The Stipulation for Orthogonality of the Nodal and Extra Currents

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Abstract **– Closed grids inherit the main qualities of two-terminal lines. In closed grids, as opposed to the radial, except for the load power losses, may be extra losses from grid non-uniformity ($X/R \neq$ const) and from voltage difference in some nodes. To eliminate extra losses, it is necessary to know where in the grid they appear and how great they are. This can be made by decomposing the losses. To do this, the initial grid should be converted to uniform (or in R-grid) one without loop emf (if such are in the initial grid) and calculate load losses in this grid, calculate extra losses in initial grid caused by joint action of circulating currents from grid non uniformity and equalizing currents from loop emf; the sums of these currents (called extra currents) is orthogonal to load branch currents in uniform grid in the sense that the sum of power losses from separate action of load currents in uniform grid and of extra currents (extra losses) in initial grid are equal to power losses in the initial grid. Any grid can be converted to uniform one. Different transformation ratios of high voltage transformers can increase the losses.**

Keywords **– circulating current, closed grids, homogenous network, loop current, non-uniform grid, power losses.**

I. INTRODUCTION

In electrical grids, the signals to rely on are the nodal currents. These currents provide energy required by loads. The task of the grid is to bring this energy to a consumer ensuring necessary quality with good economical indicators. Power losses in the grid should be minimum. This factor is highlighted in [1] and [2], in [3] entire chapter is devoted to consideration of various cases of non-uniformity impact. An example of losses calculation in non-uniform grid with transformers is considered in [4]. Under certain load currents and based on known parameters, the losses from non-uniformity of ringed grid was calculated in [5]. The issue was considered in [6] and [7] where difference of voltages at the ends of power line was taken into account. Losses in non-uniform meshed (closed) grids were considered in [8].

The material in [6] – [8] should be clarified because the attention was not drawn to some important moments. This is the first point. The second, it is necessary to research these questions for non-uniform closed grids when there are both load currents taken at grid nodes and voltage difference between some grid nodes. The term 'orthogonal' is used here to denote that power losses by joint action of load currents and loop emf in non-uniform two terminal lines or closed grids are equal to the sum of losses from separate action of load currents in uniform grid and losses from separate action of extra currents, extra currents being the sum of circulating currents (CC) from grid non-uniformity and equalizing currents from possible incorrect transformation ratios of high voltage transformers. Term 'orthogonality' is selected to refer to the independence of load losses and losses caused by other factors.

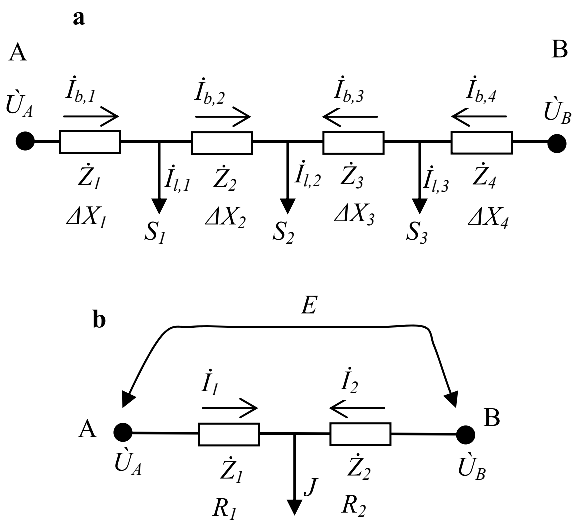

Fig. 1. Two terminal non-uniform lines
a – with three loads; b – with one load.

II. TWO TERMINAL LINE

Let's start with the simplest. Two terminal line is shown on Fig. 1a where the circuit is non-uniform. In [5] it is proved that the power losses in this circuit are equal to the sum of power losses from load current **when the circuit is uniform** and of losses from circulating current (CC). At the same time, CC can be defined as loop emf, divided by summary impedance of the circuit. It will be shown more clearly in a simple circuit with single load (Fig. 1b).

