

Simplified topological algorithm for forming a steady mode of electric power system

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Abstract. The paper presents the possibility of simplifying the algorithms for forming the parameters of the steady state mode of a complex electrical network, using the independence of the currents of its equivalent circuit. In this case, all independent currents of a complex circuit of an electrical network must be found in advance, which is, in the general case, a rather difficult task, since it requires additional calculations of the steady state. The matrix of current distribution coefficients, formalized on the basis of the topology of the electrical network, can be used to directly determine the currents in the branches of its equivalent circuit. This allows you to preliminarily estimate the values of pre-selected independent currents in the circuit branches of a complex electrical network and determine its simplified design scheme. In this case, a calculation model is established, consisting of some trees of a complex electrical network graph.

Key words: directed graph, tree, chord, current distribution coefficients, nodal voltages.

1 Introduction

The conducted studies [1,2] proved that the difficulties of obtaining real solutions in the calculation of steady-state conditions can be significantly overcome if we proceed from the inverted form of the nodal equations. The difficulties of forming the inverted form of nodal equations, to a certain extent, were overcome using various methods of matrix factorization and iterative methods [3].

Calculations of electrical networks are greatly simplified if the distribution coefficients of driving currents are known [4]. The matrix of distribution coefficients can be formalized both by circuit conversion methods and by analytical methods, which are associated with known difficulties as the electrical network circuit becomes more complex.

Topological methods for forming a matrix of distribution coefficients were developed in [5], with known difficulties in finding and determining specific 2-trees of a graph of a complex electrical network. These difficulties were overcome in [6], where an analytical approach to determining the topological content of the driving current distribution coefficients was proposed. This led to a significant simplification of the technology of searching for specific trees without defining the 2-trees of a complex network graph. The proposed method significantly reduces the amount of work performed and provides fast and reliable convergence of the steady state [7, 8].

The paper proposes simplified topological models for estimating the parameters of the steady state, using

the conditions of independent currents in the branches of the electric network circuit.

2 Formalization of the problem

The conditions for mutual independence of currents in the branches of the circuit can be determined on the basis of the matrix equation of the first Kirchhoff law [9]:

$$M \cdot \dot{i} = j \quad (1)$$

where M is a rectangular first incidence matrix; \dot{i} – column matrix of complex branch currents; j – column matrix of complex driving currents.

If we divide equation (1) into block matrices with respect to tree currents and chords, then the resulting block equation can be written as:

$$M_d \cdot \dot{i}_d + M_x \cdot \dot{i}_x = j. \quad (2)$$

where \dot{i}_d – is the column matrix of circuit tree currents; \dot{i}_x – column matrix of circuit chord currents; j – initial matrix of setting currents.

If we take into account that the matrix M_d – is square and non-singular, then the matrix of currents \dot{i}_d of the circuit tree can be determined by the formula:

$$\dot{i}_d = M_d^{-1}(j - M_x \cdot \dot{i}_x). \quad (3)$$

This expression confirms that the predetermined currents in each chord of the circuit can be expressed as terms of the driving currents applied at its vertices.

Equations (3) determine the equivalent driving current in the form:

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$$j_3 = j - M_x \cdot i_x. \quad (4)$$

In this case, at the end vertex, the chord currents are taken into account with the same signs as the currents in the branches, and at the initial vertex, with opposite signs. This leads to a significant simplification of the computational model by removing all chords from the equivalent circuit, leaving only the circuit tree.

Thus, after selecting and determining the currents in the chords of a complex circuit of an electrical circuit based on the known matrix of current distribution coefficients, it is possible to significantly simplify the design circuit of a complex electrical circuit.

3 Formation of simplified steady state models

According to the known matrix of distribution coefficients, the currents in the branches of the circuit are determined [9]:

$$i = C \cdot j. \quad (5)$$

It is known that all currents of circuit chords are independent and can be removed from the circuit after specification of the nodal driving currents according to formula (4).

