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TEYLOR'S FORMULA APPLICATION FOR THE DECOMPOSITION OF ELECTRIC NETWORKS WHILE COMPUTATION OF REACTIVE POWER COMPENSATION IN THEM

On the base of Teylor's formula division functions model of decreasing losses into two components was suggested: the first - decreasing of active power losses, caused by the operation of the separate condenser units; the second - decreasing of active power losses, caused by their mutual operation, that enables to carry out decomposition of the network.

Key words: *network decomposition, active power losses, Teylor's formula.*

Problem set up. The decreasing of electric power losses in electric nets can be achieved at the expense of reactive power compensation (RPC) in them. The basis of the existing methods for the RPC computation in these networks is the approach, based on the execution of such calculations for the entire electric net simultaneously [1,2].

Survey of the latest research and papers. To solve this task in such a way is a complex, since:

the electric network is the hierarchical system, where its parts can take decisions according to economic interests separately from the other parts;

task solution on the whole requires considerable expenditures for information acquisition.

Thus, on the one hand, technical and economic difficulties of RPC computation are appear simultaneously for the whole network, and on the other hand certain independence of the electric network parts exists during such calculation.

Thus **the objective of the paper** is the elaboration of methods for electric network division while solving RPC task into parts (electric network decomposition), that enables to simplify this task.

Materials and results of research. Main condition of decomposition is equality of factors of the RPC net state prior decomposition and after that [3].

$$\alpha_{\Sigma}(Q_{Kl}) = \sum_{i=1}^{n}\alpha_i(Q_{Ki}) + \sum_{\substack{i=1 \\ i\neq j}}^{n}\sum_{\substack{j=1 \\ j\neq i}}^{n}\alpha_{ij}(Q_{Kdi}, Q_{Kkj}), \tag{1}$$

where α_{Σ} (Q_{Kl}) – is the index of RPC state for the entire electric network, which is a function of the value of CU Q_{Kl} powers while task solving without decomposition; l=1…*s*; *s* – is number of electric network nodes, where CU are installed; $\alpha_i(Q_{Ki})$ – is RPC the index of the *i*-th subsystem, which is a function of the value of compensating units power, installed in the *i*-th subsystem Q_{Ki}; *i, j* = 1…*n*; *n* – is the number of subsystems of electric network; $\alpha_{ij}(Q_{Kdi},\ Q_{Kkj})$ – is interinfluence index of *i*-th and *j*-th subsystems, which is a function of the values of compensation units powers, installed in the *i*-th and j-th subsystems Q_{Kki}, Q_{Kkj} ; d_i=1…h_i; k_j=1…h_j; h_i, h_j – number of nodes; d_i=1…h_i; k_j=1…h_j; h_i, h_j – number of nodes correspondingly of *i*-th and *j*-th subsystems of electric network, in which CU are installed; $\sum_{i=1}^{n} h_i = s$.

From (1) it is seen, that network decomposition needs decomposition of index function of reactive power compensation. This factor in most cases is active power looses decrease.

Let us consider decomposition of loses decrease function, that depends on vector value of reactive loads decrease $\Delta Q = Q_1 - Q_2$ (Q_1, Q_2 – are, correspondingly, vectors of reactive loads of the network prior and after their decrease).

Change of the vector Q_1 coordinates by the value ΔQ stipulates the decrease of losses value function from the vector of reactive loads $\Delta P(Q)=\frac{2}{U_n^2}\cdot Q^T\cdot R\cdot Q$ by the value $\delta P(Q)$, that can be found by means of Taylor's formula [4]:

$$\delta P(Q)=\left(\nabla P(Q_1)\right)^T\cdot\Delta Q+\frac{1}{2}\cdot\Delta Q^T\cdot\nabla^2\cdot\left(\Delta P(Q_1)\right)\cdot\Delta Q, \tag{2}$$

where $\nabla P(Q_1)$, $\nabla^2(\Delta P(Q_1))$ – is, correspondingly, vector-column of the first derivatives from the function $\Delta P(Q)$ by variables of vector coordinate of reactive loads $Q_i=\nabla^2(\Delta P(Q_1))$, symmetric matrix of the second derivatives from function $\Delta P(Q)$ by variable Q_i. According to [2] matrices $\nabla P(Q)$ and $\nabla^2(\Delta P(Q))$ for the network, set by the matrix of node active resistances *R*, will be determined as

