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# CHOICE OF THE OPTIMUM CROSS-SECTIONS FOR 20–110–330 kV OVERHEAD LINES UNDER MARKET CONDITIONS

S. Guseva, L. Petrichenko

Riga Technical University, Power Engineering Institute,
1 Kronvalda Blvd., Riga, LV-1010, LATVIA
guseva@eef.rtu.lv, lubova.petricenko@rtu.lv

Approach is proposed to the choice of overhead line cross-sections that would be optimal under market conditions. For this purpose, in the design practice and at network reconstruction two methods exist: of the economic current density, and of the economic intervals. As of now, none of them works properly, since the cost of electrical materials, of building and construction as well as the total investments in a line are determined by the market prices. Therefore, a modified economic intervals' method has been developed that can work under market conditions. The method allows also considering the discrete character of standard cross-sections for the lines and concrete technical and technically-economic parameters. For practical application of the proposed method, universal economic nomograms for 20-110-330 kV overhead lines have been calculated and constructed. In the paper, a user interface is proposed for realization of the modified method in Matlab environment.

**Key words***: overhead lines, optimum cross-section, annual costs, nomograms, user interface.*

## 1. INTRODUCTION

The main tasks of the energy branch are to identify the rational directions of development and exploitation of a power system and its individual elements, and to establish methods for efficient use of materials as well as working and financial resources. These latter are required to create new and expand or renovate the existing power facilities for the building and construction works, the acquisition of electro-technical materials, the establishment of transport links, etc.

The means for the construction and reconstruction of a power object does not bring economic benefits until its exploitation. Therefore, it is necessary to carry out accurate technical and economic calculations in order to determine the balance between the construction and exploitation costs.

One of the main elements of a rational construction of electric networks is the correct choice of wire cross-sections at the design stage or at the network reconstruction. These cross-sections should be selected from economic considerations taking into account technical requirements.

The transition from the planned state economy to a market economy resulted in significant changes as to the justification of projects on the construction of overhead lines. These changes are mainly connected with uncertainty of the information on specific construction expenses for an overhead transmission line, on the prices of equipment as well as of building and construction works. Furthermore, the investments in the building of power objects are determined by the own capitals of power companies and by the interests and financial possibilities of the investors. In many countries this transition has led to a lack of uniform integrated indices of the line construction, which complicates the estimation of variants.

Nowadays, the investments are determined by the market for electrical materials as well as for building and construction works. At the same time, the projects should be technically suitable, economically justified and effective.

## 2. DISADVANTAGES OF THE EXISTING METHODS FOR THE CHOICE OF CROSS-SECTIONS

The method of economic current density proposed by Grudinsky and Priklonsky in 1957 [1] has been widely applied up to now (especially in Russia) to the choice of optimal cross-sections for the overhead lines. The method is based on using the total annual costs at the construction and exploitation of power lines. In particular, simplified tables were worked out for practical calculations in the network designing. However, the method has some shortages which do not allow obtaining the global minimum of total annual costs. These are:

- the linear character assumed for change of capital investments in the line cross-sections instead of the step change in reality;
- the continuous change of the cross-section for definition of the relevant function derivatives, while in practice this variable is changing discretely according to the scale of standard cross-sections;
- the economic current density is obtained for comparatively wide intervals of the maximum load utilization;
- impossibility to vary economic and technically-economic indices;
- the fixed values of economic current density in the tables of the Russian normative documents were calculated in the early 20th century, while the real values can differ significantly;
- in the last decades the prices on electric power losses as well as expenses of network building and construction have been increased several times;
- in the conditions of free market prices there is no accessible and trustworthy information on the electrical engineering production prices as well as on the building and construction costs.

The pointed shortages of the method can lead to incorrect decisions at definition of the wire optimum cross-section under market price conditions.

The method of economic intervals exploited by Block, V.M. in 1945 was, in fact, a development of the method of economic current density [2–6]. The proposed method takes into account the discrete character of line cross-section and allows the relevant technical and technically-economic network parameters to be concretized. However, in the conditions of free market prices this method does not work owing to the absence of reliable integrated information on the total investments in the lines.