Two signals are applied to the circuit: load current $\dot{J}$ and loop emf $\dot{E} = \dot{U}_A - \dot{U}_B$. Currents from the first signal in impedances $\dot{Z}_1$ and $\dot{Z}_2$ are:

$$\dot{I}_{J1} = \dot{J}\frac{\dot{Z}_2}{\dot{Z}_1 + \dot{Z}_2}; \;\; \dot{I}_{J2} = \dot{J}\frac{\dot{Z}_1}{\dot{Z}_1 + \dot{Z}_2}. \qquad (1)$$

If line is uniform, than

$$\dot{I}_{J1} = \dot{I}_{h1}; \;\; \dot{I}_{J2} = \dot{I}_{h2} \qquad (2)$$

Power losses caused by first signal are:

$$\Delta P_J = R_1 I_{J1}^{\ 2} + R_2 I_{J2}^{\ 2} = \frac{R_1 J^2 \left|\dot Z_2\right|^2}{\left|\dot Z_1 + \dot Z_2\right|^2} + \frac{R_2 J^2 \left|\dot Z_1\right|^2}{\left|\dot Z_1 + \dot Z_2\right|^2} . \quad (3)$$

Second signal currents in impedances $\dot Z_1$ and $\dot Z_2$ are:

$$\dot I_{E1} = \frac{\dot E}{\dot Z_1 + \dot Z_2} = \dot I_{ex} ; \ \dot I_{E2} = -\dot I_{ex} , \quad (4)$$

where I_{ex} is meant as extra current. This current may be the sum of CC and equalizing current in non-uniform line but later this line must be converted to uniform one and currents I_{j1} and I_{j2} must be obtained in **uniform** line.

Power losses caused by the second signal are:

$$\Delta P_E = R_1 \left|\dot I_{ex}\right|^2 + R_2 \left|-\dot I_{ex}\right|^2 = \Sigma R \cdot I_{ex}^{\ 2} . \quad (5)$$

The summary power losses:

$$\begin{aligned} \Delta P_{J+E} &= \Delta P_J + \Delta P_E = \\ &= \Delta P_E + \frac{R_1 J^2 \left|Z_2\right|^2}{\left|\dot Z_1 + Z_2\right|^2} + \frac{R_2 J^2 \left|\dot Z_1\right|^2}{\left|\dot Z_1 + \dot Z_2\right|^2} + \Sigma R \cdot I_{ex}^{\ 2} . \end{aligned} \quad (6)$$

Currents in impedances $\dot Z_1$ and $\dot Z_2$ caused by load current in uniform grid and emf E are:

$$\dot I_{JE1} = \dot J \frac{\dot Z_2}{\dot Z_2 + \dot Z_2} + \dot I_{ex} = \dot I_{h1} + \dot I_{ex} ; \quad (7)$$

$$\dot I_{JE2} = \dot J \frac{\dot Z_1}{\dot Z_2 + \dot Z_2} - \dot I_{ex} = \dot I_{h2} - \dot I_{ex} . \quad (8)$$

Power losses caused by joint action of both signals are:

$$\begin{aligned} \Delta P_{JE} &= R_1 I_{JE1}^{\ 2} + R_2 I_{JE2}^{\ 2} = R_1 \Big(\frac{J^2 \left|\dot Z_2\right|^2}{\left|\dot Z_1 + \dot Z_2\right|^2} + \frac{2\dot J \dot Z_2 \dot E}{(\dot Z_1 + \dot Z_2)^2} + \\ &+ \frac{E^2}{\left|\dot Z_1 + \dot Z_2\right|^2} \Big) + R_2 \Big(\frac{J^2 \left|\dot Z_1\right|^2}{\left|\dot Z_1 + \dot Z_2\right|^2} - \frac{2\dot J \dot Z_1 \dot E}{(\dot Z_1 + \dot Z_2)^2} + \frac{E^2}{\left|\dot Z_1 + \dot Z_2\right|^2} \Big) = \\ &= \frac{R_1 J^2 \left|Z_2\right|^2}{\left|\dot Z_1 + Z_2\right|^2} + \frac{R_2 J^2 \left|\dot Z_1\right|^2}{\left|\dot Z_1 + \dot Z_2\right|^2} + \Sigma R \cdot I_{ex}^{\ 2} + \\ &+ \frac{2R_1 \dot J \dot Z_2 \dot E - 2R_2 \dot J \dot Z_1 \dot E}{(\dot Z_1 + \dot Z_2)^2} \end{aligned} \quad (9)$$

Apparently, it is the last addend which interferes with ΔP_{J+E}. But this term equals to zero if the circuit is **uniform**. Indeed, in a uniform circuit $R_1 = \operatorname{Re} \dot Z_1 = Z_1 \cos\varphi$; $R_2 = \operatorname{Re} \dot Z_2 = Z_2 \cos\varphi$ and now it can be written:

$$\begin{aligned} &2JE[Z_1 \cos\varphi \cdot Z_2 (\cos\varphi + j\sin\varphi) - \\ &- Z_2 \cos\varphi \cdot Z_1 (\cos\varphi + j\sin\varphi)] = 0 \end{aligned} \quad (10)$$

In such a way it is proved that nodal current and extra current are orthogonal in two terminal lines with one load. In the uniform line with more than one load (Fig. 1a) formulas (1) – (10) are valid for all branches and all branches together keep the property. This affirms the proof in [5].

