Extra Losses in Imperfect Closed Grids

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Abstract **– Closed grids consist of two-terminal power lines or/and of rings (loops). In non-uniform two-terminal lines, equalizing and circulating currents appear, in rings – circulating current. These currents cause extra power losses. Those losses are equal to the product of summary resistance and squared said extra currents and are independent of the direction of said currents. Equalizing current causes considerable losses by phase discrepancy of terminal voltages even when voltage magnitudes are equal. Equalizing current losses do not exceed ¼ of load losses when terminal voltage difference is equal to maximum load voltage loss. The degree of non-uniformity of inhomogeneous rings can be estimated by inhomogeneous factor. The increased reliability and higher electricity quality in distribution grids can be attained by use of uniform or ameliorated ringed grids but the reservation can be implemented by controllable links between adjacent rings.**

Key words **– electricity quality, equalizing current, non-uniform grids, power losses, two-terminal line.**

1. INTRODUCTION

Meshed networks in general are not broadly enough spread. They are used mainly in high voltage networks to provide necessary reliability of electricity supply. The distribution networks [1] (primary systems [2]) as well as subtransmission systems are formed as radial lines or as closed grids. The simplest closed grid is two-terminal line. The special case of two-terminal line, when terminal voltages are equal, is named ring (loop) [3]. Imperfect two terminal line may have unequal terminal voltages or/and may be non-uniform - consist of branches with various *X/R* ratios. Imperfect closed grid (consisting of several two-terminal lines) may have unequal feeding node voltages or/and non-uniform branches. It is widely known that closed networks provide for more stable and qualitative voltage at the consumers as well as lower losses [1].

However, under certain conditions exactly electricity losses may be higher in imperfect closed grids than in the open-loop networks.

Naturally, it relates also to imperfect two-terminal lines. It is mainly for this reason that two-terminal lines are broken at sink nodes. The full picture of currents and power losses in these imperfect two-terminal lines is being cleared up in this article.

2. TWO-TERMINAL LINES BASED ON A RING

In two-terminal line (Fig.1) voltages $\dot{U}_A$ and $\dot{U}_B$ may not coincide in magnitude or direction; the difference $\Delta\dot{U}_d$ is:

$$\Delta\dot{U}_d = \dot{U}_A - \dot{U}_B \ . \tag{1}$$

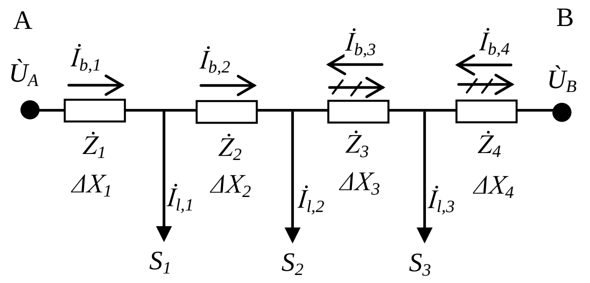

Fig. 1. Two terminal line

As a result, equalizing current $\dot{I}_{eq}$ appears:

$$\dot{I}_{eq} = \frac{\Delta\dot{U}_d}{\dot{Z}_\Sigma} \ , \tag{2}$$

where $\dot{Z}_\Sigma$ is summary impedance between line's terminals:

$$\dot{Z}_\Sigma = \sum_{m=1}^{n+1} \dot{Z}_m \ . \tag{3}$$

To determine the real currents $\dot{I}_{b,1} \ldots \dot{I}_{b,n+1}$ in the branches $b_1 \ldots b_{n+1}$, we should apply the superposition principle [4]: i.e. branch currents are the sum of the currents $\dot{I}_{rb,1} \ldots \dot{I}_{rb,n+1}$ in a ringed line as a result of load currents $\dot{I}_{l1} \ldots \dot{I}_{l,n}$ and of the equalizing current $\dot{I}_{eq}$:

$$\dot{I}_{b,1} = \dot{I}_{rb,1} + \dot{I}_{eq} \ \ldots \ \dot{I}_{b,n+1} = \dot{I}_{rb,n+1} + \dot{I}_{eq} \ . \tag{4}$$

In a ringed line both terminals of the line are connected to one feeding point, hence it has equal voltages $U_a=U_b$. It can be depicted as two-terminal line (Fig. 1) with equal voltages at its terminals.

