The Effect of Non-Uniformity in Meshed Networks

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***Abstract* – In non-uniform network the ratio of reactance to resistance is not the same for all branches. As a result, in closed networks the extra losses appear. The losses can be found in a trivial way: as the difference between the losses in the studied (non-uniform) Z-network and the losses in the same network but without branch reactance (uniform R-network). If the extra losses are considerable the measures must be undertaken to eliminate these losses. To do it, one of the measures is to insert opposing voltages in independent loops of the network which can be done if circulating currents (CC) in the loops are known. These CC can be defined using special CC matrix. Extra losses in meshed networks can be found also as a sum of products of square of the CC modules in each branch by resistance of this branch. Calculating the losses using circulating currents, the detrimental places in the networks can be found. In common for two loops branch, the CC equals to the sum of CC in these branches. Concept of non-uniformity factor is introduced to foresee the possible extra losses in non-uniform meshed networks. The scaling factor is introduced to facilitate the calculations.**

***Keywords* – circulating current, meshed network, non-uniform network, power losses.**

I. Introduction

The drawback of non-uniform networks (when branches of the network have different reactance to resistance ratios) appears when the network is closed (meshed). The losses in such a networks are greater than in closed uniform ones [1], [2], [3], [4], [5], [6].The ringed network (which has only one loop) is considered in [7]. In this case, the shortcoming of non-uniformity can be apprehended along with the ways to eliminate it.

The matter is more complicated when we have to do with meshed non-uniform network, where multiple loops can be found. As in a ringed network, here the currents do not flow in optimum path; this is what creates extra losses. These losses can be found in a trivial way: subtracting the losses in the uniform *R*-network from losses in real non-uniform *Z*-network. If the losses are considerable, the way to eliminate them should be apprehended and the place where in the network to apply necessary measures should be known. This can be done by calculation of circulating currents (CC). However in meshed networks CC cannot be found in the same way as in ringed network.

It is necessary to apprehend the value of losses in specific networks and whether it is worth to pay attention to this issue. One thing is to suspect and declare that there are extra losses [1] – [6], the other is to estimate their real value to know how much we lose not undertaking necessary measures. To disperse the uncertainty and obtain specific information, it is necessary to make calculations in real networks.

II. Considered Network

The fragment of the network in Kurzeme (west Latvia) which is a part of network shown in [8] is considered here. It consists of 330 kV power line Broceni – Grobina and 110 kV network bounded on the east by line Broceni – Kuldiga – Venspils (Fig. 1). Connection with Tume and Dundaga is weak and therefore interrupted. This made it possible to simplify the circuit diagram. Energy delivery to considered network is assumed to be from Viskali. The main energy flow is directed to Klaipeda. The circuit diagram for calculations of the network is shown in Fig. 2. The task is complicated by the fact that the network contains not only one ring but more closed loops. To solve this problem, we have to use matrix algebra and corresponding computer program. The study of this network will give us answer to the questions concerning the non-uniformity of the mentioned network and on the matter in general.

Branch impedances and loads are shown in table 1.The first task is to calculate branch currents. This can be done using matrix basic equations [9]. Nodal matrix ***M*** includes

TABLE 1

Branch Impedances and Loads

Desig-nation	Impedance (Ω)	Desig-nation	Load (MW)
Z_1	0.42+2.62i	J_1	-275.6
Z_2	0.16+5.29i	J_2	-4.1
Z_3	6.38+12.88i	J_3	0
Z_4	6.38+12.88	J_4	-3.8
Z_5	2.05+2.64i	J_5	0
Z_6	2.05+2.64i	J_6	-1.2
Z_7	6.42+13i	J_7	0
Z_8	17.8+36i	J_8	-12.7
Z_9	12.1+24.44i	J_9	-14
Z_{10}	0.36+0.72i	J_{10}	-2.8
Z_{11}	0.16+0.31i	J_{11}	-22
Z_{12}	0.15+0.3i	J_{12}	-9.2
Z_{13}	1.18+1.52i	J_{13}	0
Z_{14}	1.7+2.2i	J_{14}	0
Z_{15}	10.99+22.2i	J_{15}	0
Z_{16}	10.83+21.88i	J_{16}	0
Z_{17}	0.313+10.58i	J_{17}	0

Comment: 1) for branch current calculation using the matrix algebra, the load fluxes are negative but generating power positive; 2) emf of independent loops are designated by J_{14} ... J_{17} which are zero.

n=17 branches (all of them is not possible to show) and *k*=14-1=13 nodes (Fig. 2). Of all 14 nodes one is balancing. Circuit diagram contains *r*=4 independent loops. The loop (circulating) currents are supposed to flow counterclockwise. All loops are reflected in matrix ***N***.

