O. V. Fedorov, Dr. Sc. (Eng.), Prof.; T. A. Musaev, Cand. Sc. (Eng.)

TECHNIQUE OF NORMATIVE POWER LOSSES DETERMINATION IN THE MESHED INTERCONNECTED SYSTEMS

Problems of optimization of urban district energy supply system of 6(10)kV operation mode by means of determining the optimal division point of the grid with double way supply on condition of provision of quality and reliable energy supply of the consumers.

Key words: *energy supply system of the urban district of 6(10) kV, division point of the grid, operation mode of the grid, topology of the circuit.*

Introduction

Enterprises, servicing the energy supply systems, face the problem of efficient and quality electric energy supply, that can be achieved by means of decreasing the level of power losses and simultaneous provision of the necessary reliability level. In general, equal losses [1, 2] of electric energy ΔW in the element of the electric grid with the stable resistance R and voltage U during the interval T can be calculated by the formula:

$$\Delta W = 3R\int_0^T I^2(t)dt = \frac{R}{U}\int_0^T S^2(t)dt\,. \tag{1}$$

According to [2, 3], measures, aimed at power losses decrease are practical actions, leading to real decrease of energy losses:

1. Selection and optimization of electric grids operation modes, depending on the configaration.
2. Selection of substation circuits and development of requirements regarding the reliability of consumers energy supply.
3. Improvement of the systems of electric power fiscal accounting.
4. Decrease of the level of electric energy theft.

In the conditions of modern urban 6 (10) кV distribution grid it is expedient to apply measures, aimed at improvement of operation modes.

Due to certain characteristic features distribution grids operate in an open mode, i. e., there is a grid division point (GDP). Improvement of operation mode is connected with the control of system operation, that contains, among others, selection and support of GDP. Applying modern approaches for the selection of GDP first the problem of energy supply reliability is solved, and the problem of the provision of optimal operation mode of the grid is considered partially [3]. Thus, in order to improve the operation mode of urban distribution grid it is expedient to take into account the factors to economic energy supply during the process of the selection of GDP location.

Modern techniques of power losses calculation are stipulated by the complexity of their application to the operating distribution grid. This circumstance is stipulated by several factors:

Great number of nodes and branches in the available circuit.

1. Complexity of branches interconnection in the given circuit.
2. Dynamic location of flow distribution point.
3. Complexity of determining the flow distribution point.
4. Awkwardness and complexity of the formation of equations, describing the operation mode of the grid.

The aim of the research is reduced to the development of the technique, aimed at reduction of power losses in the conditions of the existing electric energy supply system by means of changing the approaches to the control of grid operating modes.

Improvement of the existing techniques of power losses calculation

In order to eliminate the above-mentioned problems and proceeding from the analysis of operation mode characteristics, composition of the equipment and configuration of the local distribution grid of 6(10) кV the following algorithm was developed:

1. Allocation of limited section from the complete scheme of urban electric energy supply system (SES).
2. Determination of flow distribution point for the allocated section.
3. Division of the allocated section into 2 parts, that correspond to initial location of GDP.
4. Calculation of node voltage levels.
5. Calculation of power flow distribution and calculation of power losses level, taking into account nodes voltage level, that corresponds to the location of the disconnection point.
6. Successive shifting of disconnection point in the nodes of the system.
7. Comparative analysis of the obtained results and recommendations, regarding the shifting of GDP. Limited section is allocated from the SES of one of the districts of electric grids,

where the increased levels of nodal voltage deviation and power losses are observed, Fig. 1.

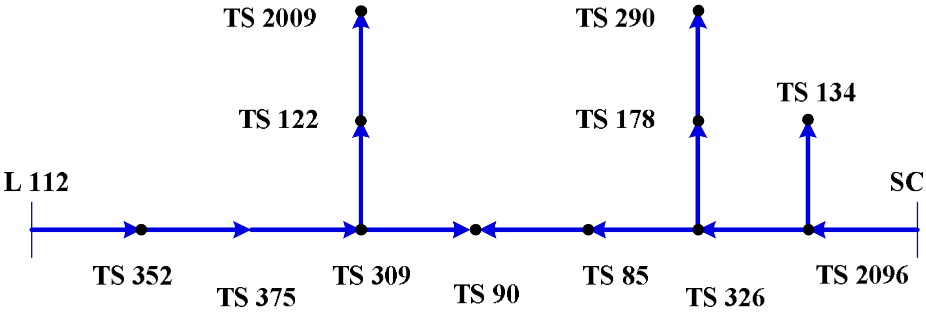

Fig. 1. Allocated section

According to the next step of the algorithm, the point of flow distribution is calculated, the known technique [1] presumes the assumption regarding the equality of voltages in the nodes of the grid, then:

