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NOMINAL VOLTAGES OF THE NETWORKS

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A great diversity of the nominal voltages in power networks can be explained based on the sizes and shape of the fed zone. To find the reason of such diversity, some assumptions should be made: the variation in parameters is continuous, the voltage is constant, the electricity consumers are spread uniformly, etc. To pass from continuous load to its discrete location, a discreteness factor is calculated for various shapes of the fed zone. The expression obtained for specific costs of the network shows that they decrease in the following cases: with voltage increasing as far as the costs of line construction are not rising too rapidly; with the load density and specific conductance of phase conductor increasing; when the consumers are located more sparsely. To reduce specific costs, an appropriate current density in phase conductors should be chosen. In the work it is shown that the choice of optimal sizes for the fed zone should be made with due consideration for the step-down transformer.

Key words: *electrical network, power losses, nominal voltage, specific costs, supply zone.*

1. INTRODUCTION

In power systems, the low-, medium-, high-, and extra-high-voltage networks are met. Nominal voltages of a transmission line (TL) are usually 110 kV and above; at a sub-transmission level they could be 66 or 33 kV, distribution network voltages – below 33 kV, while extra high are 230–765 and up to 1200 kV [1]. Worldwide, the power systems use diversified nominal voltages. For example, in Russia the voltages of 220; 380; 660 V; 3; 6; 10; 20; 35; 110; 220; 330; 500; 750; 1150 kV are adopted [2−4]; in European countries: Italy − 150; 132; 20; 15; 0.4 kV; Germany − 380; 220; 11; 20; 16; 10; 0.4 kV; UK − 33; 22; 11; 6.6; 0.4; 0.23 kV; Spain − 400; 220; 132; 66; 45; 30; 20; 15; 13; <1 kV; Poland − 400; 220; 110; 20; 15; 0.4 kV [5]; and Latvia − 380; 110; 20; 10; 6; 0.4 kV [6]. These nominal voltage values are seen as self-evident − it is implied that with them the delivery of electricity is the most profitable. Probably, there are sound reasons behind this situation; however, it allows posing some questions, e.g.: how can the most appropriate nominal voltage be chosen in particular conditions? What parameters of the network affect stronger the nominal voltage? Why are there so diversified voltages in use?

In practice of the network exploitation, a compromise is usually found between the number of nominal voltages and the most advantageous nominal voltage in every specific case. This problem is given attention also in the theoretical plane [7].

To create an appropriate mathematical model, it is necessary to make some presumptions: the capacity of transformers and the cross-section of conductors can vary gradually; the load density is continuously distributed over the entire fed zone and is constant within it; the voltage values do not change within the zone; the simultaneity factor is equal to unity (i.e. the loads of the entire zone are changing simultaneously); the transformer capacity is equal to the maximum load.

The effect of other factors can be considered separately for every real case.

The paper is essentially a framework within which, based on the results of study, it would be possible to make improvements and useful changes in each specific case.

2. STATEMENT OF THE PROBLEM

For electrical network calculations the consumers' initial data are required: the power, the maximum load time, cosφ, and some others − for example, their location. This means that for such calculations a large body of information is needed; besides, the problem can be complicated by frequent variations in the data. Whereas this last drawback is corrigible at the modern level of computing technique, such a situation does not allow the mutual relations of influencing factors to be found. To change it, some averaged indices pertaining to the consumers and their location should be taken into consideration. These indices are: the load density σ and the consumers' spacing. The load density and ratings of current equipment are theoretically considered continuous; the spacing of consumers is also assumed to be continuous. This makes it possible to use analytical dependences. In order to take into account a discrete location of consumers, the quantity A_c obtained for their continuous location should be multiplied by discreteness factor k_d:

$$A_d = k_d A_c , \tag{1}$$

where A_d is the sought-for quantity at an idealized discrete location of consumers.

The performance of a network depends on its configuration and on how the phase conductor is used (with a constant current density or a constant cross-section). We shall consider the following parameters: line length l, m; product lF, m^3 (F being the cross-section); power loss ΔP, W in the phase conductors of a power line; the real U_Δ and imaginary U_δ components of the voltage drop across the line, V (in the modelled specifically shaped supply zones). These parameters are considered for continuous load location. To pass to the discrete load case (denoted by index $_d$) according to Eq. (1), the discreteness factor k_d is determined for each quantity specified above. In the consideration, power loss ΔP is calculated for one phase. In the tables below the power loss ΔP is given for a three-phase network (i.e. three times ΔP_c).