The matrices are based on table 1 and Fig. 2.

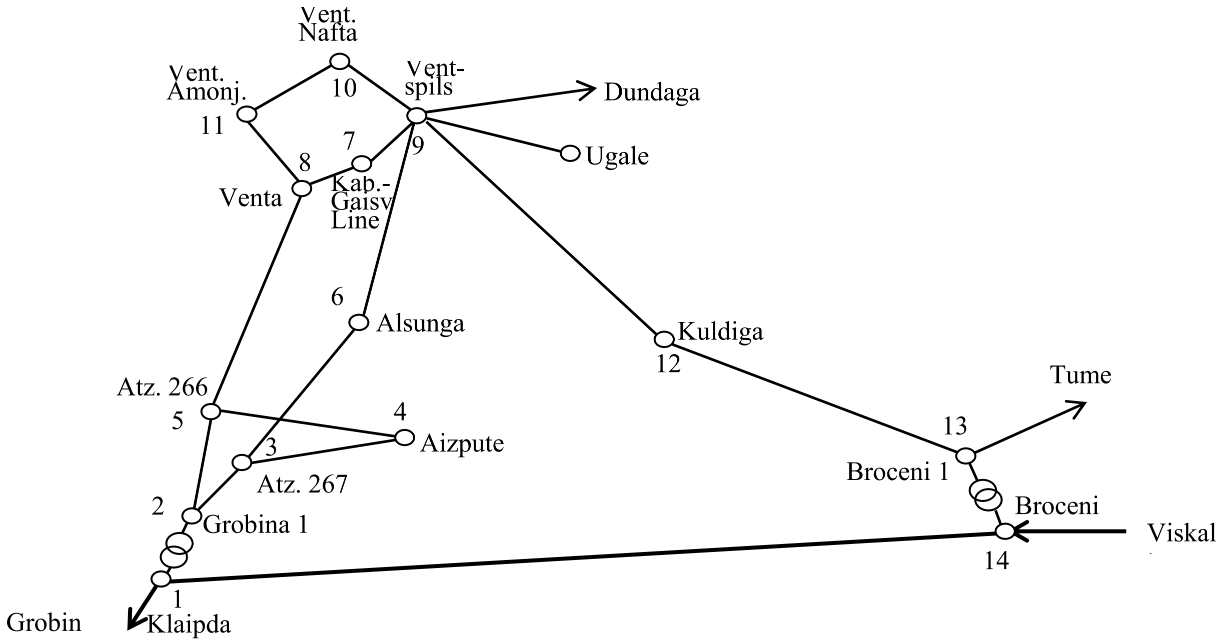

Fig. 1. Fragment of network in Kurzeme.

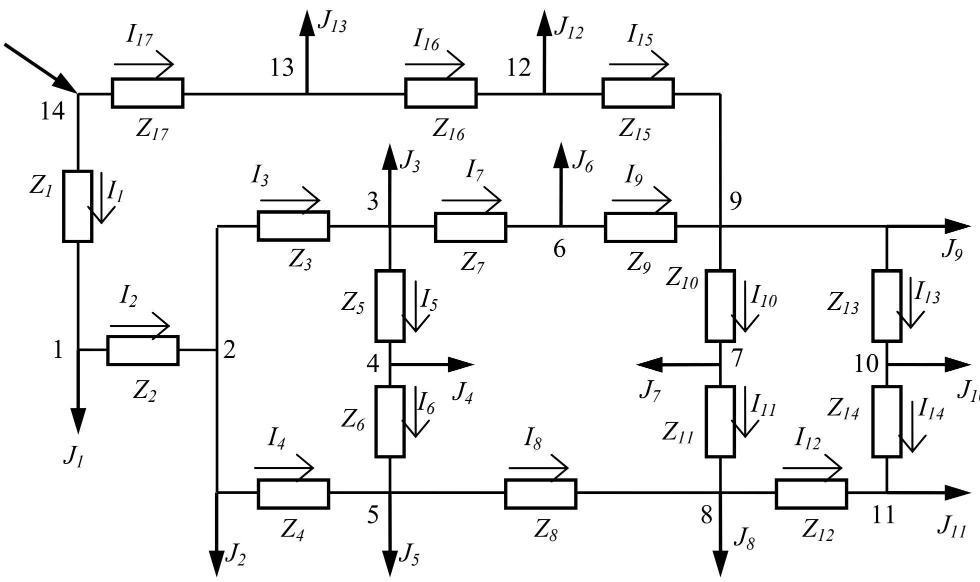

Fig. 2. Calculation diagram of the etwork.
Branches – 17 ; nodes – 14-1=13; loops – 4.