By a given load currents, branch currents in any ringed line may be calculated by known formulas [1], [3] **be the line uniform or non-uniform**; for example, the current in the first branch:

$$\dot{I}_{rb,1} = \frac{\sum_{k=1}^{n} \dot{I}_{l,k} \sum_{i=k+1}^{n+1} \dot{Z}_i}{\dot{Z}_\Sigma} \ . \tag{5}$$

Each following branch current from $\dot{I}_{rb,2}$ to $\dot{I}_{rb,n+1}$ including can be found as:

$$\dot{I}_{rb,t+1} = \dot{I}_{rb,t} - \dot{I}_{l,t} \ , \tag{6}$$

where $\dot{I}_{l,t}$ is the t-th load current.

Initially directions of all branch currents are shown from left to right (Fig. 1). Beginning with the branch with negative current, their direction on circuit diagram ought to be changed in opposite **but branch current signs must be preserved for correct summarizing of branch current $\dot{I}_{rb}$ in the ring and equalizing current $\dot{I}_{eq}$.**

But what is the voltage at which the load currents $\dot{I}_l$ can be calculated? Whether by their calculation voltage $\dot{U}_A$ or $\dot{U}_B$ should figure? Is it geometric mean or arithmetic mean or some other value as a function of voltages $\dot{U}_A$ and $\dot{U}_B$? It appears that the right value is exactly arithmetic mean $\dot{U}_{avg}$ of voltages $\dot{U}_A$ and $\dot{U}_B$:

$$\dot{U}_{avg} = \frac{\dot{U}_A + \dot{U}_B}{2} . \qquad (7)$$

The principle of superposition [5] implies that, one affecting quantity changed, the second does not change. In our case we have two quantities constituting the currents $\dot{I}_{b1} \dots \dot{I}_{b,n+1}$ which may be measured in the line branches; these quantities are $\Delta\dot{U}_d$ and $\dot{U}_{avg}$. Only by virtue of (7) $\dot{U}_{avg}$ remains the same when $\dot{U}_A$ and $\dot{U}_B$ coincide and when they diverge on the value $\Delta\dot{U}/2$ from the initial state satisfying expression (1) which causes equalizing current $\dot{I}_{eq}$. On the other hand, $\Delta\dot{U}_d$ remains the same when $\dot{U}_A$ and $\dot{U}_B$ changes by the same value.

3. Non-uniform ring

In a ringed non-uniform lines (in Fig. 1, the ring will form if $\dot{U}_A = \dot{U}_B$), branch currents can be found by formulas (5) and (6). But they can be determined applying the principle of superposition to currents in ringed uniform lines $\dot{I}_{ub,m}$ and the circulating current $\dot{I}_{ci}$ as well.

$$\dot{I}_{rb,m} = \dot{I}_{ub,m} + \dot{I}_{ci} . \qquad (8)$$

This branch current representation will help us to estimate load losses from non-uniformity of the ring.