3. SPATIAL MODELS OF CONSUMER LOCATION

Consideration of the kind is based on the shape of the fed zone. While the most convenient fed zone shape is hexagon [8], in the present paper a square is taken in order to simplify mathematical description. To pass to a hexagon the similarity factors can be employed. Besides, owing to territorial constraints which may arise in practice, some other shapes are considered.

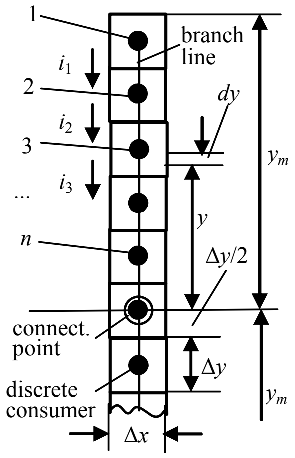

Fig. 1. A strip-shaped fed zone (half area).

First, we will study the fed zone shaped as a strip (further denoted S) (Fig. 1). The loads are located at distinct points connected by a branch line; the supply source is located at the connecting point. In the fed zone, one consumer is located at the connecting point and other n consumers are above and below the centre. They are supplied through the branch line. The central consumer is not taken into account since it is not fed through the line. Hence, the number of consumers n and the distance between consumers Δy in the strip zone are:

$$n = \frac{y_m - \Delta y/2}{\Delta y}; \quad \Delta y = \frac{2y_m}{2n+1}. \tag{2}$$

We will now determine the basic parameters of **S** model.

Determination of the branch line length

At continuous load distribution the branch line length is taken from the supplying centre to the upper and lower boundaries of a zone:

$$l_c = 2y_m. \tag{3}$$

In turn, at discrete load distribution this length is calculated from the supplying centre to the first (at the top and bottom) electricity consumers:

$$l_d = 2(y_m - \frac{\Delta y}{2}) = 2y_m \frac{2n}{2n+1}. \tag{4}$$

The discreteness factor is:

$$k_d = l_d : l_c = \frac{2n}{2n+1}. \tag{5}$$

The lF calculations

In calculations of the line length and cross-section product two cases can be met: the case **Sj**, when a phase conductor with a constant current density j is employed, i.e. its cross-section changes with load (denoted lF_j); and the case **SF**, when the cross-section of the phase conductor is constant and calculated according to the maximum current at the beginning of the line (denoted lF_F).

Case Sj$_c$. The current $i(y)$ and the cross-section with constant current density j in the phase conductor at distance y from the supply centre is:

$$i(y) = \sigma\Delta x(y_m - y); \qquad F(y) = \frac{i(y)}{j} = \frac{\sigma\Delta x(y_m - y)}{j}, \tag{6}$$

where σ is the load density, A/m^2.

Then at continuous load distribution we will have:

$$(lF_j)_c = 2\int_0^{y_m} \frac{\sigma\Delta x(y_m - y)}{j} dy = \frac{\sigma\Delta x y_m^{\ 2}}{j}. \tag{7}$$

Case Sj$_{\mathbf{d}}$. At the discrete load distribution with a constant current density in phase conductors we have line segments between two adjacent consumers from a set l_1, l_2, ..., l_n with currents i_1, i_2, ..., i_n:

$$\begin{gathered}
l_1 = l_2 = ... = l_n = \Delta y; \;\; i_1 = \sigma\Delta x 1\Delta y; \;\; i_2 = \sigma\Delta x 2\Delta y; \; ...\; F_1 = \frac{i_1}{j} = \frac{\sigma\Delta x 1\Delta y}{j}; \\
(l_1F_1)_d = \frac{\sigma\Delta x 1\Delta y^2}{j}; \;\; (l_2F_2)_d = \frac{\sigma\Delta x 2\Delta y^2}{j}; \;\; (l_nF_n)_d = \frac{\sigma\Delta x n\Delta y^2}{j}; \\
(lF_j)_d = 2\sum_{i=1}^{n} l_iF_i = \frac{2\sigma\Delta x\Delta y^2}{j}(1+2+...+n) = \frac{2\sigma\Delta x(2y_m)^2}{j(2n+1)^2}\frac{n(n+1)}{2} = \\
= \frac{\sigma\Delta x y_m^{\ 2}}{j}\frac{4n(n+1)}{(2n+1)^2}.
\end{gathered} \tag{8}$$

In (8), expression (2) and a formula for arithmetical progression sum from [9] are employed.