$$\boldsymbol{M} = \begin{bmatrix} -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \ldots & & & & & & & & & & & & & & & & \ldots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix}.$$

$$\boldsymbol{N} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & -1 \\ 0 & 0 & -1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & -1 & 1 & -1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & -1 & -1 & 0 & 0 & 0 \end{bmatrix}.$$

Z-matrix is:

$$\boldsymbol{Z} = \begin{bmatrix} Z_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & Z_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \ldots & & & & & & & & & & & & & & & & \ldots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & Z_{17} \end{bmatrix}.$$

On the basis of node matrix, loop matrix and *Z*-matrix, the square matrix $\boldsymbol{A_Z}$ and inverse matrix $\boldsymbol{B_Z}$ are obtained:

$$\boldsymbol{A_Z} = \begin{bmatrix} \boldsymbol{M} \\ \boldsymbol{NZ} \end{bmatrix}; \qquad (1)$$

$$\boldsymbol{B_Z} = \boldsymbol{A_Z}^{-1} \quad ; \qquad (2)$$

$$\boldsymbol{B_Z} = \begin{bmatrix} -0.9726 + 0.0062i & \ldots & 0.0005 - 0.0009i \\ \ldots & \ldots & \ldots \\ -0.0274 - 0.0062i & \ldots & -0.0005 + 0.0009i \end{bmatrix}.$$

The branch currents $\boldsymbol{I_Z}$ in *Z*-network are:

$$\boldsymbol{I_Z} = \boldsymbol{B_Z}\,\boldsymbol{J}, \qquad (3)$$

where $\boldsymbol{J} = [J_1;\ J_2;\ \ldots J_k;\ 0;\ 0;\ 0;\ 0]$, k=13.
Column matrix $\boldsymbol{J}$ and following matrices $\boldsymbol{I_Z}$; $\boldsymbol{I_R}$ are written to a string. Semicolons inside the square brackets indicate that the string represents column matrix (vector). The node of the element of *J*-matrix and the branch of the element of *I*-matrix belonging are determined by serial number of this element in a string. Besides, loads in table 1 are given in MW but $\boldsymbol{J}$ as a vector is given in Amperes which number is equal to number of megawatts in table 1 and currents are obtained in Amperes. This discrepancy is corrected by scaling factors (see further).

For considered network $\boldsymbol{I_Z}$= [311.64 – 1.87i; 36.04 – 1.87i; 15.95 – 0.93i; 15.99 – 0.94i; 1.98 – 0.01i; -1.82 – 0.01i; 13.97 – 0.92i; 14.17 – 0.95i; 12.77 – 0.92i; 16.45 + 0.00i; 16.45 + 0.00i; 17.92 – 0.95i; 6.88 + 0.95i; 4.08 + 0.95i; 24.56 + 1.87i; 33.76 + 1.87i; 33.76 + 1.87i] A.

The losses in the non-uniform *Z*-network are:

$$\Delta P_Z = \boldsymbol{I_{Zt}}\,\boldsymbol{R}\,\boldsymbol{I_Z}, \qquad (4)$$

where $\boldsymbol{I_{Zt}}$ is transposed conjugate matrix $\boldsymbol{I_Z}$. Formula implies multiplication of matrices. Losses are ΔP_Z =70794 W.
Now we shall determine losses in uniform *R*-network. For this reason we create in a similar way *R*-matrix, A_R-matrix, B_R-matrix and obtain branch currents $\boldsymbol{I_R}$ and losses ΔP_R.

