, we can conclude that the proposed optimization model is correct [14, 15].

#### 4. Conclusions

1. For the calculation periods of 10 and 15 years, the economic load intervals determined by the method of economic intervals and optimization models, taking into account the limiting conditions, are practically irrelevant (the relative error does not exceed 1%).
2. With a calculation period of 20 years, no upper limits of the economic load intervals were presented for the cross-section of residential cables of 50, 120, 150 and 185 mm<sup>2</sup>. For the intervals between the boundaries of economic intervals, the loads practically coincide.

3. If the calculation period is 30 years, the boundaries of the economic intervals of the load are not found for all sections. This is due to the influence of limiting conditions.

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