$$\sum_{i,j=1}^{n} S_{ij} R_{ij} = 0 \tag{2}$$

or

$$S_{12} R_{12} + S_{23} R_{23} + \ldots + S_{ij} R_{ij} = 0\,. \tag{3}$$

The equation (3) will be written in such form:

$$S_{ij} R_{ij} + (S_{ij} - S_i) R_{i+1,j+1} + (S_{ij} - S_j - S_{j+1}) R_{i+2,j+2} + \ldots = 0\,, \tag{4}$$

where S_{ij} – is the over- flow of the initial section power, MVA, R_{ij} – is the resistance of the initial section, Ohm, S_j – the power of the node j, MVA.

The equation (4) will be rewritten in the form:

$$S_{ij} R_{ij} + S_{ij} R_{i+1,j+1} + S_{ij} R_{i+2,j+2} + \ldots = S_j R_{i+1,j+1} + S_j R_{i+2,j+2} + S_{j+1} R_{i+2,j+2} + \ldots \tag{5}$$

or

$$S_{ij} (R_{ij} + R_{i+1,j+1} + R_{i+2,j+2} + \ldots) = S_j (R_{i+1,j+1} + R_{i+2,j+2} + \ldots) + S_{j+1} R_{i+2,j+2} + \ldots. \tag{6}$$

It follows

$$S_{ij} = \frac{S_j\,(R_{i+1,j+1} + R_{i+2,j=2} + \ldots) + S_{j+1}R_{i+2,j+2}}{R_{ij} + R_{i+1,j+1} + R_{i+2,j+2} + \ldots}. \tag{7}$$

Reducing the last formula to the simplified form and using the full value of branches resistance *Z,* we obtain:

$$S_{ij} = \frac{\sum\limits_{j=1}^{n} S_j \sum\limits_{i,j=2}^{k} Z_{ij}}{\sum\limits_{i=1,j=i+1}^{k} Z_{ij}}, \tag{8}$$

where n – is the number of nodes in the circuit, k – is the number of branches in the circuit.

In order to improve the known technique of flow distribution point determination, the process will be presented in the form of the sequence of stages:

1.1. The equation for determination of the power flow of the initial section $S_{ПД}$ will be written in the form:

$$S_{ПД} = \frac{\sum\limits_{i=1,j=i+1}^{k} S_i Z_i}{\sum\limits_{i=1,j=i+1}^{k} Z_{ij}}. \tag{9}$$

1.2. Due to complex configuration of the grid it is necessary to simplify the considered circuit and reduce in to the standard one with one way supply. The transformation of the circuit is shown in Fig. 2:

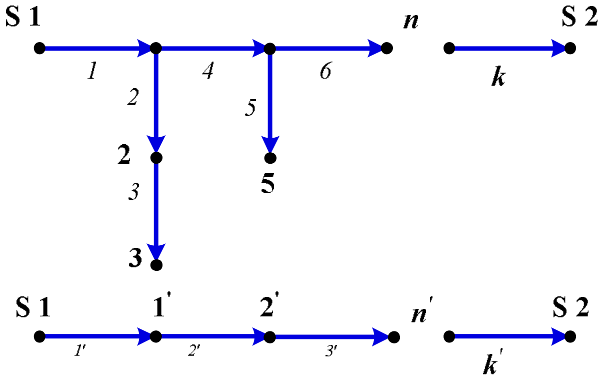

Fig. 2. Transformation of the output circuit into the standard circuit with one way supply (where n – is the number of nodes of the allocated section, k – is the number of branches of the section, n' – is the number of nodes after the transformation of the circuit, k' – is the number of branches after the transformation)

Simplification of the circuit is the transformation of the deadened branches by means of the summation of the corresponding nodal powers:

$$S_{1'} = S_1 + S_2 + S_3, \tag{11}$$

$$S_{2'} = S_4 + S_5. \tag{12}$$

The number of nodes and branches changes, that is why, it is necessary to perform new numeration n'.