B_R-matrix:

$$\boldsymbol{B_R} = \begin{bmatrix} -0.9880 & \ldots & 0.0143 \\ \ldots & \ldots & \ldots \\ -0.0120 & \ldots & -0.0143 \end{bmatrix}.$$

Branch currents and losses in (uniform) *R*-network:
$\boldsymbol{I_R}$ = [316.31; 40.71; 18.27; 18.34; 2.00; -1.8; 16.27; 16.54; 15.07; 15.50; 15.50; 19.34; 5.46; 2.66; 19.89; 29.09; 29.09] A.
Losses ΔP_R=69900 W.

Now we can define the losses from non-uniformity of meshed network (extra losses):

$$\Delta P_{ZR} = \Delta P_Z - \Delta P_R, \qquad (5)$$

They are ΔP_{ZR}=894 W.

CC in all branches of the network can be found as well:

$$\boldsymbol{I_{ci}} = \boldsymbol{I_Z} - \boldsymbol{I_R}, \qquad (6)$$

which are: $\boldsymbol{I_{ci}}$= [-4.67 – 1.87i; -4.67 – 1.87i; -2.32 – 0.93i; -2.35 – 0.94i; -0.02 – 0.01i; - 0.02 – 0.01i; -2.3 – 0.92i; -2.37 – 0.95i; -2.3 – 0.92i; 0.95 + 0.00i; 0.95 + 0.00i; -1.42 – 0.95i; 1.42 + 0.95i; 1.42 + 0.95i; 4.67 + 1.87i; 4.67 + 1.87i; 4.67 + 1.87i] A.

We see that CC are those which flow in branches pertaining only to this loop but CC which flow in branches pertaining to two adjacent loops are combined by CC in these loops and it corresponds to the first Kirchhoff's law.
CC in all branches can be found directly:

$$\boldsymbol{I_{ci}} = \boldsymbol{\Delta B}\,\boldsymbol{J}, \qquad (7)$$

where CC-matrix $\boldsymbol{\Delta B}$ is

$$\boldsymbol{\Delta B} = \boldsymbol{B_Z} - \boldsymbol{B_R}: \qquad (8)$$

$$\boldsymbol{\Delta B} = \begin{bmatrix} -0.0155 + 0.0062i & \ldots & -0.0160 - 0.0009i \\ \ldots & \ldots & \ldots \\ -0.0155 - 0.0062i & \ldots & 0.0016 + 0.0009i \end{bmatrix}.$$

Whether matrix is complex or real, is not noted in the paper, it can be seen on the relevant values in matrices.

Extra losses can be found using CC:

$$\Delta P_{ici} = \boldsymbol{I_{cit}}\,\boldsymbol{R}\,\boldsymbol{I_{ci}}, \qquad (9)$$

where $\boldsymbol{I_{cit}}$ is transposed matrix $\boldsymbol{I_{ci}}$.
ΔP_{ici}=894 W.
We can see that

$$\Delta P_{ZR} = \Delta P_{ici}. \quad (10)$$

The proof of this fact is given in [7] for ringed network.

But for what reason the CC is necessary if extra losses can be determined by (5)? The CC is helpful when we want to find out in what part of the network CC is considerable and where it is small, where it is worth to intervene and where we can belittle extra losses; and when we must interfere, than what amount of that interference should be.

It is known [1], [3], [7] that one of the methods for eliminating CC is to insert the opposing voltage into the loop in question. Exactly this opposing voltage should be determined. CC is eliminated when $\boldsymbol{I_{ci}}$ by (7) is zero. It can happen when in the $\boldsymbol{J}$ column matrix the last r positions are filled in with appropriate loop emf $E_1 \ldots E_r$, such that I_{ci} after (7) equals to zero. Then equation (7) will look out as:

$$\begin{bmatrix} \Delta B_{1,1} & \Delta B_{1,2} & \ldots & \Delta B_{1,n} \\ \Delta B_{2,1} & \Delta B_{2,2} & \ldots & \Delta B_{2,n} \\ \ldots & \ldots & \ldots & \ldots \\ \Delta B_{n,1} & \Delta B_{n,2} & \ldots & \Delta B_{n,n} \end{bmatrix} \times \begin{matrix} J_1 \\ J_2 \\ \ldots \\ E_1 \\ \ldots \\ E_r \end{matrix} = 0 \quad . \quad (11)$$