Circulating current $\dot{I}_{ci}$ can be determined [6] by formula:

$$\dot{I}_{ci} = j\frac{\sum_{k=1}^{n}\dot{I}_{l,k}\sum_{i=k+1}^{n+1}\Delta X_i}{\dot{b}_u R_\Sigma} = j\frac{\sum_{k=1}^{n}\dot{I}_{l,k}\sum_{i=k+1}^{n+1}\Delta X_i}{\dot{Z}_\Sigma} , \qquad (9)$$

where

$$\Delta X_i = X_i - R_i tg\alpha , \qquad (10)$$

X_m and R_m are reactance and resistance of branch m,

$$tg\alpha = \frac{X_\Sigma}{R_\Sigma} , \qquad (11)$$

where summary values are:

$$X_\Sigma = \sum_{m=1}^{n+1} X_m ; \quad R_\Sigma = \sum_{m=1}^{n+1} R_m . \qquad (12)$$

Impedance of branch m of the uniform grid is:

$$\dot{Z}_{u,m} = R_m(1+\dot{b}_u) ; \quad \dot{b}_u = 1 + jtg\alpha_\Sigma , \qquad (13)$$

where $\dot{b}_u$ is complex coefficient.

Branch currents in uniform ring $\dot{I}_{ub,m}$ can be determined by formulas (5) and (6) applying given branch impedances or calculated by (11) – (13) or only branch resistances.

Since denominator of expression (9) is summary impedance of the ring, the numerator must be emf inserted in the ring, hence the appropriate voltage $\dot{U}_{ci}$ inserted in the ring is:

$$\dot{U}_{ci} = j\sum_{k=1}^{n}\dot{I}_{l,k}\sum_{i=k+1}^{n+1}\Delta X_i , \qquad (14)$$

and our two-terminal non-uniform line with equal voltages (in other words, non-uniform ring) turns into uniform ring with inserted voltage $\dot{U}_{ci}$ (Fig. 2).

4. Non-uniform two-terminal line based on a uniform ring

In a non-uniform two-terminal line (Fig. 1), the branch currents can be determined as the sum of three constituent currents: branch load currents $\dot{I}_{ub,1} \dots \dot{I}_{ub,n+1}$, calculated by (5) for uniform ring with terminal voltage $\dot{U}_{avg}$, equalizing current $\dot{I}_{eq}$ calculated by (2), and circulating current $\dot{I}_{ci}$ calculated by (9). The last two currents can be pooled in one extra current:

$$\dot{I}_{ex} = \dot{I}_{eq} + \dot{I}_{ci} . \qquad (15)$$

This quantity should be understood as a sum of voltages substantiating these currents divided by summary impedance of the two-terminal line $\dot{Z}_\Sigma$ by (3).

Actual currents in two-terminal line branches are determined as:

$$\dot{I}_{b,1} = \dot{I}_{ub,1} + \dot{I}_{ex} \ \dots \ \dot{I}_{b,n+1} = \dot{I}_{ub,n+1} + \dot{I}_{ex} . \qquad (16)$$

This sum should be understood as confluence of two currents.

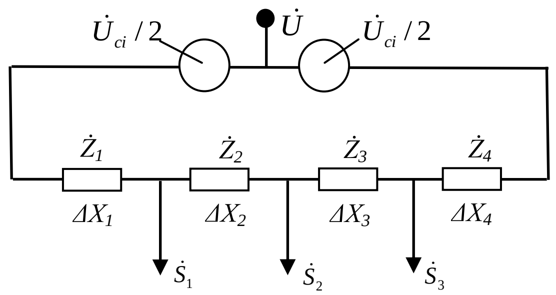

Fig. 2. Representation of non-uniform ring

5. Extra losses due to extra currents

We will consider losses in one phase.

In any case, losses in two-terminal line can be calculated as:

$$\Delta P = \sum_{i=1}^{n+1} R_i I_{b,i}{}^2 . \quad (17)$$

While losses in a uniform ring are:

$$\Delta P_{ur} = \sum_{i=1}^{n+1} R_i I_{ub,i}{}^2 . \quad (18)$$

Extra losses are:

$$\Delta\Delta P_{ex} = \Delta P - \Delta P_{ur} = \sum_{i=1}^{n+1} R_i I_{b,i}{}^2 - \sum_{i=1}^{n+1} R_i I_{ub,i}{}^2 . \quad (19)$$

But we are interested to know how great are the losses resulting from peculiarities of two-terminal line conditions: its terminal voltages and branch parameters; exactly: what is the extra losses from extra current and its components separately. As concerns the circulating current, it is proved [6] that extra power losses are:

$$\Delta\Delta P_{ci} = I_{ci}{}^2 R_\Sigma , \quad (20)$$

where R_Σ is by (12). And circulating current $\dot{I}_{ci}$ is caused by voltage $\dot{U}_{ci}$ which is inserted in the loop. It should be kept in mind that the direction of the circulating current does not play any role in loss creation.