In the paper, a modified approach is proposed to the realization of economic intervals' method under market conditions, which allows for selection of the economically feasible line cross-sections and provides the minimum total costs for the construction (reconstruction) and maintenance of the electrical network.

## 3. METHOD OF ECONOMIC INTERVALS UNDER MARKET CONDITIONS

The modified method of economic intervals is also based on the condition of equality for the total annual costs in the lines with wires of adjacent standard cross-sections:

$$C_i = C_{i+1}. \tag{1}$$

The total annual costs for the lines with adjacent standard cross-sections depending on the maximum current are defined as

$$\begin{aligned}&\left(i+p_{\Sigma}\right)\cdot K_{L,i}+3\cdot I_{\max}^{2}\cdot R_i\cdot(\tau\cdot\beta'+\beta'')\cdot 10^{-3}=\\ &\quad=\left(i+p_{\Sigma}\right)\cdot K_{L,(i+1)}+3\cdot I_{\max}^{2}\cdot R_{(i+1)}\cdot(\tau\cdot\beta'+\beta'')\cdot 10^{-3},\end{aligned} \tag{2}$$

where $i$ is the market interest rate, r.u.;

$p_{\Sigma}$ are the total deductions on amortization, running repair and maintenance from the capital investments in the line construction, r.u.;

$K_{L,i}$, $K_{L,i+1}$ are the capital investments in the lines with wires of adjacent standard cross-sections, Ls;

$I_{\max}$ is the maximum load current of line, A;

$R_i$, $R_{i+1}$ are the active resistances of the overhead lines with adjacent standard cross-sections, Ω/km;

$\tau$ is the utilization time of maximum losses per year, $\tau = f\left(T_{\max}\right)$, h;

$T_{\max}$ is the utilization time of maximum load per year, h;

$\beta'$ is the specific price of electric power losses, Ls/kWh;

$\beta''$ is the specific price of capacity at the maximum time of power system load, Ls/kW.

In the modified method the capital investments in the lines with adjacent standard cross-sections are represented as the sum of two components: the first one is for electrotechnical material $K_{met}$ (wire metal), and the second one is for building and construction works $K_{build}$:

$$\begin{aligned}&K_{L,i} = K_{met,i} + K_{build,i};\\ &K_{L,(i+1)} = K_{met,(i+1)} + K_{build,(i+1)},\end{aligned} \tag{3}$$

where $K_{met,i}$, $K_{met,(i+1)}$ are the capital investments on the conductor metal of the lines with wires of adjacent standard cross-sections;

$K_{build,i}$, $K_{build,(i+1)}$ are the capital investments in the building and construction of lines.

The capital investments on the construction and building works for different building companies can make up more than 70–80% from the total for line construction. These capital investments are so high that their difference for adjacent cross-sections could be ignored, and it does not influence the practical calculations (approx. 5% of the total investments, which is an admissible error for estimations). Therefore, it is possible to write the following equality for such investments as related to the adjacent standard cross-sections:

$$K_{build,i} \approx K_{build,(i+1)} = const\,. \tag{4}$$

In this case, approximately equal components $K_{build,i}$ and $K_{build,(i+1)}$ in Eq. (2), taking into account Eqs. (3), (4), are mutually compensated and excluded, while the difference in the investments in the metal for the lines with adjacent standard cross-sections is analyzed in detail.

The given assumption simplifies the calculations at using the economic intervals method and allows excluding uncertain information about the total capital investments in the line.

Based on Eq. (3), it is possible to introduce the total investments for an overhead line as

$$K_{OL} = n_f \cdot K_{met,OL} + K_{build,OL} \quad , \tag{5}$$

where $n_f$ is the number of phases in the line;
$K_{met,OL}$ is the price of wire metal for one phase, Ls;
$K_{build,OL}$ are the capital investments in building and construction of an overhead line, Ls.

We will consider the first component of the overhead line capital investment, which is connected with the price of wire material as more predictable and stable (mainly determined by the major manufacturers of line wires).

The capital investment in the wire material for overhead line is:

$$K_{met,OL} = F \cdot 10^{-3} \cdot l \cdot D_{met,OL} \cdot K_{0,met,OL}\,, \tag{6}$$

where $F$ is the wire cross-section, mm$^2$;
$l$ is the wire length, km;
$D_{met,OL}$ is the specific weight of metal wire, kg/m$^3$;
$K_{0,met,OL}$ is the specific price of metal wire, Ls/kg.