The r number of rows representing the branches pertaining only to one independent loop should be chosen from expression (11). Then the system of r equations can be written:

$$\begin{aligned} &\Delta B_{c1,k+1}E_1+\Delta B_{c1,k+2}E_2+\ldots+\Delta B_{c1,n}E_r = -I_{cic1}; \\ &\Delta B_{c2,k+1}E_1+\Delta B_{c2,k+2}E_2+\ldots+\Delta B_{c2,n}E_r = -I_{cic2}; \\ &\Delta B_{c3,k+1}E_1+\Delta B_{c3,k+2}E_2+\ldots+\Delta B_{c3,n}E_r = -I_{cic3}; \quad (12) \\ &\ldots \\ &\Delta B_{cr,k+1}E_1+\Delta B_{cr,k+2}E_2+\ldots+\Delta B_{cr,n}E_r = -I_{cicr}, \end{aligned}$$

where index c denotes that from (11) those rows are picked out which represent branches pertaining only to one loop (one branch for each loop).

In system (12) matrix $\boldsymbol{\Delta B_E}$ can be discerned:

$$\boldsymbol{\Delta B_E} = \begin{bmatrix} \Delta B_{c1,k+1} & \Delta B_{c1,k+2} & \ldots & \Delta B_{c1,n} \\ \Delta B_{c2,k+1} & \Delta B_{c2,k+2} & \ldots & \Delta B_{c2,n} \\ \ldots & \ldots & \ldots & \ldots \\ \Delta B_{cr,k+1} & \Delta B_{cr,k+2} & \ldots & \Delta B_{cr,n} \end{bmatrix}. \quad (13)$$

After that, we can find the necessary opposing voltages which eliminate CC in the network:

$$\begin{bmatrix} E_1 \\ \ldots \\ E_r \end{bmatrix} = \boldsymbol{\Delta B_E}^{-1} \begin{bmatrix} -I_{ci1} \\ \ldots\ldots \\ -I_{cir} \end{bmatrix}. \quad (14)$$

Of calculated opposing voltages, the significant values can be chosen to upgrade the non-uniform meshed network. The following real components of opposing voltages are obtained (the imaginary components are negligible):

$\boldsymbol{E}$ = [-189.58; -0.11; -0.15; -5.91] V.

Only the first loop deserves an attention.

To check the correctness of the procedure, the zeros in $\boldsymbol{J}$ must be filled with found loop opposing voltages and CC calculated by (7). The CC must equal zero. When checked on the considered network with eight significant figures after the decimal point, the value of CC was not more than (- 0.19 - 0.09i)$\cdot 10^{-5}$ A.

III. Characteristic of meshed non-uniform network

About non-uniformity of the networks much can be spoken, but in particular application the uncertainty and doubt can arise. To dispel these concerns, some characteristic should be found by which the conclusion can be made whether it is worth while to waste time on this question. Power loss in the network when all loads $J_1 \ldots J_k$ are the unity $\boldsymbol{J_{nu}}$ =[1; 1; ... ; 1] can be chosen for such a parameter.

$$\boldsymbol{I_{cinu}} = \boldsymbol{\Delta B\, J_{nu}}. \quad (15)$$

This parameter, call it non-uniformity factor, can be defined by formula:

$$K_{nu}=\Delta P_{icinu} = \boldsymbol{I_{cinut}\, R\, I_{cinu}}=\boldsymbol{(\Delta B\, J_{nu})_t\, R\, (\Delta B\, J_{nu})}. \quad (16)$$

To estimate possible losses through non-uniformity factor, the mean value of node load should be found:

$$\dot{S}_{mv} = \dot{S}_{\Sigma} / k , \quad (17)$$

where S_Σ is summary load of the network.

When this load S_{mv} is connected to nodes of the network instead of real loads, then we have load vector $\boldsymbol{J_{mv}}=\boldsymbol{S_{mv}}$:

$$\boldsymbol{J_{mv}}=\boldsymbol{S_{mv}}=\boldsymbol{(S_{mv}/J_{nu})J_{nu}}=S_{mv}\, \boldsymbol{J_{nu}}\, , \quad (18)$$

where S_{mv} (it is in MW but only the number without measure units is used) is non dimensional number. Estimated losses are:

$$\Delta P_{icies}=\boldsymbol{(\Delta B\, J_{mv})_t\, R\, (\Delta B\, J_{mv})}=\boldsymbol{(\Delta B}\, S_{mv}\, \boldsymbol{J_{nu})_t\, R\, (\Delta B}\, S_{mv}\, \boldsymbol{J_{nu})}= =K_{nu}\, |S_{mv}|^2. \quad (19)$$

Non-uniformity factor shows whether we should be afraid of non-uniformity. The higher the non-uniformity factor, the more likely considerable extra losses could arise.