Similarly, the two-terminal line with different voltages can be represented as a ring with voltage $\Delta\dot{U}_d$ inserted. This allows us to assert analogically with non-uniform ring that extra losses from equalizing current are:

$$\Delta\Delta P_{eq} = I_{eq}{}^2 R_\Sigma . \quad (21)$$

This result could be obtained going through the same procedure as it was for circulating current in [6] but the path of analogy enable to get formula (21) of a sudden. Said above is checked by calculations with complex numbers in Excel program.

On the base of these results, two inferences can be made.

1. The direction of equalizing current (consequently of voltage difference $\Delta\dot{U}_d$) does not influence extra losses. Terminal voltages of equal magnitude can give substantial voltage difference $\Delta\dot{U}_d$ (Fig. 3). Discrepancy in the direction of voltages $\dot{U}_A$ and $\dot{U}_B$ greatly deteriorates the situation despite the fact that their absolute values are the same:

$$\Delta U_d = \left|\dot{U}_A\right| 2\sin\frac{\Theta}{2} . \quad (22)$$

By Θ=3º, magnitude of voltage difference ΔU_d>5 % of terminal voltage, by 5º 40' it is 10 %. For example, if on the secondary side of 330/110 kV autotransformers at Grobina

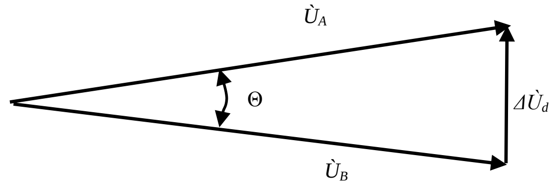

Fig.3. Special caseof voltage difference

and Broceni voltages differ only by 2 º 30', ΔU_d will be 4.855 kV and maximum extra losses – more than 704 kW. The situation can be improved solely be decreasing the angle Θ which may demand considerable cost as well.

2. If there are meshed grids with several feeding nodes (Fig.4), the calculation of equalizing currents for entire grid from magnitude inequality or/and angle discrepancy of feeding node voltages can be made by means of any known method or program. Firstly all loads should be removed from the grid, feeding node voltages, equal to differences between balancing node voltage and the feeding nodes voltages, should be applied.

Analogously, extra losses from extra current (15) should be:

$$\Delta\Delta P_{ex} = I_{ex}{}^2 R_\Sigma . \quad (23)$$

Comparing expressions (2) and (9), we see, that equalizing current depends only on line terminal voltage difference, while