After transforming expression (2) and taking into account conditions (4) and (6), the boundary current at which the transition from a smaller cross-section to a bigger one is economically justified is defined in the following way [7, 8]:

$$I_{ek,OL} = \sqrt{\sigma} \cdot \sqrt{\frac{n_f \cdot K_{0,met,OL} \cdot D_{met,OL} \cdot (F_{(i+1)} - F_i)}{3 \cdot (R_{0,OL,i} - R_{0,OL,(i+1)})}}\,, \tag{7}$$

where $\sigma$ is a factor depending on the technical and technically-economic indices of the network.

This factor is determined as:

$$\sigma = \frac{(i + p_{\Sigma})}{\tau \cdot \beta' + \beta''} \quad . \tag{8}$$

## 4. CONDITIONS FOR EXISTENCE OF ECONOMIC INTERVALS

According to work [4], two conditions for existence of economic intervals as related to the overhead lines could be considered in the modified method (also related to the overhead lines): first of them is defined by the demand on intersection of economic characteristics for the lines with adjacent standard cross-sections:

$$K_{met,OL,(i+1)} > K_{met,OL,i} \, . \tag{9}$$

The second condition for existence of economic intervals is defined from the inequality:

$$I_{ec,i,(i+1)} > I_{ec,(i-1),i} \quad . \tag{10}$$

Expression (10), taking into account (7), (3) and (4), is now written as

$$\sqrt{\sigma} \cdot \sqrt{\frac{(K_{met,OL,(i+1)} - K_{met,OL,i}) \cdot 10^3}{3 \cdot (R_{OL,i} - R_{OL,(i+1)})}} >$$
$$> \sqrt{\sigma} \cdot \sqrt{\frac{(K_{met,OL,i} - K_{met,OL,(i-1)}) \cdot 10^3}{3 \cdot (R_{OL,(i-1)} - R_{OL,i})}} \, . \tag{11}$$

If the radicand in expression (11) appears negative, one section is always more favourable than another at all values of the maximum load current.

Having converted expression (11), we obtain the second main condition for existence of economic intervals in a dimensionless form:

$$\frac{K_{met,OL,(i+1)} - K_{met,OL,i}}{K_{met,OL,i} - K_{met,OL,(i-1)}} > \frac{R_{OL,i} - R_{OL,(i+1)}}{R_{OL,(i-1)} - R_{OL,i}} \, . \tag{12}$$

## 5. GRAPHICAL USER INTERFACE

Based on the above described method of economic intervals, the graphical user interface (GUI) in Matlab environment was developed [7–11].

The algorithm created for the graphical user interface presents the successive operations at using the method of economic intervals (Fig. 1).

In compliance with the algorithm a program has been designed in the Matlab environment. However, the authors have done the related computer-aided work that made it possible to manage without Matlab software. For the calculations and the accessibility, the program was packed into an executable file that works with Matlab Runtime Compiler. Thus, the program is easy to install and available for everyone.

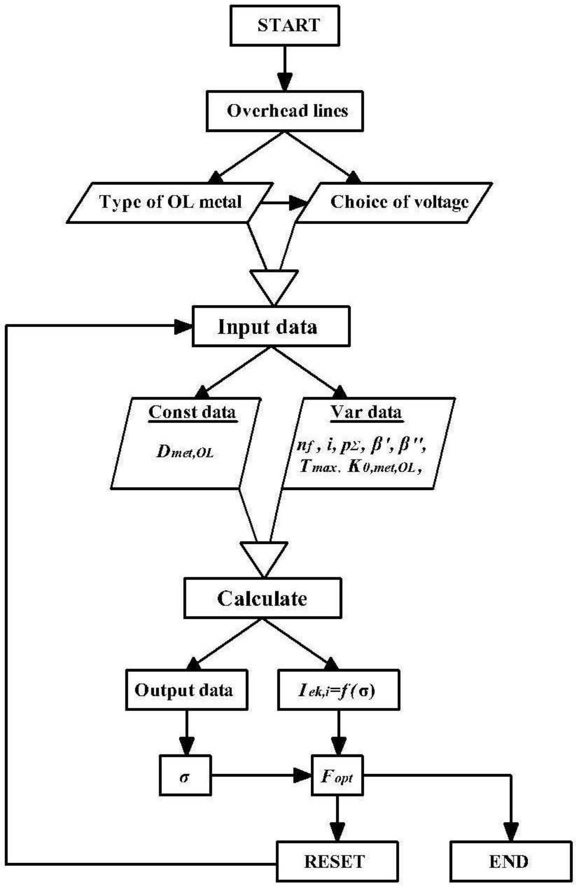


*Fig. 1.* The algorithm for the method of economic intervals.