$$\nabla P(Q)=\frac{2}{U_n^2}\cdot\begin{vmatrix}R_{11} & \dots & \dots & R_{1s}\\ R_{21} & \dots & \dots & R_{2s}\\ \dots & \dots & \dots & \dots\\ R_{s1} & \dots & \dots & R_{ss}\end{vmatrix}\cdot\begin{vmatrix}Q_1\\ Q_2\\ \dots\\ Q_s\end{vmatrix};\ \nabla^2(\Delta P(Q))=\frac{2}{U_n^2}\cdot\begin{vmatrix}R_{11} & \dots & \dots & R_{1s}\\ R_{21} & \dots & \dots & R_{2s}\\ \dots & \dots & \dots & \dots\\ R_{s1} & \dots & \dots & R_{ss}\end{vmatrix}, \tag{3}$$

where R_{ff} – is the input resistance of the *f*-th node; R_{fp} – is mutual resistance of the *f*-the and *p*-th nodes; U_n – is nominal voltage of the network; $f, p = 1\dots s; f \neq p$.

Substitute (3) in (2) taking into consideration $\Delta Q_f = Q_{Kf}$, $\Delta Q_p = Q_{Kp}$ and we will obtain:

$$\delta P(Q_K)=\frac{2}{U_n^2}\cdot\left[\begin{vmatrix}R_{11}\ \dots R_{1s}\\ R_{21}\ \dots R_{2s}\\ .\ .\ .\\ R_{s1}\ \dots R_{ss}\end{vmatrix}\cdot\begin{vmatrix}Q_1\\ Q_2\\ \dots\\ Q_s\end{vmatrix}\right]^T\cdot\begin{vmatrix}Q_{K1}\\ Q_{K2}\\ \dots\\ Q_{Ks}\end{vmatrix}+\frac{1}{U_n^2}\cdot\begin{vmatrix}Q_{K1}\\ Q_{K2}\\ \dots\\ Q_{Ks}\end{vmatrix}^T\cdot\begin{vmatrix}R_{11}\ \dots R_{1s}\\ R_{21}\ \dots R_{2s}\\ .\ .\ .\\ R_{s1}\ \dots R_{ss}\end{vmatrix}\cdot\begin{vmatrix}Q_{K1}\\ Q_{K2}\\ \dots\\ Q_{Ks}\end{vmatrix}=$$

$$=\frac{2}{U_n^2}\cdot\left(\sum_{f=1}^{s}Q_{Kf}\cdot R_{ff}\cdot Q_f+\sum_{p=1}^{s}\sum_{f=1}^{s}Q_{Kf}\cdot R_{pf}\cdot Q_f+\frac{1}{2}\cdot\sum_{f=1}^{s}Q_{Kf}^2\cdot R_{ff}\right)+$$

$$+\frac{1}{U_n^2}\cdot\sum_{f=1}^{s}\sum_{p=1}^{s}Q_{Kf}\cdot Q_{Kk}\cdot R_{fp}.$$

Formula (4) reflects decomposition of losses decrease function $\delta P(Q_{Kf},Q_{Kp})$ accordingly (1). It divides this function into two components: the first – losses decrease of active power, caused only by power Q_{Kf}; the second component $\delta P(Q_{Kf},Q_{Kp})$ takes into account losses decrease of active power, caused by common action of CU Q_{Kf} and Q_{Kk}. It enables to carry out the analysis of losses decrease, caused by each CU separately.

Let us consider the possibility of decomposition of the given function if CU is installed in one node of arbitrary network accordingly (4)

$$\delta P(Q_{Kf})=\frac{1}{U_n^2}\cdot\left(R_{ff}\cdot\left(Q_{Kf}\cdot Q_f+Q_{Kf}^2\right)+2\cdot Q_{Kf}\cdot\sum_{\substack{p=1\\ f\neq p}}^{s}Q_p\cdot R_{fp}\right). \tag{5}$$

Formula (5) distinguishes from the entire network circuit its part (Fig. 1), which takes part in the computation of reactive load compensation of the *f*-th node.