The discreteness factor (similar to (5)) is:

$$k_d = \frac{4n(n+1)}{(2n+1)^2}. \tag{9}$$

Case SF$_{\mathbf{c}}$. At constant cross-section and continuous load dislocation, we have:

$$F_F = \frac{i(0)}{j} = \frac{\sigma\Delta x y_m}{j}; \;\; (lF_F)_c = 2\int_0^{y_m} F_F dy = \frac{2\sigma\Delta x y_m^{\ 2}}{j}. \tag{10}$$

Case SF$_{\mathbf{d}}$. At the discrete load dislocation the following is valid:

$$(lF_F)_d = \frac{2\sigma\Delta x y_m\Delta y n}{j} = \frac{2\sigma\Delta x y_m 2y_m n}{j(2n+1)} = \frac{2\sigma\Delta x y_m^{\ 2}}{j}\frac{2n}{2n+1}. \tag{11}$$

The discreteness factor, similar to (5), is:

$$k_d = \frac{2n}{2n+1}. \tag{12}$$

Power loss in the phase conductor

The losses in one phase of a line and the maximum consumer load are considered.

Case Sj$_{\mathbf{c}}$. A strip-shaped network is treated, with constant current density j in the line phase conductor and continuous load distribution.

The specific linear phase conductor resistance (Ω/m) at a distance y from the supply point will be:

$$R_0(y) = \frac{1}{\gamma F(y)}, \tag{13}$$

where γ, 1/(Ω·m) is the specific conductance of the phase wire material;

$F(y)$, m^2 is the cross-section of the phase conductor in accordance with (6).

Then the $R_0(y)$, dR_Ω and $d\Delta P(y)$ values − the elementary increments of phase conductor resistance and of power losses at a distance y, respectively − will be:

$$R_0(y) = \frac{j}{\gamma i(y)}; \quad dR_\Omega(y) = \frac{j}{\gamma i(y)} dy;$$

$$d\Delta P(y) = i^2(y) dR_\Omega(y) = \frac{j}{\gamma} i(y) dy. \tag{14}$$

The power loss in a phase conductor with constant current density is:

$$\Delta P_c = 2\int_0^{y_m} d\Delta P(y) dy = \frac{j\sigma\Delta x y_m{}^2}{\gamma}. \tag{15}$$

Case Sj$_\mathbf{d}$. It is similar to the preceding case (Case **Sj$_\mathbf{c}$**) but at discrete load distribution (see Fig. 1). The considered strip zone may be part of a greater territory with uniform distribution of consumers. Then each consumer is located in the centre of a square, i.e. $\Delta x = \Delta y$. The current Δi collected from each consumer's plot area is:

$$\Delta i = \sigma \Delta x \Delta y, \tag{16}$$

consequently, currents i_1, i_2, ..., i_n in the line at distance Δy between the neighbouring consumers are:

$$i_1 = 1\Delta i; \ \ i_2 = 2\Delta i; \ ...; \ i_n = n\Delta i, \tag{17}$$

where n is determined from (2).

Cross-section F_1, specific resistance R_{01}, resistance R_1 and power loss ΔP_1 at the first distance of the phase conductor are:

$$F_1 = \frac{i_1}{j}; \quad R_{01} = \frac{j}{\gamma i_1}; \quad \Delta R_1 = R_{01}\Delta y;$$

$$\Delta P_1 = \Delta R_1 i_1{}^2 = \frac{j\Delta y i_1}{\gamma} = \frac{j\sigma\Delta x \cdot 1\Delta y^2}{\gamma}; \tag{18}$$

similarly:

$$\Delta P_2 = \frac{j\sigma\Delta x \cdot 2\Delta y^2}{\gamma}; \quad \Delta P_n = \frac{j\sigma\Delta x \cdot n\Delta y^2}{\gamma}. \tag{19}$$

The power loss in the phase conductor of the entire strip, observing (2), is:

$$\Delta P_d = 2\sum_{i=1}^{n} \Delta P_i = 2\frac{j\sigma\Delta x\Delta y^2}{\gamma}(1+2+...+n) = \frac{j\sigma\Delta x {y_m}^2}{\gamma}\frac{4n(n+1)}{(2n+1)^2}. \tag{20}$$

Discreteness factor, similar to (5), is:

$$k_d = \Delta P_d : \Delta P_c = \frac{4n(n+1)}{(2n+1)^2}. \tag{21}$$

Cases $\mathbf{SF_c}$ and $\mathbf{SF_d}$ are considered in a similar way. For three phases the power loss ΔP is three times that according to (15) and (20).