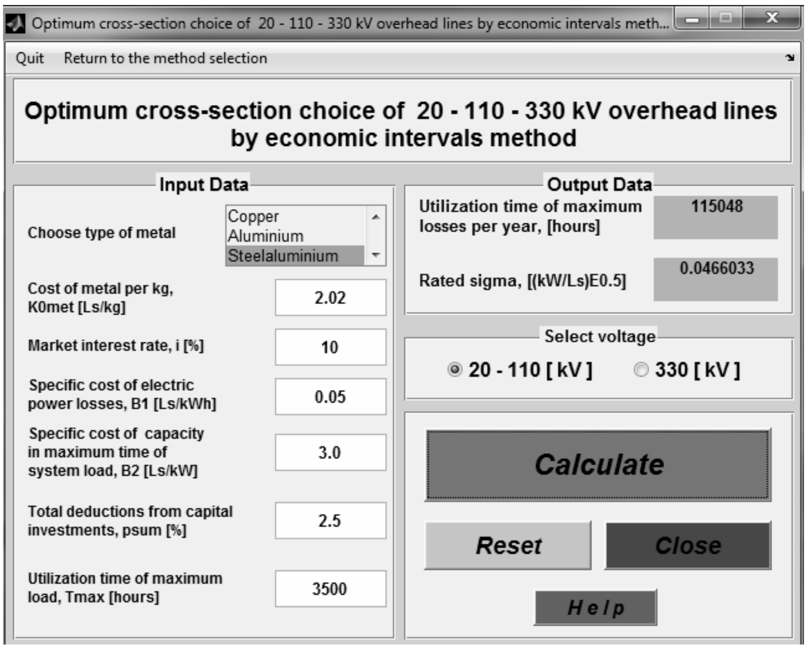


*Fig. 2.* Graphical user interface.

The parent interface consists of the main window, in which the following panels and elements are contained (Fig. 2):

1. Data input panel. This includes:
   - the choice of metal type for transmission lines;
   - the input windows of initial rated data.
2. Panel for selection of power line voltage.
3. Data output panel.
4. Action bar.

In the calculation program, three possibilities for the choice of voltage level are provided: 20–110 kV, singly 330 kV, and 20–110–330 kV simultaneously. This allows the nomograms for each voltage level to be considered separately, which makes the work with them convenient.

After filling the required fields it is possible to carry out the calculation and to construct nomograms. The window of the estimated nomograms has several properties that simplify the work with graphs and make it more comfortable (see Fig. 3).


*Fig. 3.* Property menu.

Using the calculation program it is possible to construct new economic nomograms for the lines with different voltages and construction [11].

## 6. ECONOMIC NOMOGRAMS FOR THE OVERHEAD LINES

For practical application of the modified method, nomograms were constructed for 20–110–330 kV overhead lines with steel-aluminium, aluminium and copper wires of standard cross-sections (Figs. 4–6).

