Choice of 0.4 kV Cable Cross-sections by Economic and Technical Criteria under Market Price Conditions

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***Abstract* – In paper a choice of 0.4 kV cables' cross-sections by economic and technical criteria under market price conditions is examined. Nowadays reliable and unambiguous information about the cost of the equipment for transmission lines, building and construction works, financing terms, etc., is absent because the prices are free and market. For 0.4 kV lines it is necessary to consider not only economic criterion, but also technical requirements, as they can be prevailing with considerable lengths. The modified method of economic intervals with checking by permissible heating current and voltage losses is used for reasonable choice of cross-sections. The boundary lengths by voltage losses are determined and dependences are constructed. The graphical realization for method of economic intervals using MathCAD software is offered. The modified method provides reasonable technical and economic choice of 0.4 kV cable lines' cross-sections.**

***Keywords* –Economic intervals, cable lines, voltage losses, boundary length and current.**

I. INTRODUCTION

One of the main requirements of a rational construction of electric networks is the correct choice of wire cross-sections at the stage of design or the network reconstruction. These cross-sections should be selected from economic considerations taking into account technical requirements. The main criterion at the choice of low voltage cables' optimum cross-sections is the minimum of total annual costs, taking into account permissible heating current and voltage losses.

The paper shows opportunities and field of application for method and updated nomograms of economic intervals, which can take into account the economic considerations and also permissible heating current and voltage losses. Such an approach is actual in modern conditions of the market relations in economy. Due to such choice, the cross-sections of lines are technically suitable, economically justified and effective.

II. ECONOMIC INTERVALS' UPDATED NOMOGRAMS

The modern approach to the realization of economic intervals' method under market conditions for high-voltage lines was proposed in the papers [1, 2]. It provides the minimum total annual costs on the construction (reconstruction) and maintenance of the distribution networks.

The method of economic intervals is based on the condition of equality for the total annual costs C_{CL} on the cable lines with adjacent standard cross-sections F_i and F_{i+1} for the current load I :

$$C_{CL,i} = C_{CL,i+1}\,. \qquad (1)$$

The total annual costs $C_{CL,i}$ on the cable line with adjacent standard cross-section F_i for the current load I [7]:

$$C_{CL,i} = (i + p_\Sigma)\cdot K_{CL,i} + 3\cdot I_{\max}^2 \cdot R_i \cdot (\tau\cdot\beta' + \beta'')\cdot 10^{-3}\,, \qquad (2)$$

where i is is the market interest rate, r.u.;
p_Σ are the total deductions on amortization, running repair and maintenance from the capital investments in cable line, r.u.;
$K_{CL,i}$ are the capital investments in the line with wire of standard cross-section, Ls;
I_{max} is the maximum load current of line, A;
$R_{,i}$ is active resistance for standard cross-section, Ω/km;
τ is the utilization time of maximum losses per year, where $\tau = f(T_{\max})$, h;
T_{max} is the utilization time of maximum load per year, h;
β' is the specific price of electric power losses, Ls/kWh;
β'' is the specific price of capacity at the maximum time of power system load, Ls/kW.

In modified method the capital investments in the cable lines with adjacent standard cross-sections F_i and F_{i+1} are represented as the sum of two components: the first one is on electrotechnical material K_{met} (wire metal), and the second one is on building and construction works K_{build}:

$$\begin{aligned} K_{CL,i} &= K_{met,i} + K_{build,i} \\ K_{CL,(i+1)} &= K_{met,(i+1)} + K_{build,(i+1)} \end{aligned} \qquad (3)$$

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

The capital investments for building company on construction and building works of cable lines with adjacent standard cross-sections are approximately equal:

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

In this case, approximately equal components in (1) are mutually compensated and excluded, but the difference in the investments on metal for the cable lines with adjacent standard cross-sections are different and are analyzed in detail.