But how it is when at the ends of two terminal **non-uniform** line there are different voltages? The three factors exist: load currents, line non-uniformity and loop emf. From the preceding discussion it is known that when there are load node currents and non-uniformity, the line can be reduced to **uniform** line with the same node currents and CC I_{ci}. But when there yet exist voltage difference at the ends of the line [6]; [7], then equalizing current I_{eq} must appear. The sum of I_{ci} and I_{eq} is extra current I_{ex}. Branch currents consist of load current in **uniform** line and extra currents.

Formulas (1) – (10) are indifferent to the origin of extra current; the main thing is that this current is the same in all branches of the line. Extra current, being the sum of CC from non-uniformity and equalizing current from voltage difference at the ends of the line [6], [7], preserves orthogonality. If foreign emf E_f is inserted in non-uniform two-terminal line loop and is needed to know power losses in this line, then the following must be done: 1) calculate CC I_{ci} in the initial line without E_f ; 2) calculate equalizing current I_{eq} from E_f; 3) calculate extra current I_{ex} by adding the I_{ci} to I_{eq}; 4) convert non-uniform line into uniform one (or into R-line, i.e. one consisting only of branch resistances); 5) calculate branch currents I_h from loads ***J*** in that line; 6) calculate power losses ΔP_h and ΔP_{ex} from currents I_h and I_{ex} respectively [5]; 7) calculate summary line losses adding the load losses ΔP_h to extra losses ΔP_{ex}; the summary losses are equal to losses in loaded two terminal non-uniform line with different voltages at its ends. It means that currents I_h and I_{ex} are orthogonal. To estimate the losses only from voltage difference at line ends, the losses from non-uniformity (when CC is caused only by non-uniformity) must be subtracted from **extra** losses. So much for a two terminal line.

III. Closed Grids

Closed grids contain more than one loop. As an example, the non-uniform grid is shown in Fig. 2. In [8] it is expounded how to calculate CC in closed grid.

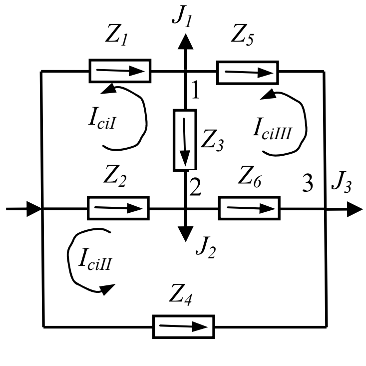

Fig. 2. Non-uniform closed network with three loops.

In Fig. 2 there are depicted three independent loops $Z_1 - Z_2 - Z_3$; $Z_2 - Z_4 - Z_6$ and $Z_5 - Z_3 - Z_6$ with loop CC $\dot I_{ciI}$; $\dot I_{ciII}$ and $\dot I_{ciIII}$. To eliminate CC, it is necessary to insert in these loops opposing voltage $\dot U_1$; $\dot U_2$ and $\dot U_3$. So far it is clearly expounded in [8] (where symbol U is replaced by symbol E).

In the shown non-uniform closed grid (Fig. 2), there are: node current input vector $\boldsymbol{J_j}$ consisting of load currents J_1, J_2, J_3; foreign emf input vector $\boldsymbol{J_f}$ consisting of inserted in loops foreign emf E_{f1}; E_{f2}; E_{f3} not shown in Fig. 2 and summary input vector $\boldsymbol{J_{jf}}$:

$$\boldsymbol{J_j}=[J_1; J_2; J_3; 0; 0; 0]; \quad \boldsymbol{J_f}=[0; 0; 0; E_{f1}; E_{f2}; E_{f3}];$$

$$\boldsymbol{J_{jf}}=[J_1; J_2; J_3; E_{f1}; E_{f2}; E_{f3}]. \quad (11)$$

The branch current matrix $\boldsymbol{B_z}$; CC branch current matrix $\boldsymbol{\Delta B}$; branch current matrix of uniform grid $\boldsymbol{B_h}$ [8] are calculated for the grid on Fig.1.

Uniform grid consists of elements

$$Z_{hm}=R_m+jX_m\,, \quad (12)$$

where m= 1... n; n is number of branches in the grid and X_m are such that X_m/R_m is constant.

R-grid consisting only of branch resistances R_m can be used as uniform grid as well.

Vectors here and further are written in a string to save space. Vectors and matrices (except ***R***-matrix) consist of complex numbers.