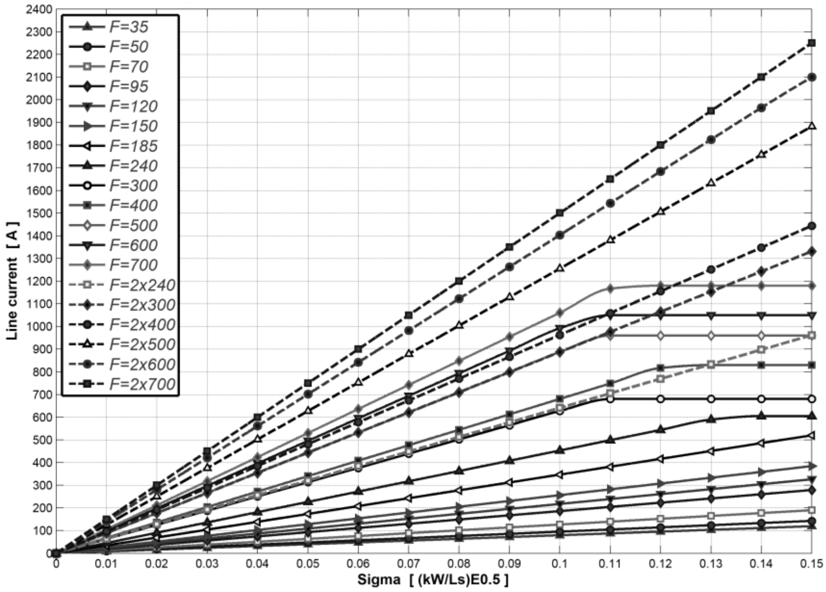


*Fig. 4.* The nomograms of current economic intervals for 20–110–330 kV overhead lines with steel-aluminium wires.

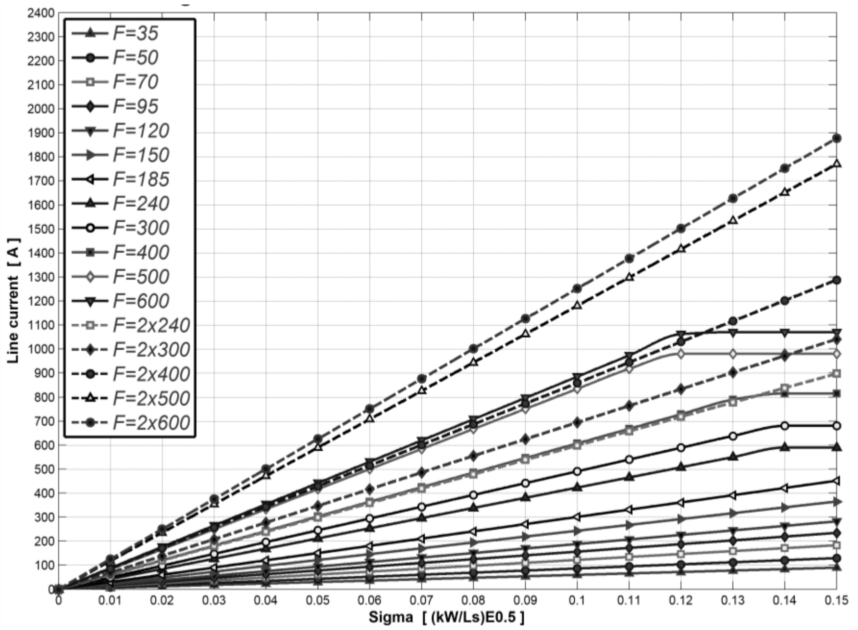


*Fig. 5.* The nomograms of current economic intervals for 20–110–330 kV overhead lines with aluminium wires.