Due to analyzes and research results in [1]:, the boundary current, at which transition from smaller cross-section to bigger is economically expedient for cable lines is defined as follows:

$$I_{ec,CL} = \sqrt{\sigma} \cdot \sqrt{\frac{A \cdot (F_{i+1} - F_i) + B \cdot (d_{core,(i+1)} - d_{core,i})}{3 \cdot (R_{0,i} - R_{0,(i+1)})}}\ , \tag{5}$$

where $A = n_{core} \cdot K_{0,met,CL} \cdot D_{met,CL} \cdot k_1 \cdot k_2 \cdot k_{res}$,

$$B = \pi \cdot D_{isol,CL} \cdot k_3 \cdot K_{0,isol,CL} \cdot S_{isol,CL}\ ,$$

$$\sigma = \frac{i + p_\Sigma}{\tau \cdot \beta' + \beta''}\ ,$$

where $K_{0,met,CL}$ is the specific price of metal, Ls/kg;
$K_{0,isol,CL}$ is price of 1 kg isolation at XLPE cable, Ls/kg;
n_{core} is quantity of cable core;
$D_{met,CL}$ is the specific weight of metal core, kg/m^3;
k_1 is twisting coefficient of core's wires (is taken k_1=1.02) [3];
k_2 is twisting coefficient of cores at cable (is taken k_2=1.0) [3];
k_{res} is reserve coefficient of the minimum weight, which is determined by a developer of technical or technological documentation, taking into account features of products and their manufacturing technology (is taken k_{res}=1.012) [3];
d_{core} is cable core's diameter, mm;
k_3 is coefficient, taking into account technological factors (uneven blending, filling the voids between the wires), (is taken $k_3=1.17$) [3];
$S_{isol,CL}$ is isolation thickness, mm;
$D_{isol,CL}$ is specific density of isolation material, kg/m^3;
$R_{0,i}$, $R_{0,\ i+1}$ is specific active resistance for adjacent standard cross-sections, Ω/km.

Using expression (5), the updated nomograms for 0.4 kV cable with XLPE isolation and with copper and aluminum cable core are constructed (Fig.1, 2). Standard cross-sections (16, 25, 35, 50, 70, 95, 120, 150, 185 mm^2) are examined for cable lines.

Using these nomograms, the economic cross-sections can be selected in Fig.1, 2 for coordinates σ and I. The factor σ contains parameters p_Σ, i, β', β'', that allows taking into account factual values of these parameters and also considering step-type behavior of cross-section.

The method considers the permissible heating current of cable under the normal operation (reflected by horizontal part of curve in Fig.2). As a result, choosing cross-section by universal nomograms individual accounting of heating conditions is not necessary.

III. CONSIDERATION OF LIMITATION BY PERMISSIBLE VOLTAGE LOSSES

The consideration of limitation by permissible voltage losses in the method of economic intervals is fulfilled. The voltage losses in line are determined as follows [4]:

$$\Delta U = \frac{\Sigma P \cdot R + \Sigma Q \cdot X}{U_{nom}}\ , \tag{6}$$

where P, Q are active and reactive power on the line or on separate section of one, MW and MVAr;
R, X are active and inductive resistance of line or separate section of one, Ω;
U_{nom} is network nominal voltage, kV.

In low voltage cable lines, the parameter X usually is much less than R and is not taking into account. The cable line's active resistance is:

$$R = \frac{l \cdot 10^3}{\gamma \cdot F}\ , \tag{7}$$

where l is length of separate sections of line, km;
γ is metal conductivity, (m/(Ω*mm^2);
F is area of cross-section of a cable, mm^2.

The active power of the line:

$$P = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi\ . \tag{8}$$

Considering and inserting (7), (8) in (6), the voltage losses can determine as:

$$\Delta U = \frac{\sqrt{3} \sum I \cdot l \cdot \cos\varphi}{\gamma \cdot F}, \tag{9}$$

where I is current of line or separate sections of one, A;
ΔU is voltage losses in line, kV.

If line has only one load, then in (9) the summation sign is eliminated and length of sites is replaced with whole length L:

$$\Delta U = \frac{\sqrt{3} \cdot I \cdot L \cdot \cos\varphi}{\gamma \cdot F}, \tag{10}$$

where L is whole length of line, km.