After that, the nodal stresses are determined, according to a simplified scheme, in the form [10,11]:

$$\dot{U} = U_0 + C_d^T Z_B C_d \overline{U_D^{-1}} \bar{S} \quad (6)$$

where $C_d = M^{-1}$ - current distribution coefficient matrix of the circuit tree, Z_B - resistance matrix of the circuit tree branch, \bar{S} - column vector of coupled powers of nodal loads and generators, T - matrix transposition sign, U_D - diagonal matrix of nodal coupled voltages

All transverse nodal conductivities, considering the no-load power of power transformers and the conductance of the power line, are represented by complex powers in the form:

$$\hat{S}_i = g_i + j \cdot (b_L - b_C)_i |U_i|^2 \quad (6)$$

where g_i - is the active conductivity of the transformer and the line of the i -th node; b_L - inductive conductivity of the transformer of the i -th node; b_C - capacitive conductivity of the line of the i -th node.

4 Implementation of the algorithm

Preliminary calculations of the steady state of the system under study are performed on the basis of its complete model with the determination of the distribution coefficients of nodal currents. After choosing independent currents, the calculation model of the electrical network is determined, according to which the steady state mode of the complex electrical network of the power system is formed. As an example, a 110 kV network diagram is shown in Figure 1 with the parameters presented in tables 1 and 2.

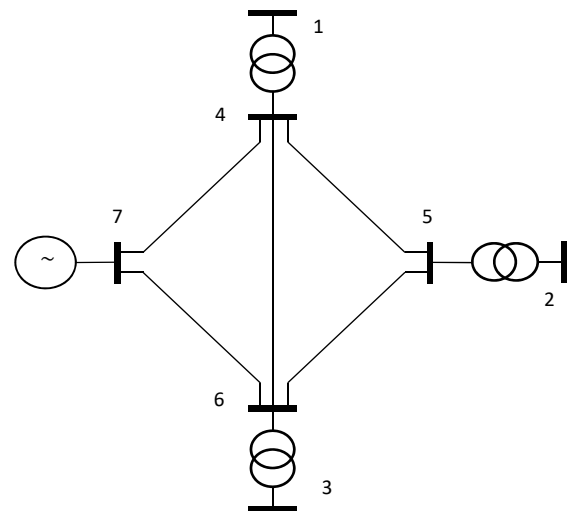


Fig.1. Network diagram 110 kV.

Table 1. Initial data by nodes.

Nodes №	U nom	Load power		Conductivity nodes	
	kV	P, MW	Q, MVar	g, mksm	b, mksm
1	10	60	40	-	-
2	10	40	35	-	-
3	10	25	15	-	-
4	110	-	-	27	162
5	110	-	-	21	-10
6	110	-	-	14	273
7	110	-	-	0.00	510

Table 2. Initial data by lines

Lines №	start	end	R, Om	X, Om	TC (transformation coefficients)
1	4	1	0,514	9,54	0,0956
2	5	2	0,81	13,4	0,0956
3	6	3	1,22	20,15	0,0956
4	7	4	6,6	19,9	-
5	4	5	16,2	25,2	-
6	7	6	6,8	16,24	-
7	6	5	24,3	37,8	-
8	6	4	13,5	21	-

The matrix of distribution coefficients is formed according to a specially developed program [13] based on the directed graph of the original network, shown in Fig.2.

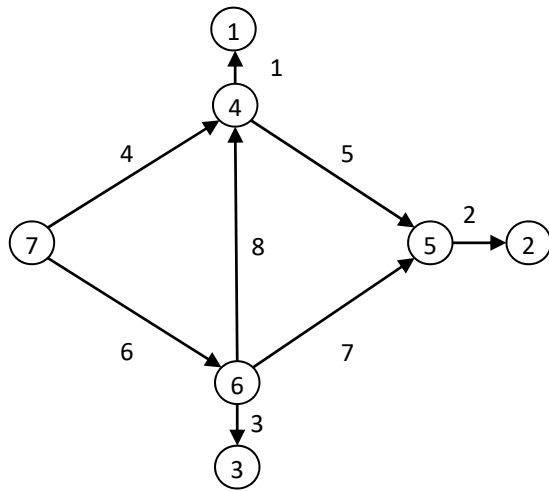


Fig.2. Directed graph of the scheme

The values of distribution coefficients are given in Table 3.