1.3. Calculation of power flows S_{ij} of other sections, proceeding from the known value of power flow of initial section S_{is} and nodal powers S:

$$S_{ij} = S_{i-1,j-1} - S_i, \quad i = 1...k, j = i+1. \tag{13}$$

1.4. Overflow less than zero, i. e. $S_{ij} \le 0$, means that the node i is the point of power flow distribution, section (Fig. 3) is divided into two parts that correspond to GDP, this method enables to simplify the calculation part.

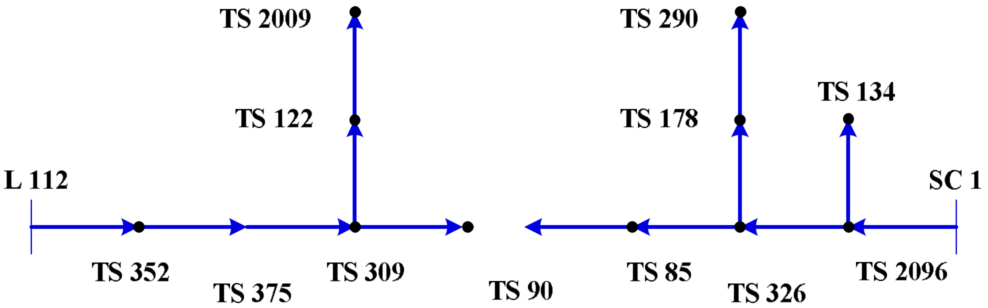

Fig. 3. Division of the allocated section

Method of nodal voltages is chosen as the basic method of calculation [4]. Power flow distribution is determined by the values of nodal powers. However, the absence of the coefficients, connecting the levels of nodal powers and values of power overflows by the branches of the system, leads to additional difficulties during the calculation of power losses level. Thus, the introduction of such coefficient will simplify the calculations. We recommend to introduce the additional coefficient – «coupling matrix of nodal powers and power overflows in the system» – **T**. Rows of this matrix correspond to branches, columns – to nodes of the considered section. Filling of **T** matrix is carried out, applying such rules: if the power flow, that corresponds to the branch, feeds the considered node of the system, then the element of the matrix equals one, if the node does not obtain the supply from the corresponding branch, then zero is added to the matrix:

$$\mathbf{S}_b = \mathbf{TS}, \tag{14}$$

where $\mathbf{S}_b$ – are power overflows in the branches of the system, **T** – is the coupling matrix of the nodal powers and power overflows, **S** – is the value of nodal powers.

Further the calculation of power losses level in the allocated sections of the grid according to the accepted technique is performed, in the process of power losses calculation the levels of nodal voltage of the grid are taken into account:

$$\Delta P_g = \sum_{i,j=1}^{n} \frac{S_{ij}^2}{U_i^2} R_{ij}. \tag{15}$$

Total power losses are obtained, adding losses by the sections of the grid:

$$\Delta \mathrm{P} = \Delta P_1 + \Delta P_2, \tag{16}$$

where ΔP_1 – is the value of power losses in the first section, ΔP_2 – is the value of power losses in the second section.

Further, according to the suggested algorithm, the shifting of the distribution point in the adjacent nodes is performed and calculation of mode parameters and power losses level on the considered sections according to the set point is carried out.

The results obtained

As a result of the calculations, carried out we obtain the value of power losses level in case of GPM change [6], the values are presented in the Table.

Table

Values of power losses level in the process of GPM shifting

Point of grid division	Node №6 – initial division	Node №5 – point A	Node №6 – point B	Node №7 – point C
Power losses ΔP, kW	23.71	30.86	19.12	17.32

By the results of the calculations carried out, the least power losses in the considered grid are provided when GDP is shifted in the node №7 (flow distribution point). Thus, in order to decrease the power losses level it is expedient to shift the point of grid disconnection in flow distribution point.

The graph of the dependence of nodal voltage level change on GDP location is shown in Fig. 4.