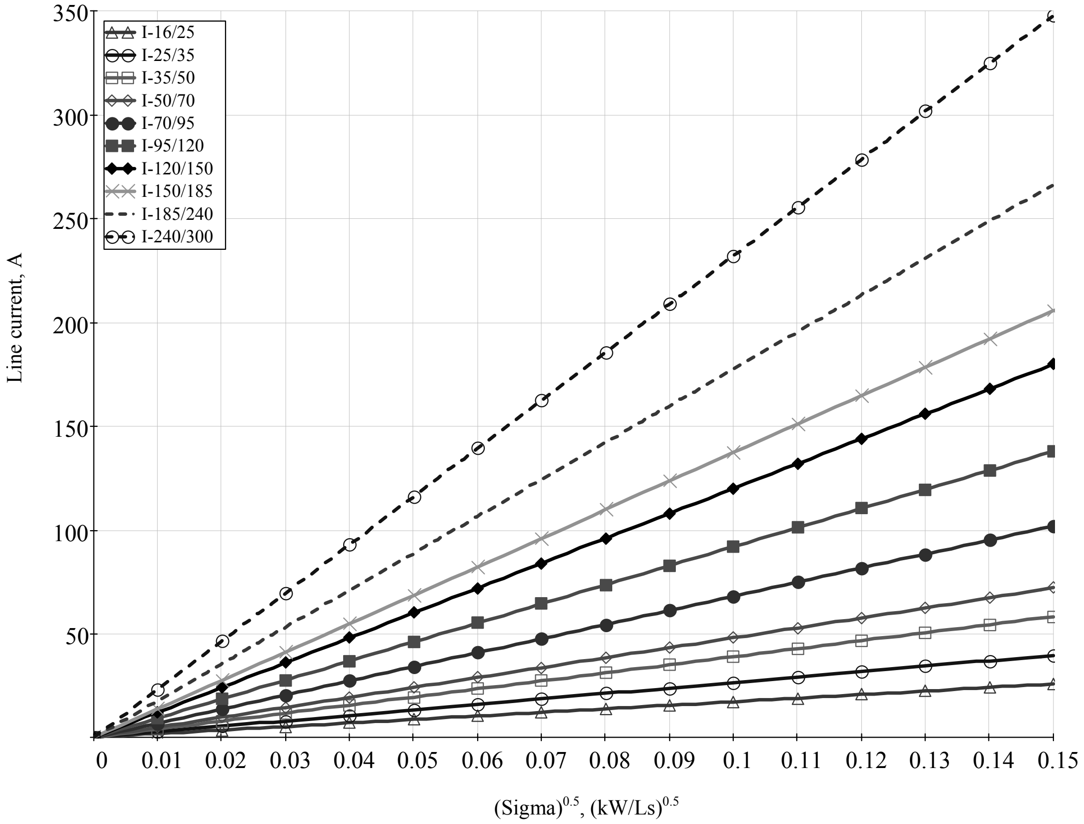

Fig.1. The universal nomograms of current’s economic intervals for 0.4 kV cable with aluminum core (the curves are constructed by prices in 2010).