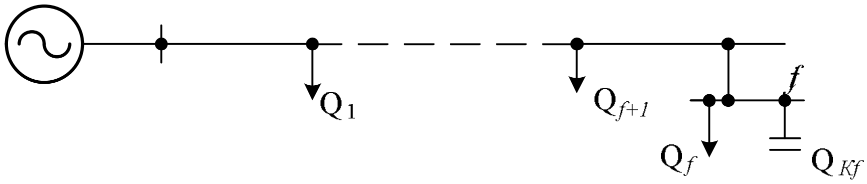

Fig. 1. Part of the computation network which takes part in the computation of reactive load compensation of the *f*-th nodes

Using formula (4), let us accomplish decomposition of elementary network, equivalent circuit of which is shown in Fig. 2, when CU is installed in the first node.

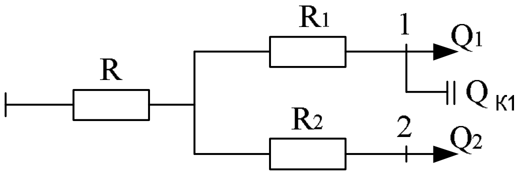

Fig. 2. Equivalent circuit of the elementary network: R – is the value of active resistance of the supplying network; R_1, R_2 – are equivalent active resistances of the first and the second parts of electric networks; Q_1, Q_2 – are reactive loadings of the first and the second nodes, correspondingly

Let us find function $\Delta P(Q)$ and value $\delta P(Q_{K1})$ for the network, shown in Fig. 2, according to the formula (2):

$$\Delta P(Q)=\frac{1}{U^2}\cdot\left[(Q_1+Q_2)^2\cdot R+Q_1^{\,2}\cdot R_1+Q_2^{\,2}\cdot R_2\right]$$

$$\delta P(Q_{K1})=\frac{2}{U^2}\cdot\begin{vmatrix}R\cdot(Q_1+Q_2)+R_1\cdot Q_1\\ R\cdot(Q_1+Q_2)+R_2\cdot Q_2\end{vmatrix}^T\cdot\begin{vmatrix}Q_{K1}\\ 0\end{vmatrix}+\frac{1}{U^2}\cdot\begin{vmatrix}Q_{K1} & 0\end{vmatrix}\cdot\begin{vmatrix}R+R_1 & R\\ R & R+R_2\end{vmatrix}\cdot\begin{vmatrix}Q_{K1}\\ 0\end{vmatrix}=$$

$$=\frac{1}{U^2}\cdot\left(2\cdot Q_{K1}\cdot\left(R\cdot(Q_1+Q_2)+R_1\cdot Q_1\right)+Q_{K1}^2\cdot(2\cdot R+R_1)\right).$$

Example. Using the elaborated decomposition method, for the network (Fig. 3) it is necessary to choose the place of CU of 50 Kvar power installation, that will provide maximum losses drops. It is assumed, that CU can be installed on the 0,4 кV side of all types of TS.

Fig. 3 shows, main parameters of the network. Calculated reactive loadings are set in Kvars. Values of active resistances of the given circuit elements are given in Table 1.

Table 1

Values of active resistances of scheme elements

Element denomination on the scheme	TM 250	TM 400	TM 630	Sections of cable lines			
				10-9	9-8	8-7	7-6
Active resistance of the element, Ohm	6	3.7	1.9	0.032	0.73	0.05	0.13

Computation will be carried out by means of exhaustive search of all possible places of CU installation. For each place of installation we define losses drop. Places of CU installation will be chosen in that node, that provides maximum losses decrease[5].

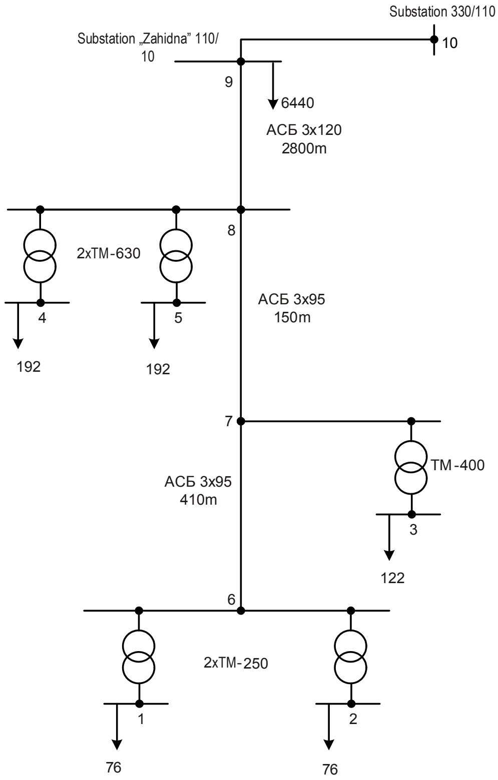

Fig. 3. Diagram of computational network

While CU installation in the first node of the elaborated decomposition method computation scheme will be (Fig. 4), and losses decrease of active power in computational network is determined as