Real component of the voltage drop

The real component U_Δ of voltage drop at distance y_m (its maximum value) from the supply point at the maximum consumer load is calculated as follows.

Case $\mathbf{Sj_c}$.

$$U_{\Delta c} = \int_0^{y_m} i(y)dR_\Omega = \frac{jy_m}{\gamma}. \tag{22}$$

Case $\mathbf{Sj_d}$. Observing (2), (17), (18) we have:

$$U_{\Delta 1} = R_{01}\Delta y i_1 = \frac{j\Delta y}{\gamma};\ \ U_{\Delta 2} = R_{02}\Delta y i_2 = \frac{j\Delta y}{\gamma};\ \ ...;$$

$$U_{\Delta n} = R_{0n}\Delta y i_n = \frac{j\Delta y}{\gamma}. \tag{23}$$

$$U_{\Delta d} = \frac{j\Delta y}{\gamma}n = \frac{jy_m}{\gamma}\frac{2n}{2n+1}. \tag{24}$$

The discreteness factor:

$$k_d = U_{\Delta d} : U_{\Delta c} = \frac{2n}{2n+1}. \tag{25}$$

Cases $\mathbf{SF_c}$ and $\mathbf{SF_d}$ are considered in a similar way.

Imaginary component of the voltage drop

The imaginary component of voltage drop U_δ (defined at the maximum consumer load) almost does not depend on the phase conductor's diameter, since specific reactance X_0, Ω/m of the line depends but slightly on the wire diameter. Hence, cases $\mathbf{Sj_c}$, $\mathbf{Sj_d}$, $\mathbf{SF_c}$, $\mathbf{SF_d}$ merge into the two cases: $\mathbf{S_c}$ and $\mathbf{S_d}$.

Case $\mathbf{S_c}$. Observing (6) we have:

$$U_{\delta c} = \int_0^{y_m} i(y)X_0 dy = \frac{X_0\sigma\Delta x {y_m}^2}{2}. \tag{26}$$

Case $\mathbf{S_d}$. Reactance Δx between adjacent consumers and voltage drops across them are:

$$\Delta x = X_0 \Delta y; \quad U_{\delta 1} = \Delta x i_1; \quad U_{\delta 2} = \Delta x i_2; \quad ...; \quad U_{\delta n} = \Delta x i_n . \tag{27}$$

Observing (2), (16) and (17) we have:

$$U_{\delta d} = \sum_{i=1}^{n} U_{\delta i} = X_0 \sigma \Delta x \Delta y^2 (1 + 2 + ... + n) = \frac{X_0 \sigma \Delta x y_m{}^2}{2} \frac{4n(n+1)}{(2n+1)^2} . \tag{28}$$

The discreteness factor:

$$k_d = \frac{4(n+1)}{(2n+1)^2} . \tag{29}$$

Calculation results are shown in Table 1 for two cases: **Sj** and **SF.** Tabulated are the characteristic quantities for continuous load distribution (l; lF, ΔP, U_Δ, U_δ, and discreteness factor k_d). The quantities for discrete load distribution are defined by (1).

Table 1

Characteristic quantities for a strip-shaped fed zone

Case	l k_d	lF k_d	ΔP k_d	U_Δ k_d	U_δ k_d
Sj	$2y_m$ $\frac{2n}{2n+1}$	$\frac{\sigma \Delta x y_m{}^2}{j}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{3 j \sigma \Delta x y_m{}^2}{\gamma}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{j y_m}{\gamma}$ $\frac{2n}{2n+1}$	$\frac{X_0 \sigma \Delta x y_m{}^2}{2}$ $\frac{4n(n+1)}{(2n+1)^2}$
SF		$\frac{2\sigma \Delta x y_m{}^2}{j}$ $\frac{2n}{2n+1}$	$\frac{2 j \sigma \Delta x y_m{}^2}{\gamma}$ $\frac{2(n+1)}{2n+1}$	$\frac{j y_m}{\gamma}$ $\frac{2(n+1)}{2n+1}$	

B. Fed zone in the shape of a bar (Fig. 2).

A bar-shaped network includes branch lines and trunk lines whose phase conductors can be made of different materials, and therefore may have their own parameters j_b, γ_b and j_t, γ_t. Whereas for a strip we had two cases: at constant j and constant F, for a bar we have four cases: two branch line cases and the other two − trunk line cases. Case **Bbj** holds for a branch line with constant j; case **BbF** – for a branch line with constant F; cases **Btj** and **BtF** concern a trunk line with constant j and F, respectively. The number of branch lines in one direction from the supply centre is N (the middle branch line is also accounted for in the calculations); the number of consumers supplied from one direction of the branch line is n. The calculation results are shown in Table 2, where the quantities are similar to those in Table 1.