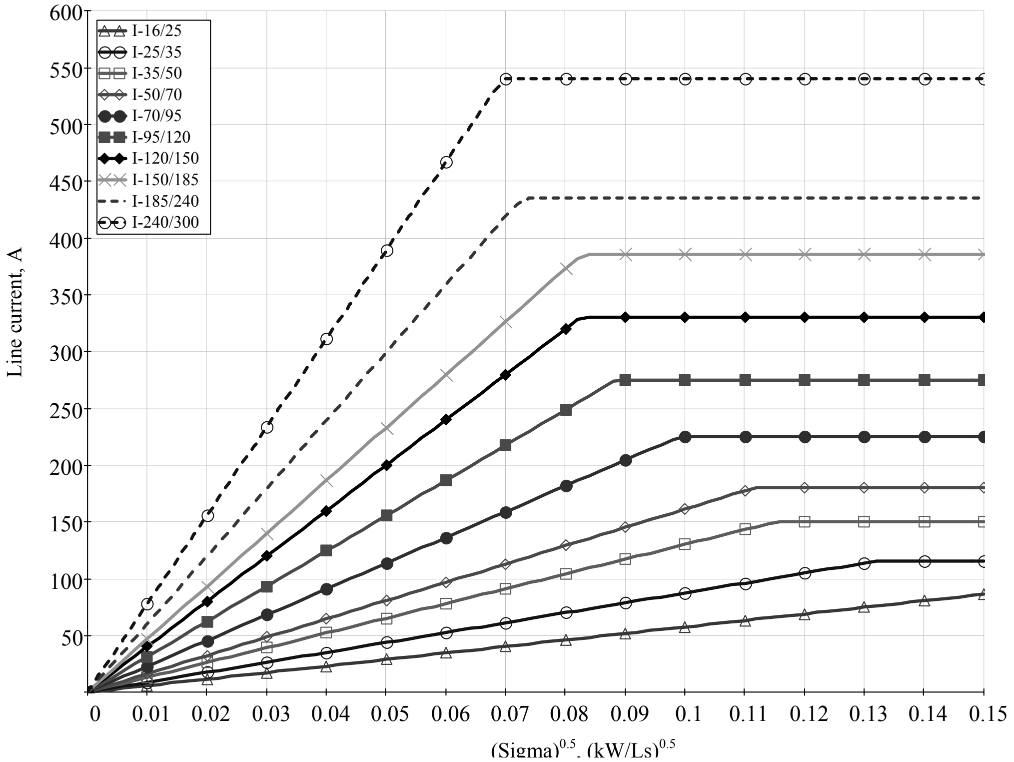

Fig.2. The universal nomograms of current’s economic intervals for 0.4 kV cable with copper core (the curves are constructed by prices in 2010)

The transition from cross-section F_i in line to another one F_{i+1} is economically justified, when the current reaches up value $I_{ec,CL}$ [5-8]. Therefore, the use of cross-section F_i is reasonable, when line current $I < I_{ec,CL}$. As a result, voltage losses are lower, than at current value $I_{ec,CL}$.

Inserting in (10) current value $I_{ec,CL}$ from expression (5) and replacing cross-section F to F_i, will receive the next expression:

$$\Delta U \le \frac{L \cdot \cos\varphi}{\gamma \cdot F_1} \cdot \sqrt{\sigma} \cdot \sqrt{\frac{A \cdot (F_{i+1} - F_i) + B \cdot (d_{core,(i+1)} - d_{core,i})}{(R_{0,i} - R_{0,(i+1)})}} \,. \quad (11)$$

Replacing parameters $R_{0,i}$ as $R_{0,i} = 10^3/\gamma \cdot F_i$ and $R_{0,\,i+1}$ as $R_{0,\,i+1} = 10^3/\gamma \cdot F_{i+1}$, the expression (11) changes as follows:

$$\Delta U \le L \cdot \cos\varphi \cdot \sqrt{\sigma} \cdot \sqrt{\frac{(A \cdot (F_{i+1} - F_i) + B \cdot (d_{core,(i+1)} - d_{core,i})) \cdot F_{(i+1)}}{10^3 \cdot \gamma \cdot (F_{(i+1)} - F_i) \cdot F_i}} \,. \quad (12)$$

Signifying

$$\sqrt{\frac{(A \cdot (F_{i+1} - F_i) + B \cdot (d_{core,(i+1)} - d_{core,i})) \cdot F_{(i+1)}}{10^3 \cdot (F_{(i+1)} - F_i) \cdot F_i}} = a \,. \quad (13)$$

Finally will receive instead (12):

$$\Delta U \le a \cdot L \cdot \cos\varphi \cdot \sqrt{\frac{\sigma}{\gamma}} \,. \quad (14)$$

The a parameter for different cable cross-sections almost does not change.