Further, the following quantities must be calculated: branch current vector $\boldsymbol{I_j}$ excited by node loads $\boldsymbol{J}$; circulating current vector $\boldsymbol{I_{ci}}$; equalizing current vector $\boldsymbol{I_{eq}}$; extra current vector $\boldsymbol{I_{ex}}$; summary branch current vector $\boldsymbol{I_{jf}}$; branch current vector $\boldsymbol{I_h}$ excited by node loads $\boldsymbol{J}$ in uniform grid; losses ΔP_j caused by load currents in non-uniform grid; losses ΔP_{ci} caused by CC; losses ΔP_{ex} caused by extra currents; losses ΔP_{jf} caused by summary branch currents; losses ΔP_h caused by load currents in uniform grid:

$$\boldsymbol{I_j}=\boldsymbol{B_z}*\boldsymbol{J_j};\ \boldsymbol{I_{ci}}=\boldsymbol{\Delta B}*\boldsymbol{J_j};\ \boldsymbol{I_{eq}}=\boldsymbol{B_z}*\boldsymbol{J_f};\ \boldsymbol{I_{ex}}=\boldsymbol{I_{ci}}+\boldsymbol{I_{eq}};\ \boldsymbol{I_{jf}}=\boldsymbol{B}*\boldsymbol{J_{jf}};$$
$$\boldsymbol{I_h}=\boldsymbol{B_h}*\boldsymbol{J_j};\ \Delta P_j=\boldsymbol{I_j}'*\boldsymbol{R}*\boldsymbol{I_j};\ \Delta P_{ci}=\boldsymbol{I_{ci}}'*\boldsymbol{R}*\boldsymbol{I_{ci}};\ \Delta P_{ex}=\boldsymbol{I_{ex}}'*\boldsymbol{R}*\boldsymbol{I_{ex}};$$
$$\Delta P_{jf}=\boldsymbol{I_{jf}}'*\boldsymbol{R}*\boldsymbol{I_{jf}};\ \Delta P_h=\boldsymbol{I_h}'*\boldsymbol{R_b}*\boldsymbol{I_h}, \quad (13)$$

where ***R***-matrix is real component of ***Z***-matrix and ***I'*** is transposed conjugate of vector ***I***.

CC has its own value in each loop of the closed grid since $\boldsymbol{\Delta B}$ – matrix strings for each loop are different. Equalizing current in each branch is different because such is $\boldsymbol{B_z}$ – matrix.

It is found that losses from summary branch currents are:

$$\Delta P_{jf}=\Delta P_h+\Delta P_{ex}, \quad (14)$$

which means that load currents in uniform grid and extra currents are orthogonal.

A special case of expression (14) is formula (15):

$$\Delta P_j = \Delta P_h + \Delta P_{ci}\,, \quad (15)$$

which is apt for non-uniform grids without foreign loop emf.

The fact that (14) is confirmed by calculations does not mean that it is always true. To be sure it must be proved. It is done in the following way.

Load current in uniform grid I_{h1} in string 1 is:

$$I_{h1}=B_{h11}\cdot J_1+B_{h12}\cdot J_2+B_{h13}\cdot J_3 \quad (16)$$

Summary current in string 1 is

$$I_{jfs}= B_{h11}\cdot J_1+B_{h12}\cdot J_2+B_{h13}\cdot J_3+\Delta B_{11}\cdot J_1+\Delta B_{12}\cdot J_2+\Delta B_{13}\cdot J_3+$$
$$+B_{14}\cdot E_{f1}+B_{15}\cdot E_{f2}+B_{16}\cdot E_{f3}=I_{h1}+I_{ex}, \quad (17)$$

where $\boldsymbol{B_h}$ branch current matrix of **uniform** grid; $\boldsymbol{\Delta B}$ – CC matrix for **non-niform** grid; [$J_1; J_2; J_3; 0; 0; 0$] – vector of load currents; [$0; 0; 0; E_1; E_2; E_3$] – vector of foreign emf.

Currents (18) in the form are the same as (7), (8) which ensure orthogonality. If orthogonality is ensured for one string, it is ensured for all strings and for all strings together. The (14) can be considered proved.