Table 3. Current distribution coefficient matrix

-1	0	0	0	0	0
0	-1	0	0	0	0
0	0	-1	0	0	0
-	-	-	-	-	-
0.634+	0.504+	-0.309-	0.634+	0.504+	-0.309-
0.039i	0.02i	0.009i	0.039i	0.02i	0.01i
-	-	-	-	-	-
0.091+	0.576+	-0.077-	0.091+	0.576+	-0.077-
0.01i	0.005i	0.002i	0.01i	0.005i	0.002i
-0.091-	-0.424-	0.077+	-0.091-	-0.424-	0.077+
0.01i	0.005i	0.002i	0.01i	0.005i	0.002i
-	-	-	-	-	-
-0.366-	-0.496-	0.691+	-0.366-	-0.496-	0.691+
0.039i	0.02i	0.009i	0.039i	0.02i	0.009i
-0.274-	-0.072-	0.232+	-0.274-	-0.072-	0.232+
0.029i	0.015i	0.007i	0.029i	0.015i	0.007i

The steady state mode of the electric power system is formed on the basis of a complete network model, the parameters of which are presented in Table 4, with the values of nodal loads [13,14]:

$$S = \begin{pmatrix} 60 + 40i \\ 40 + 35i \\ 25 + 15i \\ 0,389 - 2,333i \\ 0,302 + 0,144i \\ 0,202 + 0,391i \end{pmatrix}$$

Table 4. Steady state parameters for the complete network topological model.

Nodes number, j	U_j	$ U_j $	$\arg(U_j)$
1	99,817-12,686i	100,62	-0,126
2	89,415-13,282i	90,396	-0,147
3	105,146-10,421i	105,661	-0,099
4	104,575-7,762i	104,862	-0,074
5	95,727-8,542i	96,107	-0,089
6	108,733-6,159i	108,907	-0,057

The values of currents in the branches of the circuit, determined by formula (5), are equal to:

$$I = \begin{pmatrix} 0,315 - 0,21i \\ 0,21 - 0,184i \\ 0,131 - 0,079i \\ 0,337 - 0,254i \\ 0,1 - 0,096i \\ 0,323 - 0,192i \\ 0,111 - 0,088i \\ 0,08 - 0,042i \end{pmatrix}$$

5 Simplified Models for Calculating Steady Mode Parameters

Suppose we know the independent currents in chords 7 and 8. Then, the equivalent driving currents in the nodes, determined according to expression (4), as well as the values of the nodal powers, respectively, will be equal to:

$$J = \begin{pmatrix} 0,315 - 0,21i \\ 0,21 - 0,184i \\ 0,131 - 0,079i \\ -0,078 + 0,053i \\ -0,11 + 0,087i \\ 0,192 - 0,113i \end{pmatrix} S1 = \begin{pmatrix} 60 + 40i \\ 40 + 35i \\ 25 + 15i \\ -14,841 - 10,045i \\ -20,904 - 16,622i \\ 36,495 + 21,525i \end{pmatrix}$$

The steady state parameters are determined by (8), based on the simplified topological model shown in Fig.3.

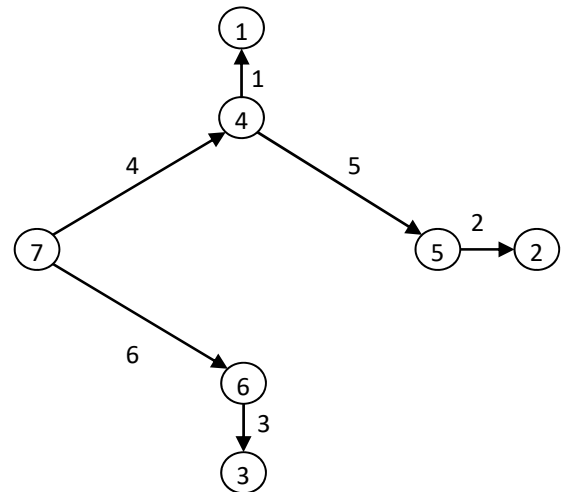


Fig.3. Simplified model of the original graph

The results of calculating the parameters of the steady state, obtained on the basis of a simplified model, are presented in Table 5. The errors of the calculation results are within the allowable values.