The consumers get the qualitative energy, if voltage losses don't exceed the permissible value:

$$\Delta U \le \Delta U_{perm.} \,, \quad (15)$$

where ΔU_{perm} is permissible voltage losses in line, kV.

Therefore, choosing the cross-section by nomograms, the mentioned above condition is satisfied, if cable line's length is lower than boundary length L_{boun}:

$$L \le L_{boun} = \frac{\Delta U_{perm.}}{\alpha \cdot \cos\varphi} \cdot \sqrt{\frac{\gamma}{\sigma}} \,. \quad (16)$$

As it seen from given expression, if line factual length L is lower than boundary length L_{boun}, then determinative factor is economic reasons, i.e. the choice of cross-section should be done by economic intervals' universal nomograms. But if $L > L_{boun}$, then determinative factor is technical condition of permissible voltage losses.

Using (16), the dependences $L_{boun.} = f(\Delta U_{perm.},\%)$ for different core of XLPE cables at $\cos\varphi = 0.9$ are constructed (Fig.3). The maximum value of a parameter is taken [9 -10].

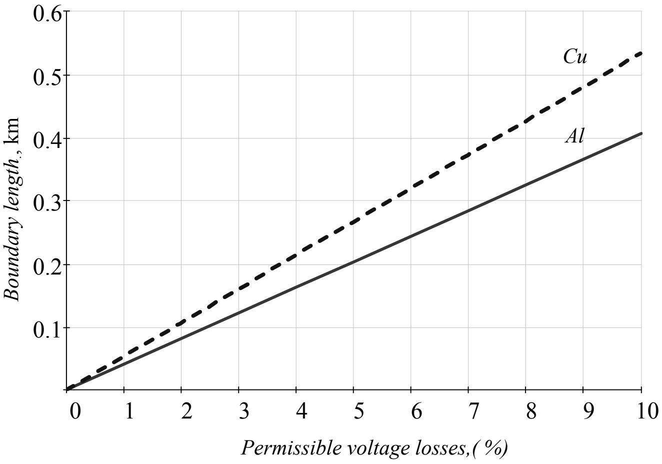

Fig.3. The dependence of 0.4kV XLPE cable's boundary length on voltage losses ($cos\varphi$=0.9)

Figure 3 shows that, for example, the boundary length $L_{boun.}$= 0.20 km for cables with aluminum core at permissible voltage losses $\Delta U_{perm.}$= 5%, but for cables with copper core - $L_{boun..}$= 0.27 km. The boundary length with aluminum core $L_{boun.}$= 0.32 km at permissible voltage losses $\Delta U_{perm.}$= 8%, , but for cables with copper core - $L_{boun.}$= 0.43 km.

It is necessary to note, that mentioned $L_{boun.}$ values are determined in the least favourable conditions:

- the highest boundary current value is taken, at which given cross-section is still economically reasonable. In fact, current and voltage losses will be lower. Accordingly, $L_{boun.}$ will be higher.
- the higher values of a and $\cos\varphi$ parameters are taken. If these parameters decrease, then $L_{boun.}$ value increases.

In result, if $L > L_{boun.}$, then calculation by permissible voltage losses is not necessary and determinative factor is cross-section, which is chosen by economic intervals' updated universal nomograms.

IV. CONCLUSIONS

The modified method of economic intervals with checking by permissible heating current and voltage losses is used for reasonable choice of 0.4 kV cable lines' cross-sections.

The updated nomograms for 0.4 kV cables with XLPE isolation and with copper and aluminum cable cores are constructed.

The consideration of limitation by permissible voltage losses in cable lines for the method of economic intervals is fulfilled.

The dependence of cable boundary length on voltage losses is analyzed and assessed.

In the event if cable line factual length is lower than boundary length, then determinative factor is economic reasons in the choice of lines' cross-sections.

In the event if cable line factual length is bigger than boundary length, then determinative factor is technical condition of permissible voltage losses.