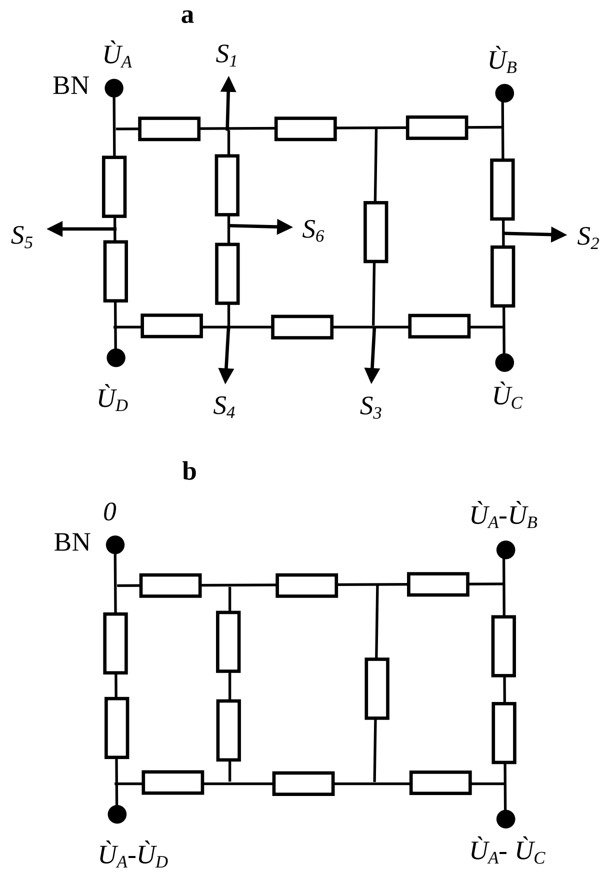

Fig. 4. Extra losses in hard-closed networks:
a – initial diagram; b – diagram for losses calculation

circulating current – on load currents and on to what extent and how two-terminal line is non-uniform. Circulating current increases when X_m/R_m steadily increases or diminishes towards one of the line terminals. The same is with the load currents. But things are not so bad, because the cost of line will not increase so strongly when it is constructed for uniform grid as compared with the line of smaller cross-section in non-uniform grid; besides, in an existing line circulating current can be diminished by certain measures [6], [7].

Let us estimate situation considering the simple case in Fig.5 of the line with active resistance and one load.
We shall compare losses from load current I_l and losses from the difference of line terminal voltages ΔU_d in the case when this voltage difference is equal to voltage loss ΔU_l from load current:

$$\Delta U_d = \Delta U_l . \qquad (24)$$

In general case when load is connected at any point in the line at a distance with active resistance R from the left line terminal, then equivalent resistance to the load is:

$$R_{ekv} = \frac{R(R_\Sigma - R)}{R_\Sigma} . \qquad (25)$$

Voltage loss to the load is:

$$\Delta U_l = I_l R_{ekv} = I_l \frac{R(R_\Sigma - R)}{R_\Sigma} . \qquad (26)$$

Power loss from load current:

$$\Delta P_l = \frac{\Delta U_l^{\,2}}{R_{ekv}} = I_l^{\,2} \frac{R(R_\Sigma - R)}{R_\Sigma} . \qquad (27)$$

Power loss from line equalizing current is:

$$\Delta\Delta P = \frac{\Delta U_l^{\,2}}{R_\Sigma} = I_l^{\,2} \frac{R^2 (R_\Sigma - R)^2}{R_\Sigma^{\,3}} . \qquad (28)$$

Correlation between power losses is:

$$\frac{\Delta\Delta P}{\Delta P_l} = \frac{R(R_\Sigma - R)}{R_\Sigma^{\,2}} . \qquad (29)$$

Maximum of this ratio is when load is connected in the middle of the line. Then this ratio is 1/4. When load is connected to any terminal (R=0), mathematically correlation is

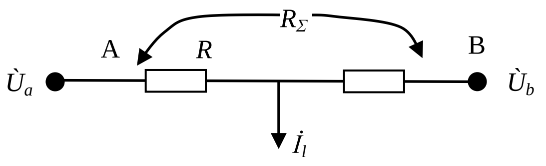

Fig. 5. Simple two terminal line case to compare losses

zero but in reality it does not make sense. When load I_l is distributed evenly along the line (Fig. 6), the current I in the line at the distance R, Ω from line terminal A is:

$$I = \frac{I_l}{R_\Sigma} R . \qquad (30)$$

Elementary power loss:

$$d\Delta P_l = I^2 dR = \left(\frac{I_l}{R_\Sigma}\right)^2 R^2 dR . \qquad (31)$$