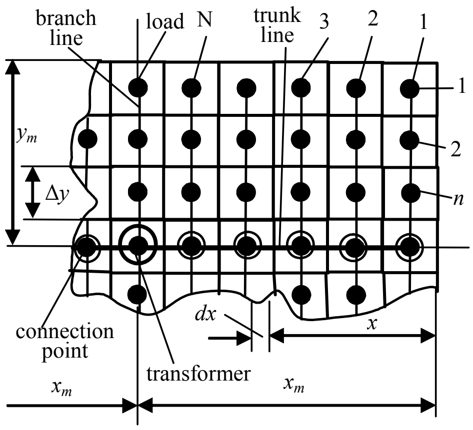

Fig. 2. Fed zone in the shape of a bar (a fourth of the area).

Table 2

Characteristic quantities for a bar-shaped fed zone

Case	l k_d	lF k_d	ΔP k_d	U_Δ k_d	U_δ k_d
Bbj	$4y_mN$ $\frac{2n}{2n+1}$	$\frac{2\sigma y_m^2 x_m}{j_b}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{6j_b\sigma y_m^2 x_m}{\gamma_b}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{j_b y_m}{\gamma_b}$ $\frac{2n}{2n+1}$	$\frac{X_0\sigma x_m y_m^2}{2n+1}$ $\frac{4n(n+1)}{(2n+1)^2}$
BbF		$\frac{4\sigma y_m^2 x_m}{j_b}$ $\frac{2n}{2n+1}$	$\frac{4j_b\sigma y_m^2 x_m}{\gamma_b}$ $\frac{2(n+1)}{2n+1}$	$\frac{j_b y_m}{2\gamma_b}$ $\frac{2(n+1)}{2n+1}$	
Btj	$2x_m$ $\frac{2N}{2N+1}$	$\frac{2\sigma y_m x_m^2}{j_t}$ $\frac{4N(N+1)}{(2N+1)^2}$	$\frac{6j_t\sigma y_m x_m^2}{\gamma_t}$ $\frac{4N(N+1)}{(2N+1)^2}$	$\frac{j_t x_m}{\gamma_t}$ $\frac{2n}{2n+1}$	$X_0\sigma y_m x_m^2$ $\frac{4N(N+1)}{(2N+1)^2}$
BtF		$\frac{4\sigma y_m x_m^2}{j_t}$ $\frac{2N}{2N+1}$	$\frac{4j_t\sigma y_m x_m^2}{\gamma_t}$ $\frac{2(N+1)}{2N+1}$	$\frac{j_t x_m}{2\gamma_t}$ $\frac{2(N+1)}{2N+1}$	

S+. The following consideration relates to the square network with cruciform trunk lines (Fig. 3). Lines of the kind are suitable for the cities with perpendicular arrangement of streets. In a square n=N, which means that the number of branch lines in one direction from the supply centre and the maximum number of consumers supplied from one direction of a branch line is n. The principle of case designation is the same as for Table 2. The results are shown in Table 3.

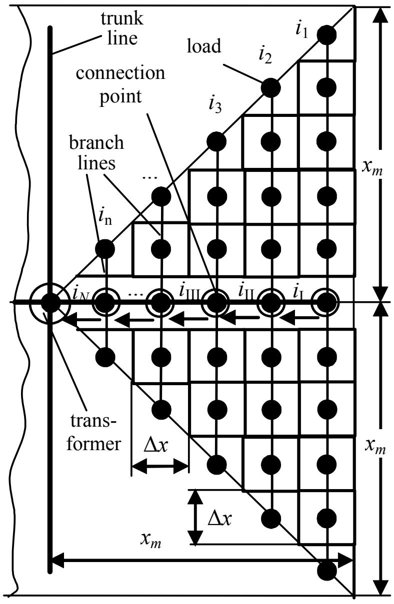

Fig. 3. A square fed zone with cruciform trunk lines (a fourth of the area). i_1, i_2, ..., i_n – currents in the entire branch line (on both sides of the trunk line); i_I, i_{II}, ... – currents in a trunk line segment.