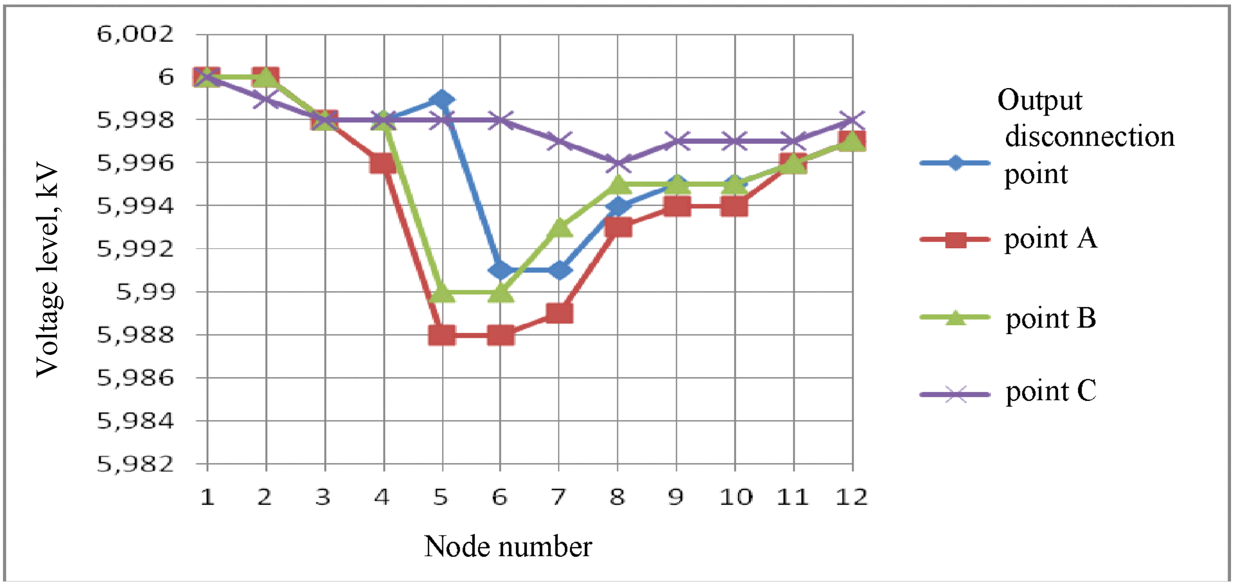

Fig. 4. Graph of dependence of nodal voltage level on GDP location

Conclusions

The analysis of the available methods of power losses level calculation in 6(10) kV electric energy supply grid and the analysis of modern approaches to the problem of the reduction of power losses level in urban distribution grid of 6(10) kV is carried out. The coefficients, enabling to improve the known methods and simplify their application in the operating grid, are suggested. Algorithm and technique of determination of power losses level of urban distribution grid of 6(10) kV is developed. The developed algorithm and the technique were used in the existing electric energy supply system.

REFERENCES

1. Gerasimenko A. A. Transmission and distribution of electric energy : manual / A. A. Gerasimenko, V. T. Fedin. – M. : КНОРУС Publishing House, 2012. – 648 p. (Rus).

2. Zhelezko Yu. S. Electric energy losses. Reactive power. Quality of electric energy : Guide for practical calculations / Yu. S. Zhelezko. – M. : ЭНАС Publishing House, 2009. – 456 p. (Rus).

3. Lezhniuk P. D. Mathematical modeling of quality index of electric grid functioning / P. D. Lezhniuk, V. A. Komar // Electric engineering and electric power engineering, Works of R. E. Alekseev NSTU. – 2012. – №3 (92). – pp. 212 – 208. (Rus).

4. Konstantinov V. N. Modeling of electric energy systems operation modes / V. N. Konstantinov. – Kazan, 2010. – 85 p. (Rus).

5. Lykin A. V. Electric systems and networks / A. V. Lykin. – Novosibirsk : Publishing House of NSTU, 2002 – 248 p. (Rus).

6. Valeev I. M. Technique of calculation of electric energy supply system operation mode of urban district: monograph / I. M. Valeev, T. A. Musaev. – Kazan : Publishing House of KNITU, 2016 – 132 p. (Rus).

Editorial office received the paper 06.03.2018.
The paper was reviewed 14.03.2018.

Fedorov Oleg – Dr. Sc. (Eng), Professor with the Department of Innovation Activity Management.

Federal state-sponsored educational establishment of higher professional education «Nizhniy Novgorod R. E. Alekseev State Technical University».

Musaev Tumyr – Cand. Sc. (Eng)., Deputy Head of Production-Engineering Department of the branch of Joint-Stock Company "Distribution company «Kazan electric grids»", musaevkgeu@rambler.ru.

Branch of Joint-Stock Company"Distribution company «Kazan electric grids»".