Entire power loss ΔP in the line from load current is:

$$\Delta P_l = 2 \int_0^{R_\Sigma/2} \frac{I_l^{\,2}}{R_\Sigma^{\,2}} R^2 dR = \frac{I_l^{\,2} R_\Sigma}{12} . \qquad (32)$$

Maximum voltage drop is:

$$\Delta U_l = \frac{1}{2}\left(\frac{I_l R_\Sigma}{4}\right) = \frac{I_l R_\Sigma}{8} . \qquad (33)$$

Power loss from line equalizing current is:

$$\Delta\Delta P = \frac{\Delta U_l^{\,2}}{R_\Sigma} = \frac{I_l^{\,2} R_\Sigma}{64} . \qquad (34)$$

Correlation between power losses is:

$$\frac{\Delta\Delta P}{\Delta P_l} = \frac{3}{16} . \qquad (35)$$

Relying on considered above, we can say that maximum losses from equalizing current are 1/4 of the load losses with provision that voltage difference is equal to maximum load voltage loss. This provision is made in order to weigh the consequences of equalizing current. In reality terminal voltage difference can strongly differ from load voltage loss. In practice we have to do with the impedance of the line. But this doesn't change significantly the situation with correlation of losses if non-uniformity of two-terminal line is not too high.

It is necessary to repeat that formulas (20); (21); (23) are valid independently on direction of circulating or equalizing currents (when only one of them flows) or extra current (the summary of circulating and equalizing currents) hence on the

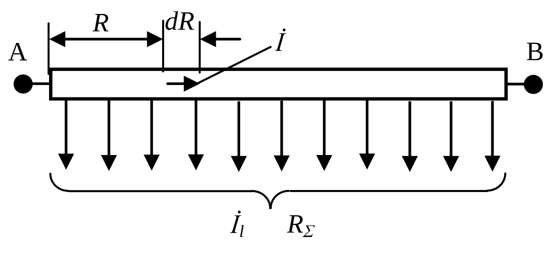

Fig. 6. Two terminal line with evenly distributed load

direction of corresponding voltages (or the sum of voltages).

Voltages U_A and U_B can differ by magnitude as well as by phase. To keep them in necessary limits, may be cost effective only for higher voltages. That is the reason why in medium and lower voltages the grid is split in the confluence nodes.

6. Characteristic of non-uniform lines

To link circulating current losses with load current we can't proceed similarly to the case of equalizing current. The reason is that by the same load current circulating current can differ strongly or it may lack at all. It depends on to what degree the grid is inhomogeneous (non-uniform).

To define this notion, let us see expression (9). Circulating current is the greater the greater is $j\sum_{k=1}^{n}\dot{I}_{l,k}\sum_{i=k+1}^{n+1}\Delta X_i / \dot{Z}_\Sigma$.

Circulating current depends on load currents as well as on the parameters of two-terminal line (of its branches). But we need to characterize the line apart from load currents in order to wait what will be the circulating current in a loaded line. And the line can be loaded in infinite number of ways but it is necessary only one parameter – the inhomogeneous factor – of this concrete two-terminal line. Hence we are compelled to exclude current from above expression. And this can be done if all load currents $\dot{I}_{lk}$ (for example, in Fig. 1) are assumed equal:

$$\dot{I}_{l1} = \dot{I}_{l2} = \ldots = \dot{I}_{l,n} = \frac{\dot{I}_{l\Sigma}}{n} . \qquad (36)$$

Now the value of circulating current can be found as:

$$\dot{I}_{ci} = j\frac{\dot{I}_{l\Sigma}\sum_{k=1}^{n}\sum_{i=k+1}^{n+1}\Delta X_i}{n\dot{Z}_\Sigma} = \frac{\dot{I}_{l\Sigma}\sum_{i=2}^{n+1}(i-1)\Delta X_i}{n\dot{Z}_\Sigma} . \qquad (37)$$

And inhomogeneous factor can be defined as:

$$\dot{k}_{inh} = j\frac{\sum_{i=2}^{n+1}(i-1)\Delta X_i}{n\dot{Z}_\Sigma} . \qquad (38)$$

Given inhomogeneous factor and the sum of all load currents connected to two-terminal line, we can estimate the circulating current:

$$\dot{I}_{ciest} = \dot{k}_{inh}\dot{I}_\Sigma . \qquad (39)$$

If the goal is the maximum value of the estimation, then the absolute values can be inserted in the formula.