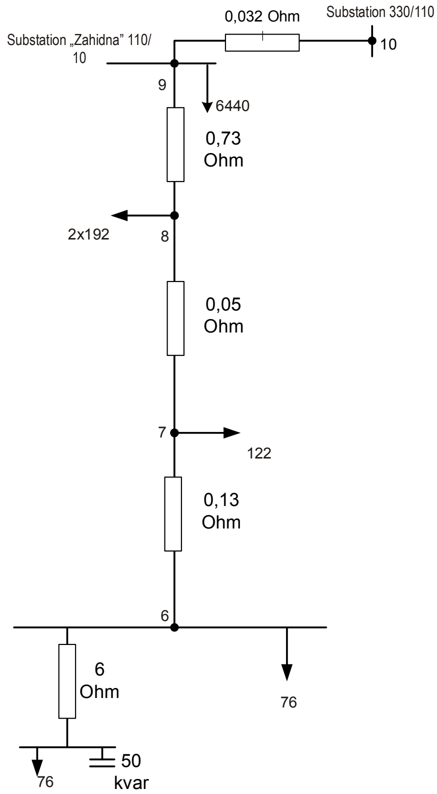

Fig. 4. Computation diagram of the network obtained on the base of decomposition

$$\delta(\Delta P)_{11} = \frac{1}{U_n^2} \cdot [Q_{КУ1} \cdot 2 \cdot (Q_2 \cdot \left(R_{6-7} + R_{7-8} + R_{8-9} + R_{9-10}\right) +$$
$$+ Q_3 \cdot \left(R_{7-8} + R_{8-9} + R_{9-10}\right) + Q_4 \cdot \left(R_{8-9} + R_{9-10}\right) + Q_5 \cdot \left(R_{8-9} + R_{9-10}\right) + Q_6 \cdot R_{9-10}) +$$
$$+ \left(R_{1-6} + R_{6-7} + R_{7-8} + R_{8-9} + R_{9-10}\right) \cdot \left(2 \cdot Q_1 \cdot Q_{КУ1} - Q^2_{КУ1}\right)] =$$
$$= \frac{1}{10^2} \cdot [50 \cdot 2 \cdot (76 \cdot (0{,}13 + 0{,}05 + 0{,}79 + 0{,}032) + 122 \cdot (0{,}05 + 0{,}79 + 0{,}032) +$$
$$+ 192 \cdot (0{,}79 + 0{,}032) + 192 \cdot (0{,}79 + 0{,}032) + 6440 \cdot 0{,}032) + (6 + 0{,}13 + 0{,}05 + 0{,}79 + 0{,}032) \cdot \left(2 \cdot 76 \cdot 50 - 50^2\right)] = 903{,}542\,(Wt).$$

In the same manner we will define the values $\delta(\Delta P)_{1j}$ for other nodes:

$$\delta(\Delta \mathrm{P})_{12} = 903{,}542\,(\mathrm{Wt});$$
$$\delta(\Delta \mathrm{P})_{13} = 960{,}45\,(\mathrm{Wt});$$
$$\delta(\Delta \mathrm{P})_{14} = \delta(\Delta \mathrm{P})_{15} = 933{,}06\,(\mathrm{Wt}).$$

Since maximum losses decrease is achieved while CU installation in the third node, then CU of 50 kvar will be installed in this node.

Conclusions

1. Model for division of losses decrease function into two components is suggested on the base of Teylor's formula: the first – losses decrease of active power, caused by the action of separate capacitor units; the second – losses decrease of active power, caused by their common action, that enables to carry out decomposition of the network.

2. During computation of reactive power compensation in the electric network Taylor's formula enables to distinguish from, which takes part in this computation, and the entire circuit. That part correspondingly, simplify this calculation.

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