When vector $\boldsymbol{E_f}$ of foreign loop emf is inserted in non-uniform closed grid, the following must be done: 1) calculate CC vector $\boldsymbol{I_{ci}}$ in the initial grid without vector $\boldsymbol{E_f}$; 2) calculate equalizing current vector $\boldsymbol{I_{eq}}$ caused by $\boldsymbol{E_f}$; 3) calculate extra current vector $\boldsymbol{I_{ex}}$ by adding the $\boldsymbol{I_{ci}}$ to $\boldsymbol{I_{eq}}$; 4) convert non-uniform grid into uniform one (or in *R*-grid); 5) calculate branch current vector $\boldsymbol{I_h}$ in uniform grid caused by loads $\boldsymbol{J}$; 6) calculate power losses $\boldsymbol{\Delta P_h}$ and $\boldsymbol{\Delta P_{ex}}$ caused by currents $\boldsymbol{I_h}$ and $\boldsymbol{I_{ex}}$ respectively using (13); 7) calculate summary grid losses adding extra losses ΔP_{ex} to load losses ΔP_h; the summary losses are equal to losses in loaded initial grid with inserted emf (if any) in some loops. Summary losses in initial grid are calculated using summary input vector $\boldsymbol{J_{jf}}$ (see (13)). To estimate the losses ΔP_{fnu} caused only by foreign emf in non-uniform grid, the non-uniformity losses (caused by CC) ΔP_{ci} must be subtracted from **extra** losses ΔP_{ex}:

$$\Delta P_{f-} = \Delta P_{ex} - \Delta P_{ci} \quad (18)$$

More exact address of node voltage irregularities can be found studying the CC and extra currents. Loop foreign emf can be found as voltage difference of nodes pertaining to the loop as a result of improper transformation ratio.

Feature (14) was checked on grid (Fig. 2) using the MATLAB program: Z_1=5+j9; Z_2=4+j11; Z_3=4+j2; Z_4=8+j9; Z_5=2+j6; Z_6=7+j5; $\boldsymbol{J_j}$=[3+j5; 4-j2; 5+j3; 0; 0; 0]; $\boldsymbol{J_f}$=[0; 0; 0; 5-j10; 40+j5; 20-j10]; $\boldsymbol{J_{jf}}$=[3+j5; 4-j2; 5+j3; 5-j10; 40+j5; 20-j10]. Obtained power loss values: ΔP_{jf}=474.48; ΔP_h=361.2274; ΔP_{ex}=113.2535. Above quantities are given in Ohms, Amperes, Volts and Watts. This and other sets of input values confirm expression (14).

Computer programs (for instance, PowerWorld) calculate losses in the grid. It is useful to know whether there is, besides load, other causes for power losses. Decomposition of losses will show whether grid non-uniformity or improper transformation ratios play significant role. When loads, and parameters of closed grid are known, the load losses in uniform grid and losses from non-uniformity of the grid can be calculated separately. If computed losses are larger than the sum of load losses and non-uniformity losses then loop voltages are in the grid, for example, as the incorrect transformation ratios of high voltage transformers.

IV. Determination of Extra Losses from Incorrect Transformer Ratios

In this section attention will be put to Kurzeme ring (KR) projected case. In the KR the total length of the 330 kV power lines is planned to be about 340 km; capacity – 800 MW; costs – about EUR 200 million, half of which is financed by the European Commission within the framework of the co-financing programmes [9]. Considered network consists of 330 kV power line rings which feeds the 110 kV meshed network inside. In total the scheme includes about 50 branches and 13 loops (Fig. 3.). New lines construction has significant influence on power system regimes and it is important to evaluate losses in branches.

The KR model consists of 38 nodes, including base node (38^{th} number), 50 branches (under this number transformers (330/110 kV), transmission lines (330 kV, 110 kV) and cables (110 kV) are understood) and they make in common 13 loops (Fig. 3), all data of 330 kV elements were reduced to 110 kV voltage. Several simplifications were made such as a parallel line combination in one equivalent line (Kandava – Tume 110 kV line), end branch load transfer to adjoining node (Ugale load is presented like a part of Ventspils substation load), wire and cable sum (excluded connection node), two transformer reduction to one and so on. All simplifications made will not affect final results [10].

So, after creating equivalent network circuit diagram, it is necessary to assume current directions in branches and direction of loop currents (in this case – clockwise in Fig. 3).

When all necessary data are available [10], it is possible to start calculations using matrix based method. MathCAD software is used for realization of this method. First, two matrices M and N are necessary. They show connection between nodes representing network topology. Then, Z impedance and R resistance matrices are needed.