For considered network non-uniformity factor K_{nu}=0.9409.

The summary load of considered network is P_Σ=345.4 MW which is connected to k nodes, k=13.

Mean value of the loads S_{mv}=26.57 MW.

Estimated value of extra losses: ΔP_{icies}= 0.9408$\cdot$26.57^2=664 W which is about 3/4 of calculated value 894 W.

IV. Consideration of network versions

Calculated extra losses are 894 W which are small and K_{nu}= 0.9409. It encourages doing more calculations. They are repeated with the same loads (table 1) but with changed impedances of branches. Proceeding further, some interesting results have been revealed. The obtained values are shown in table 2. Equality (10) is satisfied in all cases. But the results have large spread. Ratio $\Delta P_{ici}/K_{nu}$ varies within very wide limits, depending on branch impedances. This is because the loads are very uneven. Impedances that are in the largest load current path most strongly influenced the losses.

Further recalculations were made with the same branch impedance samples according to table2 but when the flow of the first node was split equally between the first node and

TABLE 2

NETWORK PARAMETERS BY CHANGED BRANCH IMPEDANCES

Sample No	Selection of changed impedances (Ω)	Extra losses ΔP_{ici} (kW)	Non-uniform factor K_{nu} (W)	ΔP_{icies} (kW)	Ratio $\Delta P_{ici}/K_{nu}$
1	No change	0.894	0.9409	0.664	950
2	Z_3=6.38+6.38i Z_7=6.42+6.42i Z_9=12.1+12.1i	1.145	22.032	15.552	51.8
3	Z_{15}=10.99+10.99i Z_{16}=10.83+10.83i	6.634	32.98	23.282	201
4	Z_{10}=0.36+0.36i Z_{11}=0.16+0.16i	0.902	0.9475	0.6689	954
5	Z_5=2.05+2.05i Z_6=2.05+2.05i	0.894	0.9479	0.6692	943
6	Z_4=6.38+6.38i Z_8=17.8+17.8i Z_{12}=0.15+0.15i	1.143	22.306	15.743	51.2
7	Z_{13}=1.18+1.18i Z_{14}=1.7+1.7i	0.905	0.9877	0.6973	916
8	Z_1=0.42+0i	0.526	0.3181	0.2246	1633
9	Z_{17}=0.313+0i	3.006	16.53	11.67	181
10	Z_2=0.16+0i	0.3004	3.2037	2.262	93.8

TABLE 3

NETWORK PARAMETERS BY CHANGED BRANCH IMPEDANCES AND LOADS

Sample No from table 2	Extra losses ΔP_{ici} (kW)	Non-uniform factor K_{nu} (W)	Ratio $\Delta P_{ici} / K_{nu}$
1	0.1361	0.9409	145
2	11.39	22.032	516
3	11.76	32.98	356
4	0.1276	0.9475	135
5	0.1352	0.9479	143
6	11.52	22.306	516
7	0.1693	0.9877	171
8	0.8216	0.3181	2 583
9	9.164	16.53	554
10	2.607	3.2037	814

initially unloaded nodes: ***J***= [-55.12; -4.1; -55.12; -3,8; -55.12; -1.2; -55.12; -12.7; -14; -2.8; -22; -9.2; -55.12; 0; 0; 0; 0]. The results displayed in table 3 are more consistent. However when loads are equal in all 13 nodes (for example 26.57 MW), the ratio $\Delta P_{ici}/K_{nu}$ remains the same (705.95) regardless of branch impedances. This fact is confirmed by the preceding considerations (15) – (19).

Now we shall consider the behavior of ratio $\Delta P_{ici}/K_{nu}$ when ***J*** is changed. The scheme parameters are not changed (table 1) and non-uniform factor remains the same K_{nu}=0.9409. The results are shown in table 4.

Ratio $\Delta P_{ici}/K_{nu}$ changes moderately by equal signs of the loads but it jumps sharply when load signs are opposite. Nevertheless non-uniform factor can be an index to whether it is necessary to proceed with further study of the particular network. Small value of non-uniform factor indicates that we should not expect great extra losses in an any case of load distribution.