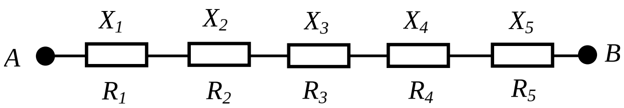

Fig. 7. Simmetrical two-terminal line:
$X_1=X_5$; $X_2=X_4$; $R_1=R_5$; $R_2=R_4$

There can be such two-terminal lines that adjacent branch impedances are different in the sense of *X/R* but as a whole the line is symmetrical relative to its middle as is shown in Fig. 7. In such symmetrical lines inhomogeneous factor k_{inh}=0, regardless of the value of medium impedance (R_3+jX_3) or its absence.

We see that extra losses do not appear when there are no closed grids. But then higher reliability and higher electricity quality, which is property of closed grids, are lost. To preserve these properties without extra losses would be possible using simple ringed grids. These may be done uniform or nearly uniform. Each loop should have at least one broken link to adjacent loop. That link is operated when feeding source of considered loop fails (Fig. 8).

Example.

The equivalent circuit of a ring network in the city of Riga is shown in Fig. 9. Two 330/115 kV autotransformers with capacity 200 MVA each are connected in parallel at substation (s-st) "Bishuciems"; the third 125 MVA is at s-st "Imanta". 330 kV power line with phase conductor 2xAC 300/39 joins s-st "Bishuciems" with s-st "Imanta". Parallel to this line, the 110 kV lines are laid. Loads are connected to their nodes at s-st B-c, B, M, Z, I as it is shown in Fig. 9. The network parameters are calculated at voltage 110 kV. Calculations are made with the same transformation ratio for all autotransformers for three options: I option – 110 kV lines are double circuit with phase conductors AC-240/39; II - 110 kV lines are single circuit with phase conductor AC-600/72; III – 110 kV lines are those of the I option but autotransformer at "Imanta" has capacity 63 MVA.

Power losses from non-uniformity of the ring are 33; 8.9 and 156.5 kW for the I, II and III option respectively. Maximum power losses are in the third option. This is understandable because at the lower rated power of autotransformer at s-st "Imanta" its reactance is greater and more power flows to the most powerful load of the ring through greater resistances of 35 kV lines. To improve the situation, it is advisable to include the complementary reactance in the circuit of the autotransformer secondary winding at s-st "Bishuciems".

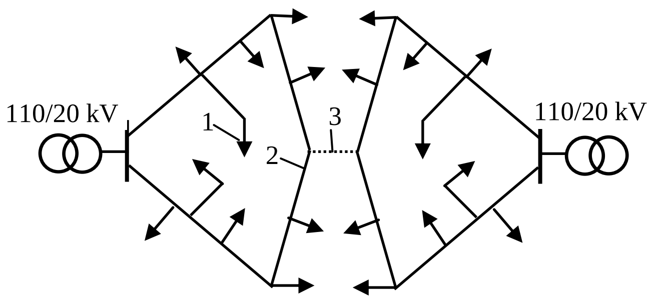

Fig. 8. Formation of medium voltage grid
1 – 20 kV ring; 2 – load (20/0,4 kV transformer); 3 – emergency link with commutation apparata