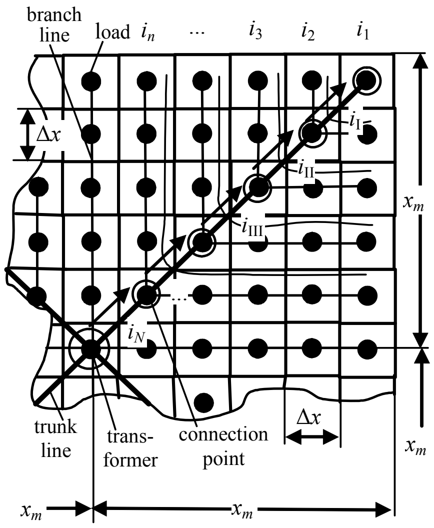

Fig. 4. A square fed zone with **x**-like. trunk lines (fourth of the area). i_1, i_2, ... i_n – currents in the entire branch line (on both sides of the trunk line); i_I, i_{II}, ... – currents in a trunk line segment.

Table 3

Characteristic quantities of a square fed zone (S+)

Case	l k_d	lF k_d	ΔP k_d	U_Δ k_d	U_δ k_d
S+bj	$4x_m n$	$\frac{4\sigma x_m^3}{3j_b}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{4j_b\sigma x_m^3}{\gamma_b}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{j_b x_m}{\gamma_b}$ $\frac{2n}{2n+1}$	$\frac{X_0\sigma x_m^3}{2n+1}$
S+bF	$\frac{2n}{2n+1}$	$\frac{8\sigma x_m^3}{3j_b}$ $\frac{4n(n+1)}{(2n+1)^2}-\frac{6n(n+1)}{(2n+1)^3}$	$\frac{8j_b\sigma x_m^3}{3\gamma_b}$ $\frac{4n(n+1)}{(2n+1)^2}-\frac{6n(n+1)}{(2n+1)^3}$	$\frac{j_b x_m}{2\gamma_b}$ $\frac{2n}{2n+1}$	$\frac{4n^2}{(2n+1)^2}$
S+tj	$4x_m$ $\frac{2n}{2n+1}$	$\frac{8\sigma x_m^3}{3j_t}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{8j_t\sigma x_m^3}{\gamma_t}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{j_t x_m}{\gamma_t}$ $\frac{2n}{2n+1}$	$\frac{2X_0\sigma x_m^3}{3}$ $\frac{4n(n+1)}{(2n+1)^2}$
S+tF	$4x_m$ $\frac{2n}{2n+1}$	$\frac{4\sigma x_m^3}{j_t}$ $\frac{8n^2(n+1)}{(2n+1)^3}$	$\Delta P=\frac{32j_t\sigma x_m^3}{5\gamma_t}$; $U_\Delta=\frac{2j_t x_m}{3\gamma_t}$; $k_{dU}=1$ $k_{dP}=\frac{15}{2}(\frac{1}{3}-\frac{n(n+1)}{(2n+1)^2}+\frac{3n^2+3n-1}{15(2n+1)^2})$		$\frac{2X_0\sigma x_m^3}{3}$ $\frac{4n(n+1)}{(2n+1)^2}$

Sx. Under consideration is a square-shaped network with **x**-like trunk lines (Fig. 4). Lines of the kind might be suitable for countryside. For the square $n = N$. The principle of case denomination is the same as in Table 2. Consideration results are shown in Table 4.

Table 4

Characteristic quantities of a square fed zone (Sx)