V. USING THE SCALING FACTORS

Proceeding with calculations, we took the loads ***J*** in megawatts. However, to receive currents, the current in Amperes should be taken instead of loads ***J*** in megawatts. To have loads in Amperes, we should recalculate 13 values. Besides, the calculated losses would be for one phase, but we consider three-phase network, so the real losses are threefold of those obtained by calculations. Hence calculated values of losses and opposing voltages should be transformed to true figures by virtue of scaling factors in such a way:

$$A_{tr} = AK, \quad (20)$$

where A_{tr} and A stand for true and calculated values respectively and K is the scaling factor.

We shall define three scaling factors: one $K_{\Delta P}$ is for power

TABLE 4

NETWORK PARAMETERS BY CHANGED LOADS

Sample No	Selection of changed loads	Extra losses ΔP_{ici} (kW)	Ratio $\Delta P_{ici} / K_{nu}$
1	No change	0.894	950
2	J_1= -220.48; J_3= -55.12	1.7858	1898
3	J_1= -165.36; J_3= -55.12; J_5= -55.12	2.8316	3009
4	J_1= -110.24; J_3= -55.12; J_5= -55.12; J_7= -55.12	2.5241	2683
5	J_1= -55.12; J_3= -55.12; J_5= -55.12; J_7= -55.12; J_{13}= -55.2	0.1351	143
6	J_1= -220.48; J_3= 55.12	0.1149	122
7	J_1= -165.36; J_3= 55.12; J_5= 55.12	0.2368	252
8	J_1= -110.24; J_3= 55.12; J_5= 55.12; J_7= 55.12	0.5215	554
9	J_1= -55.12; J_3= 55.12; J_5= 55.12; J_7= 55.12; J_{13}= 55.2	0.0294	31

losses, the second K_U is for opposing voltages and the third is K_I which correlate values in megawatts with values in Amperes.

To obtain scaling factors, we use canonical formula for three phase network:

$$\dot{S} = \sqrt{3}\dot{U}\dot{I} \; .$$

In our case, for 1 MVA at 110 kV voltage the phase current is I_{tr}=5.248638 A, hence current scaling factor is K_I = 5.248638.
We have calculated CC by (7) from load $\boldsymbol{J}$ with Ampere numbers equal to the numbers of megawatts. The calculated losses are

$$\Delta P_{ici}=(\boldsymbol{\Delta B\, J})_t\, \boldsymbol{R}\, (\boldsymbol{\Delta B\, J}). \qquad (22)$$

When CC is calculated from $K_I\boldsymbol{J}$ Amperes which corresponds to the true load currents, the true losses in three phases are:

$$\Delta P_{icitr}=3[(\boldsymbol{\Delta B}\, K_I\boldsymbol{J})_t\, \boldsymbol{R}\, (\boldsymbol{\Delta B}\, K_I\boldsymbol{J})]. \qquad (23)$$

Hence the scaling factor of power losses is:

$$K_S = \frac{\Delta P_{icitr}}{\Delta P_{ici}} = 3K_I^{\,2}, \qquad (24)$$

which is K_S=82.6446.
Some figures of true power losses from non-uniformity are given in table 5.
Voltage scaling factor for line to line voltage is:

$$K_U = \sqrt{3}K_I \qquad (25)$$

since impedance scaling factor is not used; K_U=9.091.
True line to line opposing voltages are:
$\boldsymbol{E_{tr}}$ = [1714 – 15.45i; 3.63 + 3i; 1.45 + 4.36i; 53.72 – 0.18i] V.

TABLE 5
TRUE EXTRA LOSSES IN MESHED NETWORK

Table 2	Sample 1	73.88 kW
	Sample 3	548.26 kW
Table 3	Sample 1	11.25 kW
	Sample 3	971.9 kW
Table 4	Sample 3	234.02 kW
	Sample 8	2.43 kW

VI. CONCLUSIONS

1. In meshed non-uniform networks, CC exist in all branches. CC in branches pertaining to both adjacent loops are combined of CC in these loops.
2. Extra power loss in the network is equal to the sum of extra losses in each branch which are equal to squared CC module multiplied by resistance of the branch.
3. CC can be calculated using CC matrix $\boldsymbol{\Delta B}$.
4. Opposing voltages of the loops can be found using special matrix $\boldsymbol{\Delta B_E}$.
5. To have an idea about the losses in non-uniform meshed network, the concept of non-uniformity factor is introduced.
6. Calculating the networks, input data can be used in any convenient unit and real output data can be received using scaling factors.
7. Judging by the results, extra losses are small but with changed input data they can greatly increase.