Z impedance matrix and R resistance matrix are used to obtain network square $\mathbf{A_Z}$ matrix and network square $\mathbf{A_R}$ matrix

$$\mathrm{A}_Z = \begin{bmatrix} \mathrm{M} \\ \mathrm{N} \cdot \mathrm{Z} \end{bmatrix}; \qquad (18)$$

$$\mathrm{A}_R = \begin{bmatrix} \mathrm{M} \\ \mathrm{N} \cdot R \end{bmatrix}. \qquad (19)$$

To compute branch currents $\boldsymbol{I_Z}$ in Z – network and $\boldsymbol{I_R}$ – in R – network, inverse matrices $\boldsymbol{B_Z}$ and $\boldsymbol{B_R}$ are necessary

$$B_Z = \left\lfloor \mathrm{A}_Z^{-1} \right\rfloor; \qquad (20)$$

$$\mathrm{B}_R = \left\lfloor \mathrm{A}_R^{-1} \right\rfloor. \qquad (21)$$

Special attention is paid to generated reactive power of 330 kV lines, which will be evaluated in nodes like a reactive load. According to theoretical representation, generated reactive power is divided into two equal parts and flows to appropriate nodes. Calculation of generated reactive power is possible using formula

$$Q_C = U^2 \cdot B_0 \cdot l, \quad (VAr)$$

where B_0 – capacitive susceptance, S/km;

l – line length, km.

Customer loads in nodes are represented by active power variables. Total customer's active load is 217 MW, for this network it is relatively small, but transit flows are not considered here. For estimation of load currents known formula (22) is used

$$\dot{J}_j = \frac{\hat{S}}{\sqrt{3} \cdot \hat{U}}, \quad (A) \qquad (22)$$

where $\hat{S}$ – conjugate total load, VA;

$\hat{U}$ – conjugate voltage, V.

As it is well known load (node) currents do form main part of network losses and in considered case they are equal to ΔP_j = 1.839 MW for one phase.

Circulating current vector $\boldsymbol{I_{ci}}$ can be calculated in accordance with formula (13).

Calculated losses from circulating currents are equal to ΔP_{ci} = 0.04595 MW for one phase.

The next step of losses evaluation is uniform network creation. To bring a uniform grid closer to real one, the average *X/R* ratio is chosen 2. So, new impedance matrix Z_h of uniform network elements is needed. Z_h elements are calculated using formula (23)

$$Z_h = R + j \cdot X_h \qquad (23)$$

Using formulas of the type (18) and (20), it is possible to calculate $\mathrm{A_h}$ matrix and inverse matrix $\mathrm{B_h}$:

$$\mathrm{A}_h = \begin{bmatrix} \mathrm{M} \\ \mathrm{N} \cdot \mathrm{Z}_h \end{bmatrix} \text{ and } B_h = \left\lfloor \mathrm{A}_h^{-1} \right\rfloor.$$

Using the formula (13) for node loads in uniform network currents, it is possible to calculate losses ΔP_h. In this network according to formula (13) losses ΔP_h are 1.793 MW for one phase. To check calculation precision it is necessary to summarize losses from circulating and uniform network currents and these must be equal to losses caused by load currents:

$$\Delta P_j = \Delta P_{ci} + \Delta P_h = 0.046 + 1.793 = 1.839 \ (MW).$$

Now it is important to evaluate influence of transformer tap positions. It means that some substation transformers can have different transformation ratios at the same time. Used transformers types have possible change rate 6 x 2%, what in result gives 2,2 kV voltage difference for one tap position. Transformer belongs to two loops and as a result gives two elements for J_f vector with opposite signs (2, 2 kV and – 2,2 kV, correspondingly). For calculation of equalizing currents I_{eq} formula (13) will be used taking into consideration input vector J_f. In this case chosen vector elements are (38, 42) and (46, 48), (2, 2 kV and – 2, 2 kV, as meant above) because two transformers are taken in consideration which are represented by branches 11 and 16.

Now it is necessary to analyse common case, evaluating basic loads and two transformer tap positions. First of all, it is necessary to find extra current vector, this is possible to make using formula