Case	l k_d	lF k_d	ΔP k_d	U_Δ k_d	U_δ k_d
Sxbj	$4x_m n$ $\frac{2n}{2n+1}$	$\frac{4\sigma x_m^3}{3j_b}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{4j_b\sigma x_m^3}{\gamma_b}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{j_b x_m}{\gamma_b}$ $\frac{2n}{2n+1}$	$\frac{X_0\sigma x_m^3}{2n+1}$ $\frac{4n(n+1)}{(2n+1)^2}$
SxbF		$\frac{8\sigma x_m^3}{3j_b}$ $\frac{4n(n+1)}{(2n+1)^2}-\frac{6n(n+1)}{(2n+1)^3}$	$\frac{8j_b\sigma x_m^3}{3\gamma_b}$ $\frac{4n(n+1)}{(2n+1)^2}-\frac{6n}{(2n+1)^3}$	$\frac{j_b x_m}{2\gamma_b}$ $\frac{2(n+1)}{2n+1}$	
Sxtj	$4\sqrt{2}x_m$ $\frac{2n}{2n+1}$	$\frac{4\sqrt{2}\sigma x_m^3}{3j_t}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{4\sqrt{2}j_t\sigma x_m^3}{\gamma_t}$ $\frac{4n(n+1)}{(2n+1)^2}$	$\frac{\sqrt{2}j_t x_m}{\gamma_t}$ $\frac{2n}{2n+1}$	$\frac{\sqrt{2}X_0\sigma x_m^3}{3}$ $\frac{4n(n+1)}{(2n+1)^2}$
SxtF		$\frac{4\sqrt{2}\sigma x_m^3}{j_t}$ $\frac{2n}{2n+1}$	$\frac{12\sqrt{2}j_t\sigma x_m^3}{5\gamma_t}$ $\frac{4(n+1)(3n^2+3n-1)}{3n(2n+1)^2}$	$\frac{\sqrt{2}j_t x_m}{3\gamma_t}$ $\frac{n+1}{n}$	

Taking the data from Tables 1–4, we can compare the parameters of different zone shapes. Of particular interest is a square **S+** and a bar, the latter with $n = N$ (when $x_m = y_m$). For example, **S+tj, S+tF**: $U_{\delta c} = 2X_0\sigma x_m^3/3$, $l = 4x_m$; **Btj, BtF**: $U_{\delta c} = X_0\sigma x_m^3$, $l = 2x_m$. It is also noteworthy to compare the losses in the lines.

4. CONSIDERATION OF A LOW-VOLTAGE NETWORK

The model of a supplied zone in the form of square **S+**, with a given (or assumed) number n of discrete loads is considered. The trunk line in the model has a constant current density (**S+tj**) and branch lines – a constant cross-section (**S+bF**) specific for each branch line in accordance with the maximum current at its beginning.

The annual costs according to [10] for a line are:

$$C_l = (i + p_\Sigma)(a + bF)l + \Delta P(\beta'\tau + \beta''), \tag{30}$$

where i is a bank's loan interest, %;

p_Σ are the costs of depreciation, maintenance and servicing, %;
a are the fitted costs of a line's construction, LVL/m, which comprise not only the power line itself but also its ancillary equipment (distribution nodes, minor switches, fuses, etc); b is the cost depending on the cross-section F of a phase wire, LVL/m^3;
l is the line length, m;
ΔP is the power loss at the maximum consumer load for the entire line length, W;
β' is the cost of a line's power losses, LVL/Wh;
β'' is the peak power cost, LVL/W;
τ is the time of maximum power losses, h.

Having performed the following substitutions:

$$(i + p_\Sigma)/100 = C_{pf}\,; C_{pf}a = C_a\,; C_{pf}b = C_b\,;\ \beta'\tau + \beta'' = C_w\,, \tag{31}$$

we obtain:

$$C_l = C_a l + C_b lF + C_w \Delta P\,. \tag{32}$$

We will not seek the line costs separately but those of the entire fed zone:

$$C_{nt} = C_a(l_{tj} + l_{bF}) + C_b[(lF)_{tj} + (lF)_{bF}] + C_w(\Delta P_t + \Delta P_b)\,. \tag{33}$$

The quantities l_{tj}, lF_{tj}, ΔP_{tj} for trunk lines and l_{bF}, lF_{bF}, ΔP_{bF} for branch lines are found in Table 3 for continuous load density (for discrete load distribution we have to use discreteness factor k_d). Trunk lines are taken with constant current density j in the phase conductors, whereas branch lines – with constant cross-section F. The material of phase conductors is assumed to be the same for both types of line.

Based on Table 3, expression (33) can be rewritten as

$$\begin{aligned} C_{nt} &= 4C_a x_m \frac{2n(n+1)}{2n+1} + \frac{16C_b \sigma x_m^{\,3}}{3j}\left[\frac{4n(n+1)}{(2n+1)^2} - \frac{3n(n+1)}{(2n+1)^3}\right] + \\ &+ \frac{32C_w j\sigma x_m^{\,3}}{3\gamma}\cdot\left[\frac{4n(n+1)}{(2n+1)^2} - \frac{3n(n+1)}{2(2n+1)^3}\right]. \end{aligned} \tag{34}$$

Better cost index is presented by specific costs C_{ntpS}, which are defined as the ratio of C_{nt} and the delivered maximum power S in a three-phase network.

$$C_{ntpS} = C_{nt}/S\,;\quad S = \sqrt{3}UI\,;$$

$$C_{ntpS} = C_{nt}/(\sqrt{3}UI)\,;\quad I = 4\sigma x_m^{\,2}\,, \tag{35}$$

where I, A is the current collected from the entire zone at the maximum consumer load (conjugate is not shown, since only the absolute value is significant);
U is the phase-to-phase low voltage (400 V).