Table 5. Comparative results of steady state calculations

j	By full scheme		By simplified model		Relative error	
	$ U_j $	$\arg(U_j)$	$ U'_j $	$\arg(U'_j)$	$\Delta_j, \%$	$\delta_j, \%$
1	100,62	-0,126	99,49	-0,128	1,12%	1,59%
2	90,4	-0,147	88,39	-0,147	2,22%	0,00%
3	105,66	-0,099	107,23	-0,097	1,49%	2,02%
4	104,86	-0,074	103,79	-0,074	1,02%	0,00%
5	96,11	-0,089	94,24	-0,086	1,94%	3,37%
6	108,91	-0,057	110,43	-0,056	1,40%	1,75%

If we assume that the currents in branches 5 and 8 are known, then the equivalent driving currents and, accordingly, the nodal powers will be equal to:

$$J = \begin{pmatrix} 0,315 - 0,21i \\ 0,21 - 0,184i \\ 0,131 - 0,079i \\ 0,022 - 0,044i \\ -0,099 + 0,096i \\ 0,081 - 0,025i \end{pmatrix} S1 = \begin{pmatrix} 60 + 40i \\ 40 + 35i \\ 25 + 15i \\ 4,255 + 8,332i \\ -18,842 - 18,257i \\ 15,337 + 4,782i \end{pmatrix}$$

The steady state parameters determined from the simplified model shown in fig. 4 are shown in Table 6.

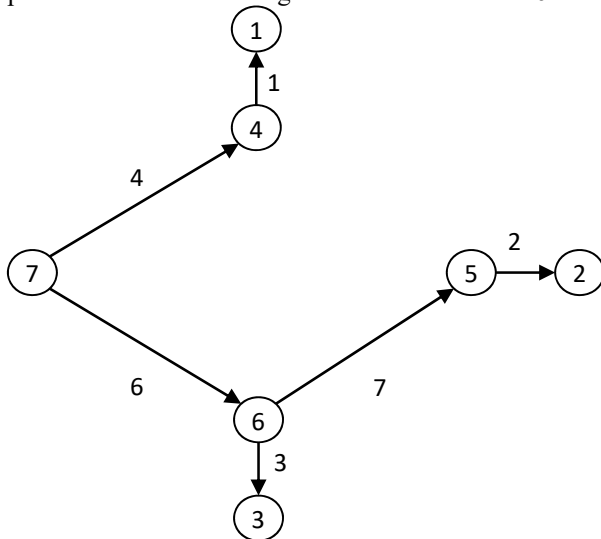


Fig.4. Simplified model of the original graph

Table 6. Comparative results of steady state calculations

j	By full scheme		By simplified model		Relative error	
	$ U_j $	$\arg(U_j)$	$ U_j' $	$\arg(U_j')$	$\Delta_j, \%$	$\delta_j, \%$
1	100,62	-0,126	101,42	-0,128	1,12%	1,59%
2	90,4	-0,147	88,84	-0,147	2,22%	0,00%
3	105,66	-0,099	105,56	-0,097	1,49%	2,02%
4	104,86	-0,074	105,63	-0,074	1,02%	0,00%
5	96,11	-0,089	94,66	-0,086	1,94%	3,37%
6	108,91	-0,057	108,81	-0,056	1,40%	1,75%

Table 6 shows that the results obtained based on the simplified model are in good agreement with the results of the calculation using the full model.

The conducted studies have shown that the same mode of the electrical network can be estimated on the basis of a different simplified model using possible independent currents of the electrical network.

6 Conclusion

1. The topological model of a complex electrical system allows you to set independent currents in the branches of its equivalent circuit.

2. To form the parameters of the steady state, simplified topological models of a complex network of the power system can be used.

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