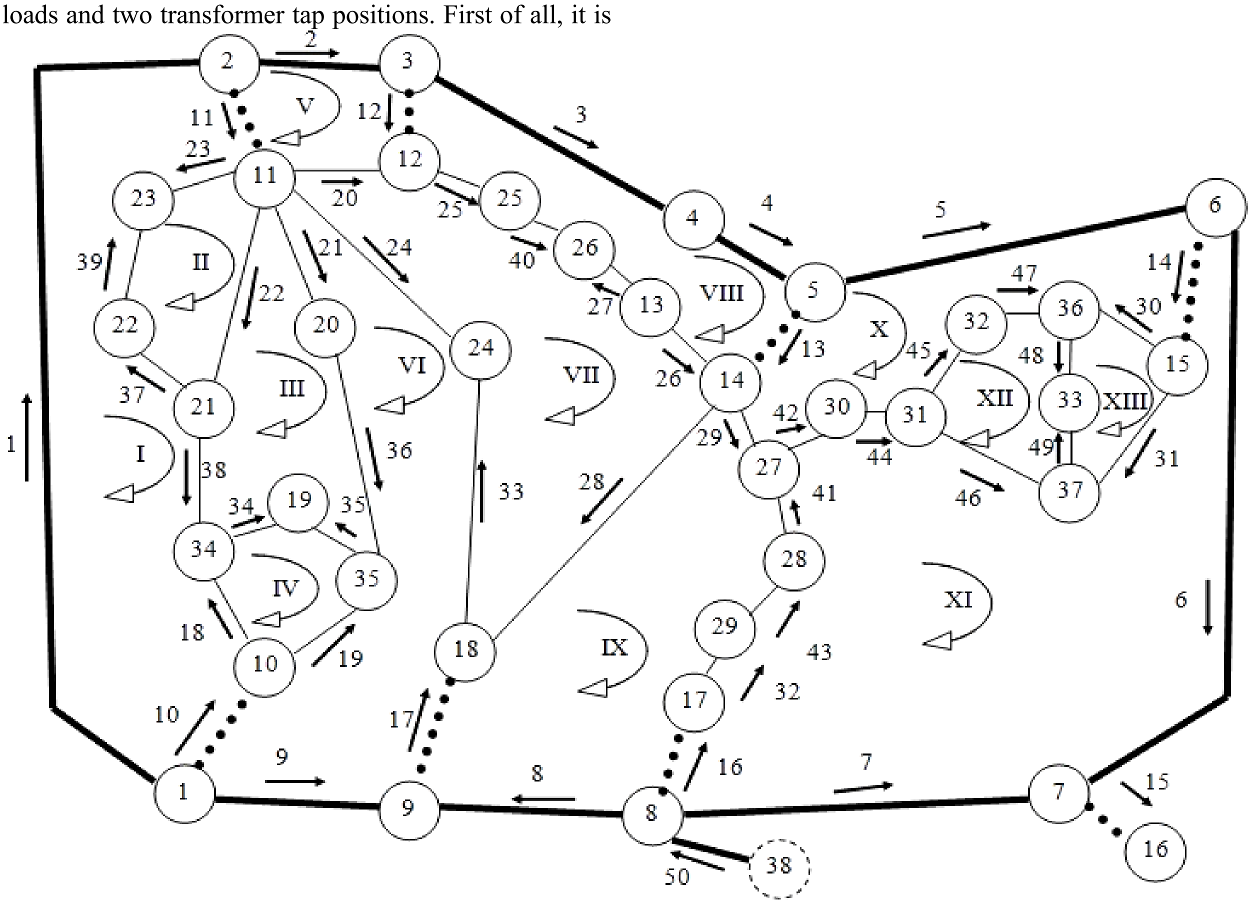

Fig. 3. The Kurzeme Ring Model Scheme.

$$I_{ex} = I_{ci} + I_{eq} .$$

Extra losses are calculated using following formula

$$\Delta P_{ex} = I_{ex}' \cdot R \cdot I_{ex}$$

and it is equal to 0.196 MW for one phase.

Total losses ΔP_{jf} caused by summarized branch currents $\boldsymbol{I_{jf}}$ are equal to 1.989 MW for one phase.

Losses from voltage difference caused by transformer tap position can be calculated like a difference between extra losses and losses from circulating currents

$$\Delta P_{f-} = \Delta P_{ex} - \Delta P_{ci}$$

and these are equal to 0.150 MW for one phase.

The result confirms the orthogonality of currents expressed by (14).

Obtained loss values are relatively small and the analysis of losses is not so actual in considered network with a given loads. The result may change if there will be large power flows in interconnected power systems. In any case it is worthwhile to check by calculations the corresponding quantities.

V. Conclusions

1. Closed grids inherit main properties of two-terminal line.
2. The orthogonality of load currents and extra currents means that power loss from joint action of these currents is equal to the sum of power losses by separate action of these currents.
3. Extra currents in initial grids are orthogonal to load currents in uniform grid.
4. CC, in contrast to two-terminal line, has its different value in each loop of closed grid, CC in common for two adjacent loops branch is a combination of CC in these loops.
5. Equalizing current also has its own value in each branch of the grid.
6. Extra currents consist of circulating currents and equalizing currents in non-uniform grid with foreign loop voltages.
7. The power losses in non-uniform closed grids can be decomposed on losses in uniform grids by given node loads, losses caused by grid non-uniformity by given node loads and losses caused by given foreign emf in grid loops.
8. Decomposition of power losses makes it possible to establish the cause of power losses.
9. Different transformation ratios in high voltage closed networks can increase the losses.

10. The obtained theoretical results applied to the network of Kurzeme Ring showed that extra losses are not considerable as compared with load losses in uniform grid by actual load flows.