The second multiplier of each term in (34) is a function of discreteness factor defined by number n, hence it is a function of n:

$$f_1(n) = \frac{2n(n+1)}{2n+1}; \quad f_2(n) = \frac{4n(n+1)}{(2n+1)^2} - \frac{3n(n+1)}{(2n+1)^3};$$

$$f_3(n) = \frac{4n(n+1)}{(2n+1)^2} - \frac{3n(n+1)}{2(2n+1)^3}. \tag{36}$$

Expressing n according to (2) by x_m and Δx and inserting it into $f_1(n)$, we obtain:

$$f_1(n) = \frac{x_m}{\Delta x} - \frac{0.25\Delta x}{x_m} \approx \frac{x_m}{\Delta x}. \tag{37}$$

At $\Delta x/x_m$=0.5 and 0.25 the difference between $f_1(n)$ and $x_m/\Delta x$ is 6.3 and 1.6%, respectively.

Observing (33)–(37), the expression for specific per unit of the network's annual costs (without transformer) is:

$$C_{ntpS} = \frac{C_a}{\sqrt{3}\sigma\Delta x U} + \frac{4C_b x_m}{3\sqrt{3} jU} f_2(n) + \frac{8C_w j x_m}{3\sqrt{3}\gamma U} f_3(n). \tag{38}$$

Functions $f_1(n)$ ... $f_3(n)$ are displayed in Fig. 5. Expression (38) shows the influence of the parameters on the specific costs of the network.

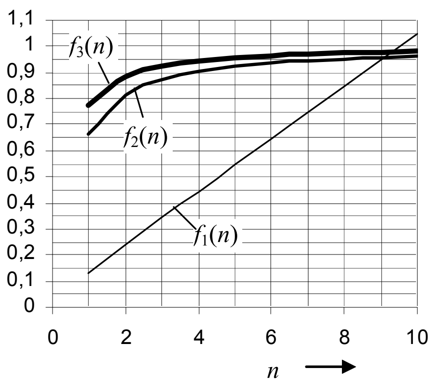

Fig. 5. Functions f_1(n)…$f_3(n)$.

To optimize a network's operation it is necessary to include a transformer into consideration.

Some remaining questions are to be considered in the next publications.

5. CONCLUSIONS

1. In order to investigate the electrical network it is more convenient to use a model with continuously changing parameters and calculate the discreteness factor for supplying zone.
2. Specific costs of a network decrease with voltage increasing as far as the fitted costs of line construction are not increasing too rapidly with voltage.

3. Specific costs of a network decrease with the load density and specific conductance of phase conductor increasing when the consumers are spread more sparsely. To reduce specific costs, an appropriate current density should be chosen.
4. To choose the optimum dimensions of the supplying zone a step-down transformer should be included into consideration.

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TĪKLU NOMINĀLIE SPRIEGUMI

J. Survilo

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

Elektriskajās sistēmās izmanto dažādus nominālos spriegumus. Kāds pamats ir tādai gradācijas pārpilnībai? Atbilde tiek meklēta uz apgādājamās zonas un tās izmēru bāzes. Novērtējums tiek veikts, izvēloties dažus pieņēmumus: parametru izmaiņa ir nepārtraukta, spriegums ir konstants, elektrības patērētāji ir izvietoti nepārtraukti ar konstantu blīvumu utt. Lai rezultātus atgrieztu reālajā situācijā, tiek aprēķināts un lietots atsevišķs koeficients dažādas formas apgādājamām zonām. Analizējot tīkla apgādājamās zonas izdevumu formulu, redzam, ka īpatnējie izdevumi samazinās: palielinot tīkla spriegumu (ja līnija pārlieku nesadārdzinās), kad patērētāji ir izvietoti retāk, kad ir lielāks slodzes blīvums un fāzes vada materiāla vadāmība, pie optimālā strāvas blīvuma fāzes vadā. Raksta nosaukumā ietvertās problēmas pētīšana turpināsies.

11.04.2011.

MISTAKE CORRECTION*

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