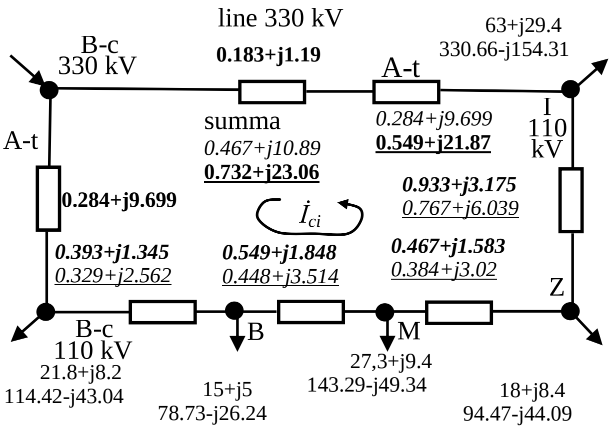

Fig. 9. Equivalent diagram of the ring network „Bishuciems" – „Imanta"

Substations: B-c –"Bishuciems"; B – "Bierini"; M – "Marupe"; Z – "Zolitude"; I – "Imanta"; impedances, Ω: a+jb – for option II, **a+jb** – III, *a+jb* – I, II, ***a+jb*** – I, III, **a+jb** – I, II, III; loads, MVA c+jd; load currents, A e-jf.

7. Conclusions

1. In two-terminal uniform power line, equalizing current causes extra power losses which are equal to the summary active resistance of the line multiplied by the said squared current.
2. In non-uniform ring, circulating current causes extra power losses which are equal to the summary active resistance of the ring multiplied by the said squared current.
3. In two-terminal non-uniform line, both equalizing and circulating current cause extra losses which are equal to the summary active resistance of the line multiplied by the squared summary of the said currents.
4. Extra losses do not depend on the phase of extra currents or the phase of their sum.
5. Angle mismatch of the terminal voltages can cause considerable extra losses.
6. Branch currents of two-terminal lines can be determined as the sum of branch currents calculated by specific terms and the said extra currents.
7. Non-uniform ring can be characterized by inhomogeneous factor which shows how great circulating current could be.
8. Ceteris paribus, equalizing current depends on difference of terminal voltages of two-terminal lines while circulating current depends on load currents.
9. When terminal voltage difference is equal to maximum voltage loss from load current in two-terminal line with equal terminal voltages, then equalizing current losses, caused by said voltage difference, do not excede 1/4 of load losses.
10. The principle of considering extra currents and losses in imperfect closed grids are the same as in two terminal lines.

8. References

[1] A. Vanags, *Elektriskie tīkli un sistēmas*, I daļa. Rīga, RTU izdevniecība, 2005, Iev. un 6.nodaļa.

[2] Turan Gönnen, *Electric Power Distribution System Engineering*. London, New York, CRC Press Taylor & Francis Group, 2008, chapter 4; 5.

[3] В. Блок, *Электрические сети и системы*, Москва, "Высшая школа", 1986, глава 4.

[4] В. Идельчик, *Электрические системы и сети*, Москва, Энергоатомиздат, 1989, глава третья.

[5] K.Tabaks, *Elektrotehnikas teorētiskie pamati. Stacionāri procesi lineārās ķēdēs*, Rīga, "Zvaigzne", 1985, 2. nodaļa.

[6] J. Survilo, "A ringed non-uniform network: how to raise its efficiency", Latvian journal of physics and technical sciences. No 6. Riga, 2008, p.20 – 32.

[7] J. Survilo, "Enhancement and comparison of simple types of closed networks", Latvian journal of physics and technical sciences. No 9. Riga, 2009, p.36 – 50.

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J. Survilo. The use of intermediate voltage in a countryside. RTU 51 st scientific conference; 2010. · J. Survilo, A. Kutjuns. Operation modes of HV/LV Substations. Rīga, RTU, Scientific Journal of Riga Technical University, series 4, 25. vol 25, pp. 81 – 86, 2009. · J. Survilo. A ringed non-uniform network: how to raise its efficiency. Latvian Journal of Physics and Technical Sciences, No6, pp. 20 – 32, 2008.
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