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Svetlana Guseva, Lubova Petrichenko. 0.4 kV kabeļu šķērsgriezuma izvēle pēc ekonomiskajiem un tehniskajiem kritērijiem tirgus ekonomikas apstākļos

Viens no pilsētas elektriskā tīkla racionālās projektēšanas nosacījumiem ir elektropārvades līnijas šķērsgriezuma pareiza izvēle sākumprojektēšanas stadijā vai tīklu rekonstrukcijas gadījumā. Elektropārvades līniju optimālais šķērsgriezums jābūt izvēlēts pēc ekonomiskajiem apsvērumiem, ievērojot tehniskos noteikumus.un ierobežojumus.

Par galveno kritēriju zemsprieguma kabeļa optimālā šķērsgriezuma izvēlei ir piedāvātas minimālās summārās ikgadējās izmaksas, ievērojot pieļaujamās silšanas strāvas un sprieguma zuduma vērtības. Dotā publikācijā šķērsgriezuma izvēlei tiek izmantota ekonomisko intervālu metode, kura tiek adoptēta tirgus ekonomikas apstākļiem. Metodes praktiskam pielietojumam ir konstruētas universālās strāvu ekonomisko intervālu nomogrammas 0.4 kV XLPE kabeļu līnijām ar alumīnija un vara dzīslām ievērojot pieļaujamās silšanas strāvas normālajā režīmā.

Tiek izpētīts un veikts kabeļu šķērsgriezumu tehniskais pārbaudījums pēc pieļaujamā sprieguma zuduma ekonomisko intervālu metodei. Tiek analizēta un novērtēta kabeļa robežgaruma atkarība no pieļaujamā sprieguma zuduma. Rezultātā iegūts secinājums: ja līnijas faktiskais garums L ir mazāks par robežgarumu $L_{rob.}$, tad noteicošs faktors ir ekonomiskais aprēķins, t.i. šķērsgriezuma izvēle jānoteic pēc ekonomisko intervālu universālām nomogrammām. Ja faktiskais garums $L>L_{rob}$, tad noteicošs faktors ir aprēķins pēc pieļaujamā sprieguma zuduma.

Šķērsgriezumu izvēle pēc ekonomiskajiem un tehniskajiem apsvērumiem ir aktuāls projektēšanas un ekspluatācijas uzdevums mūsdienu tirgus ekonomikas apstākļos, kad ir nepieciešama pamatota un racionāla elektropārvades līniju izbūve elektrisko tīklu perspektīvai attīstībai.

Светлана Гусева, Любовь Петриченко. Выбор сечения 0.4 кВ кабеля по экономическим и техническим критериям в условиях рыночной экономики

Одним из условий рационального проектирования городской электрической сети является правильный выбор сечения линий электропередачи на начальной стадии проектирования или при реконструкции сетей. Выбор оптимального сечения линии электропередачи должен осуществляться по экономическим соображениям, но при соблюдении технических условий и ограничений.

Основным критерием для оптимального выбора кабеля низкого напряжения предложен минимум ежегодных затрат, учитывая допустимый ток нагрева и допустимые потери напряжения кабеля. В данной публикации при выборе сечения использован метод экономических интервалов, который адоптирован к условиям рыночной экономики. Для практического применения данного метода построены универсальные номограммы экономических интервалов тока для XLPE кабелей 0,4 кВ с алюминиевыми и медными жилами, учитывающие ограничения по допустимому току.нагрева в нормальном режиме.

В статье произведена проверка технического требования по допустимой потери напряжения в кабеле для сечений по метода экономических интервалов. Проанализирована и оценена зависимость предельной длины кабеля от допустимой потери напряжения. Анализируя полученные результаты, можно сделать вывод, что при фактической длине кабельной линии L меньше предельной длины $L_{пред}$, определяющим является экономический расчёт, т.е. выбор сечения должен производиться по универсальным номограммам экономических интервалов. Если же $L>L_{пред}$, то определяющим является расчёт по допустимой потере напряжения.

Выбор сечения по экономическим и техническим критериям является важной проектной и эксплуатационной задачей в условиях современной рыночной экономики при необходимости обоснованного и рационального построения электрических сетей для их дальнейшего развития.