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Josifs Survilo, Dmitrijs Antonovs, Edīte Bieļa. Ortogonalitātes nosacījumi mezglu un papildus strāvām
Slēgtais tīkls iemanto galvenās īpašības no divpusēji barotām līnijām. Slēgtajiem tīkliem pretstatā radiālajiem, bez slodzes jaudas zudumiem, var rasties papildu zudumi no nehomogēna tīkla (X / R ≠ const) un zudumi no eds slēgto tīklu kontūros, ja tādi eds eksistē (piemēram no transformācijas koeficientu nevienādības). Nepieciešams zināt papildu zudumu vērtības un vietu tīklā, kur tie rodas, lai tos novērstu. Iepriekšminēto var izdarīt, ja kopējos zudumus iedala uz zudumiem no slodžu strāvām un zudumiem no papildu strāvām. Zudumi no slodžu strāvām atrod homogēnajā tīklā. Papildu strāvas ir vektoru summa no cirkulējošām strāvām (ja tīkls ir nehomogēns) un no izlīdzinošām strāvām, ja tīklā kontūros ir nevēlamās eds. Slēgtajos tīklos zudumi no slodžu strāvām un no papildu strāvām jārēķina, izmantojot matricu algebru. Šie zudumi divpusēji barotās līnijas ir atrodami vienkāršāk. Rēķinot papildu zudumus, var noteikt tīkla zarus un slēgto tīklu kontūrus , kur tie ir nozīmīgas un rast nepieciešamus pasākumus, lai tos samazinātu. Gan slēgtajos tīklos gan divpusēji barotās līnijas kopējie zudumi ir slodžu un papildu strāvu zudumu summa. Šī īpašība šeit ir nosaukta kā mezglu un papildu strāvu ortogonalitāte. Iegūtie teorētiskie rezultāti tika piemēroti tīklam Kurzemes loks. Šajā tīklā ietilpst 38 mezgli un 50 līnijas un 13 kontūri. 330 kV līnijās ģenerēta kapacitatīvā jauda tiek iznēsāta pa līniju galiem (mezgliem). Tīkla aktīva slodze ir 217 MW bez tranzītā pārvadāmās jaudas ievērības. Tiklā ir rēķināti zudumi vienai fāzei. Zudumi no slodžu strāvām 1.793 MW, papildu zudumi 0.196 MW, no tiem zudumi no nehomogenitātes 0.046 MW un no nevienādiem transformācijas koeficientiem 0.15 MW. Tas ļauj secināt ka papildu zudumi nav lieli.

Иосиф Сурвило, Дмитрий Антоновс, Эдите Беля. Обуславливание ортогональности узловых и сверхтоков
Сложнозамкнутые сети имеют основные свойства линий с двусторонним питанием. В замкнутых сетях в противоположность радиальным кроме нагрузочных потерь мощности, возникают дополнительные потери от неоднородности сети (X / R ≠ const) и от эдс в контурах сети, если такова появляется (например от неодинаковых коэфициентов трансформации). Необходимо знать значение дополнительных потерь и место их возникновения, чтобы можно было их уменьшить. Выполнить вышесказанное возможно, если разделить общие потери на потери от нагрузочных токов и на потери от дополнительных токов. Потери от нагрузочных токов определяют в однородной сети. Дополнительные токи – это векторная сумма циркулирующих токов (если сеть неоднородная) и уравнительных токов, если в контурах сети суть нежелательные эдс. В сложнозамкнутых сетях потери от нагрузочных и дополнительных токов рассчитываюся с использованием матричной алгебры. Эти потери в линиях с двусторонним питанием рассчитываются проще. Рассчитывая дополнительные потери, возможно определить ветви и контуры сложнозамкнутой сети, где эти потери значительны и определить меры для их уменьшения. Как в сложнозамкнутых сетях так и в линиях с двусторонним питанием общие потери суть сумма потерь от нагрузочных и дополнительных токов. Это свойство в статье названо ортогональностью нагрузочных и дополнительных токов. Полученные теоретические результаты использованы при расчете потерь сети Курземского кольца. В сеть входят 38 узлов, 50 линий и 13 контуров. Емкостная мощность, генерируемая в линиях 330 кВ, разнесена по концам линий (по узлам). Активная нагрузка сети 217 МВт без учета транзитной мощности. Потери мощности рассчитывались для одной фазы. Нагрузочные потери составляют 1.793 МВт, дополнительные потери 0.196 МВт, из них от неоднородности сети 0.046 МВт и от неодинаковых коэфициентов трансформации 0.15 МВт. Это позволяет заключить, что дополнительные потери невелики.