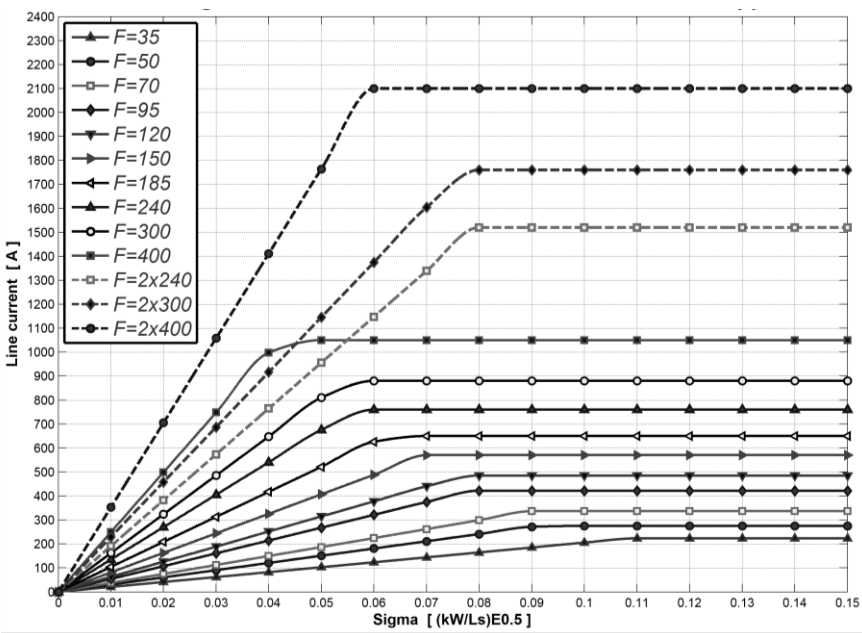


*Fig. 6.* The nomograms of current economic intervals for 20–110–330 kV overhead lines with copper wires.

These nomograms are more universal as compared with previous ones [6], since they do not depend on the type of power lines' pylons and are given for different voltage of lines simultaneously. The modified method of economic intervals allows the choice of rational cross-sections to be made for the overhead lines of medium- and high-voltage networks in the conditions of free market prices.

For the choice of wire cross-sections using the curves of economic intervals it is necessary to define the maximum current line $I_{max}$ and factor $\sigma$. The zone in which the point with coordinates $I_{max}$ , $\sigma$ corresponds to the optimum cross-section is in the range of boundary economic currents from $I_{ec,i/(i+1)}$ to $I_{ec,(i+1)/(i+2)}$.

If the intersection point with coordinates $I_{max}$, $\sigma$ is located directly on the boundary curve of two cross-sections, both could be considered identical as to the economic benefit.

This method also considers the technical requirements: the admissible heating current of wires under the normal operation (reflected by a horizontal part of the curve) and restrictions on a corona in lines (inadmissible sections are excluded from consideration).

## 7. CONCLUSIONS

1. Under the market conditions of today the economic considerations that form the basis of traditional methods for the choice of cross-sections for overhead lines need a critical analysis and certain updating.

2. The presented modified method of economic intervals makes it possible to select the optimum cross-section of overhead lines in the early design stages by the minimum total annual costs, excluding uncertain information on the total capital investments in the line.

3. The algorithm created for the graphical user interface illustrates the successive operations at using the method of economic intervals.

4. The presented graphical user interface allows the changes of any initial data to be considered, and simplifies the relevant calculations.

5. The calculated nomograms of current economic intervals for the overhead lines are universal, fitting any concrete line voltages and the wire materials applied.

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## 20–110–330 KV GAISVADU LĪNIJU OPTIMĀLO ŠĶĒRSGRIEZUMU IZVĒLE TIRGUS APSTĀKĻOS

S. Guseva, Ļ. Petričenko

K o p s a v i l k u m s

Viens no pilsētas elektriskā tīkla ekonomiskuma paaugstināšanas būtiskiem veidiem ir tīkla racionālā projektēšana. Elektriskā tīkla projekta ekonomiskuma kritērijs ir minimālās summārās ikgadējās izmaksas pie vienādām peļņas vērtībām projekta variantos. Elektropārvādes līniju optimālo šķērsgriezumu izvēle un summāro ikgadējo izmaksu minimums to izbūvei tiek nodrošināts ar ekonomisko intervālu metodes pielietojumu. Sakarā ar ekonomiskās politikas izmaiņām valstī ir izstrādāta un tiek piedāvāta ekonomisko intervālu metodes adaptācija tirgus ekonomikas apstākļiem. Tiek piedāvāts algoritms elektropārvades gaisvadu līniju optimālo šķērsgriezumu izvēlei. Metodes praktiskai realizācijai izstrādātas ekonomisko intervālu nomogrammas. Tiek izveidots lietotāja grafiskais interfeiss Matlab programmēšanas vidē. Ar šīs programmas palīdzību ir konstruētas universālās strāvu ekonomisko intervālu nomogrammas 20–110–330 kV gaisvadu līnijām ar alumīnija, vara un tēraudalumīnija vadiem. Jāatzīmē, ka šķērsgriezumu izvēle pēc ekonomiskajiem apsvērumiem ir ļoti aktuāls uzdevums mūsdienu tirgus ekonomikas apstākļos, kad ir nepieciešama pamatota un racionāla elektropārvades līniju izbūve elektrisko tīklu perspektīvai attīstībai.

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