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Josifs Survilo. Nehomogenitātes ietekme slēgtajos tīklos
Nehomogenajā tīklā proporcija starp zaru reaktīvu un aktīvu pretestību nav vienāda visā tīklā. Ja tīkls ir slēgtais, tad tā gredzenā vai sarežģītā slēgtā tīkla vairākās cilpās rodas cirkulējošā strāva (CS). No šīs strāvas rodas papildu jaudas zudumi. Uz to bieži atsaucas literatūrā. Šos zudumus var noteikt atņemot jaudas zudumus R-tīklā no jaudas zudumiem pētāmā Z-tīklā. Bet zinot CS, var noteikt kaitīgas vietas tīklā, kur rodas papildu zudumi. Gredzenveidīgā tīkla CS aprēķins ir vienkāršāks. Sarežģītajos slēgtajos tīklos ir jāizmanto matricu algebra un jāveido speciālā CS matrica. CS, kopējā diviem kontūriem zarā, ir vienāda ar šo kontūru CS summu. Papildu zudumus gredzenveidīgajā un sarežģītā slēgtajā tīklā var atrast arī izmantojot CS, proti, kā katra zara CS moduļa kvadrātu, reizinātu ar šī zara aktīvo pretestību, summu. Viens no pasākumiem, kā novērst CS kontūrā, ir ievietot šajā kontūrā pretspriegumu. Šo spriegumu var izrēķināt veidojot speciālo matricu un izmantojot izrēķinātas CS. Veiktie aprēķini konkrētajā tīklā Latvijā parādīja ka šajā tīklā papildu zudumi ir mazi. Bet ja dažu zaru reaktīvo pretestību izmainīt, zudumi stipri pieaug. Pie tam šie zudumi krasi mainās, ja slodzi pārdalīt starp tīkla mezgliem. Ir piedāvāts nehomogenitātes koeficients, kas ļauj novērtēt iespējamus papildu zudumus. Rēķinot ir jāizmanto lielu skaitu ieejas datu, kas ir mezglu slodzes megavoltampēros. Šīs vērtības var izmantot aprēķinos bez to pārvēršanās ampēros. Un lai iegūtu īstenas zudumu vērtības, ir jāaprēķina un jāizmanto mēroga koeficientus.

Иосифс Сурвило. Эффект неоднородности в замкнутых сетях

В неоднородной сети отношение реактивного к активному сопротивлению ветвей не одинаково во всей сети. Если сеть замкнутая, то появляется циркулирующий ток (ЦТ) в контуре кольцевой сети или в контурах сложнозамкнутой сети. Это вызывает дополнительные потери мощности. Об этом часто говорится в литературе. Эти потери могут быть определены путем вычитания потерь мощности в R-сети из потерь в исследуемой Z-сети. По значениям ЦТ могут быть определены ущербные места в сети, где возникают дополнителные потери,. В кольцевой неоднородной сети определение ЦТ проще. В сложнозамкнутой сети необходимо прибегать к матричной алгебре: ЦТ могут быть определены при помощи специальной матрицы. В ветви, общей для для двух соседних контуров, ЦТ может быть определен путем сложения ЦТ этих контуров. Дополнительные потери в кольцевых и сложнозамкнутых сетях могут также быть рассчитаны, использя значения ЦТ, а именно, как сумма произведений квадрата модуля ЦТ каждой веви на активное сопротивление этой ветви. Одной из мер по устранению ЦТ является введение противодействующего напряжения в ущербный контур. Это напряжение может быть рассчитано при помощи особой матрицы и с использованием полученных ЦТ. Проведенные расчеты на фрагменте сети Латвии показали, что больших доплнительных потерь в этом месте сети нет. Но, изменив реактивное сопротивление некоторых ветвей, потери сильно возрастают. Кроме того, дополнительные потери резко изменяются при перераспределении нагрузок между улами сети. Предложен коэффициент неоднородности, по которому можно судить о возможных дополнительных потерях. Многочисленные входные данные нагрузок обычно даны в мегавольтамперах. Эти данные могут быть использованы без пересчета их в фазнуе токи. Для получения истинных значений потерь и напряжений необходимо рассчитать и использовать масштабные коэффициенты.